

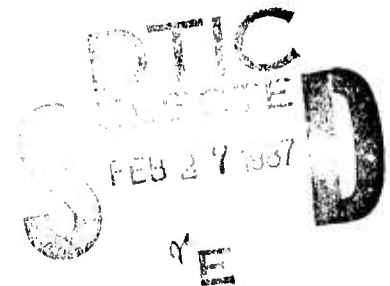
AD-A177 379

VOLUME 18, NO. 12  
DECEMBER 1986

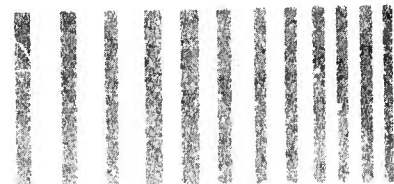


# THE SHOCK AND VIBRATION DIGEST

A PUBLICATION OF  
THE SHOCK AND VIBRATION  
INFORMATION CENTER  
NAVAL RESEARCH LABORATORY  
WASHINGTON, D.C.



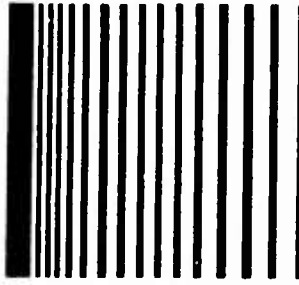
OFFICE OF  
THE UNDER  
SECRETARY  
OF DEFENSE  
FOR RESEARCH  
AND  
ENGINEERING



URS FILE COPY

Approved for public release; distribution unlimited.

87 2 25 128



# THE SHOCK AND VIBRATION DIGEST

Volume 18, No. 12  
December 1986

## STAFF

### Shock and Vibration Information Center

EDITORIAL ADVISOR: Dr. J. Gordan Showalter

### Vibration Institute

EDITOR:	Judith Nagle-Eshleman
TECHNICAL EDITOR:	Ronald L. Eshleman
RESEARCH EDITOR:	Milda Z. Tamulionis
COPY EDITOR:	Loretta G. Twohig
PRODUCTION:	Barbara K. Solt
	Betty J. Schalk

### BOARD OF EDITORS

R.L. Bort	W.D. Pilkey
J.D.C. Crisp	H.C. Pusey
D.J. Johns	E. Sevin
B.N. Leis	R.A. Skop
K.E. McKee	R.H. Volin
C.T. Morrow	H.E. von Gierke



A publication of

THE SHOCK AND VIBRATION  
INFORMATION CENTER

Code 5804, Naval Research  
Laboratory  
Washington, D.C. 20375-5000  
(202) 767-2220

Dr. J. Gordan Showalter  
Acting Director

Rudolph H. Volin

Elizabeth A. McLaughlin

Mary K. Gobbett

The **Shock and Vibration Digest** is a monthly publication of the Shock and Vibration Information Center. The goal of the Digest is to provide efficient transfer of sound, shock, and vibration technology among researchers and practicing engineers. Subjective and objective analyses of the literature are provided along with news and editorial material. News items and articles to be considered for publication should be submitted to:

Dr. R.L. Eshleman  
Vibration Institute  
Suite 206, 101 West 55th Street  
Clarendon Hills, Illinois 60514  
(312) 654-2254

Copies of articles abstracted are not available from the Shock and Vibration Information Center (except for those generated by SVIC). Inquiries should be directed to library resources, authors, or the original publishers.

This periodical is for sale on subscription at an annual rate of \$200.00. For foreign subscribers, there is an additional 25 percent charge for overseas delivery on both regular subscriptions and back issues. Subscriptions are accepted for the calendar year, beginning with the January issue. Back issues are available -- Volumes 11 through 16 -- for \$40.00. Orders may be forwarded at any time to SVIC, Code 5804, Naval Research Laboratory, Washington, D.C. 20375-5000. The Secretary of the Navy has determined that this publication is necessary in the transaction of business required by law of the Department of the Navy. Funds for printing of this publication have been approved by the Navy Publications and Printing Policy Committee.

# EDITOR'S RATTLE SPACE

## FAREWELL TO A FRIEND

It is now common knowledge that the Shock and Vibration Center (SVIC) was officially disestablished on 1 October 1986 after forty years of service to the shock and vibration community. This service included the organization of Shock and Vibration Symposia and the publication of the Shock and Vibration Bulletin, the Shock and Vibration Digest, and a monograph series. SVIC acted as a repository and clearing house for technical information on vibration and shock associated with a wide variety of equipment and environments. It is unfortunate that an important group of this type was disestablished when the exchange of technical information is so important to save time, resources, and money. While some of these services will be continued, given the present economic conditions, it is unlikely that a single focal point of the nature of the SVIC can be established again -- particularly within the government.

The Vibration Institute will continue the publication of the Shock and Vibration Digest in the same form without interruption. Since the Institute has prepared the DIGEST for SVIC for the past eleven years, similar service can be continued with ease. The continuation of the other functions present more of a challenge. Meetings at the recent 57th Shock and Vibration Symposium indicate that many persons are very interested in the continuation of the services provided by SVIC. As a result, efforts are now underway to find a means of continuation of some or all of SVIC's services. Unfortunately while some or many of these services may be reinstated, the tradition and focal point of SVIC will be lost.

From a personal view, it is with regret that I say farewell to a friend -- SVIC. As the technical editor of the DIGEST, I have been closely associated with the SVIC for the past eighteen years. The DIGEST offered me a rare opportunity to grow in the technical world. I wish to thank the SVIC personnel present and past for their cooperation, sponsorship, contributions. It was always a pleasant task working with the SVIC personnel -- four of the five directors: Drs. Mutch and Belsheim, Henry Pusey, and Gordan Showalter; Rudy Volin who served on the SVIC staff during my entire tenure on the DIGEST; and Elizabeth McLaughlin who maintained the office. While my activity with the DIGEST will continue, the association with the SVIC personnel will be missed.

Accession Per	
NTIS DA-1	X
DTIC	
NRL \$40.00	
per-copy	
A-1 21	

R.L.E.



## MECHANICAL SIGNATURE ANALYSIS

M.S. Hundal\*

**Abstract.** Literature on mechanical signature analysis (MSA) for 1983-85 is reviewed. MSA applications discussed include analytical and experimental methods, programs, and systems for machinery and process monitoring and diagnosis.

A previous article [40] that reviewed literature on mechanical signal analysis (MSA) up to the end of 1982 included analytical and experimental studies, monitoring, and diagnostics of machines. Since that time the use of sophisticated instrumentation and systems for data acquisition and processing has become well established, and new analytical techniques have been developed.

MSA includes a number of applications [8]: 1) monitoring, 2) diagnostics, 3) system identification, and 4) testing. These can further be classified into active and passive insofar as the external stimuli applied to the system by the user (see the figure). The aims of MSA include improved system design, noise and vibration attenuation, and help in developing control strategies.

Monitoring	Diagnostics	System Identifi- cation	Testing
------------	-------------	-------------------------------	---------

← Passive

Active →

### MSA Applications.

Because the published literature on MSA is so extensive, only applications to monitoring and diagnostics are covered in this paper. This literature is divided into the following groups: general monitoring and diagnostics; monitoring and diagnostic systems; specific machine elements; analytical techniques; sound, ultrasound, and acoustic emission applications; and special applications and techniques.

### GENERAL MONITORING AND DIAGNOSTICS

For the novice in MSA several papers provide a good introduction to the subject. Eshleman [25]

and Mitchell [72] discuss diagnostic capabilities of FFT analyzers. Other papers contain evaluations of data, location and types of measurements [77], high-frequency bearing monitoring [35], current trends in diagnosis and economics of monitoring [87], and different types of spectra used for diagnostics [55]. Mitchell [70] examines issues in establishing a monitoring program and provides a survey of methods.

Eshleman [26] and Buehler [10] give examples of typical vibration signals and spectra associated with different types of machinery faults. Cost-effective predictive maintenance of noncritical rotating equipment [58], factors other than machine deterioration that cause changes in vibration signature [16], and engine torque and speed for condition monitoring [46] have been presented. Fox [29] and Fuchs [31] discuss measurement of absolute and relative motion and effect of mass of system components.

Effects of misalignment in couplings and its causes and identification have been presented [23,52,80]. Ghosh [33] has presented effects of balancing, generator excitation, loading, and rebuilding on hydraulic turbine vibration signatures. The problems of identifying and diagnosing problems in vertical pumps [89], steam turbine fan system [73], freight car bearings [48], electric motors [11,12,34], and rotary blowers [44] have been discussed. Eshleman and Jones [27] have presented the use of test data and a computer model to reduce vibration in a turbine with thermal bow. A monitoring system for gas turbine cases has been given by Kidd [47].

### MONITORING AND DIAGNOSTIC SYSTEMS

The developments in instrumentation for measurement and analysis of mechanical signals have led to research in and design of complete systems for monitoring and diagnosis. Papers in this area describe design aspects, operating experience, and philosophy behind such systems [7]; systems for improving machine availability and reducing maintenance costs [5,71]; a program to schedule monitoring activities [83]; and a

\* Department of Mechanical Engineering, University of Vermont, Burlington, Vermont 05405

diagnostic system containing spectrum, balance, and predictive maintenance analyzers [67].

Remote monitoring and control systems have been discussed for gas turbines [28,32] and offshore gas turbine fatigue life prediction [98]. Such systems have been applied to a diesel engine to infer behavior of pressure and forces from vibration signal [57], to self-aligning thrust bearings in steam turbines [100], and to piping systems to determine maximum stress [84]. A portable system for data acquisition, analysis, and early diagnosis for power plants [13] and diagnostic functions of a turbomachinery system [2] have been presented.

Research projects on torsional fatigue life and development of statistics for making conclusions and recommendations on system operations have been described [103]. Systems with satellite stations at each component, communication networks, and required computer hardware and software have been presented [19,38].

Application of expert systems for monitoring and providing data for use by management has been discussed [90,91]. A system to maintain data records, compute statistical data, and prepare reports for management [20] as well as software for using stored diagnostic files for fault diagnosis as part of an expert system [14] have been described.

## MACHINE ELEMENTS

**Bearings.** Bearings are by far the most common elements monitored for machinery condition. Although most papers deal with rolling element bearings, a paper by Conway-Jones [18] discusses the measurement of oil-film pressure and journal displacement for monitoring engines.

Methods to locate defects in ball bearings with single or multiple dents have been presented by Igarashi [42,43]. Effects on vibration signals generated by defects in raceways, rolling elements, excessive clearance, and lack of lubrication have been discussed [3]. In a series of reports McFadden and Smith [61,62,64-66] have described models, experimental methods, and high-frequency resonance techniques used to detect single and multiple defects in rolling element bearings. A study to detect incipient failure has been presented [60]; links among metallography, tribology, noise, and vibration analysis [102] have been explored. Use of eddy current sensors for bearing monitoring has been discussed [37,88].

**Gears.** General papers on monitoring gearbox vibrations deal with fault identification [4,93]. Milenkovic [69] has discussed a methodology for measuring vibrations in axle carriers outside a vehicle. A method for predicting tooth surface failure [101] and detecting shaft misalignment, eccentricity, and profile errors from noise and vibration signatures [50] has been presented. Jacobs [45] has given a case history of a monitoring program that failed to detect a major fault in a gear reducer.

## ANALYTICAL TECHNIQUES

A number of papers describe new analytical techniques or the application of existing techniques to new applications in MSA. The random decrement method has been used by Yang [106, 107] to inspect offshore structures. Ranking of noise sources and disturbances has been discussed [9,99]. Tanaka [94] gives classification factors for detectability of blade vibrations. A method for finding parameters of a multi-frequency signal [36] and synthesis of periodic signals to provide improved spectral response data [79] have been presented.

Powell [78] has described a method capable of separating multiple input force signals in the presence of reverberated signals; the method involves constructing a pseudo-inverse transfer matrix. Signal recovery in reverberant structures to reveal developing faults has been given by Lyon [56]. Pavic [75,76] has developed relationships between inertial and elastic properties to detect vibrations by strain measurements. A method for tracking the progress of fracture by observing changes in mass, stiffness, and damping matrices has been discussed [108]. Cempel [17] has described a model that combines wear, vibration, and acoustic processes to predict machine condition and estimate breakdown time.

Algorithms for fault identification from vibration signatures by a method of elimination [51] and time dependent processing to enhance dynamic test data [95] have been presented. Use of redundant measurement systems with adaptive filtering, use of fault detection, and isolation methodology have been described by Ray [82]. Davies [21] has discussed three parametric methods -- prony series, recursive least squares, and instrumental variable analysis -- and compared them with Fourier methods. A frequency domain technique for fault diagnosis and computer language that reduces software cost and complexity have been given by Hitchcock [39]. Real time programs that can indicate a 0.1 percent change in rotor unbalance are available [86]. A method for simulating an impulsive

fault signal buried in background noise and modeling various stages of incipient failure have been given by White [104].

### **SOUND, ULTRASOUND, AND ACOUSTIC EMISSION SIGNALS**

Although most MSA applications involve monitoring only vibration signals, in some cases both sound and vibration signals are used for diagnostics [42,43,101]. Hundal [41] has described the use of acoustic and vibration signatures of a power plant ash conveyor to solve a community noise problem. A sound intensity measuring technique for machinery diagnostics [81] and ultrasonic signals for detecting rolling bearing defects [15] have been presented. Armor [1] has given a progress report of on-line detection of shaft cracks using vibration signature analysis, acoustic emission (AE), and eddy current sensor monitoring.

The AE technique has been used in the past mainly to detect faults in structures. It is being used in machine monitoring. AE applications for rolling bearing monitoring at low speeds [63] and for diagnosis of friction change in mating slides [92] have been given. Yoshioka [110] has described the principle of an AE source-locating system for rolling bearings. Manufacturing applications of AE have been presented in the context of grinding [24] and wood cutting [54]. More traditional applications of AE technique have also been discussed: internally leaking parallel piping in spacecraft [105], operational monitor for a towed cable system [53], and glass reinforced composites [6].

### **SPECIAL APPLICATIONS AND TECHNIQUES**

Some applications and techniques in MSA do not fall under any of the previous categories. An instrument to detect looseness of a screw in a gearbox assembly [49] and vibration monitoring of high-volume transfer machines in an automotive engine plant [97] have been presented. Timperley [96] has presented a method for incipient failure detection in rotating machines with EMI monitoring. Use of burst random excitation to eliminate leakage errors and distortion of frequency response [74] and the use of a Laser doppler sensor for turbine generator vibrations [59] have been described.

Freestone [30] used Fourier analysis of a crankshaft waveform as a diagnostic tool to estimate the power contribution of each cylinder of an engine. Use of pattern recognition techniques to distinguish waveforms from damage-related and extraneous sources has been discussed [85].

Monitoring a machine tool with strain gauges [68]; investigation of lubricant action in cutting [22]; and a system for predicting imminent failure of workpiece, tool, or worn tool [109] have been described for manufacturing applications.

### **CONCLUSIONS**

In the past three years the field of MSA has matured significantly. This is evidenced not only by the large number of published articles on monitoring and diagnostics, but also by literature in analytical and experimental modal analysis. In addition, new journals devoted exclusively to modal and signal analysis are now being published. In the last review of MSA [40] a number of areas of future work were postulated. It is satisfying to note that most of these areas have seen significant activity. At this time it appears that the following topics will be important in the next few years:

- Combination of modal analysis with monitoring and diagnostics systems
- Identification of measures of system degradations and prediction of failure
- Time domain analysis as aid in diagnostics and failure prediction
- Combination of techniques; e.g. vibration, sound, ultrasound, and AE in diagnostic systems
- Expert systems and AI

### **REFERENCES**

1. Armor, A.F., "On-Line Monitoring of Turbine-Generator Shaft Cracking," ASME Paper No. 83-JPGC-Pwr-7 (1983).
2. Arnold, W.L., "Expand Supervisory Function to Include Diagnostics," *Power*, 122 (12), pp 61-63 (Dec 1983).
3. Axton, G.E. "Antifriction Bearing Pre-Failure Detection Makes Dollars and Sense," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, New Orleans, LA, Vibration Institute, pp 105-113, (June 26-28, 1984).
4. Bagiasna, K., Suganda, H., and Suharto D., "Noise Analysis for Gear Box Defect Detection," SAE Paper No. 830924 (P-139) (1983).
5. Bannister, R.L., Bellows, J.C., and Osborne, R.L., "Steam Turbine Generators - On-line Monitoring and Availability," *Mech. Engrg.*, 105 (7), pp 55-59 (July 1983).

6. Belchamber, R.M., Betteridge, D., Collins, M.P., and Lilley, T., "Time Series Analysis of Acoustic Emission Signals from Glass Reinforced Plastics," *Acoust. Emission Monitoring Anal. Mfg.*, ASME, New Orleans, LA, pp 1-9 (1984).
7. Boyce, M.P., Meher-Homji, C., Mani, G., Lam, T., and Ansell, R., "Operating Experience with Health Monitoring and Diagnosis of M.D. Steam Turbines and Centrifugal Compressors," ASME Paper No. 83-JPGC-Pwr-28 (1983).
8. Braun, S., "MSA - Mechanical Signature Analysis," *J. Vib., Acoust., Stress, Rel. Des.*, *Trans. ASME*, **106** (1), pp 1-3 (Jan 1984).
9. Braun, S. and Shulman, D., "The Use of Signal Analysis and Identification Methods for Correction of Unbalance Computations," *J. Vib., Acoust., Stress, Rel. Des.*, *Trans. ASME*, **106** (1), pp 53-58 (Jan 1984).
10. Buehler, M.W. and Bertin, C.D., "Typical Vibration Signatures - Case Studies," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, Houston, TX, Vibration Institute, pp 191-206 (Apr 19-21, 1983).
11. Campbell, W.R., "Shaft Runout Under Eddy Current Non-contact Probes," *Proc., Mach. Vib. Monitoring Anal. Mtg.*, Houston, TX, Vibration Institute, pp 39-51 (Apr 19-21, 1983).
12. Campbell, W.R., "Diagnosing Alternating Current Electric Motor Problems," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, New Orleans, LA, Vibration Institute, pp 65-79 (May 22-24, 1985).
13. Canada, R.G., Greene, R.H., and Craig, P.J., "A State-of-the-Art Monitoring and Diagnostic Program for Main Steam Turbines in Commercial Power Plants," *Proc. Mach. Vib. Monitoring Analysis Mtg.*, Houston, TX, Vibration Institute, pp 207-213 (Apr 19-21, 1983).
14. Carey, J.H., "The Use of Software for Vibration Monitoring," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, New Orleans, LA, Vibration Institute, pp 129-134 (May 22-24, 1985).
15. Catlin, J.B., "The Use of Ultrasonic Diagnostic Techniques to Detect Rolling Element Bearing Defects," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, Houston, TX, Vibration Institute, pp 123-130 (Apr 19-21, 1983).
16. Catlin, J.B., "A Survey of Factors Which Affect the Measured Vibration Spectra of Machines," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, New Orleans, LA, Vibration Institute, pp 51-56 (May 22-24, 1985).
17. Cempel, Cz., "The Triboviscoacoustical Model of Machines," *Wear*, **102** (3), pp 297-305 (Oct 1, 1985).
18. Conway-Jones, J.M., Jones, G., and Kendrick, M., "Crankshaft Bearings: Advances in Predictive Techniques and Measurements in Engines," ASME Paper No. 84-DGP-4 (1984).
19. Cook, S.A., Crowe, R.D., Roblyer, S.P., and Toffer, H., "Vibration Monitoring of Large Vertical Pumps Via a Remote Satellite Station," *Vib. Sound Conf.*, ASME, Cincinnati, OH (Sept 10, 1985).
20. Corley, J.E., "A Vibration Monitoring Program Using Microcomputers," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, New Orleans, LA, Vibration Institute, pp 61-69 (June 26-28, 1984).
21. Davies, P. and Hammond, J.K., "A Comparison of Fourier and Parametric Methods for Structural System Identification," *J. Vib., Acoust., Stress, Rel. Des.*, *Trans. ASME*, **106** (1), pp 40-48 (Jan 1984).
22. DeChiffre, L., "Frequency Analysis of Surfaces Machined Using Different Lubricants," *Trans. ASLE*, **22** (3), pp 220-226 (July 1984).
23. Dewell, D.L., and Mitchell, L.D., "Detection of a Misaligned Disk Coupling Using Spectrum Analysis," *J. Vib., Acoust., Stress, Rel. Des.*, *Trans. ASME*, **106** (1), pp 9-16 (Jan 1984).
24. Dornfield, D. and He Gao Kai, "An Investigation of Grinding Wheel Loading Using Acoustic Emission," *J. Engrg., Indus.*, *Trans. ASME*, **106** (1), pp 28-33 (Feb 1984).
25. Eshleman, R.L., "Machinery Diagnostics and Your FFT," *S/V Sound Vib.*, **12** (4), pp 12-18 (Apr 1983).
26. Eshleman, R.L., "Machinery Vibration Monitoring and Analysis - A Maintenance Tool," *Proc. Intl. Coil Winding Assn.*, pp 76-80 (Oct 3-6, 1983).
27. Eshleman, R.L. and Jones, D., "Vibration Analysis and Balancing of a 192 MW Turbine Generator," *Proc. Mach. Vib. Monitoring Anal. Mtg.*, New Orleans, LA, Vibration Institute, pp 87-94 (June 26-28, 1984).
28. Fanuele, F. and Rio, R.A., "Automated Diagnostic System for Engine Maintenance," ASME Paper No. 83-GT-103.

29. Fox, R.L., "Comparative Phase Measurements Aid Vibration Analysis," Proc. Mach. Vib. Monitoring Anal. Mtg., Houston, TX, Vibration Institute, pp 117-122 (Apr 19-21, 1983).
30. Freestone, J.W. and Jenkins, E.G., "The Diagnosis of Cylinder Power Faults in Diesel Engines by Flywheel Speed Measurement," Vehicle Condition Monitoring Fault Diag., I.Mech.E. Conf. Public. 1985-2, pp 15-24 (1985).
31. Fuchs, H.P., "Prevention of Vibration Damage by Maintenance," (Instandhaltung Schwingschaeden vermeiden), Industrie Anzeiger, 102 (79), pp 30-32 (Oct 5, 1983).
32. Geer, D.H., Johnson, D., and Pilcher, J.A., "A Modern Condition Monitoring and Gas Turbine Control System," ASME Paper No. 84-GT-220 (1984).
33. Ghosh, M. and Reddy, A.K., "Study of Vibration Behaviour of a Hydraulic Turbine," Proc. 5th Soc. Exptl. Stress Anal. Conf., pp 412-416 (June 1984).
34. Glew, C.A.W. and Reinhardt, W.A., "The Development of Vibration and Rundown Time Norms as a Quality Control Tool for Overhauled Electric Motors," Proc., 8th Canada Mach. Dynam. Sem., Halifax, Natl. Res. Council Canada, NRC No. 23619, pp 18.1-18.21 (Oct 1-2, 1984).
35. Goldman, S., "Periodic Machinery Monitoring: Do It Right," Hydrocarbon Processing, 63 (8), pp 51-56 (Aug 1984).
36. Grandke, T., "Interpolation Algorithms for Discrete Fourier Transforms of Weighted Signals," IEEE Trans., Instrum. Meas., IM-32 (2), pp 350-355 (June 1983).
37. Hansen, J.S. and Harker, R.G., "A New Method for Rolling Element Bearing Monitoring in the Petrochemical Industry," Proc. Mach. Vib. Monitoring Anal. Mtg., New Orleans, LA, Vibration Institute, pp 139-145 (June 26-28, 1984).
38. Harrington, T.P., Roblyer, S.P., and Toffer, H., "Vibration Monitoring Using a Computer Network Approach," ASME Paper No. 83-DET-72 (1983).
39. Hitchcock, K.N., "Recent Development in the Non-intrusive Diagnosis of Engine Faults," Vehicle Condition Monitoring Fault Diag., I.Mech.E. Conf. Public. 1985-2, pp 101-108 (1985).
40. Hundal, M.S., "Mechanical Signature Analysis," Shock Vib. Dig., 15 (6), pp 19-26 (June 1983).
41. Hundal, M.S., "Narrow-band Spectral and Propagation Analysis as Aids to Noise Source Identification," INTEP-NOISE 85, Proc. Intl. Conf. Noise Control Engrg., Munich, pp 1335-1338 (Sept 18-20, 1985).
42. Igarashi, T. and Yabe, S., "Studies on the Vibration and Sound of Defective Rolling Bearings; Second Report: Sound of Ball Bearings with One Defect," Bull. JSME, 26 (220), pp 1791-1798 (Oct 1983).
43. Igarashi, T. and Kato, J., "Studies on the Vibration and Sound of Defective Rolling Bearings; Third Report: Vibration of Ball Bearings with Multiple Defects," Bull. JSME, 28 (237), pp 492-499 (Mar 1985).
44. Jacobs, R.W., "Detection of Mechanical Faults in Rotary Blowers," Proc. Mach. Vib. Monitoring Anal. Mtg., Houston, TX, Vibration Institute, pp 31-37 (Apr 19-21, 1983).
45. Jacobs, R.W., "Gear Reducers - Overall Readings are Not Enough!," Proc. Mach. Vib. Monitoring Anal. Mtg., New Orleans, LA, Vibration Institute, pp 81-86 (May 22-24, 1985).
46. Jewitt, T.H.B. and Lawton, B., "The Use of Speed Sensing for Monitoring the Condition of Military Vehicle Engines," Vehicle Condition Monitoring Fault Diag., I.Mech.E. Conf. Public. 1985-2, pp 67-74 (1985).
47. Kidd, H.A., "Development of a Cast Vibration Measurement System for the DC-9/0 Gas Turbine," J. Engrg. Gas Turbines Power, Trans. ASME, 106 (4), pp 935-939 (Oct 1984).
48. Kim, P.Y. and Lowe, I.R.G., "A Review of Rolling Element Bearing Health Monitoring," Mach. Vib. Monitoring Anal. Mtg., Houston, TX, Vibration Institute, pp 145-154 (Apr 19-21, 1983).
49. Kolitsch, J., "A Noncontacting Measurement Technique for a Continuous Monitoring of Screw Connections," (Ein beruehrungsloses Messverfahren zur kontinuierlichen Ueberwachung von Schraubenverbindungen). VDIZ, 125 (3), pp 61-66 (Feb 1983).
50. Krishnappa, G., "Noise and Vibration Measurements of 50 kW Vertical Axis Wind Turbine Gear Box," Noise Control Engrg., J., 22 (1), pp 18-24 (Jan/Feb 1984).

51. Kubiak, J.A., Rothhirsch, L., and Aguirre, R., "An Algorithm of Fault Diagnosis for Turbine Generator Operations," Proc. Mach. Vib. Monitoring Anal. Mtg., Houston, TX, Vibration Institute, pp 91-100 (Apr 19-21, 1983).
52. Kubiak, J.A. and Aguirre, J.R., "Identification of Misalignment in Turbomachinery," Proc. Mach. Vib. Monitoring Anal. Mtg., New Orleans, LA, Vibration Institute, pp 23-30 (May 22-24, 1985).
53. Laura, P.A.A. and Matthews, J.R., "Monitoring the Status of a Mechanical Cable While in Operation by Means of the Acoustical Emission Method," Ocean Engrg., 12 (3), pp 211-219 (1985).
54. LeMaster, R.L., Tee, L.B., and Dornfeld, D.A., "Monitoring Tool Wear during Wood Machining with Acoustic Emission," Wear, 101 (3), pp 273-282 (Feb 1, 1985).
55. Leon, R.L., "Is Your Periodic Machinery Monitoring Program Telling You the Truth, the Whole Truth, and Nothing But ...?," S/V Sound Vib., 12 (6), pp 24-26 (June 1985).
56. Lyon, R.H., "Source Signature Recovery in Reverberent Structures," Shock Vib. Bull., Naval Res. Lab., Proc. 53, Pt. 4, pp 141-144 (May 1983).
57. Lyon, R.H. and DeJong, R.G., "Design of a High-Level Diagnostic System," J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 106 (1), pp 17-21 (Jan 1984).
58. Makansi, J., "New Monitors Expand Benefits of Machine Condition Surveys," Power, 128 (5), pp 75-76 (May 1984).
59. Mannava, S.R., Mielke, W.R., and Armor, A.F., "A Noncontacting Laser Doppler Sensor for Monitoring Turbine Generator Vibrations," ASME Paper No. 83-JPGC-Pwr-26 (1983).
60. Mathew, J. and Alfredson, R.J., "The Condition Monitoring of Rolling Element Bearings Using Vibration Analysis," J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 106 (3), pp 447-453 (July 1984).
61. McFadden, P.D. and Smith, J.D., "Vibration Produced by a Single Point Defect on the Inner Race of a Rolling Element Bearing Under Radial Load," Dept. Engrg., Cambridge Univ., UK, Rept. No. CUED/C-MECH/TR-32-1983, PB84-139617 (1983).
62. McFadden, P.D. and Smith, J.D., "Implementing the High-Frequency Resonance Technique for the Vibration Monitoring of Rolling Element Bearings," Dept. Engrg., Cambridge Univ., UK, Rept. No. CUED/C-MECH/TR-31-1983, PB84-14003 (1983).
63. McFadden, P.D. and Smith, J.D., "Acoustic Emission Transducers for Vibration Monitoring of Bearings at Low Speed," Dept. Engrg., Cambridge Univ., UK, Rept. No. CUED/C-MECH/TR-29-1983, PB84-139526 (1983).
64. McFadden, P.D. and Smith, J.D., "Vibration Monitoring of Rolling Element Bearings by the High-Frequency Resonance Technique: A Review," Dept. Engrg., Cambridge Univ., UK, Rept. No. CUED/C-MECH/TR-30-1983, PB84-139591 (1983); also Trib. Intl., 17 (1), pp 3-10 (Feb 1984).
65. McFadden, P.D. and Smith, J.D., "Vibration Produced by a Single Point Defect on the Inner or Outer Race of Rolling Elements of a Bearing under Radial or Axial Load," Dept. Engrg., Cambridge Univ., UK, Rept. No. CUED/C-MECH/TR-34-1983, PB84-169887 (1983).
66. McFadden, P.D. and Smith, J.D., "The Vibration Produced by Multiple Point Defects in a Rolling Element Bearing," J. Sound Vib., 28 (2), pp 263-273 (Jan 22, 1985).
67. McGuckin, W.J. and Schramm, E.J., "Diagnostic Analysis of Machinery with State-of-the-Art Equipment," S/V Sound Vib., 12 (6), pp 6-10 (June 1985).
68. Menz, P. and Heinke, H., "Signal Extraction for Automatic Monitoring of Machine Tool Drives," (Signalgewinnung zur automatischen Ueberwachung von Werkzeugmaschinenantrieben), Maschinenbautechnik, 33 (12), pp 544-547 (1984).
69. Milenkovic, V., Shmutter, S., and Field, N., "On-Line Diagnostics of Rear Axle Transmission Errors," J. Engrg. Indus., Trans. ASME, 106 (4), pp 331-338 (Nov 1984).
70. Mitchell, J.S., "How to Develop a Machinery Monitoring Program," S/V Sound Vib., 18 (2), pp 14-20 (Feb 1984).
71. Miell, J.S., "Efficient Machinery Screening for Improved On-Line Performance," S/V Sound Vib., 18 (9), pp 16-25 (Sept 1984).
72. Mitchell, L.D., "Signal Processing and the Fast Fourier Transform (FFT) Analyzer," Exptl. Tech., 2 (10), pp 3s-15s (Oct 1985).

73. Natlloo, N.S. and Crenwelge, O.E., "Case History of a Steam Turbine Rotordynamic Problem: Theoretical versus Experimental Results," Proc. Mach. Vib. Monitoring Anal. Mtg., Houston, TX, Vibration Institute, pp 81-89 (Apr 19-21, 1983).
74. Olsen, N., "Burst Random Excitation," S/V Sound Vib., 12 (11), pp 20-23 (Nov 1983).
75. Pavic, G., "Measurement of Vibration by Strain Gauges; Part I: Theoretical Basis," J. Sound Vib., 102 (2), pp 153-163 (Sept 22, 1985).
76. Pavic, G., "Measurement of Vibrations by Strain Gauges; Part II: Selection of Measurement Parameters," J. Sound Vib., 102 (2), pp 165-188 (Sept 22, 1985).
77. Peters, G., "Machinery Vibration Measurement and Monitoring," (Schwingungs-Messung und -Ueberwachung an Maschinen), Industrie Anzeiger, 105 (1/2) pp 32-33 (1983).
78. Powell, R.E. and Seering, W., "Multichannel Structural Inverse Filtering," J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 106 (1), pp 22-28 (Jan 1984).
79. Pumplun, J., "Low-Noise Noise," J. Acoust. Soc. Amer., 98 (1), pp 100-104 (July 1985).
80. Quigley, W.I., "Fault Diagnosis Method for a Vibration Phenomenon on an Exciter for a Turbo-Alternator, through a Vibration Analysis Discrete Instant Motion Study Using Accelerometers and a Supporting Instrumentation System," Proc., 8th Canada Mach. Dynam. Sem., Halifax, Natl. Res. Council Canada, NRC No. 23619, pp 9.0-9.18 (Oct 1-2, 1984).
81. Rasmussen, G., "Application of Intensity Measuring Technique to Vibration Diagnostics in Machinery," Proc., 8th Canada Mach. Dynam. Sem., Halifax, Natl. Res. Council Canada, NRC No. 23619, pp 14.1-14.10 (Oct 1-2, 1984).
82. Ray, A. and Desai, M., "A Calibration and Estimation Filter for Multiply Redundant Measurement Systems," J. Dynam. Syst. Meas. Control, Trans. ASME, 106 (2), pp 149-156 (June 1984).
83. Remillard, R.L., "Data Management System for Predictive Maintenance Programs," S/V Sound Vib., 12 (9), pp 20-24 (Sept 1985).
84. Sampson, R.C., "Remote Sensing of Pipe Vibration," Exptl. Mech., Proc. 1985 SEM Spring Conf., Las Vegas, NV, pp 329-336 (June 9-14, 1985).
85. Scala, C.M. and Coyle, R.A., "Pattern Recognition and Acoustic Emission," NDT Intl., 16 (6), pp 339-343 (Dec 1983).
86. Schnittger, J.R., "Monitoring Mechanical Vibration using a Histogram Recorder," Intl. J. Fatigue, 2 (3), pp 145-153 (July 1983).
87. Smiley, R.G., "Rotating Machinery: Monitoring and Fault Diagnosis," S/V Sound Vib., 12 (9), pp 26-28 (Sept 1983).
88. Spencer D.E. and Hansen, J.S., "A Better Way to Monitor Bearings," Hydrocarbon Processing, 64 (1), pp 75-76 (Jan 1985).
89. Starr, D.E., "Troubleshooting Vertical Pumps Utilizing Vibration Techniques," Proc. Mach. Vib. Monitoring Anal. Mtg., Houston, TX, Vibration Institute, pp 131-133 (Apr 19-21 (1983).
90. Steward, R.M., "The Way Ahead for Machinery Health Monitoring as a Subset of Plant Control," Noise Vib. Control, 16 (2), pp 53-56 (Feb 1985).
91. Stewart, R.M., "A Systematic Approach to Automated Machinery Management," S/V Sound Vib., 12 (6), pp 14-23 (June 1985).
92. Sturm, A. and Uhlemann, S., "Diagnostic Analysis of Slide Matings by Means of Sound Emission," (Diagnostik an Gleitpaarungen durch Schallemissionsanalyse), Maschinenbautechnik, 34 (3), pp 129-132 (1985).
93. Szrom, D.B., "Analysis and Correction of Gearbox Faults," Proc. Mach. Vib. Monitoring and Analysis Mtg., New Orleans, LA, Vibration Institute, pp 147-153 (June 26-28, 1984).
94. Tanaka, S., Hayashida, M., Umemura, S., and Katayama, K., "Monitoring of Blade Vibration through Detecting of Bearing Pedestal Vibration," ASME Paper No. 83-JPGC-Pwr-10 (1983).
95. Taylor, J.S.W., "Digital Techniques for Enhancing and Processing Dynamic Stress Analysis Data," Exptl. Tech., 2 (6), pp 31-35 (June 1983).
96. Timperley, J.E., "Incipient Fault Identification through Neutral RF Monitoring of Larger Rotating Machines," IEEE, Trans., Power Appl. Syst., PAS-102 (3), pp 693-698 (Mar 1983).

97. Tjong, J.S.-Y., Moore, T., and Reif, Z., "Application of Vibration Monitoring to High Volume, Multi-station Transfer Machines," *Intl. Modal Anal. Conf.*, Orlando, FL, Vol. II, pp 915-919 (Jan 28-31, 1985).
98. Toler, D.F. and Yorio, R.M., "Operational Mode Monitoring of Gas Turbines in an Offshore Gas-Gathering Application," *J. Engrg. Gas Turbine Power*, *Trans. ASME*, 106 (4), pp 940-945 (Oct 1984).
99. Trethewey, M.W., Evenson, H.A., and Shapton, W.R., "Combination of Multiple Input Models and Experimental Modal Analysis for Identification of Structural Noise Generating Mechanisms: With Application to Forge Hammers," *Noise Control Engrg. J.*, 21 (3), pp 89-102 (Nov/Dec 1983).
100. Tuncel, O., Carter, D.B., and Sert, B., "Remote Monitoring of Steam Turbine Parameters of the New Self-aligning Thrust Bearing," *ASME Paper No. 83-JPGC-Pwr-13* (1983).
101. Umezawa, K., Ajima, T., and Houjoh, H., "An Acoustic Method to Predict Tooth Surface Failure of Inservice Gears," *NDT Intl.*, 16 (4), pp 201-204 (Aug 1983).
102. Volker, E. and Martin, H.R., "Early Detection of Damage in Rolling Bearings," *ISA Trans.*, 23 (3), pp 27-32 (1984).
103. White, J.C., Walker, D.N., and Perez, A.J., "Torsional Monitoring of Large Steam Turbine Generators," *ASME Paper No. 83-JPGC-Pwr-2* (1983).
104. White, M.F., "Simulation and Analysis of Machinery Fault Signals," *J. Sound Vib.*, 23 (1), pp 95-116 (Mar 8, 1984).
105. Wichmann, H. and Phillips, D., "Acoustic Emission Techniques for Locating Internal Leakage of Redundant Components," *J. Spacecraft Rockets*, 21 (1), pp 36-40 (Jan/Feb 1984).
106. Yang, J.C.S., Dagalakis, N.G., Everstine, G.C., and Wang, Y.F., "Measurement of Structural Damping Using the Random Decrement Technique," *Shock Vib. Bull.*, U.S. Naval Res. Lab., *Proc. 53, Pt. 4*, pp 63-71 (May 1983).
107. Yang, J.C.S., Chen, J., and Dagalakis N.G., "Damage Detection of Off-Shore Structures by Random Decrement Technique," *J. Energy Res. Tech.*, *Trans. ASME*, 106 (1), pp 38-42 (Mar 1984).
108. Yang, J.C.S., Tsai, T., Pavlin, V., and Chen, J., "Structural Damage Detection by System Identification Technique," *Shock Vib. Bull.*, U.S. Naval Res. Lab., *Proc. #55, Pt. 3*, pp 57-66 (June 1985).
109. Yee, K.W. and Blomquist, D.S., "Rotating Tool Wear Monitoring Apparatus," *Dept. Commerce, Washington, D.C.*, U.S. Patent No. 4 471 444.
110. Yoshioka, T. and Fujiwara, T., "Application of Acoustical Emission Technique to Detection of Rolling Bearing Failure," *Acoustic Emission Monitoring Anal. Mfg.*, *ASME*, New Orleans, LA, pp 55-75 (1984).

# LITERATURE REVIEW: survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four reviews each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the **DIGEST** reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

## FRACTURE ANALYSIS — A REVIEW

D. Broek\*

**Abstract.** This article is a review of practical methods for fracture mechanics analysis. Linear elastic methods can yield useful results. Elastic-plastic methods are becoming useful with the development of simple expressions for  $J$  that contain only one geometry factor. Present limitations are due only to limited availability of geometry factors.

Fracture mechanics analysis based on linear elastic concepts developed in the 1960s has become established during the last decade as a practical analytic method for studying structural fracture. Its use has become institutionalized by damage tolerance requirements implemented in the late 1970s for both military and civil airplanes. Fracture analysis is also prescribed in the ASME boiler and pressure vessel code. During the last decade a fracture analysis method based on elastic-plastic concepts has emerged and become practical because simple expressions containing only one geometry parameter can be used for the fracture parameter.

This review emphasizes fracture analysis methods that are useful for predicting structural fracture; other developments are mentioned but not discussed in detail. The bases for the practical methods are presented with sufficient detail to enable the reader to appreciate similarities and differences. Because all fracture analysis, whether elastic or elastic-plastic, must be combined with collapse analysis, the latter is discussed first. Results and examples of the accuracy of the methods are presented after the discussion of concepts.

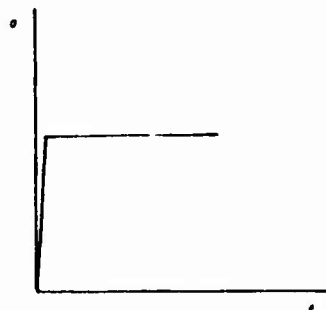
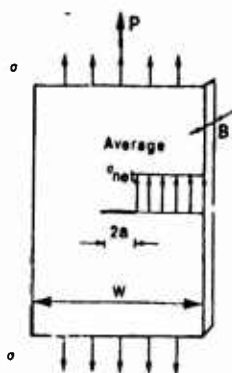


Figure 1. Maximum Load Carrying Capacity Reached at Net Section Yield for Ideally Plastic Material.

### FRACTURE CONCEPTS

#### **Collapse.**

Although given a new name and a slightly different interpretation, collapse is the same as the classical limit load concept [1]. The limit load is reached when the average stress in the smallest section exceeds the yield stress. The concept is trivial for an ideally plastic material and a center crack as shown in Figure 1. After the stress equals the yield stress of the material,  $\sigma_{ys}$ , the limit load,  $P_{lim}$  of a plate of width  $W$  and thickness  $B$  with a center crack of size  $2a$  is:

$$P_{lim} = (W - 2a)B\sigma_{ys} \quad (1)$$

The limit load is the highest load a panel can sustain under any circumstances; hence, the limit load is the absolute maximum failure load.

At the limit load the nominal stress in a panel is  $\sigma_f = P_{lim}/WB$ , so that the absolute maximum failure stress is:

$$\sigma_{fmax} = \frac{W - 2a}{W} \sigma_{ys} \quad (2)$$

Note that for a center crack the failure stress depends linearly upon crack size, as illustrated in

\* FractureResearch Inc., 9049 Cupstone Drive, Galena, Ohio 43021

Figure 2. For other geometries and other loading the limit load can be calculated just as easily.

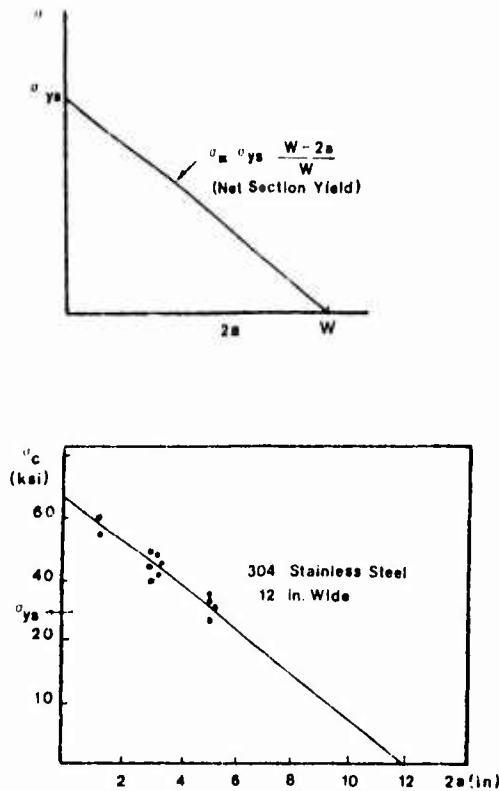


Figure 2. Net Section Yield and Net Section Collapse.

- a. Stress at net section yield for panel of width  $W$  and crack  $2a$ .
- b. Net section collapse in stainless steel [1].

For materials with slightly rising stress-strain curves the use of the yield stress in equation (2) is slightly conservative [2,3]. Materials that can be treated with linear elastic fracture mechanics usually belong in this category. No fracture mechanics analysis is complete without evaluation of the limit load. If the analysis indicates a fracture stress higher than the stress calculated by equations (2), failure will occur by collapse. The actual failure stress is the lower of the values calculated for fracture stress and stress at collapse by equation (2).

It was originally proposed [2] that fracture stress applied only in plane stress, but it also applies in plane strain. No matter how low the toughness, the calculated fracture stress for very small cracks will be higher than the yield. In such a case failure occurs by collapse. The

regime is similar for very large cracks. If a structure is very small, failure always almost occurs by collapse even if the toughness is low [2,3].

In the case of materials with considerable work hardening -- that is, for cases in which a large difference exists between yield stress and ultimate tensile stress -- equation (2) is too conservative. Thus, it has been proposed [1] that collapse load should be defined as the load at which the average net section stress is the collapse stress  $\sigma_{coll}$ , which is higher than the yield stress but less than the ultimate tensile strength. Although the value of the collapse stress can be measured readily in a test [1], it is often arbitrarily taken as equal to the average of the yield stress and the ultimate tensile stress [4].

Using collapse stress means that equation (1) and equation (2) become

$$P_{lim, collapse} = (W - 2a)k\sigma_{coll} \quad (3)$$

and

$$\sigma_{f, max} = \frac{W - 2a}{W} \sigma_{coll} \quad (4)$$

The collapse load is the absolute highest load a structure can sustain regardless of any fracture mechanics, be it elastic or elastic-plastic. The stress at collapse  $\sigma_{f, max}$  is the nominal stress at the collapse load;  $\sigma_{coll}$  is the average net section stress at collapse. Collapse load and stress at collapse must be evaluated in any fracture analysis. The actual failure stress is the lower of the values for calculated fracture stress and stress at collapse. Omission of this trivial step is one of the reasons why fracture predictions are often not conservative.

**Linear elastic concept based on stress.** The elastic stress distribution at the tip of an arbitrary crack in an arbitrary body subjected to arbitrary crack opening loading by tension or bending is given as [5].

$$\sigma_x = \frac{k}{\sqrt{2\pi x}} \quad (5)$$

where  $\sigma_x$  is the tensile stress on the section through the crack, and  $x$  the distance from the crack front (Figure 3). The stresses in other directions can be described in a similar manner.

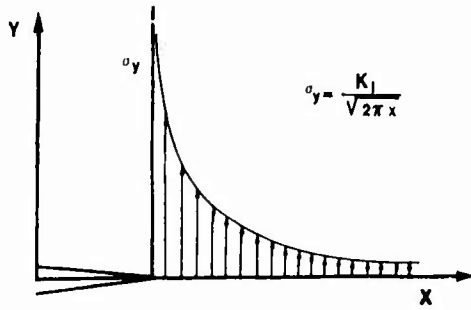


Figure 3. Crack Tip Stresses.

Because equation (5) is for an arbitrary case, it is valid for any and all crack tips. Crack tip stress  $\sigma_y$  apparently depends only on the parameter  $K$ , called the stress intensity factor. Equation (5) is for elastic stress; hence  $\sigma_y$  must be proportional to the applied stress  $\sigma$ . Crack tip stress also depends upon crack size. For equation (5) to have the proper dimension,  $\sigma_y$  must depend upon the square root of crack size. Without any analysis it can readily be seen that

$$\sigma_y = \frac{K}{\sqrt{2\pi x}} = \frac{C\sigma\sqrt{a}}{\sqrt{2\pi x}}$$

so that

$$K = C\sigma\sqrt{a} \quad (6)$$

The numerical factor  $C$  depends upon geometry. Because equation (6) shows  $C$  as dimensionless,  $C$  can depend upon geometry only as  $C = f(a/L)$ .  $L$  is a characteristic length parameter. It has become common practice to replace  $C$  by  $\beta$ , with  $\beta = C\sqrt{\pi}$ . This leads to equation (7).

$$K = \beta\sigma\sqrt{\pi a} \quad \text{with } \beta = f(a/L)$$

(7)

From equation (6) and equation (7) the crack tip stresses are known completely if  $\beta$  is known for the geometry at hand. Handbooks [6-8] for  $\beta$  exist; any of many procedures [9] can be used to determine  $\beta$  for new geometries.

The fracture criterion in linear elastic fracture mechanics (LEFM) states that fracture occurs when the crack tip stress field becomes critical. For  $\sigma_y$  in equation (6) to exceed a critical value,  $K$  must exceed a critical value. (This condition holds when a small amount of plastic deformation occurs at the crack tip [3].) If the

critical value of  $K$  is called  $K_{Ic}$ , the fracture criterion is that fracture occurs if

$$K \geq K_{Ic} \quad (8)$$

The critical value  $K_{Ic}$  is called the toughness of the material. Toughness depends upon the crack tip state of stress (plane stress or plane strain) [3]. Toughness is lowest for the case of plane strain and is generally denoted  $K_{Ic}$ .  $K_{Ic}$  denotes toughness in non-plane strain conditions. LEFM applies in the same manner in both cases.

The fracture criterion of equation (8) can be rewritten

$$\beta\sigma_f\sqrt{\pi a} = K_{Ic} \quad (9)$$

where  $\sigma_f$  is the applied stress. Thus, the stress at fracture is

$$\sigma_f = \frac{K_{Ic}}{\beta\sqrt{\pi a}} \quad (10)$$

The fracture condition is given by equation (10) whether or not the fracture toughness  $K_{Ic}$  is known. If the toughness is not known, fracture stress  $\sigma_f$  can be measured in a test and the toughness determined with equation (9). (Any specimen will suffice; there is no need to use a standard [10] specimen. If such a need existed the result would be useless for fracture predictions other than for that specimen.) If the toughness is known, the fracture stress of any structure with a crack follows from equation (10). The actual failure stress is the lower value of the stresses calculated by equation (2) and equation (10).

#### Linear elastic concept based on strain energy.

Energy conservation requires that no energy is lost when a body is loaded. Therefore, the work  $F$  done by a load must equal the strain energy  $U$  in the body.

$$F = U = 0 \quad (11)$$

The equation holds when a body is cracked. But, if the crack propagates, a new energy term comes into play; namely the work of fracture  $W$ . If crack size equals  $a$ , fracture over a distance  $da$  would require a small quantity of energy  $dW$ . This energy must be delivered by another source, either  $F$  or  $U$ . In the process of frac-

ture over  $da$ , the work done by the load is  $dF$ , and the change in strain energy is  $dU$ . Energy conservation requires that [3,11]

$$\frac{d}{da} (F - U - W) = 0 \quad (12)$$

or

$$\frac{d}{da} (F - U) = \frac{dW}{da} \quad (13)$$

Equation (13) is a fracture criterion. Fracture over  $da$  will occur when equation (13) can be satisfied; i.e., if enough energy can be delivered to provide  $dW$ . If not enough energy is delivered, equation (11) remains in effect. Assigning different symbols to the terms in equation (13), allows the equation to be written in the form:

$$G = R \quad (14)$$

$G$  is the released energy (energy release rate);  $R$  is the fracture resistance. Fracture will occur according to equation (14) when the released energy  $G$  is sufficient to deliver the required energy  $R$ . It can be shown [3] that the released energy is  $G = K^2/E$ , where  $E$  is Young's modulus. Equation (14) thus means that fracture occurs if

$$\frac{K^2}{E} = R \quad (15)$$

or

$$\frac{\beta^2 \sigma_n^2 a}{E} = R \quad (16)$$

In order for equation (16) to be the same as equation (9),  $R$  must equal  $K_c^2/E$ . The work of fracture is thus equal to the square of the toughness divided by the modulus.

$R$  depends upon the amount of crack extension  $\Delta a$  [3]. The energy for fracture increases as fracture progresses. The conclusion is that fracture can be stable or unstable (uncontrollable). An uncontrollable fracture occurs when

$$\frac{dG}{da} < \frac{dR}{da} \quad (17)$$

The rising fracture resistance  $R$  is referred to as the R-curve. Fracture analysis based on equation (16) and equation (17) is referred to as the energy method, or the R-curve method. Its principles were established as early as 1960. Almost all material under all circumstances exhibit a rising R-curve; in cases of low toughness, the rise is so small that the curve is essentially flat.

Because  $G = K^2/E = \beta^2 \sigma_n^2 \pi a / E$ , the condition of equation (17) is the point of tangency between the  $G$  curve and the  $R$  curve. The  $G$ -line is straight and is a function of  $a$  when  $\beta = 1$ . The slope of the line depends upon the stress. For the case shown in Figure 4a fracture begins at  $a_1$ , proceeds stably from  $a_1$  to  $a_c$ , and becomes unstable at  $a_c$ . If the R-curve rises gently, as is often the case in plane strain, instability is immediate, so that the rise of the R-curve may go unnoticed.

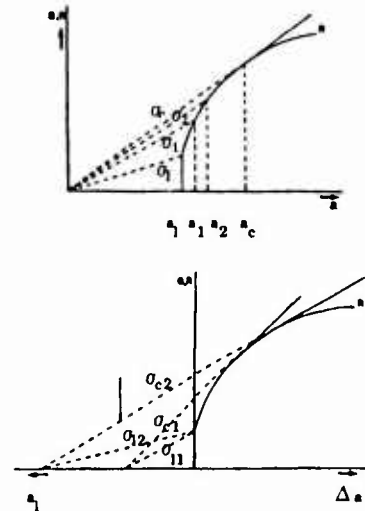


Figure 4. Energy Conservation Criterion for Fracture.

- a. R-curve and G-lines
- b. Instability points

Because Young's modulus can be divided out of equation (16), equation (16) and equation (17) can be rewritten

$$\left. \begin{aligned} K &= K_R \\ \frac{dK}{da} &\geq \frac{dK_R}{da} \end{aligned} \right\} \quad (18)$$

$K_R$  is the same as  $\sqrt{ER}$ . The procedure does not change.

**Elastic-plastic concept.**

The most useful elastic-plastic fracture mechanics (EPFM) concept developed thus far is based on the energy conservation concept of equation (13) and equation (17). Unfortunately, the energy quantities involved have been given different names. The new name for  $G$  is  $J$ , and the new name for  $R$  is  $J_R$ . Thus, equation (14) becomes equation (19). Fracture occurs if

$$J = J_R \tag{19}$$

With the usual rising  $R$ -curve (now  $J_R$ -curve) equation (18) becomes:

$$\frac{dJ}{da} \geq \frac{dJ_R}{da} \tag{20}$$

Because of the original definition [12] the quantity  $J$  is known as the  $J$ -integral. However, it can be shown [3,12] that  $J$  is essentially the energy release rate. Equation (19) and equation (20) are valid for materials with nonlinear stress-strain curves and are therefore useful for EPFM.

The various mathematical expressions for  $J$  in approximate form are called estimation schemes. The most elegant solution is obtained when the plastic strain of a material can be expressed as

$$c_p = \frac{\sigma^n}{F} \tag{21}$$

in which  $n$  is known as the strain hardening exponent; and  $F$  is a plastic modulus. Note that for  $n = 1$  and  $F = E$  the equation reduces to Hooke's law, for which the energy equation for fracture is  $G = R$ . It is written

$$\frac{\beta^2 \sigma^2 \pi a}{E} = R \text{ or } \frac{\beta^2 \sigma^{n+1} a}{E} = R \tag{22}$$

A similar expression is obtained when  $n$  is not equal to 1 and  $F$  is not equal to  $E$ . In that case

$$H \sigma_0^{n+1} a = J_R \tag{23}$$

$H$  is a geometric parameter similar to  $\beta$ , but  $H$  also depends on  $n$ .

Indeed, equation (23) is the plastic fracture criterion [3]. Unfortunately, instead of using equation (23) the developers of the geometric functions [13,14] elected to write equation (21) as

$$\frac{\epsilon}{\epsilon_0} = \left( \frac{\sigma}{\sigma_0} \right)^n \tag{24}$$

Where  $\sigma_0$  is called the flow stress and  $\epsilon_0 = \sigma_0 / E$ . The stress  $\sigma_0$  is only a reference stress that can be chosen arbitrarily at any value so long as  $\epsilon_0 = \sigma_0 / E$  and

$$\alpha = \frac{\sigma_0^n}{\epsilon_0 F} \tag{25}$$

Thus, calling  $\sigma_0$  the flow stress suggests incorrectly that this arbitrary reference stress should have physical significance.

This new definition of the stress-strain curve also changes the fracture equation from equation (23) into

$$\alpha \sigma_0 \epsilon_0 c h_1 \left( \frac{P}{P_0} \right)^{n+1} = J_R \tag{26}$$

Compare equation (23) and equation (26); it appears that crack size  $a$  is replaced by the uncracked ligament  $c$  and that the geometric function  $H$  is replaced by  $h_1$ . Stress is replaced by load  $P$ ; load  $P_0$  is introduced.  $P_0$  is the limit load if  $\sigma_0$  were the collapse stress, but, because  $\sigma_0$  is arbitrary,  $P_0$  is a fictitious limit load. It is trivial that  $c$ ,  $P_0$ , and  $P$  are related to  $a$ ,  $\sigma_0$ , and  $\sigma$  by geometric functions. Equation (25) can be used to reduce fracture equation (26) readily [15] to equation (23).

Equation (26) raises the false expectation that fracture stress depends upon collapse load. The collapse load is indeed the limiting condition, but this condition must be evaluated separately. Equation (26) does not account for collapse load

because it is equivalent to equation (23). Artificial introduction of a limit load to equation (26) does not make the fracture stress dependent upon this limit load [15].

Equation (20) and equation (23) can be used if elastic deformations can be neglected. Otherwise the elastic energy release must be included. Fracture thus occurs if

$$G + J = J_R \quad (27)$$

Equation (27) requires combination of equation (16) and equation (23) or equation (26).

In EPFM the toughness is given by  $J_R$ , which is a rising curve as a function of the amount of crack extension  $\Delta a$ , just as the R-curve discussed previously. This toughness can be obtained from a test that involves measuring the fracture stress to evaluate equation (23) to obtain  $J_R$ . After  $J_R$  is known, equation (23) can be used to calculate the fracture stress of a structure for which  $H$  ( $h_1$ ) is known [13,14]. Note that the actual failure stress is still the lower value of the stress calculated from equation (4) and equation (23). Failure occurs by collapse if the collapse stress on the net section is reached before the fracture condition. Collapse is still the limiting condition and must be evaluated separately.

Another estimation scheme is generally used [16] to obtain  $J$  in a test. Because  $J$  is the energy release rate,  $J_R$  equals the energy release rate at fracture. Energy release can be expressed as the change in strain energy; strain energy can be related to the load-displacement curve. Appropriate simplifications and assumption can be used to obtain directly an approximate value for  $J$  from the load-displacement diagram, provided the displacement is due only to the crack. If a compact tension specimen is used, virtually all displacement is due to the crack. Thus,  $J_R$  is obtained from the area under the load-displacement diagram. Attempts have been made to use the reverse procedure to predict structural fracture [17]; the results are debatable however, because grossly simplifying assumption must be made to obtain the displacement-due-to-the-crack-only of a cracked structure.

#### Variations on the theme.

The most commonly used alternative criteria for fracture are based upon crack (tip) opening displacement [18] or crack opening angle [19]; that is, fracture occurs when the crack opening displacement exceeds a critical value. These

criteria are not really different from those discussed above. Both quantities can be expressed directly [13,14] in  $G$  or  $J$ ; the critical values of these quantities can be directly expressed in  $R$  or  $J_R$  by the same mathematical relation. Therefore, the fracture criteria are identical to equation (10) and equation (23). The criteria chosen are a matter of personal preference unless certain ones can be more easily measured in a test.

Crack tip opening quantities can be measured directly;  $R$  and  $J_R$  must be obtained by mathematical manipulation from other measurements. Direct measurement may be useful for obtaining the material property that represents toughness (e.g., critical COD). Alternative criteria do not provide anything new or make anything easier. If the criteria discussed in previous sections work, those based on crack tip opening will work.

Other alternative approaches often introduce an artificial second parameter [3,20]. A cleverly selected second parameter can eliminate some anomalies but usually introduces new ones. One of the oldest parameters is the so-called plastic zone correction [3]. The crack size  $a$  is artificially increased to  $a + r_p$ ;  $r_p$  is the plastic zone at fracture given by

$$r_p = \frac{K_c^2}{b^2 \pi \sigma^2} \quad (28)$$

Substitution of  $a + r_p$  for  $a$  in equation (9) gives as the fracture condition

$$\beta \sigma_f \sqrt{(a + K_c^2 / b^2 \pi \sigma_f^2)} = K_c \quad (29)$$

Although this equation seemingly solves a problem, it introduces a new anomaly: if  $a = 0$  the predicted fracture stress is  $h \sigma_{ys} / \beta$ . To obtain a fracture stress equal to  $\sigma_{11}$  the ultimate tensile strength at  $a = 0$  (if  $\beta = 1$ ) is

$$\sigma_f \sqrt{(a + K_c^2 / \pi \sigma_{11}^2)} = K_c \quad (30)$$

Equation (28) and equation (29) are two-parameter fracture criteria. Many more can be created

in a similar manner. Some will work; however, most will not because they are artificially constructed and misrepresent the problem.

The tearing modulus concept seems to be a new approach but is the same as equation (17), which was established in the late 1950s. The quantities in the equation are made dimensionless by multiplication of both sides by  $E / \sigma_{ys}^2$

$$(E / \sigma_{ys}^2)(dJ / da) \geq (E / \sigma_{ys}^2)(dJ_R / da) \quad (31)$$

The quantities in the equation are then given new symbols

$$T \geq T_{\text{material}} \quad (32)$$

where  $T$  is called the tearing modulus. Equation (32) is nothing more than another form of equation (17).

The so-called R6 approach is not a new approach. The concept was originally proposed in England [21] and is now being suggested [22] as an alternative fracture criterion, which it is not. The concept merely recognizes that fracture occurs when  $K = K_c$  or that collapse occurs when net section stress equals collapse stress. The result is the fracture locus shown in Figure 5. The curved part of the fracture locus cannot be defined other than by a plastic fracture criterion. In the R6 approach the curved part is defined on the basis of  $J_R$ . The curve is then (with some modifications) used to predict fracture. If the criteria based on  $K$  and  $J$ , as discussed in the previous sections, are applicable, the R6 approach is useful. If the R6 approach leads to different answers, it is because the material properties used as input are different (which they should not be) or simplifications or errors were introduced.

#### Other fracture problems.

The fracture criteria discussed above have been developed to the point of practical application. For some time research has been in progress in applying these criteria to nonstructural materials such as rocks and eye glasses and to structural materials of the future such as ceramics and composite materials. Applications to brittle and semi-brittle materials are relatively straight forward; applications to composite materials are not.

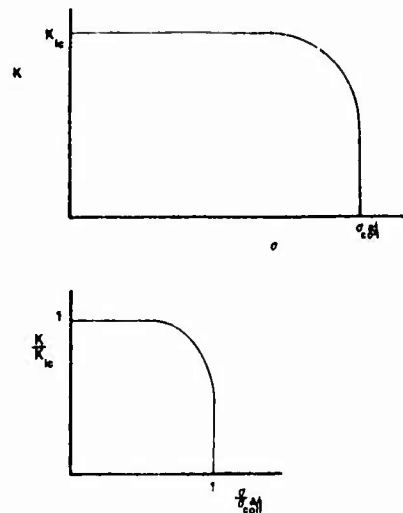


Figure 5. Fracture analysis Diagram [21].

- a. Fracture locus
- b. Normalized diagram

Research on fracture mechanics of composites has not yet passed the point of testing and material characterization. The meaning of test results is often not understood; the criteria used are often primitive [23].

Another area of research, dynamic fracture, is of special interest with regard to armor and weapons penetration. Considerable progress has been made [24]. In essence the fracture condition of equation (13) is modified to account for another energy term, the kinetic energy. The fracture resistance  $J_R$  or  $R$  is different; it accounts for strain rate sensitivity of the material.

### APPLICATIONS

The usefulness of LEFM for structural fracture predictions is well established. Fracture of a cracked structure can be predicted on the basis of equation (10). The geometric factor for the structural crack must be obtained first. Among various procedures for obtaining  $Y$ , the most common and simple one is superposition and compounding of solutions compiled in handbooks [6-8]. For a certain crack size the fracture stress follows from equation (10). Solving the equation for a range of crack sizes provides a residual strength diagram; i.e., the remaining structural strength in the presence of a crack as a function of crack size.

Care should be taken that the collapse or limit load condition is also evaluated. The actual failure stress is the lower of the value calculated for fracture stress and the stress at collapse. In many cases the collapse condition prevails; e.g., Figure 6. Failure to assess collapse is one of the reasons LEFM is claimed to have limited use; but combination of collapse analysis and LEFM can solve many fracture problems with accuracy. Figure 7 compares predicted fracture stresses for cracks at holes with actual test data [25].

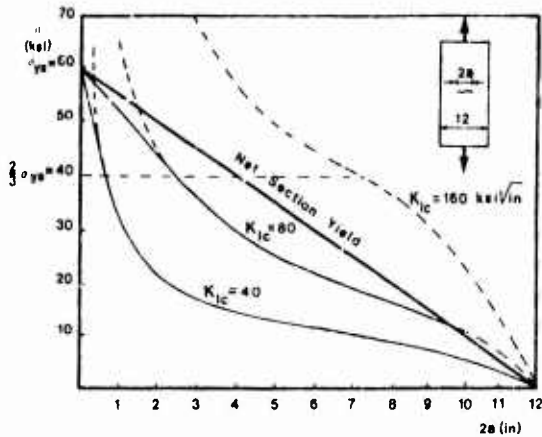


Figure 6. Cases of Elastic Fracture and Collapse.

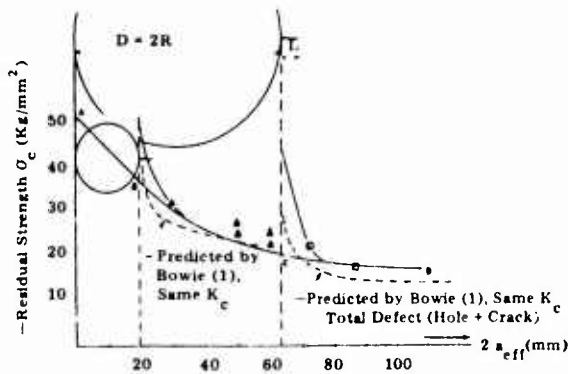


Figure 7. Predictions of Fracture Stress for Cracks at Holes and Test Data [25].

Fracture prediction by EPFM requires solution of equation (23) or equation (26). The geometric factor  $H$  (or  $h_1$ ) must be known. If the use of EPFM is still somewhat limited, it is because geometric factors are available for only a few geometries [13,14]. Extensive applications will require the generation of many more geometric factors. At present only problems for which  $H$

is available can be solved; e.g. cracks in cylinders. A simple method for estimating  $H$  on the basis of  $\beta$  has been proposed [15]. In the case of EPFM the failure stress is the lower value of the stress calculated at collapse and the predicted fracture stress. Failure stress can then be predicted with reasonable accuracy [4,15] as shown in Figure 8 and Figure 9. The collapse load is sometimes inaccurate because the collapse stress was not measured; rather, it was arbitrarily assumed to be equal to the average of yield stress and ultimate tensile stress.

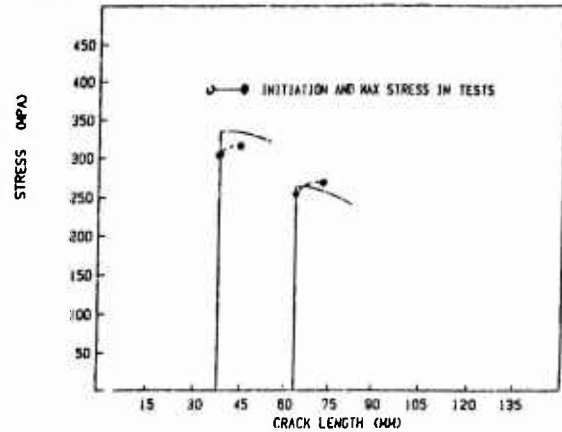


Figure 8. Elastic-Plastic Fracture Predictions [15] and Test Results [4].

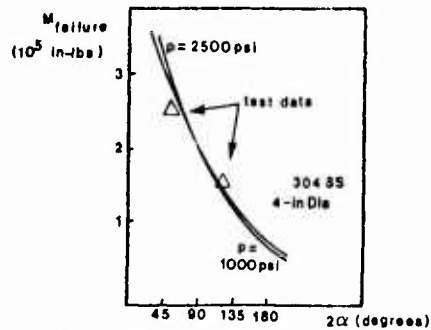
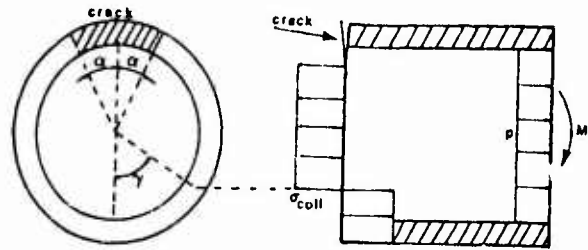


Figure 9. Failure by Collapse of Cracked Stainless Steel Pipe [1].

- Collapse analysis model
- Predicted curves and test data

Typical  $J_R$  curves are shown in Figure 10.  $J$  can vary, depending on the way the test is evaluated. Consider equation (23); a slight error in stress or load calculation has a very large effect on  $J_R$ . That is when  $n = 9$  an error of 5% in stress leads to an error of  $(1.05)^{10} = 1.63$  or 63% in  $J_R$ . (Similar errors occur with other estimation schemes for the same reason; namely the gentle slope of the load-displacement curve.) On the other hand, if these  $J_R$  values are used to predict a fracture stress, an error of 63% in the toughness  $J_R$  would cause an error of only 5% in fracture stress if  $n = 10$ . Thus, EPFM is very forgiving. Reasonable results can be obtained even with approximate values.

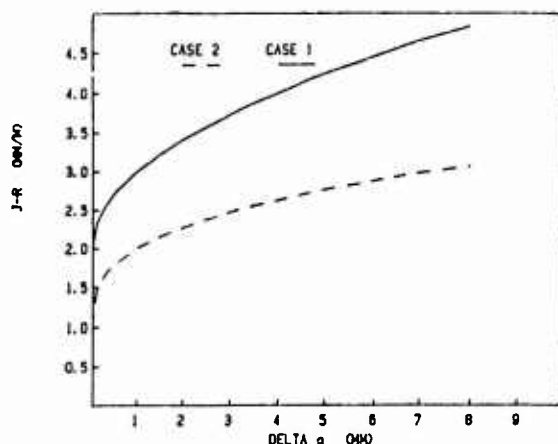


Figure 10.  $J_R$ -Curves for Stainless Steel.

Other fracture criterias, if they are applied correctly, should give the same answers. The criteria based on crack tip displacements are identical for the  $J$ -criterion. Thus, different results are due to interpretations of tests used to obtain material parameters, use of approximations, or errors in any of the procedures used. That different  $J$ -estimation schemes may lead to different results is an indication of the accuracy of a  $J$  estimate, not of a fracture analysis.

Fracture analysis is an inherently inaccurate process because of scatter in material properties. Yield stress and ultimate tensile strength are measured for the bulk of the test coupon (integrated over the coupon). On the other hand, fracture properties are only for the small amount of material that happens to be at the crack tip at the time of fracture. Thus, the lack of homogeneity of the material plays a much larger role in determining scatter. Fracture in the structure is affected. LEM toughness values typically suffer by 15%. LEM fracture stress prediction can be off by 15%.

This is not a shortcoming of fracture mechanics but is due to less-than-ideal material behavior. In this respect EPFM is an advantage because the method is forgiving.

## CONCLUSION

Progress in fracture analysis during the last decade has been in the consolidation of linear elastic methods (LEFM). LEFM in combination with collapse analysis provides answers to most structural fracture problems. A usable elastic-plastic method (EPFM), which must be used in combination with collapse analysis, has also been developed. EPFM has become useful in a practical sense due to the development of a  $J$ -estimation scheme that permits an expression for  $J$  with only one geometric parameter, as in the case of  $K$ . Present limitations are due to limited availability of geometry factors. Fracture analysis methods not based on  $K$  or  $J$  are essentially equivalent to geometric factors and should give the same results unless errors are made in interpretation or simplification. Fracture analysis of metals and ceramics yields useful results considering the inherent inaccuracy of fracture analysis due to scatter in material behavior. Fracture analysis procedures of composites are nonexistent; research in this area is in the material-characterization stage.

## REFERENCES

1. Kanninen, M.F. et al., "Towards an Elastic-Plastic Fracture Mechanics Capability for Reactor Piping," *Nuclear Engrg. Des.*, **48**, pp 117 (1976).
2. Feddersen, C.E., "Evaluation and Prediction of the Residual Strength of Center Cracked Tension Panels," *ASTM STP 486*, pp 50-78 (1971).
3. Broek, D., Elementary Engineering Fracture Mechanics, Nijhoff, 3rd Ed. (1982).
4. Wilkowski, G.M. et al., "Degraded Piping Program - Phase II," *NURFG/CR-4082* (1985).
5. Paris, P.C. and Sih, G.C., "Stress Analysis of Cracks," *ASTM STP 381*, pp 30-81 (1965).
6. Tada, H. et al., The Stress Analysis of Cracks Handbook, Del Research Corp. (1973).
7. Sih, G.C., Handbook of Stress Intensity Factors, Lehigh Univ. Press (1973).

8. Rooke, D.P. and Cartwright, D.J., Compendium of Stress Intensity Factors, H.M. Stationery Office (1976).
9. Rooke, D.P. et al., "Simple Methods of Determining Stress Intensity Factors," AGARD-ograph 257 (1980).
10. The Standard K<sub>Ic</sub> Test, ASTM Standard E-399.
11. Griffith, A.A., "The Phenomena of Rupture and Flow in Solids," Phil. Trans. Royal Soc., Ser. A, 221, pp 163-197 (1921).
12. Rice, J.R., "A Path Independent Integral and the Approximate Analysis of Strain Concentrations by Notches and Cracks," J. Appl. Mech., Trans. ASME, pp 379-386 (1968).
13. Kumar, V. et al., "An Engineering Approach for Elastic-Plastic Fracture Analysis," EPRI NP-1931 (1981).
14. Kumar, V. et al., "Advances in Elastic-Plastic Fracture Analysis," EPRI NP-3607 (1984).
15. Broek, D., "J Astray and Back to Normalcy," Paper to European Congress of Fracture (1986).
16. Merkle, J.G. and Corten, H.T., "A J-integral Analysis for the Compact Specimen Considering Axial Force as well as Bending Effects," J. Pressure Vessel Tech., 26, pp 286-292 (1974).
17. Paris, P.C. and Tada, H., "The Application of Fracture Mechanics Methods Using Tearing Instability Theory to Nuclear Piping Postulating Circumferential through Wall Cracks," NUREG/CR-3464 (1983).
18. Burdekin, F.M. and Stone, D.E.W., "The Crack Opening Displacement Approach to Fracture Mechanics in Yielding," J. Strain Anal., 1, pp 145-153 (1966).
19. Kanninen, M.F. et al., "Instability Predictions for Circumferentially Cracked Type 304 SS Pipes Dynamic Loading," EPRI NP-2347 (1982).
20. Newman, J.C. and Loss, F.J. (eds.), Elastic-Plastic Fracture Mechanics Technology, ASTM STP896 (1985).
21. Chell, G.C., "A Procedure for Incorporating Thermal and Residual Stresses into the Concepts of a Failure Analysis Diagram," ASTM STP 668 (1979).
22. Bloom, J.M., "Deformation Plasticity Failure Assessment Diagram," ASTM STP 896, pp 114-127 (1985).
23. NASA, Tough Composite Materials, Noyes Publ. (1985).
24. Hahn, G.T. and Kanninen, M.F. (eds.), Fast Fracture and Crack Arrest, ASTM STP 627 (1977).
25. Broek, D. and Vlieger, H., "Cracks Emanating from Holes in Plane Stress," Intl. J. Fract. Mech., 8, pp 353-356 (1972).

# BOOK REVIEWS

## PROBLEMS IN PERTURBATION

Ali H. Nayfeh  
John Wiley & Sons, New York, NY  
556 pages + xi, 1985

The development of the theory of nonlinear differential equations has promoted the study of several engineering problems that were regarded difficult in the past. The theory helped engineers to understand complex system characteristics that could not be explained within the framework of the linear theory of differential equations. The importance of nonlinear theory has been realized by several schools that currently offer courses in nonlinear vibrations or nonlinear differential equations. Although there are several books on nonlinear oscillations and differential equations, students and researchers frequently encounter difficulties concerning the applicability of existing theories of perturbation techniques. Professor Nayfeh is an authority in perturbation methods and his book Problems in Perturbation contains detailed solutions of all the problems in his earlier book Introduction to Perturbation Techniques (John Wiley & Sons, 1973). The book contains 15 chapters; each chapter is followed by a number of solved problems and an equal number of unsolved supplementary problems.

The first four chapters contain a mathematical background of basic concepts and methods for solving nonlinear differential equations. Chapter 1 presents definitions of parameter and coordinate perturbations, gauge functions, order symbols, asymptotic series and expansions, and nonuniform expansion. Chapter 2 summarizes a number of methods for solving algebraic and transcendental equations. Differential equations, the solution of which is represented in the form of integrals, are outlined in chapter 3. They include asymptotic expansions of functions defined by definite integrals, expansions of integrands, integration by parts, Laplace's method, method of stationary phase, and the method of steepest descent. Several integrals encountered in differential equations are given as exercises. Chapter 4 treats nonlinear differential equations of conservative systems. Applications of the Lindstedt-Poincare method, the method of renormalization, the method of multiple scales, and

the method of averaging are well demonstrated with a number of solved problems.

Chapters 5 and 6 deal with free oscillations of nonlinear systems with sources of positive and negative damping respectively. Although both the Lindstedt-Poincare technique and the method of renormalization account for the shift in frequency caused by the perturbation, they do not adequately provide approximations to the transient response for the problems because neither accounts for variations in amplitude. In contrast, both the method of multiple scales and the method of averaging provide uniform expansions for the transient response. Chapter 7 considers the free oscillations of undamped systems with quadratic and cubic stiffness nonlinearities. For these systems the Lindstedt-Poincare technique, the method of renormalization, the method of multiple scales, the generalized method of averaging, or the Krylov-Bogoliubov method can be used to derive approximate solutions.

Chapters 9 through 11 deal with the responses of nonlinear systems when subjected to different types of external excitations. External harmonic excitations are considered in chapter 9, multi-frequency excitations are treated in chapter 10, and parametric excitations are analyzed in chapter 11. In chapter 9 the method of multiple scales is used for solving systems with quadratic nonlinearity; the methods of averaging and multiple scales are used to treat systems with cubic nonlinearity. Systems with quartic nonlinearity are solved using the straightforward expansion, the method of multiple scales, and the averaging method. In chapter 10 on multi-frequency excitations the author introduces possible resonance conditions that depend on the number of excitation components and the order of nonlinearity. Methods of multiple scales, averaging, or Krylov-Bogoliubov are used to determine amplitude and phase of the response. For parametric excitations (chapter 11) the method of strained parameters and Whittaker's technique are used to determine the stability regions of linear systems. When nonlinearity is included, Floquet theory fails to predict the response limit cycle. In this case the author recommends the methods of multiple scales, averaging, or Krylov-Bogoliubov to determine uniform expansions for linear as well as nonlinear systems with periodic and non-periodic coefficients.

Chapter 12 deals with a different class of differential equations known as boundary-layer problems. These problems are described by linear or nonlinear differential equations with variable coefficients; the highest derivative is multiplied by a small parameter. The differential equations are usually handled by fast, magnified, or stretched scales. The mathematical techniques used with these problems include the method of matched asymptotic expansions, the method of composite expansions, and the method of multiple scales. Because of the versatility and effectiveness of the method of matched asymptotic expansions, the author briefly outlines this method and demonstrates its application to a number of solved problems the solutions to which are also obtained by other methods.

The asymptotic solutions of linear ordinary differential equations with variable coefficients in the neighborhood of a given finite point are analyzed in chapter 13. The conditions under which asymptotic solutions are developed are outlined in terms of the nature of the point in questions and its relation to the coefficients of the differential equation. Chapter 14 treats approximate solutions of differential equations with a large parameter. The Liouville problem is selected as a model for demonstrating the WKB method and the Langer transformation.

Chapter 15 deals with essential solvability conditions in perturbation techniques. The origin of these conditions is due mainly to the presence of secular or resonance terms that appear in higher-order perturbational equations. In other cases, such as boundary value problems, the perturbational equations may not possess solutions unless certain conditions are satisfied. The solvability conditions for vibration and boundary-value problems are well demonstrated with a number of solved problems. This chapter is the corner-stone of perturbation techniques; the solved problems serve several engineering applications.

The book succeeds in meeting its main objectives: to provide researchers and graduate students with an excellent account of perturbation techniques and an extensive number of supporting solved problems.

R.A. Ibrahim  
Professor of Mechanical Engineering  
Texas Tech University  
Department of Mechanical Engineering  
Lubbock, Texas 79409

## EARTHQUAKE DESIGN OF CONCRETE MASONRY BUILDINGS -- VOL. I

R.E. Englekirk, G.C. Hart, and Concrete  
Masonry Assoc. of California and Nevada  
Prentice Hall, Inc., Englewood Cliffs, NJ  
1982, 144 pp

This book is the first in a three-volume set for the earthquake design of concrete masonry buildings. It presents the background material required to calculate earthquake loads on buildings by means of response spectrum analysis. The authors have taken care to present this material in a simple, understandable form. The reader is not expected to have a knowledge of structural dynamics or a familiarity of earthquake terminology or design codes. The book is brief, consisting of six chapters and only 144 pages.

The six chapters provide 1) a brief overview of the concepts of earthquake design; 2) a limited introduction to common terms used in earthquake engineering, including an introduction to earthquake response spectrum; 3) the earthquake design approach used in the Uniform Building Code; 4) methods used to obtain a simple stiffness and mass model of shear wall buildings; 5) the elastic analysis of a simple system using elastic response spectra; and 6) the inelastic analysis of a simple system using inelastic response spectra. The two Appendices provide a description of a geotechnical consultant's role in earthquake design and an introduction to multi-degree-of-freedom response spectra analysis.

Several well-chosen examples provide clear demonstrations of the techniques. This book should be well received by those who desire a working knowledge of simplified methods of earthquake analyses.

S.E. Benzley  
Professor of Civil Engineering  
Brigham Young University  
Provo, Utah 84602

# SHORT COURSES

1987

## JANUARY

### VIBRATION DAMPING TECHNOLOGY

**Dates:** January, 1987

**Place:** Clearwater, Florida

**Objective:** Basics of theory and application of viscoelastic and other damping techniques for vibration control. The courses will concentrate on behavior of damping materials and their effect on response of damped systems, linear and nonlinear, and emphasize learning through small group exercises. Attendance will be strictly limited to ensure individual attention.

**Contact:** David I. Jones, Damping Technology Information Services, Box 565, Centerville Branch USPO, Dayton, OH 45459-9998 - (513) 434-6893.

## FEBRUARY

### RANDOM VIBRATION IN PERSPECTIVE -- AN INTRODUCTION TO RANDOM VIBRATION AND SHOCK, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION, WITH EMPHASIS ON STRESS SCREENING

**Dates:** February 2-6, 1987

**Place:** Santa Barbara, CA

**Dates:** March 9-13, 1987

**Place:** Washington, D.C.

**Dates:** April 6-19, 1987

**Place:** Ottawa, Ontario

**Dates:** June 1-5, 1987

**Place:** Santa Barbara, CA

**Dates:** August 17-21, 1987

**Place:** Santa Barbara, CA

**Dates:** October 19-23, 1987

**Place:** Copenhagen, Denmark

**Objective:** To show the superiority (for most applications) of random over the older sine vibration testing. Topics include resonance, accelerometer selection, fragility, shaker types, fixture design and fabrication, acceleration/power spectral density measurement, analog vs digital controls, environmental stress screening (ESS) of electronics production, acoustic (intense noise) testing, shock measurement and testing.

This course will concentrate on equipment and techniques, rather than on mathematics and theory. The 1984 text, "Random Vibration in Perspective," by Tustin and Mercado, will be used.

**Contact:** Wayne Tustin, 22 East Los Olivos St., Santa Barbara, CA 93105 - (805) 682-7171.

### ROTATING MACHINERY VIBRATIONS

**Dates:** February 9-11, 1987

**Place:** Orlando, Florida

**Objective:** This course provides participants with an understanding of the principles and practices of rotating machinery vibrations and the application of these principles to practical problems. Some of the topics to be discussed are: theory of applied vibration engineering applied to rotating machinery; vibrational stresses and component fatigue; engineering instrumentation measurements; test data acquisition and diagnosis; fundamentals of rotor dynamics theory; bearing static and dynamic properties; system analysis; blading-bearing dynamics examples and case histories; rotor balancing theory; balancing of rotors in bearings; rotor signature analysis and diagnosis; and rotor-bearing failure prevention.

**Contact:** Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254.

### APPLIED VIBRATION ENGINEERING

**Dates:** February 9-11, 1987

**Place:** Orlando, Florida

**Objective:** This intensive course is designed for specialists, engineers and scientists involved with design against vibration or solving of existing vibration problems. This course provides participants with an understanding of the principles of vibration and the application of these principles to practical problems of vibration reduction or isolation. Some of the topics to be discussed are: fundamentals of vibration engineering; component vibration stresses and fatigue; instrumentation and measurement engineering; test data acquisition and diagnosis; applied spectrum analysis techniques; spectral analysis techniques for preventive maintenance; signal analysis for machinery diagnostics;

random vibrations and processes; spectral density functions; modal analysis using graphic CRT display; damping and stiffness techniques for vibration control; sensor techniques for machinery diagnostics; transient response concepts and test procedures; field application of modal analysis for large systems; several sessions on case histories in vibration engineering; applied vibration engineering state-of-the-art.

**Contact:** Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

#### **MACHINERY VIBRATION ANALYSIS I**

**Dates:** February 24-27, 1987

**Place:** San Diego, California

**Dates:** August 18-21, 1987

**Place:** Nashville, Tennessee

**Dates:** November 17-20, 1987

**Place:** Oak Brook, Illinois

**Objective:** This course emphasizes the role of vibrations in mechanical equipment instrumentation for vibration measurement, techniques for vibration analysis and control, and vibration correction and criteria. Examples and case histories from actual vibration problems in the petroleum, process, chemical, power, paper, and pharmaceutical industries are used to illustrate techniques. Participants have the opportunity to become familiar with these techniques during the workshops. Lecture topics include: spectrum, time domain, modal, and orbital analysis; determination of natural frequency, resonance, and critical speed; vibration analysis of specific mechanical components, equipment, and equipment trains; identification of machine forces and frequencies; basic rotor dynamics including fluid-film bearing characteristics, instabilities, and response to mass unbalance; vibration correction including balancing; vibration control including isolation and damping of installed equipment; selection and use of instrumentation; equipment evaluation techniques; shop testing; and plant predictive and preventive maintenance. This course will be of interest to plant engineers and technicians who must identify and correct faults in machinery.

**Contact:** Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

#### **MARCH**

#### **MEASUREMENT SYSTEMS ENGINEERING SHORT COURSE**

**Dates:** March 9-13, 1987

**Place:** Phoenix, Arizona

**Objective:** Electrical measurements of mechanical and thermal quantities are presented through the new and unique Unified Approach to the Engineering of Measurement Systems. Test requestors, designers, theoretical analysts, managers, and experimental groups are the audience for which these programs have been designed. Cost-effective, valid data in the field and in the laboratory, are emphasized. Not only how to do that job, but how to tell when it's been done right.

**Contact:** Peter K. Stein, Director, 5602 East Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603 and (602) 947-6333.

#### **MEASUREMENT SYSTEMS DYNAMICS SHORT COURSE**

**Dates:** March 16-20, 1987

**Place:** Phoenix, Arizona

**Objective:** Electrical measurements of mechanical and thermal quantities are presented through the new and unique Unified Approach to the Engineering of Measurement Systems. Test requestors, designers, theoretical analysts, managers, and experimental groups are the audience for which these programs have been designed. Cost-effective, valid data in the field and in the laboratory, are emphasized. Not only how to do that job, but how to tell when it's been done right.

**Contact:** Peter K. Stein, Director, 5602 East Monte Rosa, Phoenix, AZ 85018 - (602) 945-4603 and (602) 947-6333.

#### **MAY**

#### **ROTOR DYNAMICS & BALANCING**

**Dates:** May 4-8, 1987

**Place:** Syria, Virginia

**Objective:** The role of rotor/bearing technology in the design, development and diagnostics of industrial machinery will be elaborated. The fundamentals of rotor dynamics; fluid-film bearings; and measurement, analytical, and computational techniques will be presented. The computation and measurement of critical speeds vibration response, and stability of rotor/bearing systems will be discussed in detail. Finite elements and transfer matrix modeling will be related to computation on mainframe computers, minicomputers, and microprocessors. Modeling and computation of transient rotor behavior and nonlinear fluid-film bearing behavior will be described. Sessions will be devoted to flexible rotor balancing, including

turbogenerator rotors, bow behavior, squeeze-film dampers for turbomachinery, advanced concepts in troubleshooting and instrumentation, and case histories involving the power and petrochemical industries.

**Contact:** Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

## NOVEMBER

### VIBRATIONS OF RECIPROCATING MACHINERY AND PIPING

**Dates:** November 10-13, 1987

**Place:** Oak Brook, Illinois

**Objective:** This course on vibrations of reciprocating machinery includes piping and foundations. Equipment that will be addressed includes reciprocating compressors and pumps as well as engines of all types. Engineering problems will be discussed from the point of view of computation and measurement. Basic pulsation theory -- including pulsations in reciprocating compressors and piping systems -- will be described. Acoustic simulation in piping will be reviewed. Calculations of piping vibration and stress will be illustrated with examples and case histories. Torsional vibrations of systems containing engines and pumps, compres-

sors, and generators, including gearboxes and fluid drives, will be covered. Factors that should be considered during the design and analysis of foundations for engines and compressors will be discussed. Practical aspects of the vibrations of reciprocating machinery will be emphasized. Case histories and examples will be presented to illustrate techniques.

**Contact:** Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

### MODAL TESTING OF MACHINES AND STRUCTURES

**Dates:** November 17-20

**Place:** Oak Brook, Illinois

**Objective:** Vibration testing and analysis associated with machines and structures will be discussed in detail. Practical examples will be given to illustrate important concepts. Theory and test philosophy of modal techniques, methods for mobility measurements, methods for analyzing mobility data, mathematical modeling from mobility data, and applications of modal test results will be presented.

**Contact:** Dr. Ronald L. Eshleman, Director, The Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254

# REVIEWS OF MEETINGS

## 57th SHOCK AND VIBRATION SYMPOSIUM

14-16 October, 1986  
Monteleone Hotel  
New Orleans, Louisiana

The 57th Shock and Vibration Symposium, sponsored by the Shock and Vibration Information Center (SVIC), was held in New Orleans in October. It was hosted by the Defense Nuclear Agency and the U.S. Army Engineer Waterways Experiment Station. The formal technical program consisted of more than 60 papers (see Vol. 18, No. 9 of the Digest for the complete program; papers will be published in the Shock and Vibration Bulletin). Plenary sessions were conducted during the Symposium. Plenary A was given on nondevelopment items from a manager's point of view by Robert H. Lehn of the U.S. Army Communications-Electronics Command, Ft. Monmouth, New Jersey. Plenary B was given by Dr. Allen J. Curtis of Hughes Aircraft Company titled "Dynamic Testing -- Seven Years Later". The talk of Dr. Curtis was referenced to an assessment of the area seven years earlier. An interesting session on short discussion topics covering many areas of mechanical vibration and shock was given on Thursday afternoon. A comprehensive workshop on nondevelopment items including methods and case histories was given on Wednesday. Dr. J. Gordan Showalter, Acting Director of SVIC, the members of the SVIC staff, and the program committee are to be congratulated for the assembly of an outstanding program on shock and vibration technology. Among the participants were representatives of the federal government, industry, academic institutions, and foreign nationals. The combination of formal and informal technical programs effected a meaningful transfer of shock and vibration technology. This Symposium was of particular interest to many persons who attended for years because of the uncertainty of its continuation (see Rattlespace).

### The Opening Session

An extended welcoming address was given by Dr. Robert W. Whalin, Technical Director of the U.S. Army Engineer Waterways Experiment Station (WES). In view of the fact that a site visit was not practical, a detailed description of the WES facility and its activities was provided by Dr. Whalin. WES, one of four U.S. Army Corp

of Engineers' laboratories, works for sponsors in the military and civil areas. It is composed of the Environmental, Hydraulics, Information Technology, Geotechnical, and Structures laboratories and the Coastal Engineering Research Center. The Information Technology Laboratory has a computer program library and does software evaluation. The Environmental Laboratory is involved in toxic and hazardous waste and aquatic water plant research. The Hydraulic Laboratory performs structural math modeling, flood control modeling, and ship and tow simulation. The spectral wave generator of the Coastal Engineering Research Center and 42 ton dolos water breakers were described by Dr. Cohalin. The Geotechnical Laboratory of WES does earthquake engineering studies as well as vehicle wheel and track experiments. The Structures Laboratory is involved in modeling such facilities as the Richard Russell Dam. Some of the shock and vibration related research projects currently being performed at WES were described. Defense Nuclear Agency research on underwater cratering was described along with numerical models of projectile impact and penetration. Finally, hardened silo component tests were described by Dr. Whalen.

The keynote address was given by Dr. Eugene Sevin of the Office of the Secretary of Defense on "ICBM Modernization -- A Shock and Vibration Perspective". In his background remarks on the ICBM program, Dr. Sevin noted the political and technological implications of this program -- to provide protection within political bounds. He noted that the MX-Peacekeeper, the largest missile allowed by SALT II, has had many basing schemes -- from hard underground structures to mobile deployment. However, it has been found that the public does not like missiles roving around the countryside. Therefore the use of public land was explored. Dr. Sevin discussed the effect of overpressure on vulnerability and the different results obtained from tests using similar overpressures. As a result of uneven test results a boundary layer effect was postulated and a new test method evolved. Land based hardened missile launchers subjected to testing were shown to illustrate test results. The dense pack concept of the early eighties and its associated problems were described. He noted that the super hard silos have been revived. However, both super hard silos and hard mobile

launchers have their problems. It is a tradeoff between hardness and mobility. An alternative would involve concealment of small missiles among a large number of shelters. All these concepts have important shock and vibration considerations. Dr. Sevin showed the shock isolation aspects of super hard silo concepts along with new stronger concrete materials -- properties that approach the strength and ductibility of mild steel. Stress time behavior in the silos where peak stress decays prior to bottom silo loading was discussed with respect to material properties and site geology. Missile shock isolation solutions were discussed in detail. Acceleration versus rattlespace is always a consideration. The rattlespace can be decreased by using a canister which distributes the loads better. Liquid springs have given way to foam and crushable elements. The effect of backfill in mitigating shock waves prior to reaching the silo was discussed. This increases the shock isolation system limit performance.

Progress made since the 46th Symposium in simulation of weapons effects was discussed. The HEST tests are improved with greater progress in understanding the air blast phenomenon and the simulation of it. However, thermal effects still need work. The improved new techniques involve the gas dynamic and wall jet physics of the event. Use of lower molecular weight gas to simulate nuclear event was discussed. Dr. Sevin showed an example of a test setup in a 40 acre field.

In closing, he noted the desirability of a continuing Shock and Vibration Symposium with a rotating sponsor system similar to the present arrangement; and, he is looking forward to a DNA-WES sponsored Symposium four years from now.

The second invited speaker in the opening session was Mr. Bob O. Benn of the U.S. Army Corps of Engineers Military Research and Development Programs. He gave an overview of their programs and laboratories. The activities of the Cold Regions Research and Engineering Lab at Hanover, New Hampshire, the Civil Engineering Lab (CERL) at Champaign, Illinois, the Waterways Experiment Stations (WES) at Vicksburg, Michigan, and the Engineering Topology Lab at Ft. Belvoir, Virginia were described. The labs at CERL and WES are of direct interest to the shock and vibration community. At CERL installation and facility planning, engineering materials, environmental qualification, and construction management are principal activities. Funding relationships and customer services were discussed for the WES facility, which does military and civil basic and applied research.

## The Plenary Sessions

Plenary Session A was chaired by Rudy Volin of SVIC who commented on the motivations for the plenary and subsequent workshop on nondevelopment items -- cost savings versus the qualification of nondevelopment items.

The speaker for the plenary on nondevelopment items was Robert H. Lehnes of the U.S. Army Communications-Electronics Command, Ft. Monmouth, New Jersey. He described the Mobile Subscriber Equipment (MSE) communications program which is nondevelopment based. He described the bidding system, performance specifications, and encouragement to use commercial equipment. The standard acquisition life cycle was compared to the MSE life cycle. The shock and vibration requirements of the nondevelopment items were discussed. He noted that this method is not a panacea but costs and time can be saved.

The second plenary presentation was given by Dr. Allen J. Curtis of Hughes Aircraft Company on dynamic testing. Dr. Curtis noted that seven years ago at the Symposium he discussed three limitations in test engineering -- low cost screening systems, multiplexible controllers, and on-line response control testing. Advances have been made in low cost screening. He noted that it is best to have tests done in the manufacturing area -- people see results immediately. Some progress has been made in multiplexible controllers; however the need has evaporated since one test at a time has become acceptable. No advances have been made on on-line response control testing. He noted that we still have over conservative testing which is costly. It is related to inadequate analytical and experimental treatment of impedance effects.

Dr. Curtis discussed new development in testing specifications -- the issuance of MIL STD 810D, flexibility of digital controllers, and the maturing of screening, TAAF, and CERT testing. We have found that we do not have to combine environments. There are problems with inconsistent requirements -- qualification and reliability tests. Screening should be separate from acceptance testing.

Dr. Curtis gave a preview of the results from a study on screening. He showed relationships between flaws remaining versus time which were developed in the study -- after screening field failures are reduced. The screening test must be accelerated -- otherwise failures follow normal pattern. He showed a graph of the ratio of flaws out to in versus screening level -- thus establishing an optimum level.

Dr. Curtis described the innovative use of digital controllers including some history of their use. He showed a helicopter example and transient testing to achieve different load factors in different parts of the equipment. He noted that the tuned transient was quite practical when generated by a digital controller. Slewing in small steps lets the controller maintain control.

In his concluding remarks Dr. Curtis, who gave his first Symposium paper in 1956, thanked the SVIC for its service to the shock and vibration community and their role in the development of shock and vibration technology.

### **The Technical Sessions**

Technical sessions were held on instrumentation, shock analysis, structural dynamics, isolation and damping, shock testing, vibration test criteria, modal test and analysis and vibration analysis and test. The instrumentation session contained papers on accelerometer evaluation, random vibration data, and sensor layouts. In the area of shock analysis, papers on testing of plates, panels, and structures were presented. Results of an analysis of shock loading of a vessel by an underwater explosion were compared to a full scale test. In the area of structural dynamics, two sessions were held. Papers on analyses of reinforced concrete structures under blast and shock analysis were presented. Other papers were concerned with optimum design, model validation, reliability, frequency response functions of nonlinear structures, and in interactive-graphics method for dynamic system modeling.

A session on isolation and damping included papers on liquid spring design and applications, a free decay damping test and design and test of a spacecraft instrument shock isolator. In the area of shock testing, a basic study on impact was reported along with rocket sled tests, pyrotechnic shock measurements and data analysis, and a microcomputer used in shock testing.

Papers on vibration test criteria included papers on dynamic environments, the development of laboratory vibration test schedules, and proposed techniques for ground vehicle packaged loose cargo vibration simulation. In the area of modal testing and analysis, a paper on vibration of structures through modal testing coupled with component mode synthesis was given. Papers on hardware modal tests with analytical validation were presented. Finally an approach for modal testing using multiple input sine excitations was

given. A session on vibration analysis and test contained papers on vibration specifications for acoustic environments, fatigue effects of a sine sweep test, flow excitation in piping systems, analysis of clipped random signals, rotor unbalance, and three dimensional sine testing.

### **Conclusion**

The fifty-seventh Shock and Vibration Symposium was both technically informative and interesting yielding a large number of excellent papers. Again the opening and plenary sessions with their overviews and philosophical insights added incomprehensible value to the meeting for new and experienced engineers. The workshop on nondevelopment items was a successful addition to the program yielding insight and experience

for those who participated. The Shock and Vibration Symposium remains the major annual event in the field. Even as it was on its last days SVIC can be congratulated for their continued maintenance of the quality of the technical presentations. It is hoped that this important

forum for the discussion of shock and vibration technology will be continued. The Symposium papers will be published in the 57th Shock and Vibration Bulletin.

R.L.E.

## ABSTRACT CONTENTS

<b>MECHANICAL SYSTEMS</b> .....	34	Beams.....	54
Rotating Machines.....	34	Plates.....	55
Reciprocating Machines.....	38	Shells.....	59
Power Transmission Systems.....	38	Pipes and Tubes.....	60
Metal Working and Forming.....	38	Ducts.....	61
		Building Components.....	61
<b>STRUCTURAL SYSTEMS</b> .....	39	<b>ELECTRIC COMPONENTS</b> .....	62
Buildings.....	39	Electronic Components.....	62
Towers.....	40	<b>DYNAMIC ENVIRONMENT</b> .....	63
Foundations.....	40	Acoustic Excitation.....	63
Harbors and Dams.....	40	Shock Excitation.....	65
Construction Equipment.....	41	Vibration Excitation.....	66
Power Plants.....	41	<b>MECHANICAL PROPERTIES</b> .....	66
Off-shore Structures.....	41	Damping.....	66
<b>VEHICLE SYSTEMS</b> .....	42	Fatigue.....	67
Ground Vehicles.....	42	Wave Propagation.....	67
Ships.....	43	<b>EXPERIMENTATION</b> .....	68
Aircraft.....	43	Measurement and Analysis.....	68
Missiles and Spacecraft.....	45	Dynamic Tests.....	81
<b>BIOLOGICAL SYSTEMS</b> .....	47	Scaling and Modeling.....	86
Human.....	47	Diagnostics.....	86
<b>MECHANICAL COMPONENTS</b> .....	47	Balancing.....	86
Absorbers and Isolators.....	47	Monitoring.....	88
Springs.....	50	<b>ANALYSIS AND DESIGN</b> .....	89
Tires and Wheels.....	50	Analytical Methods.....	89
Blades.....	51	Numerical Methods.....	89
Bearings.....	51	Parameter Identification.....	89
Gears.....	52	Computer Programs.....	90
Fasteners.....	53	<b>GENERAL TOPICS</b> .....	90
Seals.....	53	Useful Applications.....	90
<b>STRUCTURAL COMPONENTS</b> .....	54		
Cables.....	54		

## AVAILABILITY OF PUBLICATIONS ABSTRACTED

None of the publications are available at SVIC or at the Vibration Institute, except those generated by either organization.

**Periodical articles, society papers, and papers presented at conferences** may be obtained at the Engineering Societies Library, 345 East 47th Street, New York, NY 10017; or Library of Congress, Washington, D.C., when not available in local or company libraries.

**Government reports** may be purchased from National Technical Information Service, Springfield, VA 22161. They are identified at the end of bibliographic citation by an NTIS order number with prefixes such as AD, N, NTIS, PB, DE, NUREG, DOE, and ERATL.

**Ph.D. dissertations** are identified by a DA order number and are available from University Microfilms International, Dissertation Copies, P.O. Box 1764, Ann Arbor, MI 48108.

**U.S. patents and patent applications** may be ordered by patent or patent application number from Commissioner of Patents, Washington, D.C. 20231.

**Chinese publications**, identified by a CSTA order number, are available in Chinese or English translation from International Information Service, Ltd., P.O. Box 24683, ABD Post Office, Hong Kong.

**Institution of Mechanical Engineers publications** are available in U.S.: SAE Customer Service, Dept. 676, 400 Commonwealth Drive, Warrendale, PA 15096, by quoting the SAE-MEP number.

When ordering, the pertinent order number should always be included, not the DIGEST abstract number.

A List of Periodicals Scanned is published in issues, 1, 6, and 12.

# MECHANICAL SYSTEMS

## ROTATING MACHINES

86-2369

### **Random Vibration of Rotating Machines Under Earthquake Excitation**

KiBong D. Kim

George Washington Univ., Washington, DC

351 pp (1986) DA8604768

**KEY WORDS:** Rotating machinery, Seismic response, Random vibration

Random vibration of rotating machines subjected to seismic excitations is analyzed in which the six-component earthquake ground motions are modeled as nonstationary random processes. The six-component earthquake inputs, including the rotational components of base excitations, result in not only nonhomogeneous excitations but also parametric excitations -- the classical spectral analysis of random vibration is not applicable. The method of Monte Carlo simulation is used to simulate sample functions of six-component seismic base motions, and a step-by-step numerical integration is performed to obtain the dynamic response of the rotorbearing system. By simulating sufficient number of sample function, meaningful statistics of the system response are obtained. The random parametric excitations result from the three-component earthquake base rotations. Hence, by neglecting the earthquake ground rotations the spectral analysis of random vibration is performed to determine the system response statistics. The results of the spectral analysis serve as a basis for determining the number of sample functions required for the method of Monte Carlo simulation.

86-2370

### **Dynamic Analysis of Large Rotor -- Fluid Film Bearing -- Elastic Foundation Systems Using Component Mode Synthesis**

Zhao-chang Zheng, Kui-yuan Ding, Ruo-jing Zhang

Tsinghua Univ., Peking, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1540-1546, 5 figs, 2 tables, 8 refs

**KEY WORDS:** Experimental modal analysis, Rotors, Fluid-film bearings, Elastic foundations, Component mode synthesis

A method of component mode synthesis used in the dynamic analysis of rotorbearing foundation

systems is presented. In contrast to the classical method of component mode synthesis, the fluid-film bearing is treated separately as a connector, not associated with any substructures. The gyroscopic terms are neglected in the rotating substructures. Because of the influence of the fluid-film bearings, the stiffness matrix and the damping matrix in the equations of motion of a complete system are nonsymmetric and dependent on the shaft speed. The damped and undamped critical speeds are discussed. As a numerical example, the undamped critical speeds of a (1:10) model of a 300MW turbogenerator are calculated and compared with the experimental results.

86-2371

### **The Dynamic Analysis of Rotor-Bearing Systems Using Experimental Bearing Support Compliance Data**

L.E. Barrett, J.C. Nicholas, D. Dhar

Univ. of Virginia, Charlottesville, VA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1531-1535, 6 figs, 16 refs

**KEY WORDS:** Experimental modal analysis, Rotors, Steam turbines, Stiffness coefficients, Damping coefficients

The results of computer analyses of the response of an industrial steam turbine to unbalance excitation are described. To account for the flexibility of the bearing supports, compliance FRE data were experimentally obtained by impact testing during customer acceptance tests. The FRE data was used to modify the calculated tilting pad bearing stiffness and damping coefficients. The modified bearing coefficients were used in a response analysis program. Comparison of the calculated rotor response to vibration data measured during acceptance test runs are presented and the method used to modify the bearing stiffness and damping coefficients is presented. This method may be easily incorporated into forced response rotordynamics programs that do not include effects of support structures.

86-2372

### **On Transient Dynamics of Rotors with Asymmetric Cross-Section Supported on Fluid Film Bearings**

J.S. Rao, K.V. Bhaskara

Embassy of India, Washington, DC

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1110-1116, 7 figs, 12 refs

**KEY WORDS:** Rotors, Fluid-film bearings, Experimental modal analysis

Power plant turbogenerator rotors are asymmetric in cross-section having unequal stiffnesses causing parametric instabilities. A Jeffcott rotor model of the generator taking into account the asymmetry and modal damping is considered to obtain the transient orbital analysis of rotors at different speeds. Fluid film bearings with linear parameters (eight coefficients) are considered. The coupled differential equations of motion with variable coefficients are solved by a modified Euler's method using a time marching technique to obtain the whirl orbits of an asymmetric rotor taking into account both unbalance and gravity effects. Under stable operating conditions the final orbit is shown to be in good agreement with the closed form solution. A major feature of this analysis is to predict the possible maximum whirl amplitudes under unstable conditions of operation. The influence of linear fluid film bearings on the orbital motion is also discussed.

**86-2373**

**Determination of Modal Parameters of Rotors Supported on Hydrodynamic Bearings through Experimental Modal Analysis**

R. Subbiah, R.B. Bhat, T.S. Sankar  
Concordia Univ., Montreal, Quebec, Canada  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1450-1456, 11 figs, 5 tables, 6 refs

**KEY WORDS:** Experimental modal analysis, Rotors, Fluid-film bearings

Modal parameters of a single disk rotor, supported on hydrodynamic bearings at the two ends, are identified by modal testing. The experimentally measured frequency response functions of the rotor are used to extract the left and the right eigenvectors in addition to the eigenvalues and damping ratios, in order to construct the modal model of such a nonsymmetrical system. Two different configurations of the rotor system are studied and the natural frequencies obtained by modal analysis are compared with those obtained by the extraction techniques.

**86-2374**

**Vibrations of Rotors, Noise of Measurement, Circularity and Coaxiality**

R. Bigret  
Materiaux et de la Construction, Mecanique, France

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1388-1392, 15 figs, 2 refs

**KEY WORDS:** Experimental modal analysis, Rotors, Vibration measurement, Error analysis, Critical speeds

Defects of circularity and coaxiality, noises of electric, and magnetic origin influence the measurements which express the vibratory behaviors of rotors of rotating machinery. Their supervision, balancing, behavior, and modal analysis require that the basic signals rough data be clarified to facilitate the interpretations. Examples are given which show results for the determination of critical speeds (maximum values of the vibration amplitudes) and the modal analysis (transient state). Systems which enable the management of measured signals are also studied.

**86-2375**

**Predicted Effect of Aerodynamic Detuning on Coupled Bending-Torsion Unstalled Supersonic Flutter**

D. Hoyniak, S. Fleeter  
NASA Lewis Res. Ctr., Cleveland, OH  
Rept. No. NASA-TM-87240, 30 pp (1986) (31st Intl. Gas Turbine Conf., Dusseldorf, W. Germany, June 8-12, 1986, spon. by ASME) N86-21513/4/GAR

**KEY WORDS:** Turbomachinery, Flutter, Aerodynamic stability, Tuning

A mathematical model is developed to predict the enhanced coupled bending-torsion unstalled supersonic flutter stability due to alternate circumferential spacing aerodynamic detuning of a turbomachine rotor. The translational and torsional unsteady aerodynamic coefficients are developed in terms of influence coefficients, with the coupled bending-torsion stability analysis developed by considering the coupled equations of motion together with the unsteady aerodynamic loading. The effect of this aerodynamic detuning on coupled bending-torsion unstalled supersonic flutter as well as the verification of the modeling are then demonstrated by considering an unstable 12 bladed rotor, with Verdon's uniformly spaced Cascade B flow geometry as a baseline. For both uniform and nonuniform circumferentially spaced rotors, a single-degree-of-freedom torsion mode analysis was shown to be appropriate for values of the bending-torsion natural frequency ratio lower than 0.6 and higher than 1.2. When the elastic axis and center of gravity are not coincident, the effect of detuning

on cascade stability was found to be very sensitive to the location of the center of gravity with respect to the elastic axis. In addition, it was determined that when the center of gravity was forward of an elastic axis location at midchord, a single-degree-of-freedom torsion model did not accurately predict cascade stability.

**86-2376**

**Internal Resonance in a Rotating Shaft System (The Coincidence of Two Critical Speeds for Subharmonic Oscillation of the Order 1/2 and Synchronous Backward Precession)**

Yukio Ishida, Takashi Ikeda, Toshio Yamamoto, Tetsuyoshi Akita

Nagoya Univ., Chikusaku, Nagoya-city, Japan  
Bull. JSME, 29 (251), pp 1564-1571 (May 1986) 7  
figs, 16 refs

KEY WORDS: Shafts, Critical speeds, Subharmonic oscillations, Internal resonance

Vibration phenomena due to an internal resonance in a symmetrical rotating shaft system with nonlinear spring characteristics is discussed. The coincidence of critical speeds of subharmonic oscillation of the order 1/2 and synchronous backward precession is investigated. It is revealed that these oscillations are coupled by nonlinear components expressed by polar coordinates and that unique shapes of resonance curves appear due to internal resonance.

**86-2377**

**Dynamic Stress Analysis of Hollow Rotating Discs**

S. Amada

Ship Res. Institute, Tokyo, Japan  
Bull. JSME, 29 (251), pp 1381-1395 (May 1986)  
12 figs, 3 tables, 11 refs

KEY WORDS: Disks, Shafts, Rotating structures

Dynamic radial and circumferential stresses are analyzed for hollow rotating disks which rotate at arbitrarily varying speeds, the inner boundary of which is fixed on a rigid shaft. The problem is solved by using the Laplace transform, the convolution and Cauchy's integral theorems. The numerical computations are carried out for the disks which rotate with a constant angular acceleration up to  $N=10,000$  rpm, and keep their rotation thereafter. The dynamic stresses give rise to the cyclic variations with respect to time in a constant rotating process. The obtained results are compared with the quasi-static stresses.

**86-2378**

**Types of Rotors Fit and the Gyroscopic Moments Effect on Multi Disc Rotor Supported on Several Bearing**

E.M. Badawy, H.M. Metwally, F.K. Salman  
Alexandria Univ., Alexandria, Egypt

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1382-1387, 6 figs, 10 refs

KEY WORDS: Shafts, Whirling, Supports, Damping effects

A calculation method incorporating the transfer matrix method and the characteristic vector locus method has been developed for stability analysis of the self-excited vibration of a rotating shaft system with many bearings and disks. The analysis is made for a rigid and elastic bearing mass, relatively large damping forces due to types of rotors fit, anisotropic foundation and rotors gyroscopic effect. A two rotors-model is presented to show the influence of rotor and its gyroscopic action, support stiffness characteristic, internal and external damping on stability. A computer solution of the transfer matrix method shows the rotor stability improved by damped support. Comparison of the rotor types fit, support types and its gyroscopic action are obtained.

**86-2379**

**Modal Testing and Parameter Identification of Rotating Shaft/Fluid Lubricated Bearing System**

D.E. Bentley, A. Muszynska

Bentley Rotor Dynamics Research Corp., Minden, NV

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1393-1402, 15 figs, 34 refs

KEY WORDS: Shafts, Fluid-film bearings, Experimental modal analysis, Parameter identification technique

Specific aspects of the application of modal analysis to rotating machines are discussed. For lowest mode analysis, the circular-force perturbation testing and dynamic stiffness method give the best results. An example of the application is presented. It yields identified parameters for the whirl mode (solid/fluid interaction mode) and whip mode (first bending mode of the shaft) and establishes a simple rotor/bearing system model.

**86-2380**

**Modifications to a Timoshenko Beam-Shaft Finite Element to Include Internal Disks and Changes in Cross-Section**

S. Akella, A. Craggs

Univ. of Alberta, Edmonton, Alberta, Canada  
J. Sound Vib., 106 (2), pp 227-239 (Apr 22, 1986) 14 figs, 2 tables, 17 refs

KEY WORDS: Shafts, Beams, Timoshenko, Finite element technique

A high order Timoshenko beam-shaft element is modified to include the effect as disks within its length. The method leads to a great reduction in the system matrix, without loss of accuracy of the results when compared to the classical method of lumping the disks at nodal points. A stepped element is also formulated which includes the variation in inertia and stiffness terms due to the changes in the cross-section of an axially discontinuous shaft. The stepped element performs better than the linearly tapered element in representing shaft discontinuities.

#### 86-2381

##### **Damping of Subsynchronous Resonance Using a Load Commutated Inverter Synchronous Motor Drive**

Soebagio

Ph.D. Thesis, Univ. of Wisconsin, Madison, WI, 165 pp (1985) DA8601124

KEY WORDS: Shafts, Subsynchronous vibration, Damping effect, Resonant response

Subsynchronous resonance (SSR) has been considered a serious problem since 1970 when incidents of severe generator shaft damage occurred at a generating station in southern Nevada. This problem is caused by inserting a series capacitor in transmission lines for the purpose of raising line capacity to transmit very huge amounts of power over long distances. The installation of the series capacitor in the lines may cause oscillation due to the light damping in the electrical or mechanical system. If there is a small perturbation in the accelerating torque of the generator, this perturbation will introduce negative damping to the mechanical system, so that the system becomes unstable. This research proposes a method using a load commutated inverter (LCI) synchronous motor drive. The advantage of the proposed method is that an inductor converter unit is used which is already available as part of a LCI synchronous motor drive to operate a variable speed induced fan or compressor for cooling purposes.

#### 86-2382

##### **Sensor for Torque Measuring on the Basis of Amorphous Metals (Sensor zur Drehmomentmessung mit amorphen Metallen)**

D. Juckenack, J. Molnar

Fraunhofer-Institut, Freiburg, Fed. Rep. Germany  
Techn. Messen-TM, 53 (6), pp 242-248 (June 1986) 13 figs, 18 refs (in German)

KEY WORDS: Shafts, Torque, Measurement techniques

With the help of amorphous metals mounted on a rotating shaft and a coil system fixed in a housing, the static and dynamic torque is detected without any signal transmission parts and with good sensitivity.

#### 86-2383

##### **Response of a Rigid Disc Mounted on a Flexible Shaft Under Non-Linear Excitations**

V. Steffen, Jr., F.P. Lepore N., E.B. Teodoro  
Fed. Univ. of Uberlandia, Uberlandia, Brazil  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1536-1539, 6 figs, 1 table, 7 refs

KEY WORDS: Experimental modal analysis, Disks, Flexible shafts, Ball bearings

A mathematical model of a rigid disk mounted on a flexible shaft supported by ball bearings is presented. The disk is excited by a magnetic force. The equations of motion are integrated using a Runge-Kutta technique and the frequency response is obtained by an FFT technique. The response of the system is discussed for different situations.

#### 86-2384

##### **Coupled Bending Vibrational Characteristics of an Idealized Vertical Pump Model**

Jang Moo Lee, Chan-Gi Pak, Jin Sun Hong  
Seoul National Univ., Seoul, Korea  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 877-883, 12 figs, 7 tables, 10 refs

KEY WORDS: Pumps, Rigid foundations, Flexural vibrations, Experimental modal analysis

Coupled bending vibrational characteristics of a vertical pump due to foundation stiffness are investigated through the vibration analysis of an idealized vertical pump model. The model assumes the upper motor casing and the lower water lifting pipe as uniform beams, the motor and the pump impeller as concentrated masses, the discharging pipe as a translational spring and the foundation stiffness as a rotational spring. The equations of motion corresponding to each portion of the pump are solved simultaneously with the matching boundary conditions. The

eigenvalues and eigenvectors are computed as dimensionless design variables and the effects of foundations stiffness are discussed. The validity of the analysis results is checked through comparison with the results of previous studies and impulse modal testing.

## RECIPROCATING MACHINES

**86-2385**

### **Effect of Entrained Air on Dynamic Characteristics of Hydraulic Servosystem with Asymmetric Linear Motor**

B.N. Datta, A.S.R. Murty, G.L. Sinha

B.E. College, Howrah, India

Meccanica, **21** (1), pp 51-57 (Mar 1986) 7 figs, 6 refs

**KEY WORDS:** Hydraulic systems, Servomechanisms, Stiffness coefficients, Damping coefficients, Natural frequencies

A theoretical investigation into the effect of entrained air on dynamic behavior of a hydraulic servosystem is made. The nonlinear system equation developed in dimensionless form is linearized to obtain stiffness, damping ratio and natural frequency in generalized dimensionless form that includes the effects of underlap, leakage, area ratio, per cent air content and the process of change of state of air. A nomogram is developed that helps in quick determination of the dynamic properties directly without any computation. The analysis shows that a decrease in area ratio or an increase in the amount of air entrained into the system reduces both damping ratio and natural frequency.

## POWER TRANSMISSION SYSTEMS

**86-2386**

### **A Study on Forced Torsional Vibration of Automobile Power Train**

Wang Zhi un, Wu Huile

Shanghai Univ. of Engrg. Science, Shanghai, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 972-978, 5 figs, 2 tables, 6 refs

**KEY WORDS:** Driveline vibrations, Automobiles, Torsional vibrations

A theoretical study based on the forced vibration theory and a new complete experimental method are used to reveal the torsional vibration behav-

ior of an automobile power train. A dynamic model is developed for CA-630 coach power train, the parameters of the system are determined, an experimental investigation is made, and results are presented.

**86-2387**

### **Modal Analysis for Bending Vibration of Vehicle Power Trains**

Wu Huile, Feng Zhendong, Li Chengde, Sun Fangning

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 965-971, 6 figs, 3 tables, 3 refs

**KEY WORDS:** Experimental modal analysis, Modal synthesis, Flexural vibrations, Driveline vibrations, Buses

A method of combining testing modal analysis with modal synthesis techniques is used to investigate the bending vibration of a vehicle's power trains. The mechanical and mathematical model for bending vibration of a DD680 bus power train are developed and the natural vibration property is calculated. A test is made to check the validity of the model.

## METAL WORKING AND FORMING

**86-2388**

### **Using Frequency Response Function Measurements to Predict Workpiece Noise Radiation during Face Milling**

T. Moore, Jimi Sauw-Yoeng Tjong, Z. Reif

Queen's Univ., Kingston, Ontario, Canada

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 930-935, 9 figs, 11 refs

**KEY WORDS:** Milling (machining), Noise prediction, Frequency response functions

A simple method is described which predicts the spectral characteristics of the noise generated by a workpiece of complex geometry while one of its surfaces is being face milled. Such information can be used to design quiet cutters; i.e., mills which produce a minimum of noise during a given cutting cycle. The method consists of the generation of frequency response functions with the input being force and the output being sound pressure. Such measurements provide a direct link between input force and the resulting noise generation, thus measurements require no simplifying assumptions to link surface movement to resulting sound pressure at a point in space.

If the measurements are made with the work-piece mounted in its machining fixture, the results automatically include the complex boundary conditions imposed on the workpiece.

**86-2389**

**Computer Aided Milling Machine Modal Analysis**

Hsin-Yi Lai

North Carolina A&T State Univ., Greensboro, NC  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1140-1148, 9 figs, 1 table, 16 refs

**KEY WORDS:** Machine tools, Milling (machinery), Modal analysis, Time domain method, Computer programs

A time-domain modal analysis method with application to the identification of a milling machine structure is presented. In a systematic modeling procedure, the model structure and the related parameters of each dynamic mode are identified in sequence. The relative vibration amplitudes are displayed in terms of animated mode shapes. The structural weak points are pinpointed and the model refinement is made based on the modification of physical means. Results, as compared with those of finite element and fast fourier transformation approaches, show the time-domain modal analysis method possesses the advantages of practicality and accuracy in dynamic data processing. It can be used as a powerful structure analysis tool, vital for various CAD/CAM applications including dynamic verification, model developed and design refinement of components in flexible manufacturing cells.

**86-2390**

**The Static and Dynamic Analyses of Machine Tools Using Dynamic Matrix Reduction Technique**

V.R. Reddy, A.M. Sharan

Memorial Univ. of Newfoundland, St. John's, Newfoundland, Canada

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1104-1109, 1 fig, 2 tables, 8 refs

**KEY WORDS:** Machine tools, Matrix reduction methods, Experimental modal analysis

An approach, for condensing the system matrices of machine-tool structures, based on dynamic condensation, is presented. The selection of the number of degrees-of-freedom to be retained in the condensed system is based on the accurate representation of the first five modes of the original system. This is illustrated by an example of a lathe spindle-workpiece system.

**86-2391**

**Evaluation of Optimum Stiffness and Damping for Structural Design of Machine Tools**

M. Rahman, V. Narayanan, V.C. Venkatesh

National Univ. of Singapore, Kent Ridge, Singapore

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1553-1557, 9 figs, 9 refs

**KEY WORDS:** Machine tools, Stiffness coefficients, Damping coefficients, Optimization, Structural modification techniques

An attempt is made to optimize stiffness and damping for the structural design of machine tools. These factors were tried on a widely used stability theory based on a feedback control system. Actual machining tests were carried out varying these factors. Calculated stability prediction has been found to agree qualitatively with the experimental values.

## STRUCTURAL SYSTEMS

### BUILDINGS

**86-2392**

**Sound Transmission by Coupled Structures: Application to Flanking Transmission in Buildings**

J.L. Guyader, C. Boisson, C. Lesueur, P. Millot  
Institut National des Sciences Appliquees, Cedex, France

J. Sound Vib., 106 (2), pp 289-310 (Apr 22, 1986) 12 figs, 17 refs

**KEY WORDS:** Buildings, Sound transmission

A new formulation for sound transmission by coupled structures with special application to flanking transmission is presented. As distinct from other approaches in which the couplings are considered to be similar, this method treated each type of coupling specifically: the mechanical/mechanical coupling is rigorously treated; the mechanical/acoustic coupling is considered to be weak, this hypothesis being generally admissible when air is the acoustic medium fluid. The formulation proceeds from the general to the specific; in this way it is easier to measure the effect of the hypothesis introduced. The theoretical procedure for defining the transmissions leads to an experimental method in which measured data of the energy and spectral densities of the forces is used. The application of

this method to the case of sound transmission in buildings was carried out to serve as an example.

## TOWERS

**86-2393**

### **Wind Loads on Windmills at Stand Still**

O. Christensen  
Risoe National Lab., Roskilde, Denmark  
Rept No. RISO-M-2521, 60 pp (Jul 1985)  
DE86751137/GAR (in Danish)

**KEY WORDS:** Towers, Wind turbines, Wind-induced excitation

The report deals with calculation of static and dynamic wind loads on windmills at stopped condition, including induced vibrations in the construction. The assumptions for the calculations are a total stiff tower, a three-bladed rotor and that the wind is at right angles to the rotor plane.

## FOUNDATIONS

**86-2394**

### **Dynamic Soil-Structure Analysis by Boundary Element Method**

M.H.M. Abdalla  
Ph.D. Carleton Univ., Canada (1985)

**KEY WORDS:** Soil-structure interaction, Seismic response, Boundary element technique

A method is developed to analyze the earthquake response of a two-dimensional soil-structure system. The semi-infinite soil domain is modeled by boundary elements, while the structure is modeled as an assemblage of finite elements. A substructure technique of analysis is used and the soil material as well as the superstructure material are considered homogeneous, isotropic and linearly elastic. The analysis is carried out by first resolving the earthquake excitation into a series of harmonic components. The steady state response of the system to each harmonic component is obtained next. The component response is then Fourier synthesized to obtain the resultant response in time domain. The Fourier analysis is accomplished by using Fast Fourier Transform method.

## HARBORS AND DAMS

**86-2395**

### **On Phase and Modal Parameter Measurement for Large Structures**

Zhong Liang, Qiang Gao, D.J. Inman  
State Univ. of New York, Buffalo, NY  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 993-999, 3 figs, 5 refs

**KEY WORDS:** Dams, Parameter identification technique, Mode shapes, Phase methods, Time domain method

The identification of modal parameters for a large structure, such as a dam, is plagued with unusual difficulties. In particular, excitation, phase angle measurement (between two measuring points) and the need to consider a large number of degrees-of-freedom complicate the process. Based on the stochastic process of microvibration, excited water waves or a seismic tremor, formulas for the phase angle and three cross-correlation functions between two measuring points are developed. Phase measurement is important for developing a new method of identifying complex modes and providing a determination of natural frequencies. A time domain method is used to determine the complex mode shapes, natural frequencies and the damping ratios accurately and quickly.

**86-2396**

### **Modal Analysis of Inflatable Dams under Hydrodynamic Conditions**

A.D. Alwan  
Univ. of Basrah, Basrah, Iraq  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1502-1509, 16 figs, 7 refs

**KEY WORDS:** Experimental modal analysis, Dams, Inflatable structures, Finite element technique

An inflatable dam consisting of a single sheet of rubberized fabric folded into a tubular shaped bag which is then sealed into place during installation is investigated. The bag is fixed at the base and inflated by air, water or a combination of both. A numerical modal based on the finite element approach to analyze the dam under hydrodynamic conditions is presented. The forces acting on the dam due to variation of overflow head, downstream head, and inflated pressure are analyzed to study the behavior and performance of the dam and to find the shape of the profile of the dam and the tension of the fabric.

## CONSTRUCTION EQUIPMENT

86-2397

### **Modelling of the Dynamic Processes of Excavator**

Zhang Hui Jiao, Fang Dan Ping  
Shanghai Jiao Tong Univ., China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1215-1219, 9 figs, 2 tables, 3 refs

KEY WORDS: Excavators, Modal analysis

A new method combining theoretical analysis with practical measured data is developed for modeling the dynamic processes of excavators. Using this method, a realistic model and a high accuracy load spectrum can be established.

## POWER PLANTS

86-2398

### **Seismic and Dynamic Qualification of Safety Related Electrical and Mechanical Equipment**

M. Subudhi, J. Currier, M. Reich  
Brookhaven National Lab., Upton, NY  
Rept. No. BNL-NUREG-51643, 66 pp (Mar 1986)  
NUREG/CR-3137/GAR

KEY WORDS: Nuclear power plants, Nuclear reactor components, Seismic tests

The report presents a summary of methods and procedures that may be used for seismic qualifications of nuclear power plant mechanical and electrical equipment. Incorporated into text are sections that explain and clarify commonly used qualification terminology and that delineate methods used for dynamic environment simulations used for qualification. The report also presents a scenario of what occurs at a typical seismic qualification review team audit of a NTOL nuclear power station.

86-2399

### **A Combined Method of Testing and Analysis for Dynamic Qualification of Equipment**

K.Y. Shye, K.M. Skreiner  
NUTECH Engineers, San Jose, CA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1370-1373, 1 fig, 2 tables, 4 refs

KEY WORDS: Experimental modal analysis, Linking analysis and test, Nuclear power plants, Nuclear reactors

Equipment in operating nuclear power plants cannot be qualified in a practical manner by analysis or testing alone. This paper addresses new procedures in combined methods of testing and participation which enable an estimate of modal participation factors to be developed without recourse to a conventional mass survey. The procedures generate the required response spectra for instruments or devices mounted at elevated positions in equipment or structures using in-situ measured modal parameters and postulated base excitations as inputs. Examples are given to demonstrate the ability of the procedures to develop the parameters of modal participation factors necessary to predict the elevated response spectra.

## OFF-SHORE STRUCTURES

86-2400

### **The Mechanics of a Compliant Motion Suppression System for Semisubmersibles**

M.H. Patel, J.H. Harrison  
Univ. College, London, England  
J. Sound Vib., 106 (3), pp 491-507 (May 8, 1986)  
13 figs, 11 refs

KEY WORDS: Submerged structures, Offshore structures, Drilling platforms, Wave forces, Vibration control

Experimental and theoretical work on a passive motion suppression system for semisubmersible vessels are described. The system incorporates a pneumatic compliancy which is designed to enhance the wave induced motion characteristics of such a vessel for offshore drilling and production service. The pneumatic compliancy is achieved through the use of open bottom tanks mounted on the vessel. Test data is compared with a multi-degree-of-freedom dynamic response calculation in the frequency domain in which the Morison equation is used for calculating wave induced drag and inertia loads on the semisubmersible. The paper is concluded with a discussion on the relative merits and drawbacks of incorporating a pneumatic compliancy into hitherto hydrodynamically rigid semisubmersible designs.

86-2401

### **Decomposition of Wave Forces into Linear and Non-Linear Components**

J.S. Bendat, A.G. Piersol  
J.S. Bendat Co., Los Angeles, CA  
J. Sound Vib., 106 (3), pp 391-408 (May 8, 1986)  
19 figs, 5 refs

KEY WORDS: Off-shore structures, Wave forces

This paper details a methodology for analyzing nonlinear systems involving a square-law operation with sign. The analysis is applied specifically to the problem of decomposing random wave forces on an ocean structure into their inertial (linear) and drag (nonlinear) components. A procedure is presented for identifying the individual inertial and drag force parameters based solely upon measurements of the input wave velocity and the output wave force, where the wave velocity has an arbitrary spectral density function and mean value, and the inertial and drag forces have an arbitrary frequency dependence and phase. It is assumed only that the wave velocity is a Gaussian random process. Experimental verifications of the analysis procedure are presented.

## VEHICLE SYSTEMS

### GROUND VEHICLES

**86-2402**

#### **Some Problems About Acoustic and Vibration Comfort in Vehicle Design**

A. Garro, E. Pellegrino, V. Vullo

Fiat Auto S.p.A., Turin, Italy

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 957-964, 6 figs, 1 table, 16 refs

**KEY WORDS:** Modal analysis, Automobile noise, Interior noise

A mathematical model is presented to analyze the acoustics of a small cavity such as the interior of a vehicle. The mathematical fundamentals of the calculation procedure are outlined. This procedure uses discretization methods and allows for acoustic analysis of the cavity in a more general case where it is delimited by partly stiff and partly flexible walls.

**86-2403**

#### **A Substructure Synthesis Method for Finding the Weak Points of Complex Structure**

Wu Jian-ji, Zheng Zhao-chang

Tsinghua Univ., Beijing, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 979-983, 1 fig, 1 table, 4 refs

**KEY WORDS:** Automobile bodies, Trucks, Modal synthesis, Substructuring methods

The mode synthesis technique and least squares method are adopted for finding the weak points of a structure. A spectrum of system normal frequencies in the range of interest and their associated mode shapes can be produced with the mode synthesis method. These modes are drawn up by the cubic curves obtained by the least squares method. The deformations of the complex structure are represented by these curves and by which the relative stress values of the system can be calculated. This method provides some advantages, such as mathematical simplicity and computer time saving.

**86-2404**

#### **The Study of Vibration Characteristics of a Whole Truck**

Li Tong, Li Cheng De, Yu Hui Ran

Changchun Automobile Research Institute, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1640-1652, 19 figs, 10 tables, 4 refs

**KEY WORDS:** Trucks, Modal analysis, Finite element technique, Modal synthesis, Design techniques

Using modal analysis theories, the dynamic finite element method, and the modal synthetic technique, a mathematical model of a whole truck has been established. This model includes the modal coordinates and independent coordinates of frame, engine, radiator, cab, front and rear axles, cargobody, etc. -- all main components of a truck. Using finite element and modal truncation theories, this model having 33 degrees-of-freedom, realistically describes the complicated system of a whole truck. Dynamic calculations are carried out on a computer.

**86-2405**

#### **Modal Analysis as a Tool to Evaluate Off-Road Vehicle Body Mounts**

S. Sankar, S. Rakheja, J. Alanoly

Concordia Univ., Montreal, Quebec, Canada

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1471-1475, 8 figs, 1 table, 7 refs

**KEY WORDS:** Experimental modal analysis, Off-highway vehicles, Mounts, Finite element technique, Road roughness

A four wheel drive off-road vehicle with a combination of rigid and flexible mounts between the chassis and body shell is considered to study the deflection behavior of the body. The deflection modes of the body chassis structure are

obtained through analytical and experimental modal analyses. The analytical results obtained through finite element modeling show good agreement with experimental results. Based on deflection behavior of the body shell, conclusions on location of rigid and flexible connections are drawn to improve the integrity of body shell structure.

## SHIPS

86-2406

### **The Identification of System Modal Parameters of the Ship Hull Girder Vibrating in Its Vertical Plane by the Sea Trial Time Series**

Chang-Sheng Li, Wen-Jiunn Ko  
National Taiwan Univ., Taipei, Taiwan, Rep. China

Ind. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1011-1019, 17 figs, 7 tables, 11 refs

**KEY WORDS:** Ship hulls, Parameter identification technique, Experimental modal analysis, Experimental data, Autoregressive/moving average models

In the sea trial for a newly constructed tanker, under prescribed loading conditions, six sets of pick-up devices were distributively mounted on the main deck of the ship along its longitudinal direction. The analog signals of structural responses or the time history of dynamic response of the ship hull box girder were recorded on a multi-channel tape recorder simultaneously, while the ship was sailing on calm seas. The recorded data was processed using a band-pass filter and A/D converter. With these data, a time series analysis was conducted by the autoregressive moving average model, from which the modal frequencies can easily be identified according to the index of energy dispersion.

## AIRCRAFT

86-2407

### **STEP and STEPSPL: Computer Programs for Aerodynamic Model Structure Determination and Parameter Estimation**

J.G. Batterson  
NASA Langley Res. Ctr. Hampton, VA  
Rept. No. NASA-TM-86410, 142 pp (Jan 1986)  
N86-21549/8/GAR

**KEY WORDS:** Aircraft, Computer programs, Parameter identification technique

The successful parametric modeling of the aerodynamics for an airplane operating at high angles of attack or sideslip is performed in two phases. First the aerodynamic model structure must be determined and second the associated aerodynamic parameters (stability and control derivatives) must be estimated for that model. The purpose of this paper is to document two versions of a stepwise regression computer program which were developed for the determination of airplane aerodynamic model structure and to provide two examples of their use on computer generated data. References are provided for the application of the programs to real flight data. The two computer programs that are the subject of this report, STEP and STEPSPL, are written in FORTRAN IV (ANSI 1966) compatible with a CDC FTN4 compiler. Both programs are adaptations of a standard forward stepwise regression algorithm.

86-2408

### **The Planning of an Environmental Testing Program for an Externally Carried Store**

Z. Sherf, A. Gilan, P. Hopstone, R. Klein  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 20-25, 11 figs, 29 refs

**KEY WORDS:** Aircraft wings, Wing stores, Vibration tests

The planning of a vibration and temperature testing program for an external airborne store is summarized. In the absence of field measurements for the test item, use is made of measured data for similar systems of empirical models and of laboratory acquired data. Tailoring of the testing conditions is performed with respect to the mission profile of the system.

86-2409

### **Equivalent Plate Analysis of Aircraft Wing Box Structures with General Planform Geometry**

G.L. Giles  
NASA Langley Res. Ctr., Hampton, VA  
Rept. No. NASA-TM-87697, 12 pp (Mar 1986)  
(Pres. at 27th AIAA/ASME/ASCE/ANS Structures, Structural Dynamics & Matrls. Conf., San Antonio, TX, May 19-21, 1986) N86-21954/0/GAR

**KEY WORDS:** Aircraft wings, Equivalent plate analysis method

A new equivalent plate analysis formulation is described which is capable of modeling aircraft wing structures with a general planform such as

cranked wing boxes. Multiple trapezoidal segments are used to represent such planforms. A Ritz solution technique is used in conjunction with global displacement functions which encompass all the segments. This Ritz solution procedure is implemented efficiently into a computer program so that it can be used by rigorous optimization algorithms for application in early preliminary design. A direct method to interface this structural analysis procedure with aerodynamic programs for use in aeroelastic calculations is described. This equivalent plate analysis procedure is used to calculate the static deflections and stresses and vibration frequencies and modes of an example wing configuration. The numerical results are compared with results from a finite element model of the same configuration to illustrate typical levels of accuracy and computation times resulting from use of this procedure.

**86-2410**

**Noise Transmission into Enclosures**

R. Vaicaitis, D.A. Bofilios  
Columbia Univ., New York, NY  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1088-1097, 9 figs, 41 refs

KEY WORDS: Enclosures, Noise transmission, Aircraft noise, Interior noise, Experimental modal analysis

Analytical and experimental studies of noise transmission into rectangular and cylindrical enclosures is described. The solutions of the governing acoustic-structural equations are developed by modal decomposition of structural vibrations and the interior acoustic field. Particular attention is directed toward the low frequencies; that is, frequencies up through the first few structural and cavity resonant modes. The structural vibrations are driven by the external acoustic and/or mechanical point loads which are taken to be Gaussian stationary random processes. The structural models include rectangular panels and cylindrical shells.

**86-2411**

**The Methods Implemented at ONERA to Improve Airplane Ground Vibration Tests**

R. Dat, P. Lubrina  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 844-849, 5 figs, 15 refs

KEY WORDS: Experimental modal analysis, Aircraft vibration, Vibration tests, Testing techniques

The Office National d'Etudes et de Recherches Aeronautiques (ONERA) has at its disposal full instrumentation and computing equipment installed in a trailer-truck to perform ground vibration tests of aircraft prototypes. The tests must be carried out in a relatively short time and the test results (eigenfrequencies, damping, mode shapes, and generalized masses) must be accurate enough to make aeroelastic analyses reliable. In order to meet those requirements, ONERA has implemented a computation code, which is currently used to analyze frequency responses, and several testing methods which are used when nonlinear structural characteristics make the structural identification difficult.

**86-2412**

**Measurement of Noise from Airplanes Traveling at Heights 3500 to 6000M**

M. Linde, S. Meijer  
Aeronautical Res. Inst. of Sweden, Stockholm  
Rept. No. FFA-T1-AU-2168, 19 pp (Sep 1985)  
N86-22312/0/GAR

KEY WORDS: Aircraft noise, Noise measurement

The noise on the ground produced by overflights of jet and propeller airplanes, at different flight levels, was studied to provide a basis for the estimation of the noise from future propeller airplanes. The noise on the ground from airplanes at heights 3500 to 6000m was measured.

**86-2413**

**Contribution to the Digital Compensation of Periodic Disturbances with Frequencies in Bounded Intervals**

R. Froriep  
Deutsche Forschungs-und Versuchsanstalt fuer Luftund Raumfahrt e.V., Oberpfaffenhofen, Fed. Rep. Germany  
Rept. No. DFVLR-FB-85-55, 141 pp (Sept 1985)  
N86-21553/0/GAR (in German)

KEY WORDS: Helicopter vibration, Active vibration control

A general design method for the simplest possible compensator was developed in order to satisfy the requirement of stationary disturbance compensation within given tolerance limits for all helicopter rotor speeds within a given bounded interval. The approach to the suppression of rotor induced vibrations is to suspend the fuselage from the rotor by electrohydraulic actuators. Using a digital computer the most dominant harmonics of the disturbance can be actively compensated. For compensation at

sampling instants, a structure of a digital controller is introduced and motivated, in which a minimal number of parameters is adapted to a varying rotor speed. The remaining parameters are to be held constant during operation independent of rotor speed.

**86-2414**

**Developments in Helicopter Ground Vibration Testing**

J.A. Fabunmi

Univ. of Maryland, College Park, MD

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 984-992, 8 figs, 9 refs

**KEY WORDS:** Helicopter vibration, Vibration tests, Single point excitation technique, Experimental modal analysis, Experimental data

A basic review of existing techniques for helicopter mobility testing is presented along with some recent formulations and techniques for efficient measurement of structural dynamic characteristics of a helicopter during ground vibration testing. For single point shaking, a new method is described for calculating the transfer mobility between excitation and response coordinates which results in substantial saving in testing duration, while assuring acceptable accuracy. Test results using this method are presented and compared with existing methods. The formulation for extending this method to multiple shaker testing is also presented.

## MISSILES AND SPACECRAFT

**86-2415**

**Quality of Modal Analysis and Reconstruction of Forcing Functions Based on Measured Output Data**

H. Ory, H. Glaser, D. Holzdeppe

Institut für Leichtbau, Aachen, Fed. Rep. Germany

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 850-857, 9 figs, 9 refs

**KEY WORDS:** Spacecraft, Modal analysis, Launch vehicles, Forcing function

The accuracy of the flight load prediction for a launch vehicle payload greatly depends on the quality of the mathematical model and the representativity of the used forcing functions. These can be deduced from structural responses (accelerations, stresses, etc.) measured during

prior launches. In this paper some criteria influencing the accuracy of the reconstruction of the transient active load and its time history are analyzed. It is shown by some simple examples that the purpose of the reconstruction, either forces and their distribution or main structural loads only, defines the quality required for the mathematical model of the measured prior spacecraft. The knowledge of the spacecraft stiffness matrix and of some few eigenmodes enables the use of the inverse Williams procedure, which delivers forcing functions precise enough for the strength analysis of the primary structure.

**86-2416**

**Substructure Coupling of Analytical and Test Models for an Experimental Structure**

F. Charron, V.K. Jha, H. Lapiere, S.J. Sorocky

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1463-1470, 3 figs, 11 tables, 6 refs

**KEY WORDS:** Experimental modal analysis, Spacecraft, Substructuring methods

Substructure coupling as a means of synthesizing the structural model for a large structure is demonstrated. An experimental satellite structure consisting of two substructures was built and tested. Substructure experimental and analytical models were generated and coupled by using SYSTAN software. The synthesized results were compared with the NASTRAN and test results of the complete structure. Results showed that modes of the coupled structure sensitive to clamped boundary conditions between substructures were better synthesized by using analytical substructure models, while those sensitive to certain asymmetries in substructure material properties were synthesized by using the test derived model for the substructure.

**86-2417**

**Transient Modal Tuning**

G.D. Shepard

Univ. of Lowell, Lowell, MA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1482-1486, 3 figs, 2 tables, 3 refs

**KEY WORDS:** Experimental modal analysis, Spacecraft, Impulse response, Tuned frequencies

For space structures that are too large and fragile to be dynamically tested on earth, system identification must be conducted in space. The space environment, however, restricts many of

the modal testing techniques normally used on earth. For instance, actuators are too sparse and poorly positioned to efficiently excite structural dynamic modes, and energy limitations favor transient inputs with narrow bandwidths. This report considers the advantages of using the impulse response of a particular complex structural mode as an input to selectively enhance that mode. For this case, the response of the desired single mode increases monotonically relative to the undesired responses.

**86-2418**

**Boundary Integral Equation Approach to Non-linear Response Control of Large Space Structures: Alternating Technique Applied to Multiple Flaws in Three-Dimensional Bodies**

P.E. O'Donoghue

Ph.D Thesis, Georgia Institute of Technology, 248 pp (1985) DA8605280

**KEY WORDS:** Spacecraft, Vibration control, Boundary integral equation method, Plates

The topic of vibration control of large space structures is addressed. This control involves the calculation of forces that must be applied to the structure so as to damp out any excessive motion and to maintain the shape at some desired configuration. In particular the large space structure is idealized by a flat plate where equivalent continuum models are employed to establish the characteristics of such a structure. Both linear and nonlinear systems are controlled. In the linear case the well known linear optimal control principles, using a quadratic performance index, are used to calculate the appropriate feedback control forces. In the nonlinear problem, which is related to the large deformation of a thin flat plate, the controlling forces are designed from the linear portion of the equations and the resulting system is shown to be asymptotically stable.

**86-2419**

**Simulation Efficiency in Acoustic Testing of Shuttle Payloads**

F.J. On, E.J. Kirchman

NASA Goddard Space Flight Ctr.

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 202-209, 16 figs, 1 table, 6 refs

**KEY WORDS:** Acoustic tests, Test facilities, Space shuttles

Based on the results of this study, the assumption that imposing ground acoustic test levels repre-

sentative of the Shuttle cargo bay acoustic environment in the payload will yield a satisfactory (or conservative) test has been found to be invalid.

**86-2420**

**Derivation of Captive Carry Vibration Environment**

R.E. Thaller, D. Brown

Wright-Patterson Air Force Base, OH

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 215-223, 20 figs, 4 refs

**KEY WORDS:** Air launched missiles, Acoustic tests

Designed to withstand a projected 8 hours of B-52 takeoff acoustics, the AGM-86B air launched cruise missile (ALCM) will be exposed to an expected lifetime of 125 hours of more severe boundary layer noise environment during B-1B external carriage. External carriage acoustic estimates exceeded the ALCM design requirements in the 500 Hz octave band and below. Because no analysis techniques or transfer functions existed to convert the input below 200 Hz into vibration response, an ALCM acoustic test was initiated. The test was also an opportunity for a preliminary evaluation of missile endurance.

**86-2421**

**Recent Trends in Acoustic Test Facilities**

R.M. Slone, Jr.

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 155-156

**KEY WORDS:** Test facilities, Acoustic tests, Space shuttles

Special purpose acoustic test facilities are springing-up around the world for system level testing of space flight hardware. These facilities differ very little in size or test capability from their predecessors in the U.S. The refinements in these contemporary acoustic facilities are evolutionary improvements on earlier facilities in the U.S. The nature of these refinements is such as to help promote high intensity acoustic testing to a more repeatable and standardized form of qualifying space flight hardware.

**86-2422**

**System Level Acoustic Test Effectiveness**

D.A. Smith

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 148-151, 8 figs

KEY WORDS: Spacecraft, Acoustic tests

This analysis indicated that system level acceptance testing detected 64 potential failures that may have resulted from exposure to the high intensity acoustic dynamic environment for 81 vehicles analyzed. Only one of these potential failures occurred and was detected while monitoring during acoustic testing at the system level. The other 63 were detected during post acoustic functional testing. The one failure was ultimately corrected with a design change. This one failure was not verified during the post acoustic functional since it was a dynamic environment susceptible failure mode only. It was verified during subsequent failure analysis and was determined to have been caused by the deck flutter damper assembly that was an integral part of the tape recorder itself.

## BIOLOGICAL SYSTEMS

### HUMAN

86-2423

#### Effects of Helmet Weight and Center-of-Gravity on the Vibratory Dynamics of the Head-Neck System: A Modeling Approach

C.D. Hayes, J.F. Wasserman, B.P. Butler  
Univ. of Tennessee, Knoxville, TN  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1201-1207, 3 figs, 2 tables, 9 refs

KEY WORDS: Helmets, Head (anatomy), Mathematical models, Vibration excitation

A four-degree-of-freedom mathematical model was developed to describe the effects of varying helmet weight and center-of-gravity (CG) on the vibration characteristics of the head-neck-helmet system. The model consists of two pivot points connected by a system rotational springs. Experimental data, collected from six subjects exposed to single- and multiple-axis vibration while wearing a variable weight/variable CG helmet, was used to determine rotational spring coefficients. Data from a simplified model was compared to experimental head-neck motion data to illustrate the change in head-neck-helmet motion due to the change in helmet weight and CG.

## MECHANICAL COMPONENTS

### ABSORBERS AND ISOLATORS

86-2424

#### Design and Testing of Base Isolators

J.M. Kelly  
Univ. of California, Berkeley, CA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1305-1311, 9 figs, 3 tables, 5 refs

KEY WORDS: Experimental modal analysis, Base isolation, Elastomers, Buildings, Seismic isolation

This report describes a series of tests carried out to verify the performance of prototype natural rubber bearings designed for the first building in the United States built on the principles of base isolation. The cylindrical base isolation bearings consist of layers of natural rubber and thin steel plates. The tests demonstrated that the bearings were able to sustain large lateral cyclic displacements without distress. Effective vertical and lateral stiffnesses of the bearings were determined. Equivalent viscous damping ratios were calculated from the hysteretic plots. The displacement demand on the bearings was predicted on the basis of dynamic analysis.

86-2425

#### Modal Properties of a Base Isolated Building

G.C. Pardoan, G.C. Hart  
Univ. of California, Irvine, CA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1312-1316, 7 figs, 5 refs

KEY WORDS: Experimental modal analysis, Base isolation, Seismic isolation, Buildings

The modal properties of the first building in the US located in a seismic zone that is on a base isolation system are described. The design objective involves the isolation of the building from the ground with a shock isolation system which filters out the majority of the earthquake input to the structure. The modal properties are obtained by subjecting the structure to a calibrated impact (a large pendulum striking a reaction mass at the top story) while simultaneously measuring velocity data at a number of strategic locations. Estimates of damping and frequency are compared to the ambient vibration results.

**86-2426**

**Horizontal Isolation of Sensitive Building Contents**

K.L. Merz, J.C. Stoessel, J. Yagoubian, R. Haskell

ANCO Engineers, Inc., Culver City, CA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1317-1321, 5 figs

**KEY WORDS:** Experimental modal analysis, Base isolation, Seismic isolation, Buildings, Equipment-structure interaction

While buildings and other similar structures have design criteria for earthquake-induced loads, no similar criteria exist for the sometimes sensitive contents inside buildings. In some cases, these contents may represent the heart of the business (computers and assorted items) or valuable items such as those in a museum. Two studies were undertaken to experimentally verify horizontal isolation systems designed for a computer unit and a museum cabinet. The designs proved successful in reducing horizontal accelerations to an acceptable level.

**86-2427**

**Base Isolating High Frequency Seismic Events**

P.R. Millarke

Martin Marietta Corp., Denver, CO  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1322-1326, 4 figs, 8 refs

**KEY WORDS:** Experimental modal analysis, Base isolation, High frequency excitation

Some time-dependent forcing functions taken from accelerometer recordings of seismic events in California indicate that high accelerations associated with high frequency motion may be possible. Analysis by the modal acceleration method shows that for structures not designed to resist this high frequency motion, high base shears may occur. Base isolation is suggested as a method of avoiding the possibility of unacceptably high loads.

**86-2428**

**Damped Modal Analysis of Full Base Isolation**

K. Delinic

Kraftwerk Union AG, Postfach, West Germany  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1327-1334, 6 figs, 2 tables, 1 ref

**KEY WORDS:** Experimental modal analysis, Base isolation, Nuclear power plants, Helical springs

Damped modal analysis based on a newly developed quadratic eigenvalue solver is presented. Its special feature is the capability to analyze the free vibration mode of a multi-degree-of-freedom system as a function of the variable physical damping attached to the system at its nodes. The modal flow analysis is a helpful tool to control the structural behavior independently from the excitation. However for each excitation and desired damping value the modal integration can be performed. The method is applied to analyze the base isolation of the reactor building supported on helical springs and damper elements.

**86-2429**

**Role of Base Isolation in the Aseismic Design of Structures**

N.R. Valdya

Paul C. Rizzo Assoc., Inc., Pittsburgh, PA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1045-1051, 6 figs, 3 tables, 5 refs

**KEY WORDS:** Base isolation, Seismic design

Shaker table tests in the laboratory have demonstrated the feasibility of base isolation. Even more than conventional structures, sensitivity and probabilistic studies of seismic response of base-isolated structures need to be performed to augment the relatively insignificant data base. The study reported here contributes to the data base. Using relatively simple analytical models, which include material nonlinearities, probabilistic analysis of a few base-isolated structures is performed. Distributions of probabilities of exceedance of pertinent design quantities is established. Physical parameters, which are dominant in affecting seismic response, are identified. Important design considerations are discussed and, from this point of view, the role of base isolation in the aseismic design is examined.

**86-2430**

**Design and Cost/Benefit Issues for Seismically Isolated Structures**

R.L. Mayes, M.R. Button

Dynamic Isolation Systems, Inc., Berkeley, CA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1036-1044, 4 figs, 3 tables, 13 refs

**KEY WORDS:** Seismic isolation, Base isolation, Buildings, Bridges, Elastomers

Seismic (or base) isolation is a design concept that offers significant benefits for reducing the

earthquake damage potential in both buildings and bridges. This paper addresses the feasibility, design philosophy and cost/benefit issues of building base isolation design. Also included is a detailed design procedure for a lead-rubber bearing seismic isolation system. This is illustrated by means of an example on a twelve-story structure.

**86-2431**

**Basic Concept and Applications of Base Isolation**

I.G. Buckle, T.E. Kelly, L.R. Jones

Computech Engineering Services, Inc., Berkeley, CA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1026-1035, 8 figs, 2 tables, 13 refs

**KEY WORDS:** Buildings, Base isolation, Seismic isolation

Base isolation is a design strategy founded on the premise that a structure can be substantially decoupled from damaging horizontal components of earthquake motions, significantly reducing levels of force and acceleration in the structure. This paper outlines the basis of a practical base isolation system which may include energy dissipation in special purpose mechanical devices. Topics covered include basic elements of base isolation, and an overview of recent applications.

**86-2432**

**Active Motion Compensation System for Towed Chain Arrays**

G.B. Andrews

"Improve Your Odds with Sound Basic Sci. and Creative Engrg.", Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 563-543, 8 figs

**KEY WORDS:** Active vibration control, Towed systems

A motion-compensation system that controls the position of a cable towed behind an ocean-going vessel is discussed. An active control system that will operate in conjunction with a passive compensation system is proposed. A system model, developed from Lagrange's equations, is coded into software using ACSL, a simulation language. Data from actual at-sea tests of the passive system is fed into the model in order to establish system parameters. The effect of an active control system using a torque motor is introduced into the simulation. General results are described, with recommendations for future enhancements and improvements.

**86-2433**

**On the Suppression of Ground Vibration by Active Force Control (4th Report; On the Hybrid Force Control)**

N. Tanaka, Y. Kikushima

1-2Namiki Tsukuba Science City, Ibaraki, Japan  
Bull. JSME, 29 (251), pp 1548-1556 (May 1986)  
19 figs, 8 refs

**KEY WORDS:** Machinery-induced vibrations, Ground vibration, Vibration control, Active force control

For the purpose of suppressing ground vibration as pollution produced by vibrating machines such as forge hammers, press machines, etc., this paper presents a new active hybrid force control method. By using both the characteristics of a low pass filter of an elastic support and that of a high pass filter of an active force control method, the method aims to eliminate the exciting force in the frequency range. The principle of the hybrid force control is proposed and the fundamental characteristics of the dynamic compensator are shown. From the viewpoint of the phase compensation method, the design procedure of the hybrid force control system is presented and the effectiveness of this method is clarified. To verify the control effect, an experiment is conducted.

**86-2434**

**On the Suppression of Ground Vibration by Active Force Controller (5th Report; Experiment of the Hybrid Force Control Method)**

N. Tanaka, Y. Kikushima

1-2Namiki Tsukuba Science City, Ibaraki, Japan  
Bull. JSME, 29 (251), pp 1557-1563 (May 1986)  
16 figs, 1 table, 5 refs

**KEY WORDS:** Machinery-induced vibrations, Ground vibration, Vibration control, Active force control

This paper discusses the realization of the hybrid force control method from a practical point of view. First, based upon the experimental data, the design procedure of the system is presented. Second, in the suppression of the exciting force, the control effect in terms of an active damper is considered. Third, from a viewpoint of dynamic compensation, the effectiveness as well as the stabilization of the system is shown. Finally, the hybrid force control method including both the characteristics of a low-pass filter of an elastic support and that of a high-pass filter of an active force control method is realized experimentally.

86-2435

**Computer Aided Design of Vibration Isolators Regarding Soil Interaction (VID)**

A. Nasser, S. Serag, A. El Khatib, H. Gaffer  
Menoufia Univ., Shebin El-Kom, Egypt  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1132-1139, 8 figs, 5 refs

KEY WORDS: Vibration isolators, Machine foundations, Soil-foundation interaction, Computer aided design, Computer programs

The main objective of this paper is to aid designers of vibration isolators in obtaining a more exact solution to the isolation problem, taking into account soil interaction. A computer aided design technique using the machinery and soil information is introduced.

86-2436

**Dynamic Vibration Absorbers for Reducing Resonance Amplitudes of Hysteretically Damped Beams**

B. Candir, H.N. Ozguven  
Middle East Tech. Univ., Ankara, Turkey  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1628-1635, 5 figs, 2 tables, 12 refs

KEY WORDS: Dynamic vibration absorption (equipment), Beams, Hysteretic damping

The parameters of a viscously damped dynamic vibration absorber can be optimized to minimize a specific resonance of a structure. In this study, the optimum absorber parameters are found by solving a min-max problem (minimization of the maximum response in the frequency range of interest). The response of a structurally damped beam and absorber system is determined by the assumed-modes method. Harmonic excitations with constant and frequency-squared amplitudes are considered. The optimum parameters of the absorber suppressing the first or second resonance amplitudes of a cantilever beam are numerically determined and the results are presented in the form of nondimensional graphs. The graphs are prepared for a given structural damping factor after studying the effect of structural damping on the optimum absorber parameters. The optimum absorber parameters found by this method are compared with those obtained by the approximate method employing an equivalent single-degree-of-freedom system.

86-2437

**An Active Vertical Suspension for Track/Vehicle Systems**

T. Yoshimura, N. Ananthanarayana, D. Deepak

Tokushima Univ., Tokushima, Japan

J. Sound Vib., 106 (2), pp 217-225 (Apr 22, 1986) 6 figs, 14 refs

KEY WORDS: Suspension systems (vehicles), Tracked vehicles, Active vibration control

Optimal control theory is used to formulate and solve the problem of design of an active suspension system to control vertical vibration of a track/vehicle system. The active suspension system is taken as a cascade arrangement of a Kalman filter and the optimal controller. A noisy measured data sequence of the track unevenness is used as the input. As a numerical example, and active suspension of a simple carbody of the Indian Railways is presented.

## SPRINGS

86-2438

**Segmented Tubular Cushion Springs and Spring Assembly**

L.A. Haslim  
NASA Ames Res. Ctr., Moffett Field, CA  
U.S. Pat. Appl. 6-746 160/GAR, 39 pp (June 1985)

KEY WORDS: Springs, Energy absorption

A spring which includes a tube with an elliptical cross section, with the greater axial dimension extending laterally and the lesser axial dimension extending vertically is disclosed. A plurality of cuts in the form of slots passing through most of a wall of the tube extend perpendicularly to a longitudinal axis extending along the tube. An uncut portion of the tube wall extends along the tube for bonding or fastening the tube to a suitable base, such as a bottom of a seat cushion.

## TIRES AND WHEELS

86-2439

**Identification of the Damping Matrix for Tires**

D.J. Inman, S.K. Jha  
State Univ. of New York, Buffalo, NY  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1078-1080, 6 refs

KEY WORDS: Tires, Elastomers, Linking analysis and test, Viscous damping, Modal analysis

In modeling structures, the dissipation in the system is usually the most difficult element to

represent. This is especially true in complex structures such as the cord rubber composite materials used in tires. The work presented here applies a method of modeling the dissipation in a structure from experimental data combined with accepted nondissipative finite element models. The result of the described procedure is a linear nonconservative multiple degree-of-freedom model of a test structure that correctly predicts the transient response of the structure to arbitrary inputs.

## BLADES

86-2440

### Modal Analysis of a Moving Band Under Cutting Loads

W.Z. Wu, C.D. Mote, Jr.  
Univ. of Missouri, Rolla, MO  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1621-1627, 10 figs, 11 refs

KEY WORDS: Modal analysis, Band saws, Woodworking machines, Blades,

Excessive band vibration directly contributes to the poor cutting accuracy and surface quality, raw material waste, gullet cracking, and increased downtime of bank mills. Bending-torsional coupled transverse vibrations of a cutting blade are investigated by using a linear undamped axially moving thin beam model. An accurate, comprehensive, fast and inexpensive numerical method for efficient analyses of the natural frequencies and mode shapes of a cutting blade has been developed. Cutting speed, cutting loads and possible constraints are incorporated in the analysis.

86-2441

### Finite Element Modal Analysis of Steam Turbine Blades

J.M. Steele  
Stress Technology Inc., Rochester, NY  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1374-1381, 16 figs, 3 tables, 7 refs

KEY WORDS: Modal analysis, Turbine blades, Finite element technique

Finite element analysis is particularly well suited to dynamic analysis of steam turbine blades. The blades have a complex geometry, are affected by high centrifugal stresses which raise natural frequencies and are subjected to signifi-

cant harmonic forcing which can produce significant dynamic stresses. Modal finite element analyses of two, typical steam turbine blades are presented. Parametric studies, for one of the blades were performed to determine the convergence of natural frequencies as functions of element density and number of retained master degrees of free freedom.

86-2442

### Modelling of Turbine Blades for Stress and Dynamic Analysis

M.S. Gadala, T.P. Byrne  
Ontario Hydro Research, Toronto, Ontario, Canada  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1220-1227, 13 figs, 4 tables, 11 refs

KEY WORDS: Turbine blades, Mathematical models

Modeling of turbine blades is of major importance for the analysis and design of turbines for power plants. Various design features for locking grooves, blade root serrations, and lacing wires must be assessed via stress and dynamic analysis. This paper presents a comparative study and assessment for various 2-D and 3-D blade models addressing one or more of the above considerations. Basic steps of a complete blade dynamic analysis are then provided. Through an actual working example, it is shown that the analysis of full-scale blade models can be achieved through the analysis of reduced models.

## BEARINGS

86-2443

### Calculation of the Dynamic Coefficients of a Journal Bearing, Using a Variational Approach

P. Klit, J.W. Lund  
Engineering Academy of Denmark, Lyngby, Denmark  
J. Trib., Trans. ASME, 108 (3), pp 421-425 (July 1986) 3 figs, 4 refs

KEY WORDS: Journal bearings, Dynamic coefficients

The dynamic bearing coefficients are obtained from a solution to the variational equivalent of Reynolds equation. A perturbation method is applied to find the individual dynamic coefficients. The finite element method is used in the numerical evaluation of the equations. The flow

is assumed to be laminar, the lubricant is Newtonian. Allowance is made for viscosity-temperature dependency in circumferential and axial directions.

**86-2444**

**Ball Bearing Response to Cage Unbalance**

P.K. Gupta, J.F. Dill, J.W. Artuso, N.H. Forster  
PKG Inc., Clifton Park, NY  
J. Trib., Trans. ASME, 108 (3), pp 462-467 (July 1986) 11 figs, 2 tables, 9 refs

**KEY WORDS:** Ball bearings, Unbalance mass response, Computer programs, Experimental data

Motion of the cage in a high-speed angular contact ball bearing is experimentally investigated as a function of prescribed unbalance, up to operating speeds corresponding to three million DN. The predictions of cage motion made by the recently developed computer model, ADORE, are validated in the light of the experimental data. It is shown the cage whirl velocity is essentially equal to its angular velocity at all levels of unbalance and over a wide range of operating conditions. ADORE predictions, over the entire range of unbalance and bearing operating conditions, are in very good agreement with the experimental observations.

**86-2445**

**Quasi-Modal Vibration Control by Means of Active Control Bearings**

K. Nonami, D.P. Fleming  
NASA Lewis Res. Ctr., Cleveland, OH  
Rept. No. NASA-TM-87232, 12 pp (1986) N86-21856/7/GAR

**KEY WORDS:** Modal analysis, Bearings, Active vibration control, Modal control

A design method of an active control bearing system with only velocity feedback is investigated. The study provides a new quasi-modal control method for a control system design of an active control bearing system in which feedback coefficients are determined on the basis of a modal analysis. Although the number of sensors and actuators is small, this quasi-modal control method produces a control effect close to an ideal modal control.

## GEARS

**86-2446**

**Lubricant and Additive Effects on Spur Gear Fatigue Life**

D.P. Townsend, E.V. Zaretsky, H.W. Scibbe

NASA Lewis Res. Ctr., Cleveland, OH  
J. Trib., Trans. ASME, 108 (3), pp 468-475 (July 1986) 4 figs, 8 tables, 19 refs

**KEY WORDS:** Spur gears, Fatigue life, Fatigue tests, Lubrication

Spur gear endurance tests were conducted with six lubricants using a single lot of consumable-electrode vacuum melted (CVM) AISI 9310 spur gears. The sixth lubricant was divided into four batches each of which had a different additive content. Lubricants tested with a phosphorous-type load carrying additive showed a statistically significant improvement in life over lubricants without this type additive.

**86-2447**

**Approximate Solution of a Gear System Subjected to Random Excitation**

K. Sato, S. Yamamoto, O. Kamada, N. Takatsu  
Utsunomiya Univ., Utsunomiya, Japan  
Bull. JSME, 29 (251), pp 1586-1589 (May 1986) 5 figs, 14 refs

**KEY WORDS:** Gears, Random excitation, Approximation methods

Forced vibration of a gear system excited by transmission error having a period equal to the meshing period and by a random external force, is analyzed approximately by means of an averaging method. Some numerical examples are given. To facilitate analytical treatment, the time varying parameter system is transformed into a time invariant parameter system.

**86-2448**

**Vibration of Power Transmission Helical Gears (Approximate Equation of Tooth Stiffness)**

K. Umezawa, T. Suzuki, T. Sato  
Tokyo Institute of Technology, Yokohama, Japan  
Bull. JSME, 29 (251), pp 1605-1611 (May 1986) 15 figs, 2 tables, 18 refs

**KEY WORDS:** Helical gears, Torsional vibration, Finite difference technique

An approximate equation has been proposed to clarify the rotational vibration behavior of power transmission helical gear pairs with comparatively narrow facewidth. It has been based on the theoretical deflection solved by one of the authors using the finite difference method. And the rotational vibration has been treated as a single-degree-of-freedom system and the meshing resonance frequency of it has been obtained. Its propriety is verified by measuring the accelera-

tion for each gear pair belonging to the three categories classified by contact ratio. It is found that the meshing resonance frequencies calculated by use of the proposed equation agrees with experimental values.

## FASTENERS

86-2449

### LCC Solder Joint Fatigue Analysis Procedure

W.E. Desaulnier, Jr., T.E. LaFlamme, W.B. Ammerman, M.C. Binder  
Hamilton Standard Div, United Tech. Corp., Windsor Locks, Canada  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 6-19, 15 figs, 2 tables, 12 refs

KEY WORDS: Joints, Electronic instrumentation, Fatigue life

A simplified procedure has been developed which now makes it practical to perform a reasonably accurate inelastic fatigue analysis of critical LCC solder joints in any electronic unit. The procedure requires only elastic stress analysis results and it is completely general regarding the loads and designs it can handle. Both post-mounted and card guide mounted PCB electronic unit designs can be analyzed. Vibration curvature and thermal shear and curvature loadings are all handled by the procedure. It includes a general fatigue curve equation which can account for temperature, rate, grain size, gold content and stress state triaxiality effect. The entire procedure has been programmed and effectively applied to evaluate various designs.

86-2450

### Loosening of Threaded Fastenings by Vibrations

S. Harnchoowong  
Ph.D. Thesis, Univ. of Wisconsin, Madison, WI, 200 pp (1985) DA8601103

KEY WORDS: Fasteners, Bolts, Loosening, Vibration excitation

Loosening of threaded fastenings by vibrations was divided into two processes: an increasing bolt load process and a decreasing bolt load process. There were two parts of calculation manipulated in each process. The first part was to calculate the load distribution in the engaged threads by modifying Sopwith's model. This thread load was used to compute stress, strain, and displacement in a bolt and a nut. The

second part was to calculate the angle of nut loosening by using the results obtained from two torque equilibrium equations, one for a bolt and the other for a nut.

## SEALS

86-2451

### Pressure and Squeeze Effects on the Dynamic Characteristics of Elastomer O-Rings Under Small Reciprocating Motion

I. Green, I. Etsion  
Technion Univ., Haifa, Israel  
J. Trib., Trans. ASME, 108 (3), pp 439-445 (July 1986) 5 figs, 3 tables, 8 refs

KEY WORDS: Rings, Seals, Elastomers

A test procedure is described by which quick measurements of stiffness and damping coefficients of elastomer O-rings can be made for a wide range of the parameters affecting O-ring dynamics. Tests were performed to investigate the effects of squeeze and pressure on the dynamic characteristics of Nitrile (Buna N) and Fluorocarbon (Viton 75) O-rings. Results of these tests are presented and discussed.

86-2452

### Theory Versus Experiment for the Rotordynamic Coefficients of Annular Gas Seals: Part 1 -- Test Facility and Apparatus

D.W. Childs, C.E. Nelson, C. Nicks, J. Scharret  
Texas A&M Univ., College Station, TX  
J. Trib., Trans. ASME, 108 (3), pp 426-432 (July 1986) 11 figs, 10 refs

KEY WORDS: Seals, Dynamic coefficients, Experimental data, Testing techniques, Testing instrumentation

A facility and apparatus are described for determining the rotordynamic coefficients and leakage characteristics of annular gas seals. The apparatus has a current top speed of 8000 cpm with a nominal seal diameter of 15.24 cm (6 in). The airsupply unit yields a seal pressure ratio of approximately 7. The inlet tangential velocity can also be controlled. An external shaker is used to excite the test rotor. The apparatus has the capability to independently calculate all rotordynamic coefficients at a given operating condition with one excitation frequency.

86-2453

**Theory Versus Experiment for the Rotordynamic Coefficients of Annular Gas Seals: Part 2 — Constant-Clearance and Convergent-Tapered Geometry**

C.C. Nelson, D.W. Childs, C. Nicks, D. Elrod  
Texas A&M Univ., College Station, TX  
J. Trib., Trans. ASME, 108 (3), pp 433-438 (July 1986) 9 figs, 8 refs

**KEY WORDS:** Seals, Dynamic coefficients, Stiffness coefficients, Experimental data

An experimental test facility is used to measure the leakage and rotordynamic coefficients of constant-clearance and convergent-tapered annular gas seals. The results are presented along with the theoretically predicted values. Of particular interest is the prediction that optimally tapered seals will have significantly larger direct stiffness than straight seals. The experimental results verify this prediction. Generally the theory does quite well, but fails to predict the large increase in direct stiffness when the fluid is prerotated.

## STRUCTURAL COMPONENTS

### CABLES

86-2454

**Modal Coupling in the Free Nonplanar Finite Motion of an Elastic Cable**

F. Benedettini, G. Rega, E. Vestroni  
Meccanica, 21 (1), pp 38-46 (Mar 1986) 12 figs, 1 table, 18 refs

**KEY WORDS:** Cables, Elastic properties, Modal coupling

In the finite motions of a suspended elastic cable the in-plane and out-of-plane oscillations are coupled, which is in contrast with what is predicted by the theory of small oscillations. To study the phenomenon of nonlinear coupling, a simple but meaningful two degree-of-freedom model is referred here, one parameter being used to describe the in-plane motion and the other the out-of-plane motion. The solution of the dynamic equilibrium equations is accomplished by an order-three perturbational expansion, which furnishes the time solution of the two displacement parameters. The modification of the free oscillations due to the exchange of energy between the two modes in absence of

internal resonance is studied for different initial conditions and the effect of modal coupling is evidenced.

86-2455

**Spectral Analysis of Cable Stay Vibration**

F. Eken  
Ph.D. Thesis, Tulane Univ., 157 pp (1985)  
DA8606163

**KEY WORDS:** Cables, Cable stayed structures, Suspension bridge, Spectrum analysis

Cable stay vibration data was obtained from the cable-stay suspension bridge at Luling, Louisiana. Cable stay motion is harmonic in nature and is modeled as a linear system consisting of a set of second-order resonances. While traditional processing of this data using harmonic analysis provides information about the harmonic frequencies and the average excitation at these frequencies, in this investigation additional features of this data such as the instantaneous modal excitations and estimates of modal damping coefficients were obtained using the methods of complex demodulation and the ZOOM FFT. Modal resonance characteristics of the cable stay vibration were examined using the ZOOM-FFT technique. The input to the system is assumed to be band limited white noise having a constant power spectrum over a very narrow band of frequencies. The output of the system is either the output from a single accelerometer or the semi-major axis of the elliptical trajectory computed from the output of two accelerometers. Estimates of modal damping coefficients were obtained for both representations of the output.

### BEAMS

86-2456

**A Study on Non-Proportionally Damped Beams**

H.N. Ozguven  
Middle East Technical Univ., Ankara, Turkey  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1081-1087, 4 figs, 1 table, 13 refs

**KEY WORDS:** Beams, Damped structures, Linking analysis and test, Modal analysis

Vibrational characteristics of nonproportionally damped structures can quite accurately be predicted by complex mode superposition. However, solving a complex eigenvalue problem and using complex modes increase the computational effort considerably. Approximate methods,

therefore, are preferred in several applications. Almost in all approximate modal analysis methods, real modal vectors are employed by making proportional damping approximation. In this work dynamic behavior of damped beams, harmonically excited at frequencies around a resonance frequency is investigated by using results of a set of experiments conducted with proportionally and nonproportionally damped aluminum beams. The main attention is focused on the contribution of the in-phase component of the receptance (or inertance) to the total response at undamped natural frequencies as well as at resonance frequencies. The change of this contribution by the point of excitation and/or point of measurement is also investigated.

**86-2457**

**A Finite Element for Dynamic Analysis of Beams and Space Frames**

M. Olsson

Lund Univ., Lund, Sweden

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 884-890, 3 figs, 2 tables, 11 refs

**KEY WORDS:** Modal analysis, Beams, Finite element technique, Coupled response

A finite element for analysis of beams and beam structures has been developed. Its use in dynamic analysis is emphasized in this paper. The beam element is capable of handling coupled vibrations and, as options, second-order effects, bending shear deformations, rotatory inertia and warping torsion (Vlasov torsion). The choice of reference axes is not restricted to the centroidal and shear center axes but can be chosen arbitrarily. Two numerical examples demonstrate some of the possibilities of the element presented.

**86-2458**

**Determination of Boundary Conditions on African Xylophone Beams Using Modal Analysis**

J. Njock Libii

Indiana Univ.-Purdue Univ., Ft. Wayne, IN

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1071-1077, 5 figs, 6 tables, 4 refs

**KEY WORDS:** Beams, Musical instruments, Modal analysis, Linking analysis and test, Geometric effects

Xylophone beams are modeled as Euler beams in free lateral vibration with free ends. The response of such beams to a sudden impact at

their midpoint is investigated analytically and experimentally to determine the boundary conditions that are applicable. The material properties as well as the boundary conditions were assumed constant for all beams and the relationship between fundamental frequency and geometry was studied. Theoretical frequencies were found to be consistently lower than measured ones by thirteen percent.

## PLATES

**86-2459**

**Free Vibrations of a Plate with an Inner Support**

P.A.A. Laura, V.H. Cortinez

Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina

J. Sound Vib., 106 (3), pp 409-413 (May 8, 1986)  
2 figs, 8 refs

**KEY WORDS:** Plates, Fundamental frequencies, Flexural vibrations

The title problem is tackled by using a simple polynomial coordinate function and the Rayleigh-Schmidt method. It is assumed that the inner support is parallel to the free edge. When the support coincides with the free edge the frequency equation degenerates properly into the case of a simply supported edge. Numerical results are presented for the situation where two opposite edges are simply supported and the edge parallel to the free edge is either clamped or simply supported.

**86-2460**

**A Study of Noise Source Identification on Plate Excited by Structure-Borne Sound Using the Acoustic Intensity Method**

Jae Eung Oh, Jun Chul Park, Sung Ha Yum

Han Yang Univ., Seoul, Korea

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 952-956, 9 figs, 1 table, 6 refs

**KEY WORDS:** Plates, Noise source identification, Acoustic intensity method

In studies on noise reduction, it is necessary to know the generation mechanism of sound to identify the noise sources. As there is a complex relation between the structural surface vibration and the radiated sound power resulting from these vibrations, a simplified radiation model is used which originally was developed as a verification tool for the acoustic intensity measurement procedure. Cross correlation

between the displacement pattern of the resonant vibrational mode and experimentally determined intensity pattern was found.

**86-2461**

**Impulse Response of an Infinitely Long Thick Strip Plate**

S. Chonan, N. Nozawa

Tohoku Univ., Sendai, Japan

J. Sound Vib., 106 (3), pp 481-489 (May 8, 1986)

6 figs, 10 refs

**KEY WORDS:** Plates, Elastic foundations, Impulse response, Rotatory inertia effects, Transverse shear deformation effects

A study of the dynamic response of an infinitely long thick strip plate subjected to an impulsive load is presented. The plate is simply supported along the edges and resting on an elastic foundation. The problem is studied on the basis of a plate theory in which the effects of rotatory inertias and shear deformations are retained. Governing equations are solved by applying the methods of the Laplace transform with respect to time and the Fourier transform with respect to a longitudinal space variable. Dynamic coefficients (maximum dynamic displacement/static displacement, maximum dynamic bending moment/static bending moment) are calculated numerically for plates subjected to a step line load and shown graphically for various values of the parameters included.

**86-2462**

**Natural Frequency of an Edge-Fixed Disc in Contact with a Liquid**

H. Takada, K. Ohno

Yokohama National Univ., Yokohama, Japan

Bull. JSME, 22 (251), pp 1544-1547 (May 1986) 6

figs, 4 refs

**KEY WORDS:** Plates, Disks, Fluid-induced excitation, Natural frequencies,

This paper deals with the natural frequency of an edge-fixed disk in contact with a liquid, which acts as an added mass to the disk reducing its natural frequency. Calculations and experiments are carried out for two cases. The experimental results agree well with the calculations by means of the finite element method within 4.3% error for the nodeless mode and for the mode with one diametral- and zero circular node. A reduction formula for the reducing ratio of the frequency is derived for arbitrary disk thickness, radius and density and also for arbitrary liquid density.

**86-2463**

**Response of Plates to Pulse Excitation**

G. Chandrasekharappa, H.R. Srirangarajan

Indian Institute of Technology, Bombay, India

Mech. Res. Comm., 13 (2), pp 107-117 (Mar/Apr 1986) 2 figs, 1 table, 7 refs

**KEY WORDS:** Plates, Large amplitude vibrations, Pulse excitation, Nuclear weapons effects, Aircraft

In this paper, the ultraspherical polynomial approximation technique is presented for the large-amplitude vibrations of thin plates subjected to step function loading, neglecting the longitudinal and rotatory inertia forces.

**86-2464**

**Coupling of Lagrange Interpolation Modal Analysis and Sensitivity Analysis in the Determination of Anisotropic Plate Rigidities**

W.P. DeWilde, H. Sol, M. Van Overmeire

Univ. of Brussels, Brussels, Belgium

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1058-

1063, 4 figs, 3 tables, 3 refs

**KEY WORDS:** Plates, Linking analysis and test, Experimental modal analysis, Numerical methods

The paper presents further developments of a problem previously exposed by the authors in 2nd IMAC, namely the coupling of experimental modal analysis and numerical analysis in order to obtain the plate rigidities. The knowledge of these plate rigidities enables the calculation of elastic material constants which can be used e.g. as input data for finite element models. The tuning operation is based on the calculation of sensitivities of the eigenvalues for parameter changes. The initial guess for the plate rigidities is calculated using the measured mode shapes of the test plates. The whole procedure is programmed in a FORTRAN program NATIDEN.

**86-2465**

**Natural Frequencies and Mode Shapes of a Free Rectangular Plate as a Function of the Aspect Ratio**

D.L. Gregory, D.O. Smallwood

Sandia National Laboratories, Albuquerque, NM

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1000-

1005, 5 figs, 1 table, 6 refs

**KEY WORDS:** Rectangular plates, Natural frequencies, Mode shapes, Geometric effects, Experimental modal analysis

Numerous modal systems are now available and new users are continually being introduced to these systems. A simple test structure would be useful to compare these systems on a common basis and would also provide a means to help train new users. Efforts to develop such a structure led to the analysis of free rectangular plates. The natural frequencies as a function of the aspect ratio (ratio of width to length) were analyzed to find an aspect ratio which would yield a desirable distribution of modal frequencies. A desirable distribution includes both widely separated and closely coupled modes. Results for sensitivity studies of mode shapes and frequencies to plate parameters are also given.

**86-2466**

**Experimental Investigation of Asymptotic Modal Analysis for a Rectangular Plate**

Y. Kubota, E.H. Dowell  
Duke Univ., Durham, NC  
J. Sound Vib., **106** (2), pp 203-216 (Apr 22, 1986), 10 figs, 10 refs

KEY WORDS: Rectangular plate, experimental modal analysis, Point source excitation

Experimental investigations of the response of a rectangular plate under a point random force have been performed to verify the asymptotic behavior predicted by asymptotic modal analysis (AMA). Measurements have been made for various frequency bandwidths, center frequencies, and locations of the point force. The experimental results approach the results predicted by AMA as the frequency bandwidth becomes large. Moreover, experimental results show that the responses at all points of the plate except for some special areas become the same as the frequency bandwidth becomes large. However, the ratio of experimental results to AMA results has a greater variation from unity when the location of the point force is near the edge of the plate, than when the location of the point force is at the center of the plate. All experimental results show good agreement with the expected results from AMA.

**86-2467**

**A Note on Transverse Vibrations of a Rectangular Plate with a Free, Rectangular, Corner Cut-Out**

P.A.A. Laura, P.A. Laura, V.H. Cortinez  
Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina  
J. Sound Vib., **106** (2), pp 187-192 (Apr 22, 1986) 4 figs, 10 refs

KEY WORDS: Rectangular plates, Flexural vibrations, Hole-containing media, Rayleigh-Ritz method

An approximate solution to the title problem is presented, obtained by using the Rayleigh-Ritz method. The analysis is presented for the case of simply supported and clamped plates. For the case of a rigidly clamped plate results are presented of numerical experiments on minimizing the calculated value of the fundamental frequency coefficient by using Schmidt's approach. An experimental investigation is described on a clamped square plate with a free square, corner cut-out, which has led to the conclusion that the fundamental frequency coefficient remains practically invariant with respect to size when compared with the frequency coefficient of the fully clamped plate. A similar conclusion is arrived at by means of the mathematical model. The problem under consideration is important from a practical viewpoint since cut-outs of the type considered here are quite common in engineering practice.

**86-2468**

**Static and Dynamic Deflections of Plates of Arbitrary Geometry by a New Finite Difference Approach**

M.C. Bhattacharya  
Univ. of Liverpool, Liverpool, England  
J. Sound Vib., **107** (3), pp 507-521 (June 22, 1986) 4 figs, 3 tables, 12 refs

KEY WORDS: Rectangular plates, Finite difference technique

Finite difference solutions for the static and dynamic displacements of a plate undergoing vibration are presented. The approach presented differs from the conventional methods in which the derivatives are expressed by their difference equivalents. Here the difference equations are obtained as solutions to the fourth order biharmonic equation. A single space varying drive number is found which varies from node to node and characterizes the true mode shape of the plate at a node. The technique presented can be applied to finite elements of triangular, rectangular or quadrilateral geometry without any restriction.

**86-2469**

**Numerical Analyses of Flexural Vibrations of Tapered Thickness Rectangular Plates**

P.A.A. Laura, C. Shangchow, R. Gelos, R.D. Santos  
Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina

J. Sound Vib., **106** (3), pp 415-418 (May 8, 1986)  
1 fig, 1 table, 5 refs

**KEY WORDS:** Rectangular plates, Flexural vibrations, Variable cross section, Fundamental frequencies, Numerical methods

The fundamental frequencies of vibration of a clamped rectangular plate with thickness varying in a bilinear fashion in the *x*-direction are determined, for various values of the plate parameters, by two different approaches: the Rayleigh-Schmidt minimization procedure; and a finite element algorithm.

**86-2470**

**Free Vibration Analysis of Right Triangular Plates with Combinations of Clamped-Simply Supported Boundary Conditions**

D.J. Gorman

University of Ottawa, Ottawa, Ontario, Canada  
J. Sound Vib., **106** (3), pp 419-431 (May 8, 1986)  
10 figs, 7 tables, 5 refs

**KEY WORDS:** Plates, Triangular bodies, Boundary condition effects, Method of superposition

An accurate analytical solution is obtained for the free vibration of right triangular plates with all possible combinations of clamped and simply supported edge conditions. The method of superposition as described by the author in an earlier publication is utilized. A slight modification is made to the earlier building blocks in order to facilitate computations. Eigenvalues and mode shape information are provided for the first four modes of free vibration with a large range of plate aspect ratio. This appears to constitute the first accurate and comprehensive treatment of this family of problems.

**86-2471**

**Dynamic Response of Circular Plates in Contact with a Fluid Subjected to General Dynamic Pressures on a Fluid Surface**

K. Nagaya, K. Nagai

Gunma Univ., Gunma, Japan

J. Sound Vib., **106** (2), pp 333-345 (Apr 22, 1986) 12 figs, 15 refs

**KEY WORDS:** Circular plates, Fluid-induced excitation

A method for solving dynamic response problems of a circular plate in contact with a fluid whose surface is excited by general dynamic pressures is presented. By utilizing the Fourier expansion and the Laplace transform methods, the expres-

sion for the dynamic response of displacement is obtained in a general form which is applicable to general dynamic pressures. As applications, numerical calculations have been carried out for three types of sinusoidal, trapezoidal and explosive pressures. The results obtained in a certain type of impact pressure are compared with the exact ones.

**86-2472**

**Vibration of a Circular Disk as a Test Method for Damping Characteristics of Constrained Layer Material**

V.O. Shestopal, P.C. Goss

National Materials Handling Bureau, New South Wales, Australia

J. Sound Vib., **106** (3), pp 377-390 (May 8, 1986)  
5 figs, 5 tables, 9 refs

**KEY WORDS:** Disks, Circular plates, Sandwich structures, Damping coefficients

The theoretical analysis of free vibrations of a disk of constrained layer sandwich material is considered. The results enable the real and imaginary parts of the shear parameter to be determined from experimental data. A correction for a small mass attached to the center of a disk is introduced. An example of test results illustrates the method. An exact method involving numerical solution of the governing differential equation has been checked by approximate formulae based on potential energy of deformation.

**86-2473**

**A Note on Vibrating Polar Orthotropic Circular Plates Carrying Concentrated Masses**

R.O. Grossi, P.A.A. Laura, Y. Narita

Institute of Applied Mechanics, Puerto Belgrano Naval Base, Argentina

J. Sound Vib., **106** (2), pp 181-186 (Apr 22, 1986) 1 fig, 4 tables, 10 refs

**KEY WORDS:** Circular plates, Mass-plate systems

The fundamental frequency of vibration of a circular plate of polar orthotropy carrying concentrated masses is determined by using an extension of the Rayleigh-Schmidt technique and a Ritz-Lagrange multipliers method. Numerical results are presented for clamped and simply supported plates for several combinations of orthotropic parameters and values of the concentrated mass to plate mass ratio.

86-2474

**Transient Far Field Waveform on the Axis of an Elastic Circular Plate Excited by a Pulsed Axial Point Source**

I. Nakayama, A. Nakamura

Osaka Univ., Osaka, Japan

J. Sound Vib., 106 (2), pp 267-274 (Apr 22, 1985) 3 figs, 1 table, 5 refs

**KEY WORDS:** Circular plates, Point source excitation, Pulse excitation

The transient waveform radiated from a thin elastic clamped circular plate set in a baffle is investigated when the plate is excited axisymmetrically by a spherical single triangular sound pulse. An expression for the on-axis transient waveform in the far field is obtained in the time domain. Some numerical calculations are made for a circular plate of duralumin, and then the deformation of the waveform due to the spherical excitation is discussed and compared with that in the case of plane wave excitation.

## SHELLS

86-2475

**An Analytical Method for the Vibrational Frequencies of Shells Having Uniformly Distributed Holes**

L. Papa, R. Catcano

Rome Univ., Italy

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1367-1369, 2 figs, 6 refs

**KEY WORDS:** Cylindrical shells, Hole-containing media, Experimental modal analysis, Linking analysis and test

The vibrational frequencies are investigated for circular cylindrical thin-walled shells having uniformly spaced holes and height characteristic wave-length. A sinusoidal law to take into account holes distribution and hence the variation of inertial moment and mass, is proposed. A formula for the determination with good approximation of the first bending vibrational frequency is obtained by the application of the Bubnov-Galerkin method.

86-2476

**Geometric and Material Nonlinear Dynamic Analysis of Complex Shells**

S. Saigal

Ph.D. Thesis, Purdue Univ., 169 pp (1985)  
DA8606610

**KEY WORDS:** Shells, Nonlinear theories, Tires

A 48 degree-of-freedom doubly curved quadrilateral thin shell element, including the effect of both material and geometric nonlinearities, is formulated and appropriate numerical procedures are adopted for the development of a systematic and efficient approach for static and dynamic nonlinear analysis of general shell structures. A systematic choice of examples is solved and compared with available solutions to evaluate the formulations and procedures recommended. As an application of the present element, a detailed study of the static contact of an inflated radial automotive tire with rigid surface is conducted.

86-2477

**Vibration of Rotating Prestressed Cylindrical Shells**

T. Saito, Y. Tsukahara, M. Endo

Tokyo Institute of Tech., Tokyo, Japan

Bull. JSME, 29 (251), pp 1572-1578 (May 1986) 7 figs, 13 refs

**KEY WORDS:** Cylindrical shells, Rotating structures, Natural frequencies

The frequency analysis is presented for rotating cylindrical shells subjected to the initial stresses which are generated by torque, external pressure or axial compression load. Consequently, it is found that, though the natural frequencies decrease depending upon the state of the initial stresses, even in the case of rotating prestressed cylindrical shells the instability phenomenon cannot be observed. The dependence of the frequencies upon the rotating speeds is approximately represented by the simple relation for a thin rotating ring provided the frequencies and rotating speeds are normalized by the natural frequencies of a nonrotating cylindrical shell.

86-2478

**Analytical and Experimental Comparisons of Modal Properties of a Flood Water Storage Tank**

G.L. Thinnes, W.T. Dooley, V.W. Gorman

EG&G Idaho, Inc., Idaho Falls, ID

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1064-1070, 8 figs, 2 tables, 5 refs

**KEY WORDS:** Storage tanks, Water, Linking analysis and test, Experimental modal analysis

Comparisons of measured frequencies, mode shapes, and damping from experimental modal testing and analytical predictions have been performed on a vertically standing 90,000 liter flood water storage tank. The purpose of the study was to compare the accuracy of analytical

calculations with experimentally obtained data. The need for this comparison arises because safety assessments of the integrity of such vessels are normally based upon analyses which have not usually been validated by experiments. Results of the analyses are presented, comparisons to test data are shown, and conclusions and recommendations are made as a result of these studies.

## PIPES AND TUBES

86-2479

### **Dynamics of Finite-Length Tubular Beams Conveying Fluid**

M.P. Paidoussis, T.P. Luu, B.E. Laithier  
McGill Univ., Montreal, Quebec, Canada  
J. Sound Vib., 106 (2), pp 311-331 (Apr 22, 1986) 8 figs, 3 tables, 24 refs

KEY WORDS: Pipes, Tubes, Beams, Timoshenko theory, Fluid-filled containers

The dynamics of stability of short tubes conveying fluid is re-examined by means of Timoshenko beam theory for the tube and a three-dimensional fluid-mechanical model for the fluid flow, rather than the plug-flow model utilized heretofore. The tubes considered are either clamped at both ends or cantilevered; in the latter case, special "outflow models" were introduced to describe the boundary conditions on the fluid exiting from the free end. By comparison with experiments, it is shown that this refined theory is necessary for describing adequately the dynamical behavior of extremely short tubes, although Timoshenko beam theory, together with a plug-flow model, are quite satisfactory for relatively longer short tubes; for long tubes, Euler-Bernoulli beam theory and a plug-flow model are perfectly adequate.

86-2480

### **A Flow Visualization Study of Flow Development in a Staggered Tube Array**

A. Abd-Rabbo, D.S. Weaver  
McMaster Univ., Hamilton, Ontario, Canada  
J. Sound Vib., 106 (2), pp 241-256 (Apr 22, 1986) 10 figs, 23 refs

KEY WORDS: Tube arrays, Fluid-induced excitation

A flow visualization technique has been used to examine the flow development and behavior in a rotated square array of flexible tubes with a pitch-to-diameter ratio of 1.41 in a water cross-

flow. Also examined is the case of a single flexible tube in an otherwise rigid tube array. Results pertinent to the basic tube excitation mechanisms, vorticity shedding, turbulence and fluidelastic instability are presented including tube response curves, frequency response spectra and flow visualization photographs.

86-2481

### **Automotive Exhaust Pipe: The Modal Analysis Approach for Design and Testing**

B. Piombo, R. Dardano, G. Belingardi, M. Pavese  
Politecnico de Torino, Torino, Italy  
Ind. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1020-1025, 4 figs, 2 tables, 1 ref

KEY WORDS: Exhaust systems, Pipes, Fatigue life, Experimental modal analysis

The application of the modal analysis to the vibrational study of an automotive exhaust pipe is illustrated. The knowledge of the vibrational response of the pipe is fundamental for the fatigue life prediction and for duration tests. The test procedure is discussed, pointing out the necessity of the use of a three axis accelerometer and a four channel signal analyzer to get a convenient picture of the motion of the pipe. The advantages obtained using the modal analysis technique are enhanced, both for design and testing.

86-2482

### **Pulsatory Flow in Curved Pipes of Rectangular Cross-Section**

M. Sumida, K. Sudou  
Yonago National College of Technology, Yonago, Japan  
Bull. JSME, 29 (251), pp 1471-1478 (May 1986) 14 figs, 10 refs

KEY WORDS: Curved pipes, Rectangular bodies, Fluid-induced excitation, Pulse excitation

Numerical analysis was made of a fully developed laminar flow in curved pipes of square cross-section under conditions where an oscillatory component of flow was superimposed on a steady mean flow. Velocity profiles, stream lines of secondary flow and distribution of wall shearing stresses were calculated in a wide range of various parameters. The kinetic energy of the secondary flow and the resistance factor were described.

## DUCTS

86-2483

### **Numerical Modelling for Acoustic Fields in Multimode Waveguide**

V. Martin

Laboratoire de Mécanique et d'Acoustique, Marseille, France

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1208-1214, 5 figs, 4 refs

**KEY WORDS:** Ducts, Waveguide analysis, Acoustic waves, Wave propagation, Modal analysis

In order to control sources which have to reproduce a given vibratory field, the propagation in a multimode waveguide is simulated. Helmholtz's equation describes the harmonic field. The inverse problem is to find to what voltage the sources must be submitted in order to radiate modes of a given amplitude, this on a cross-section of the duct. The iterative method of conjugate gradient allows one to obtain the solution. A method which is almost direct; i.e., that of multiplicative coefficients, gives more accurate results more rapidly. To conclude on these numerical aspects, a simulation of active suppression of an acoustic multimode wave is developed.

86-2484

### **Numerical Analysis of the Wave Propagation in a Duct with an Area Change by Random Choice Method**

H. Kashimura, N. Iwata, M. Nishida

Kitakyushu College of Technology, Kitakyushu, Japan

Bull. JSME, 29 (251) pp 1440-1445 (May 1986) 13 figs, 1 table, 16 refs

**KEY WORDS:** Ducts, Variable cross section, Shock wave propagation, Numerical methods

The random choice method (RCM) was used to numerically solve shock propagation in a Laval nozzle and a Ludwig tube. In quasi-random sampling procedure the van der Corput method was used. The RCM analysis predicts five unique possible wave patterns. The starting process of the Ludwig tube was also numerically analyzed using the RCM.

## BUILDING COMPONENTS

86-2485

### **Monte Carlo Method of Predicting Sound Pressure Levels in Enclosed Spaces**

A. Marshall, J. Gibb

Central Electricity Generating Board, Southampton, England

Rept. No. TPRD/M/1521/N85, 48 pp (1985) PB86-184033/GAR

**KEY WORDS:** Enclosures, Rooms, Noise prediction, Monte Carlo method

An existing Monte Carlo ray tracing computer program has been adapted to predict sound pressure levels in rooms with multiple sources of known sound power. Comparisons of the technique are made with existing analytical and empirical calculation methods with satisfactory agreement.

86-2486

### **Simultaneous Resonances in Non-Linear Structural Vibrations Under Two-Frequency Excitation**

R.H. Plaut, N. HaQuang, D.T. Mook

Virginia Polytechnic Institute and State Univ., Blacksburg, VA

J. Sound Vib., 106 (3), pp 361-376 (May 8, 1986) 6 figs, 10 refs

**KEY WORDS:** Structural members, Resonant response

A system of equations with quadratic and cubic nonlinearities is considered which models structural elements having initial curvature and exhibiting mid-surface stretching during motion. The excitation has two harmonic components. Attention is focused on cases in which two external resonances exist simultaneously. Primary, subharmonic, superharmonic, and combination resonances are included in the eight cases which are analyzed. Quenching occurs for some cases, where the response due to one resonance can be significantly decreased by application of a second harmonic component associated with another resonance. The results are obtained by the method of multiple scales and are presented as frequency-response curves and as plots of modal amplitude versus excitation amplitude.

86-2487

### **Disturbance Propagation in Structural Networks**

A.H. von Flotow

German Space Operations Center, Wessling, Fed. Rep. Germany

J. Sound Vib., 106 (3), pp 433-450 (May 8, 1986) 10 figs, 29 refs

**KEY WORDS:** Structural members, Periodic structures, Wave propagation

A structural network is taken to be an assemblage of slender structural members connected to

each other at structural junctions. The junctions may include flexible bodies which, in this work, are restricted to those whose dynamics are described by a finite set of ordinary differential equations. A consistent analytical framework is constructed within which descriptions of various member types and junctions can be accommodated. The analysis is set up for computer implementation. Computational examples are used to demonstrate the techniques.

**86-2488**

**Behaviour of Brick Masonry Walls Under Lateral Loading**

S.J. Lawrence

Ph.D. Thesis, Univ. of New South Wales, Australia (1984)

**KEY WORDS:** Walls, Masonry, Panels, Lateral response

This thesis is concerned with the behavior of unreinforced brick masonry wall panels subjected to lateral loading. Single-leaf rectangular panels with uniformly distributed out-of-plane loading and no superimposed vertical loading are considered. Various arrangement of supports on three or four sides are examined, and different configurations of simply supported edges and built-in edges which allow in-plane forces to develop are considered. An essential part of the investigation is a detailed study of the behavior of brick masonry in pure flexure, including the form and extent of random variation in these properties.

**86-2489**

**Coupled Response Spectrum Analysis of Secondary Systems Using Uncoupled Modal Properties**

A.K. Gupta, J.-W. Jaw

North Carolina State Univ., Raleigh, NC

Nucl. Engrg. Des., 92 (1), pp 61-68 (Mar 1986) 3 figs, 5 tables, 9 refs

**KEY WORDS:** Floors, Equipment-structure interaction, Spectrum analysis, Perturbation theory

A method of performing coupled response spectrum analysis of secondary systems is presented. The response spectrum specified at the base of the primary system is used as the input. The complex coupled mode shapes along with frequencies and damping values are calculated using an efficient and accurate perturbation scheme. The new method is applied to a two-degree-of-freedom secondary system coupled with a six-degree-of-freedom secondary system. It is shown that the response values from the present method are in good agreement with those from the

coupled time history analysis. It is concluded that the present method is sufficiently straightforward and efficient, and that it yields accurate response values.

## ELECTRIC COMPONENTS

### ELECTRONIC COMPONENTS

**86-2490**

**Finite-Element Analysis and Testing of Complex Busbar Structures Under Short-Circuit Conditions**

M. Iordanescu, C. Hardy, J. Noutry

Institut de recherche d'Hydro-Quebec, Varennes, Quebec, Canada

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1457-1462, 6 figs, 9 refs

**KEY WORDS:** Experimental modal analysis, Busboxes, Finite element technique

A general method has been developed for calculating the dynamic stresses and displacements of busbar structures with rigid conductors, under simultaneous-short-circuit conditions with or without rapid reclosing of a fault. Based on a finite-element technique and modal-response superposition, this method can be used to study a complex busbar structure in its entirety, taking into account both the three-dimensional aspect of the structural components and the paths followed by the fault currents. The analytical procedure and the corresponding computer program DYNBUS have been validated by laboratory tests on a low-profile busbar model and by extensive field tests performed on the busbars of a 315 kV substation.

**86-2491**

**Empirical Determination of Damage Threshold for Leadless Chip Carriers on Printed Wiring Boards**

E.A. Szymkowiak, H.S. Gruenberger

Westinghouse Electric Corp., Baltimore, MD

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 235-241, 5 figs, 7 refs

**KEY WORDS:** Circuit boards, Vibration tests, Fatigue life

A simple method is proposed for determining the maximum safe vibration response level for

printed wiring boards (PWB) which contain leadless chip carrier (LCC) devices. A comparison of the proposed failure threshold with vibration results obtained for three LCC-PWB test setups demonstrates the validity of the new method, in which geometric board bending relationships, combined with appropriate random vibration stress formulations, are used to determine a maximum input excitation consistent with reasonable fatigue life.

**86-2492**

**Dynamic Analysis of Electronic Assemblies (For the Purpose of Environmental Stress Screening)**

J.G. Schlagheck

Cincinnati Electronics Corp., Cincinnati, OH  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 128-131, 5 figs, 2 refs

KEY WORDS: Electronic instrumentation, Circuit boards, Testing techniques, Screening

The purpose of this paper will illustrate and provide in a tutorial manner the dynamic mathematical solutions to predict the displacement of a printed wiring board and to develop a peaked and/or notched random spectrum utilizing the NAVMAT(P)-9492 spectrum. The resultant or modified spectrum will provide a safe margin as not to overstress or fatigue the assembly undergoing vibration.

**86-2493**

**Establishment of Random Vibration Screening for Fragile Modules**

R.G. Lambert

General Electric Co., Utica, NY  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 113-116, 5 figs, 2 tables, 4 refs

KEY WORDS: Electronic instrumentation, Testing techniques, Random vibration, Screening

This paper describes the establishment of a random vibration screen for an electronics assembly in development having a hybrid module piece-part containing fragile elements. The effectiveness of the screen is evaluated using experimental results and closed-form analytical expressions for damage accumulation assessment.

**86-2494**

**Dynamic Performance Analysis and Optimization of Damping Treatments on Printed Circuit Board**

Dai De Pei, Hu Xuan Li

Xian Jiaotong Univ., Xian, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1494-1501, 5 figs, 3 tables, 7 refs

KEY WORDS: Experimental modal analysis, Circuit boards, Damping coefficients, Optimization

With an experimental modal analysis method, the dynamic performance of a typical printed circuit board, carried out by additive partial damping layer treatment and boundary damping treatment, is presented. Theoretical analysis and experimental research have been performed on the treatments' optimization of formation, location and damping effect. The maximum resonant response of the printed circuit board is finally reduced to 1:10 of the initial structure by using damping treatments.

## DYNAMIC ENVIRONMENT

### ACOUSTIC EXCITATION

**86-2495**

**Normal-Mode Sound Propagation in an Ocean with Sinusoidal Surface Waves**

G.V. Anand, M.K. George

Indian Institute of Science, Bangalore, India  
J. Acoust. Soc. Amer., 80 (1), pp 238-243 (July 1986) 2 figs, 6 refs

KEY WORDS: Sound waves, Wave propagation, Ocean

The normal-mode solution to the problem of acoustic wave propagation in an isovelocity ocean with a wavy surface is considered. The surface wave amplitude is assumed to be small compared to the acoustic wavelength, and the method of multiple scales is employed to study the interaction between normal-mode acoustic waves and the surface waves.

**86-2496**

**Nonlinear Acoustic Wave Propagation in Atmosphere**

S.I. Hariharan

Univ. of Tennessee, Tullahoma, TN  
Rept. No. N86-22309/6/GAR, 28 pp (Oct 1985)  
N86-22309/6/GAR

KEY WORDS: Sound waves, Wave propagation

A model problem that simulates an atmospheric acoustic wave propagation situation that is nonlinear is considered. The model is derived from the basic Euler equations for the atmospheric flow and from the regular perturbations for the acoustic part. The nonlinear effects are studied by obtaining two successive linear problems in which the second one involves the solution of the first problem. Well posedness of these problems is discussed and approximations of the radiation boundary conditions that can be used in numerical simulations are presented.

86-2497

**Acoustic Emission Signal Analysis. 1975-May 1986 (Citations from the INSPEC: Information Services of the Physics and Engineering Communities Database)**

National Technical Information Service, Springfield, VA, 118 pp (May 1986) PB86-867504/GAR

KEY WORDS: Acoustic emission, Signature analysis, Bibliographies

This bibliography contains 245 citations concerning the detection, monitoring, and analysis of acoustic emission signals occurring during evaluation tests of different metals. Innovative methods, instrumentation, and recording devices for acoustic emission analysis; generation and propagation mechanisms of acoustic emissions; and pattern recognition techniques relative to signal classification technology are among the topics discussed. Applications for acoustic emission signal tests are included for electrical and mechanical engineering.

86-2498

**Radiation Fields Far from Point or Ring Source on a Rigid Cylindrical Baffle**

M. Tohyama

Nippon Telegraph and Telephone Public Corp., Tokyo, Japan

Acustica, 60 (3), pp 230-235 (May 1986) 6 figs, 6 refs

KEY WORDS: Sound waves, Wave radiation, Baffles

Results are shown for calculations of the frequency and directional characteristics of the far fields radiated by a point or a ring source on a rigid cylindrical baffle whose length is infinite. Asymptotic representations of the far fields are used for calculations. The asymptotic forms are obtained using the stationary phase method.

86-2499

**High Intensity Acoustic Noise Generation Closed Loop System**

J.P. Lee

Scientific-Atlanta, San Diego, CA

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 170-180, 12 figs, 5 refs

KEY WORDS: Acoustic tests, Test facilities, Digital techniques, Computer-aided techniques

An automatic digital control system built for high-intensity acoustic testing is described. System software was designed to simultaneously control up to four acoustic noise generators, each operating in its own frequency range. Test definition, control, and graphics are provided in 1/3, 1/6, full octave, and narrowband formats. The system may be controlled from its own front panel as a stand alone system or from a remote host computer.

86-2500

**Propagation of Finite Amplitude Sound Waves Radiated from a Pulsating Sphere**

Y. Inoue, S. Ishii, T. Okigami

Osaka Univ., Osaka, Japan

J. Sound Vib., 106 (2), pp 257-265 (Apr 22, 1986) 1 fig, 8 refs

KEY WORDS: Sound waves, Wave propagation

The propagation of weakly nonlinear acoustic waves radiated from a harmonically pulsating sphere in an inviscid perfect gas is studied. A representation of the solution is presented for a far field equation of the first order, which is closely related to the solution obtained by the method of renormalization. The applicability of the method to the present problem is proved within the first order approximation.

86-2501

**Excitation of Gas Bubbles for Free Oscillations**

K. Vokurka

Czech Technical University, Prague, Czechoslovakia

J. Sound Vib., 106 (2), pp 275-288 (Apr 22, 1986) 11 figs, 26 refs

KEY WORDS: Bubble dynamics, Oscillation

Methods for excitation of gas bubbles into free oscillations are classified and discussed. The analysis is based on Rayleigh's model of a medium-sized bubble. A nonlinear amplitude is

selected to be a universal measure of bubble oscillation intensity and its relation to natural intensity measures is determined.

**86-2502**

**Response and Noise Transmission of Double Wall Circular Plates and Laminated Composite Cylindrical Shells**

D.A. Bofilios

Ph.D. Thesis, Columbia Univ., 126 pp (1985)  
DA8604596

**KEY WORDS:** Circular plates, Cylindrical shells, Layered materials, Fiber composites, Noise transmission

An analytical study is presented to predict the response and noise transmission of double wall circular plates and double wall laminated composite fiber reinforced cylindrical shells to random loads. The core of the double wall construction is taken to be soft so that dilational motions can be modeled. The analysis of laminated shells is simplified by introducing assumptions similar to those in the Donnell-Mushtari theory for isotropic shells. From the parametric study it was found that by proper selection of dynamic parameters, viscoelastic core characteristics and fiber reinforcement orientation, vibration response can be reduced and specific needs of noise attenuation achieved.

**SHOCK EXCITATION**

**86-2503**

**Frequency Domain Analysis of High Explosive Simulation Technique Fidelity**

B.L. Bingham

Applied Res. Assoc., Inc., Albuquerque, NM  
Rept. No. DNA-TR-85-149, 132 pp (Mar 30, 1985) AD-A166 106/5/GAR

**KEY WORDS:** Explosion effects, Simulation, Frequency domain method

The high explosive simulation technique (HEST) is a method of simulating the airblast from a nuclear deformation. HEST cavities are usually designed to match an idealized Speicher-Brode representation of a nuclear airblast overpressure-time waveform, but significant differences often occur. Of particular interest in this report is the high frequency spiking characteristic of HEST cavities and its possible effect upon ground shock and structural response. One product of this work effort was a computer code, FRFQRES, which calculates soil or structural

response due to an ideal Speicher-Brode airblast waveform input. This response to a Speicher-Brode input can then be compared to the measured HEST response to obtain a qualitative indication of the effect of HEST anomalies.

**86-2504**

**Blasting and Blast Effects in Cold Regions. Part 1. Air Blast**

M. Mellor

Cold Regions Research and Engineering Lab., Hanover, NH

Rept. No. CRREL-SP-85-25, 68 pp (Dec 1985)  
AD-A166 315/2/GAR

**KEY WORDS:** Air blast, Explosion effects

This report contains the following: ideal blast waves in free air; the shock equations for air blast; scaling procedures for comparison of explosions; reflection and refraction of air blast; effect of charge height, or height of burst; attenuation of air blast and variation of shock front properties; air blast from nuclear explosions; air blast from underground explosions; air blast from underwater explosions; air blast damage criteria; effects of ambient pressure and temperature; explosion in vacuum or in space; air blast attenuation over snow surfaces; shock reflection from snow surfaces; shock velocity over snow; variation of shock pressure with charge height over snow; and release of avalanches by air blast.

**86-2505**

**Analysis and Prediction of Outrunning Ground Motion**

S. Hassiotis

Applied Res. Assoc., Inc., Albuquerque, NM  
Rept. No. DNA-TR-85-155, 51 pp (Jan 1985)  
AD-A166 112/3/GAR

**KEY WORDS:** Ground shock

With the advent of the hard mobile launcher, the need for an accurate prediction procedure for the outrunning ground shock, i.e., the wave that arrives before the airblast, has increased. Most methods developed in the past for prediction of the outrunning wave concentrate on a limited number of HE experiments. This report describes the development of a new method to predict the outrunning portion of the ground shock. It is based on the empirical analysis of data provided by several recent HE experiments at various heights-of-burst. A characteristic velocity time history waveform, which is normalized by the outrunning velocity peak and a site

dependent time scale factor, is introduced. The method is evaluated against data from several experiments and the results are considered satisfactory.

**86-2506**

**Maribo Structural Response: A Pilot Study**

R.B. Burdick, H.J. Weaver, D. Trummer  
Lawrence Livermore Nat'l. Lab., CA  
Rept. No. UCID-20670, 55 pp (Nov 1985)  
DE86007248/GAR

**KEY WORDS:** Underground explosions, Nuclear explosion effects, Test equipment

The effects that ground motion from underground nuclear tests have on critical testing equipment used in neighboring events often concern Nuclear Test Program personnel. Currently, little is known about the structural amplification that occurs in NTS structures subject to strong base motions. This study seeks to investigate the feasibility of using collected frequency response functions and acceleration data to enable more efficient response predictions.

## VIBRATION EXCITATION

**86-2507**

**Dynamic Responses of Structure to Multiple Support Seismic Excitations — A Random Vibration Time History Analysis**

G.D. Gazis  
Ph.D. Thesis, Univ. of Illinois at Chicago, 234 pp  
(1985) DA8602377

**KEY WORDS:** Seismic response, Supports, Random vibration, Multistory buildings

A modal state space random vibration analysis is presented to obtain the responses of a general multiple-degree-of-freedom (MDOF) system subjected to excitation at multiple support points. The excitation, whether earthquake- or wind-type loading, is modeled as a colored, correlated, vector-valued, nonstationary random process. A new filter is used so that the excitation can have more than one predominant frequency and a wide range of spectral shapes. The time history of the root mean square (RMS) of the earthquake excitation at support points or the wind force at nodal points, which is the output of the filter, is prescribed directly. The corresponding input to the filter, a fictitious piecewise linear strength envelope, is estimated before engaging the filter with the actual system. In addition, for earthquake excitations the filter allows the support

motions to be prescribed in terms of displacement, velocity or acceleration. The time history of the cross correlation between any two components of the excitation can also be prescribed.

**86-2508**

**Earthquake Response of Multi-Degree Nonlinear Structures to Real and Multi-Modal Synthetic Ground Motions**

D. Davani  
Ph.D. Thesis, George Washington Univ., 191 pp  
(1985) DA8604307

**KEY WORDS:** Seismic response, Multi-degree-of-freedom systems, Energy transfer, Soil-structure interaction, Simulation

A multi-modal analytical scheme is developed that duplicates the time-rate of energy transfer from the ground to the structure, taking into account the frequency content of the structure and time duration of the earthquake. Contrary to the more detailed and sophisticated statistical approaches, this model uses calibration parameters that are developed from power spectral density analysis of the neutral environment of a particular site. This model uses a superposition of several filters to better represent the energy transfer mechanism between the ground and the structure. The proposed model takes explicitly into consideration the effects of the free ground motions but can be easily expanded to include the soil/structure interaction.

## MECHANICAL PROPERTIES

### DAMPING

**86-2509**

**A Nonlinear Theory of Dynamic Systems With Dry Friction Forces**

A.V. Srinivasan, B.N. Cassenti  
United Technologies Research Center, East Hartford, CT

J. Engrg. Gas Turbines Power, Trans. ASME, **108** (3), pp 525-530 (July 1986) 17 figs, 2 refs

**KEY WORDS:** Coulomb friction

Structural systems with interfaces where one component may rub against another are not uncommon in aircraft and other engineering structures. The dynamic characteristics of such systems need to be calculated for use in design

and such calculations depend on the law of friction used to represent the interacting boundaries. This paper proposes a nonlocal law of dynamic friction and establishes a procedure to incorporate such laws in a general structural dynamic analysis.

**86-2510**

**Prediction of Total Loss Factor of Structures Part III: Effective Loss Factors in Quasi-Transient Conditions**

H.B. Sun, J.C. Sun, E.J. Richards

Univ. of Southampton, Southampton, England

J. Sound Vib., 106 (3), pp 465-479 (May 8, 1986)  
15 figs, 13 refs

**KEY WORDS:** Damping coefficients, Loss factors, Plates

The effective loss factors of coupled structures in quasi-transient conditions are considered which are thought to be important parameters in the prediction of ringing noise radiated from impacting machines. SEA is used and Maidanik's arguments are re-examined in analysis and discussion. A series of measurements have been carried out on two coupled plates (a structure having two substructures) and a randomly chosen complicated structure. An equation derived from the two coupled substructures model is used to estimate the effective loss factors of the two coupled plates. Good agreement is obtained between the estimated and measured values.

**86-2511**

**Improvement and Optimization of Internal Damping of Fiber Reinforced Composite Materials**

C.T. Sun

Univ. of Florida, Gainesville, FL

Rept. No. AFOSR-TR-86-0049, 174 pp (Dec 17, 1985) AD-A166 173/5/GAR

**KEY WORDS:** Fiber composites, Internal damping, Optimization, Material damping, Stiffness coefficients

Analysis of material damping and optimization of both material damping and specific stiffness of laminated, continuous or discontinuous fiber reinforced polymer matrix is the major objective of this study. The analytical solution was achieved by using a force-balanced model to derive the equivalent modulus of unidirectional aligned short fiber composites. Analytical results are compared with those obtained from the classical two-dimensional lamination theory. Sequential simplex method, laminated plate theory, and an elastic-viscoelastic correspondence

principle are used to optimize both material damping and a specific stiffness of composites.

## FATIGUE

**86-2512**

**Dynamic Stress Analysis and Fatigue Life Prediction for Structures Subjected to Random Excitations**

Fei Guan, Ping Chen

Tsinghua Univ., Beijing, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1558-1563, 6 figs, 10 refs

**KEY WORDS:** Experimental modal analysis, Fatigue life, Random excitation, Component mode synthesis, Ground vehicles

A general method, based on the methods of component mode synthesis, is presented for calculating the dynamic stress of complex structures subjected to random excitations. From the relationship between the responses and excitations in frequency domain, the spectral density function of response stress can be developed. As an example of the application of this method, the dynamic stress is calculated for the frame of a vehicle moving on a given rough road. A computer program for this method has been proposed. As a practical example, the fatigue life prediction of a vehicle frame is completed using this computer program.

## WAVE PROPAGATION

**86-2513**

**Path Integrals for Wave Intensity Fluctuations in Random Media**

B.J. Uscinski, C. Macaskill, M. Spivack

Univ. of Cambridge, Cambridge, England

J. Sound Vib., 106 (3), pp 509-528 (May 8, 1986)  
6 figs, 12 refs

**KEY WORDS:** Wave propagation

Approximate expressions for the fourth order moment of a wave propagating in a random medium are derived by using the path integral formulation. These solutions allow the spectrum of intensity fluctuations of a multiple scattered wave to be found, and they are valid at all distances in the medium. The spatial frequency spectra of intensity fluctuations are evaluated for a medium in which the irregularities have a single scale and also for one in which there is a range of scale sizes.

86-2514

**Multiple Scattering of Compressional and Shear Waves by Fiber-Reinforced Composite Materials**

V.K. Varadan, Y. Ma, V.V. Varadan  
Pennsylvania State Univ., University Park, PA  
J. Acoust. Soc. Amer., 80 (1), pp 333-339 (July 1986) 13 figs, 1 table, 11 refs

KEY WORDS: Fiber composites, Wave scattering

A multiple scattering formalism using a T matrix to characterize the response of a single fiber to an incident wave is presented to describe P- and SV-wave propagation in a fiber-reinforced composite. A convenient numerical procedure is then developed to compute the effective elastic moduli, attenuation, and phase velocity as a function of frequency and fiber concentration.

## EXPERIMENTATION

### MEASUREMENT AND ANALYSIS

86-2515

**Response of Structures to Random Excitations in Time Domain**

Chang Jiu, Gu Yi  
Northwestern Polytechnical Univ., Xian, Shaanxi, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 891-896, 1 fig, 1 table, 8 refs

KEY WORDS: Modal analysis, Random response, Time domain method, Power spectral density

A new and easily used state variable method of structural response analysis to random excitations in the time domain developed and its application is illustrated by two numerical examples. The method readily applies to any type of excitation characterized by power spectral densities. The random excitations can be mathematically matched as the output of a linear system which has a stationary white-noise process as its input. The equations of an augmented system driven by white-noise can then be obtained.

86-2516

**On Fitting Continuous Model of the Series for Modal Parameter Identification**

Yang Shuzi, Zhao Xing, Wang Zhifan, Yang Kechong  
Huazhong Univ. of Science and Technology, Wuhan, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1596-1600, 7 refs

KEY WORDS: Modal analysis, Parameter identification technique, Autoregressive/moving average model

Based on a discrete model of time series, the autocovariance function and the unit impulse response function (Green's function) in time and other domains are applied to transform a discrete model of time series into a corresponding continuous one for modal parameter identification. The relationship between model parameters and modal parameter are deduced. The possibility of identification of all modal parameters using a time series model are discussed.

86-2517

**Global Modal Parameter Estimation Methods: An Assessment of Time Versus Frequency Domain Implementation**

J. Leuridan, J. Lipkens, H. Van der Auweraer, F. Lembrechts  
Leuven Measurement & Systems, Leuven, Belgium  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1586-1595, 12 figs, 5 tables, 10 refs

KEY WORDS: Experimental modal analysis, Parameter identification technique, Global identification technique, Frequency domain method, Time domain method

Many new global parameter estimation techniques have been developed over the past few years. Most of these techniques analyze data in the time domain (time domain implementation); fewer are designed to analyze data in the frequency domain (frequency domain implementation). This paper discusses some of the fundamental differences between both kinds of implementations. Cases are discussed to illustrate when a particular implementation is more advisable.

86-2518

**A New Cepstrum Technique for Cancelling the Effects of Sound Reflection**

Shaoquan Lin, Zhongyi Chen  
Tongji Univ., Shanghai, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 936-942, 7 figs, 5 refs

KEY WORDS: Experimental modal analysis, Noise source identification, Measurement techniques, Cepstrum analysis

For correct measurement of an acoustic signal, it is necessary to eliminate the disturbance caused by reflection. In this paper a new cepstrum technique for cancelling the effects of reflection is described. After computer simulations, a series of experiments in an anechoic chamber are carried out. The results of both computer simulations and experiments show the proposed technique is effective.

**86-2519**

**Sound Power Measurement of a Digital Computer Using Surface Velocity**

A. Chawla, N. Popplewell

Sperry Inc., Winnipeg, Manitoba, Canada

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 924-929, 3 figs, 5 refs

**KEY WORDS:** Modal analysis, Computer systems hardware, Sound power levels, Measurement techniques

This paper describes a pragmatic approach for measuring the sound power of a digital computer by using surface velocity measurements. The method is based upon the idealization of the computer as a sphere pulsating in its breathing mode. The practical implications of such an approach are also discussed.

**86-2520**

**Using and Understanding Electrodynamic Shakers in Modal Applications**

N.L. Olsen

Hewlett-Packard Co., Everett, WA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1160-1167, 20 figs, 5 refs

**KEY WORDS:** Experimental modal analysis, Electrodynamic shakers, Test facilities

Electrodynamic shakers are commonly used when acquiring frequency response functions to provide the excitation force during modal testing. Experimental measurement errors attributed to impedance mismatch between the shaker and the structure under test can often be eliminated or significantly reduced by understanding the aspects of armature mass and suspension stiffness effects, back EMF (electromotive force) and current versus voltage amplifiers. Proper choice of the shaker characteristics can often eliminate the need to try alternative methods of computing the frequency response function.

**86-2521**

**Non-Contact Stress Pattern Analysis of Structures Loaded with Complex Waveforms**

D.E. Cliver, W.R.S. Webber, J. Gilbey

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1181-1186, 14 figs, 14 refs

**KEY WORDS:** Experimental modal analysis, Proximity probes, Stress analysis

The stress pattern analysis of structures (SPATE) technique is summarized. Development of the technique for complex mechanical loads which are other than single frequency and uniform amplitude as may exist during in-service or modal analysis loading conditions is described. Some early results are reported from a hole in a steel plate specimen and a beam in bending both excited with pseudo-random load waveforms.

**86-2522**

**Improvement to Monoreference Modal Data by Adding an Oblique Degree of Freedom for the Reference**

O. Dossing

Bruel & Kjaer, Denmark

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1175-1180, 13 figs, 2 tables, 4 refs

**KEY WORDS:** Experimental modal analysis, Testing techniques

In modal testing using monoreference techniques; i.e., the measurement of one row or one column of the frequency response function matrix, careful consideration must be given to the choice of reference degree-of-freedom (DOF). The reference, or driving point, measurement must contain all the modes of vibration in the frequency range of interest, and these should ideally be of equal strength. In this paper a transducer head is presented whereby an oblique DOF can be introduced for the driving point with both ease and precision examples are given of the improvements obtained using this as compared to traditional measurement methods. The experiments prove the efficiency of the technique in terms of more accurate modal parameters.

**86-2523**

**Modern Sinusoidal Frequency Response Analysis**

R. Iax

Solartron Instruments, Irvine, CA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1445-1449, 6 figs, 4 refs

**KEY WORDS:** Experimental modal analysis, Vibration tests, Periodic excitation, Testing techniques

The technique of sinewave correlation filtering as applied to the problem of vibration testing is investigated, in particular the accurate and repeatable measurement of transfer function gain and phase as required for modal analysis.

**86-2524**

**Identification of System Physical Parameters from Force Appropriation Technique**

M. Thomas, M. Massoud, J.-G. Beliveau  
Quebec Industrial Research Center, Canada  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1098-1103, 9 figs, 2 tables, 6 refs

**KEY WORDS:** Phase methods, Parameter identification technique, Experimental modal analysis

In the area of harmonic excitation techniques for modal analysis, the analyst can use single or multi excitation forces to tune real or complex modes and to measure mobility readings from which modal parameter estimations can be derived. The accuracy of the results depends on the ability of the experimentalist to select the appropriate values of the damped natural frequencies which, in turn, depends on the basic assumptions of the damping mechanism. This paper proposes experimental and analytical procedures based on multi-harmonic excitation of the structure and does not impose any condition on damping.

**86-2525**

**Modal Parameter Estimation Using Difference Equations**

B.J. Dobson  
Royal Naval Engineering College, Devon, England  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1006-1010, 3 figs, 1 ref

**KEY WORDS:** Experimental modal analysis, Difference equations, Parameter identification technique

The computation of modal parameters for experimental data may be achieved in many ways; however, the majority of the available methods involve complicated curve fitting routines and interpolation procedures. A technique based upon difference equations is described that eliminates many of the problems associated with current methods. The equations are based upon linear

relationships that enable the direct calculation of the modal parameters for the case of a model containing a general form of hysteretic damping.

**86-2526**

**Development of Uncoupling Technique and its Application**

N. Okubo, M. Miyazaki  
Canal Chuo Univ., Tokyo, Japan  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1194-1200, 25 figs, 2 refs

**KEY WORDS:** Experimental modal analysis, Uncoupling technique, Component mode analysis

With the building block approach, the total dynamic behavior of the system can be predicted from each component's dynamic characteristics which can be individually measured. In some cases, the dynamic characteristics are hard to measure because of difficulty in decomposing it from the system. An uncoupling technique is developed to extract the component's dynamic characteristics based on total behavior of the system which can be measured. The basic theory of this technique is described and confirmed by numerical simulations. The technique is then applied to the actual structure to extract the component's dynamics.

**86-2527**

**"The Mode Synthesis -- Weighted Residual Method" for Solving the Dynamic Response of a Multidegree-of-Freedom System**

Yin Xuegang, Li Bin  
Chongqing Univ., Sichuan, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 870-876, 5 figs, 1 table, 6 refs

**KEY WORDS:** Modal analysis, Modal synthesis, Weighted residual technique, Multidegree of freedom systems

A new method for solving the dynamic response of a multi-degree-of-freedom system is presented. Three recurrent formulae are derived using the third order spline function as piecewise trial functions in discrete regions of time according to the weighted residual method.

**86-2528**

**Comparison of Some Time Domain System Identification Methods for Free Response Data**

J.E. Cooper, J.R. Wright  
Queen Mary College, London, England

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 831-836, 6 figs, 9 refs

**KEY WORDS:** Modal analysis, Parameter identification technique, Time domain method, Least squares method, Correlation techniques

Structural modal parameters may be identified from free decay response data using a number of different time domain methods which make use of multi-degree-of-freedom mathematical models in the form of either a summation of exponential weighted trigonometric functions or an autoregressive difference equation. In this paper the Smith least squares, ordinary least squares, and correlation fit methods are described and compared statistically upon simulated two mode single output data in the presence of measurement noise.

**86-2529**

**Global Parameter Estimation Using Rational Fraction Polynomials**

R. Jones, Y. Kobayashi

Hewlett-Packard, Everett, WA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 864-869, 5 figs, 1 table, 3 refs

**KEY WORDS:** Experimental modal analysis, Parameter identification technique, Global fitting method, Least squares method

Two methods are described to identify global modal parameters from a set of measured frequency response functions. Included is a theoretical development of each approach and a comparison of the results obtained from the analysis of a test structure. Both methods are based on the rational fraction polynomial curve fitter previously presented.

**86-2530**

**Improved Starting Vectors for Subspace Iteration Eigensolution Using Dynamic Condensation**

J.C. O'Callahan, R.T.F. Koung, C.-M. Chou

Univ. of Lowell, Lowell, MA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 858-863, 3 tables, 10 refs

**KEY WORDS:** Experimental modal analysis, Finite element technique, Subspace method, Iteration, Dynamic condensation method

Continuous system can be discretized using finite element techniques to predict their linear struc-

tural response. The subspace iteration procedure provides an efficient method of obtaining eigensolution of the discretized system matrices. The resulting mode shapes and frequencies can be used in conjunction with experimental and analytical modal analyses and structural modifications to describe the system's dynamic characteristics. The convergence rate of the subspace solutions depends on a linearly independent set of starting vectors and their alignment with the system subspace. This paper proposes a dynamic condensation procedure to transform the original system matrices to a reduced space on which a generalized Jacobi solution is performed.

**86-2531**

**Detection, Identification and Quantification of Nonlinearity in Modal Analysis — A Review**

G.R. Tomlinson

Univ. of Manchester, England

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 837-843, 9 figs, 29 refs

**KEY WORDS:** Experimental modal analysis, Nonlinear response

A brief review of the methods employed in modal testing and analysis for the detection and identification of nonlinearity is presented. Several procedures are described and compared where possible in relation to their range of usefulness, ease of application and quality of results. In addition, the possible direction of future trends for the treatment of nonlinear systems in modal analysis is discussed.

**86-2532**

**Identification of Vibration Parameters Using Nonstationary-Response**

Yao Yingxian

Nanjing Aeronautical Institute, Nanjing, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1601-1608, 5 figs, 2 tables, 5 refs

**KEY WORDS:** Modal analysis, Parameter identification technique, Time domain method, Cantilevers

Two new time domain methods for identifying vibratory system parameters using nonstationary response signals are presented. Five types of signals can be used by these methods. The algorithms based on difference equations of sampled vibratory systems are described. Proposed data preprocessing procedures can improve

calculation efficiency and reduce required computer memory. The results of applying the methods to a cantilever and a large scale concrete frame have shown considerable effectiveness and improvement in vibratory system identification.

**86-2533**

**A Component Mode Synthesis Method Using the Retransformed Physical Coordinates**

E. Imanishi, T. Fujikawa, Y. Hamazaki, H. Zui  
Kobe Steel, Ltd, Kobe, Japan  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1609-1614, 6 figs, 4 tables, 8 refs

**KEY WORDS:** Modal analysis, Component mode synthesis

A new method is proposed for analyzing complex structures by a component mode synthesis method. Mass and stiffness matrices of components are expressed by using unconstrained modes and can be applied for both theoretical and experimental modal analysis. Several numbers of the modal coordinates of each component are retransformed to the physical coordinates of the coupling regions by using normal mode shapes. Therefore, each component can be treated as one of the finite elements in FEM analysis making it possible to connect them to each other or to connect them with nonlinear elements obtained by FEM.

**86-2534**

**Comparison of Modal Test Results from Non-Contacting and Conventional Response Measurements**

B.G. Musson, J.R. Stevens  
LTV Aerospace and Defense Co., Dallas, TX  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1487-1493, 14 figs, 1 table, 3 refs

**KEY WORDS:** Experimental modal analysis, Acoustic fatigue, Measuring techniques, Proximity probes, Rectangular plates

A band limited random amplitude acoustic field is used to excite a square, flat plate with clamped edges. Response measurements are made with an accelerometer that is moved from point to point, and measurements of the near field acoustic response are made by moving a microphone from a point to point over the same grid. The accelerometer and microphone are each referenced to a fixed microphone in the acoustic forcing field and modal results are

obtained. Results are compared with analytical solutions and conclusions are presented concerning the use and possible applications of the noncontact measurement method.

**86-2535**

**A New Fibre Optic Sensor for Inprocess Measurement of Machine Tool Vibration**

T.I. El-Wardany  
Alexandria Univ., Egypt  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1438-1444, 8 figs, 7 refs

**KEY WORDS:** Experimental modal analysis, Measuring instrumentation, Fiber optics, Detectors, Machine tools

Optical fiber sensors are now introduced in various types of measurement and control techniques. These fiber optics are characterized by features such as wide band width, non-conductivity that eliminates electro-magnetic interference, wideness of linear range, high sensitivity, small sizes, light weight, etc. In this paper fiber optics has been adapted for developing a sensor for determining the relative vibration by measuring the change of the gap length between the fiber optic probe and the workpiece surface as a function of the change of intensity of the reflected beam of light received by the sensor. The simplicity and low cost of the fiber optic set up make it possible to be used as a continuous vibration monitor for assessment of machine tool performance.

**86-2536**

**A Study of Digital Signal Processing Errors Caused by Improper ADC Settings**

T.A. Mouch, S. Akers, J. Hicks  
Structural Measurement Systems, Inc, Southfield, MI  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1432-1437, 10 figs, 2 tables, 5 refs

**KEY WORDS:** Experimental modal analysis, Measuring instrumentation, Digital techniques, Signal processing, Error analysis

The effects of digital signal processing errors caused by improper analog to digital conversion settings are discussed. Four signal types are analyzed: overload and underload on the input channel; overload and underload on the response channel. The errors will be shown to affect the quality and accuracy of the measured frequency response function. The errors which are present

in the measurement are also shown to exist as an inaccurate estimate of the modal residue obtained through curvefitting.

**86-2537**

**The New Integral Electronic Microphones & Accelerometers**

J.E. Judd

Vibra-Metrics, Inc., Hamden, CT

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 157-162, 13 figs, 2 refs

KEY WORDS: Accelerometers, Measuring instrumentation

Improved noise immunity, high reliability, and more accurate test results are just a few of the advantages offered by these new devices. Equally important is the lower initial system hardware cost and the decreased risk of rapid facility obsolescence. The instrumentation engineer planning a new vibration or acoustic facility should look closely at the new low impedance accelerometers and give careful consideration to their many advantages.

**86-2538**

**Numerical Analysis of Ultrasonic Transducer Vibrations from Optically Measured Beam Profiles**

F. Holzer, R. Reibold

Technical Univ. of Graz, Graz, Austria

Acustica, 60 (3), pp 236-243 (May 1986) 6 figs, 5 refs

KEY WORDS: Transducers, Ultrasonic vibrations, Numerical methods

The steady-state, water-loaded vibrational behavior of four plane ultrasonic transducers in the lower MHz range was analyzed by calculating the normal velocity distribution of the transducer surface from the ultrasonic pressure distribution measured in both magnitude and phase in a given cross-section of the beam. The pressure data were obtained by using the light diffraction tomography method, from which the axial component of the particle velocity in the medium can be calculated in any cross-section by a two-dimensional FFT technique. The validity of our numerical method was tested taking the well-known (simulated) case of a circular position radiator.

**86-2539**

**Energy Transfer During Impact Testing**

A. Soom, B.-J. Wang, T. Trachsler

State Univ. of New York, Buffalo, NY

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1424-1431, 13 figs, 1 table, 6 refs

KEY WORDS: Experimental modal analysis, Impact tests, Energy transfer, Measuring instrumentation

The quality of measured frequency response functions in vibration testing depends both on the temporal (or frequency) characteristics of the excitation as well as on the response. In this paper the energy transfer to the test structure in both time and frequency domains is generalized in terms of dimensionless pulse duration, peak force, and system response parameters. It is found that excitation and system response can be combined to determine optimal pulses for both single and multi-degree-of-freedom system testing.

**86-2540**

**Transducers and Instrumentation**

G. Rasmussen

Bruel & Kjaer, Denmark

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1417-1423, 27 figs, 3 refs

KEY WORDS: Experimental modal analysis, Accelerometers, Mounts, Standards and codes

Measurements on structures are often carried out using accelerometers. ISO has issued a standard, ISO/DIS 5348, covering the mounting of accelerometers. The effect of loading on the structure can be important. The measurement of rotational components is important for the measurement of energy flow in plates. Accelerometers can be calibrated and used for this purpose. On plates and foils, acoustic methods offer great advantages for such measurements. Comparison of acceleration measurements and acoustic pressure measurements shows under the correct circumstances very good agreement.

**86-2541**

**A Digital Data Input Channel for the Multiple Input Multiple Output Environment**

D.W. Morton

Hewlett-Packard, Lake Stevens, WA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1410-1416, 5 figs, 7 refs

KEY WORDS: Experimental modal analysis, Measuring instrumentation

An input channel architecture which uses advanced triggering, hardware zoom and FIFO functions to improve versatility and data storage capabilities while allowing real time processing of the data is discussed. This architecture is presented in the context of a large system/MIMO environment, and an implementation using a CMOS chipset is suggested.

**86-2542**

**Computation of Total Response Mode Shapes Using Tuned Frequency Response Functions**

R. Brillhart, D.L. Hunt

SDRC, Inc., San Diego, CA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1228-1236, 7 figs, 1 table, 5 refs

**KEY WORDS:** Experimental modal analysis, Data processing, Mode response on trace method, Mode shapes, Natural frequencies

A new approach which allows rapid computation of mode frequencies and shapes immediately following data acquisition is presented. The technique is applicable to multiple-input modal tests in which frequency response functions are obtained. When this technique was applied to an aerospace structure, the results compared well with the polyreference approach, yielding results in considerably less time with less user interaction.

**86-2543**

**Design of a Highly Interactive Software Environment for Versatile Vibration Testing and Signal Processing on Microcomputers**

P. Kopff

Electricite de France

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1156-1159, 5 refs

**KEY WORDS:** Vibration tests, Signal processing techniques, Experimental modal analysis, Computer programs, Data processing

Specialization of the FORTH language as a control language for unified access to vibrational data acquisition and processing, and to various modal post-processing software tools, is described. To get the best of the particular advantages of the hardware architecture of the host computer and its peripherals, an optimized machine-oriented module communicates with FORTH to take care of basic input-output and most processing inner levels. Apart from this very compact module, and of the kernel of

FORTH (which is very compact too) the whole software might be considered portable.

**86-2544**

**The  $H_2$  Frequency Response Function Estimator**

A.L. Wicks, H. Vold

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 897-899, 1 fig, 3 refs

**KEY WORDS:** Modal analysis, Frequency response function, Coherence function technique, Data processing

The classic model used to estimate the frequency response function from measured data assumes uncorrelated noise operating on the response measurement. Since measurements for both the input or forcing function and the response are commonly made, the classic model ignores the likelihood of noise in the input measurement. An alternative model was developed which considered the uncorrelated noise solely on the input measurement and has been called the  $H_2$  estimator. A more general model may be postulated which acknowledges the presence of uncorrelated noise on both the input and the response measurement. This being the most common case, the estimators  $H_1$  and  $H_2$  contain a bias error resulting from the unaccounted for noise. This paper presents a formulation which accounts for the uncorrelated noise on both the input and the response measurement for the general model.

**86-2545**

**Practical Application of the Modal Confidence Factor to the Polyreference Method**

D.L. Hunt, R. Brillhart

SDRC, Inc., San Diego, CA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 900-907, 8 figs, 2 tables, 6 refs

**KEY WORDS:** Experimental modal analysis, Parameter identification technique, Polyreference method, Modal confidence method, Data processing

The polyreference method estimates modal parameters from sets of frequency response functions referenced to multiple exciter locations. The method requires little user interaction, except in determining the optimum number of poles to use in computing mode shapes. A recent addition to polyreference, the modal confidence factor (MCF) assists the user by assigning a value to each pole, which can quickly allow separation of structural modes from

computational roots. An extension to MCF using the mode indicator function has resulted in a more automated and straightforward approach for determining the optimum number of poles in the analysis.

**86-2546**

**A Comparison of Some Frequency Response Function Measurement Techniques**

J. Leuridan, D. De Vis, H. Van der Auweter, F. Lembregts  
Leuven Measurement & Systems, Leuven, Belgium  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 908-918, 13 figs, 2 tables, 14 refs

**KEY WORDS:** Experimental modal analysis, Frequency response functions, Measurement techniques, Data processing

Recent developments in multiple input measurement technology are reviewed. Several estimation techniques and several excitation methods are discussed. Their influence on the FRF measurements is illustrated with a practical example.

**86-2547**

**Precorrection of On-Line Measured Data and Modal Analysis of Machine Tool Structures**

B.H. Lu, Z.H. Lin, C.H. Ku  
Xi'an Jiaotong Univ., Xi'an, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 919-923, 10 figs, 1 table, 6 refs

**KEY WORDS:** Modal analysis, Machine tools, Error analysis, Data processing

The effect of coherent noise on the result of modal analysis is discussed. Based on the theory of multi-input process a formula for measured data precorrection is derived. By such precorrection the bias errors, caused by coherent input noises, can be eliminated and the result of modal analysis becomes more accurate. Good agreement between the prediction of machining chatter during the cutting tests on five lathes has proved the validity of this method.

**86-2548**

**A Rectangular Plate is Proposed as an IBS Modal Test Structure**

D.O. Smallwood, D.L. Gregory  
Sandia National Labs., Albuquerque, NM  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1246-1255, 5 tables

**KEY WORDS:** Experimental modal analysis, Data processing, Rectangular plates, Test facilities

Numerous modal systems are now marketed by commercial companies and new users are continually being introduced to these systems. A simple test structure would be useful to compare these systems on a common basis. The structure would also provide new users with a means to evaluate their newly acquired experimental and analytical skills. This paper discusses a particular proposed rectangular plate. The physical description of the plate is given, the modal properties of the plate are discussed, and experimental results are given to illustrate the plate behavior.

**86-2549**

**Virtual Coherence: A Digital Signal Processing Technique for Incoherent Source Identification**

S.M. Price, R.J. Bernhard  
Purdue Univ., West Lafayette, IN  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1256-1262, 21 figs, 9 refs

**KEY WORDS:** Experimental modal analysis, Data processing, Signal processing techniques, Coherence function technique

The digital signal processing techniques for identification of noise or vibration energy sources; ordinary, multiple and partial coherence techniques, either require incoherence of the measured input data or a degree of a priori knowledge of the system. This paper discusses a transformation technique for conditioning the measured spectra to determine how many real incoherent sources exist and to create a virtual image of those sources at the measurement plane. In addition, the conditioned spectra can be used to generate a virtual coherence function between the measured output and each of the incoherent inputs.

**86-2550**

**A Frequency Domain Holo-Estimation Method of Vibration Parameters**

He Hang-An, Jiang Jie-Sheng, Gu Song-Nian  
Northwestern Polytechnical Univ., Xi'an, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1263-1267, 4 tables

**KEY WORDS:** Experimental modal analysis, Data processing, Frequency domain method, Parameter identification technique, Holographic techniques

A new performance index is proposed for identifying parameters of a vibration system. The performance index considers not only the norm but also phase of error vector. A new least squares estimation formula is presented for estimated parameters. Some computational examples from practical systems demonstrate that a notable improvement of vibration parameters estimation is obtained by use of the proposed method.

**86-2551**

**Some Applications of Frequency Domain Polyreference Modal Parameters Identification Method**

Lingmi Zhang, Hiroshi Kanda, F. Lembrechts  
Nanjing Aeronautical Institute, Nanjing, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1237-1245, 17 figs, 11 refs

**KEY WORDS:** Modal analysis, Parameter identification technique, Multireference method, Finite difference technique, Data processing

This paper describes the utilization of a new multi-input/multi-output modal parameter identification method, which is called the frequency domain polyreference method, and provides some practical applications illustrating the algorithm and features. A comparison with the modern time domain polyreference complex exponential method is presented. The results show that the two polyreference methods have the ability to extract accurate and consistent modal parameters, and to handle very closely spaced modes. Compared to the time domain method, this new technique demonstrates less sensitivity to computational modes, user interaction and judgment.

**86-2552**

**A New Development on Transfer Function Fitting**

Huang Dun-Pu, Liu Man  
Changchun Automobile Research Institute, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1359-1366, 3 tables, 3 refs

**KEY WORDS:** Experimental modal analysis, Linking analysis and test, Transfer functions, Linearization methods, Automobiles

A successive linearization method which is principally derived from the linear optimization theory has been developed which can be used in the process of transfer function fitting to improve its accuracy. The method and its principle

of transfer function fitting on frequency division are presented. Test data and analytical values obtained indicate that the transfer function calculated by means of the software developed in this paper is quite accurate.

**86-2553**

**Modal Analysis of a Two Axis Gimbal: Finite Element Model vs Test Results**

J.D. Getber  
Ball Aerospace Systems Division, Boulder, CO  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1352-1358, 3 figs, 5 tables, 2 refs

**KEY WORDS:** Experimental modal analysis, Linking analysis and test, Gimbals, Spacecraft components, Finite element technique

The primary resonances and mode shapes of a spacecraft two axis gimbal were evaluated with a NASTRAN finite element model solution and compared with extensive test results. Test results were obtained from .05g and .25g sine sweeps as well as exciting resonance by dithering the gimbal drive motors. Results showed excellent correlation between analysis and data on the first four modes.

**86-2554**

**Critical Application of the Error Matrix Method for Localisation of Finite Element Modeling Inaccuracies**

H. Gysin  
Swiss Fed. Institute of Technology, Zurich, Switzerland  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1339-1351, 19 figs, 2 tables, 7 refs

**KEY WORDS:** Experimental modal analysis, Linking analysis and test, Error analysis, Matrix reduction methods

With the error matrix method it should be possible to locate stiffness respectively mass matrix differences between a finite element calculation and a modal analysis measurement. The method was tested on a 9 degrees-of-freedom spring-mass-system and on a bending beam. Three different reduction techniques were tested on the spring-mass-system. The results of these examples show that the efficiency of the error matrix method depends very much on the type of matrix reduction and on the number of modes used to build up the error matrix.

86-2555

**Modal Survey Test of the Oriented Scintillation Spectrometer Experiment**

D.W. Paule

Ball Aerospace Systems Division, Boulder, CO  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1335-1338, 3 figs, 3 tables, 2 refs

**KEY WORDS:** Experimental modal analysis, Linking analysis and test

This paper describes the modal survey test and the revision to the mathematical model associated with it. Some of the more important modeling features are discussed.

86-2556

**Model Refinement Using Test Data**

B.P. Wang, T.-Y. Chen, F.H. Chu

Univ. of Texas, Arlington, TX  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1052-1057, 2 figs, 1 table, 6 refs

**KEY WORDS:** Experimental modal analysis, Linking analysis and test

To improve the test/analytical data correlation, various methods have been developed to correct the stiffness matrix and/or the mass matrix of the finite element models using modal test data. In this paper some of the methods in the literatures are tested with a sample problem to show the effectiveness of the various methods. Discussions and comparisons of these methods are given.

86-2557

**Rigid Body Mode Enhancement and Rotational DOF Estimation for Experimental Modal Analysis**

M. Furusawa, T. Tominaga

Yamaha Motor Co., Ltd., Shizuoka-ken, Japan  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1149-1155, 14 figs, 3 tables, 3 refs

**KEY WORDS:** Experimental modal analysis, Computer programs, Constraint modes method, Least squares method, Rigid body modes

This paper presents the theory of rigid body mode enhancement using constraint equations and least squares solution techniques for experimental modal analysis. It examines some of the applications and advantages, especially for the estimation of rotational degree-of-freedom, and presents examples illustrating its usage.

86-2558

**Software Architecture for a Multiple Input/Output Dynamic Signal Analyzer**

T. Kraemer

Hewlett-Packard, Lake Stevens, WA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1126-1131, 2 figs, 5 refs

**KEY WORDS:** Frequency response functions, Computer programs, Signature analysis, Multi-point excitation technique, Experimental modal analysis

A multiple input/output frequency response measurement is used to illustrate a proposed software architecture for a general purpose dynamic signal analyzer instrument. The system described is object-oriented rather than procedure-oriented or menu based. This approach results in a more reliable and flexible software system. Application to modal analysis and general signal analysis is described.

86-2559

**A Microcomputer Based System for Measuring Natural Frequencies and Mode Shapes of Structures**

D.K. Rao

Materials Laboratory, Wright-Patterson AFB, OH  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1117-1125, 15 figs, 13 refs

**KEY WORDS:** Natural frequencies, Mode shapes, Frequency response functions, Loss factors, Computer programs

This paper describes the application of microcomputers to measure natural frequencies and mode shapes, as well as frequency response functions and loss factors of structures. The developed software, mostly written in a high level language, has two segments. The first segment, called STEPSINE, excites the structure over a specified frequency range in specified frequency increments. The second segment of the software, called MIP (modal image processor) measures and displays the mode shape on-line.

86-2560

**Investigating into the Effective Use of Structural Modification**

S.C. Ulm

General Electric CAE International, Inc., Milford, OH  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1279-1286, 2 figs, 6 tables, 7 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques

Structural modification is growing in importance in the modal analysis arena, particularly in troubleshooting applications. Unfortunately, since it is a relatively new technique, there is a lack of general understanding and practical experience with its application. This paper addresses these issues by evaluating the accuracy of structural modification relative to errors and deficiencies of typical modal data. The studies evaluate the effects of important potential errors with structural modification including: modal truncation, the lack of rotational degrees-of-freedom in the modal model, and the effect of inaccuracies in mode shape coefficients.

**86-2561**

**The Estimation of Rigid Body Mode Shapes for Use with Structural Dynamics Modification**

D.J. Macioce

Structural Measurement Systems, San Jose, CA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1287-1291, 2 figs, 5 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques, Rigid body modes, Computer programs

A structure which is dynamically modeled or tested in an unconstrained configuration contains up to six rigid body modes of vibration. Finite element analysis methods can easily compute these modes; however, when using experimental modal analysis to characterize the dynamic properties of a structure, the rigid body modes of vibration are typically not measured. Since these modes contain the inertial information of the structure, they are essential when joining two unconstrained substructures together, or to accurately reconstruct a frequency response function. This paper describes a method for estimating these rigid body modes using only the structural geometry and an estimate of the lumped mass distribution of the structure. The results of a computer program which was developed to estimate the rigid body mode shapes is presented along with test cases to demonstrate the use of the method.

**86-2562**

**A Perturbation Method for the Complex Mode Theory of Linear Non-Conservative Dynamic Systems**

Zheng Zhao-chang, Tan Ming-yi  
Tsinghua Univ., Beijing, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1292-1298, 3 tables, 16 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques, Perturbation theory

The second order system of linear nonconservative dynamic equations cannot be decoupled by real mode theory unless some conditions are satisfied. The conventional method used in this case is so called complex mode theory in state space, but is it rather complicated and uneconomical in practical problems. In this paper, the perturbation method based on the real mode theory is utilized to solve the complex eigenpairs of such systems.

**86-2563**

**Determination of Optimal Design Modifications Using Experimental Modal Parameters**

P. Gudmundson

Tre Konsulter AB (3K), Vaxholm, Sweden

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1299-1304, 7 figs, 6 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques

Experimentally measured modal parameters are used as input data for the optimization technique described in this paper. The present method predicts the structural modifications necessary to achieve desired changes in eigenfrequencies of a structure. The determined modifications are optimal in the sense that an objective function is minimized. Since the theory is based on sensitivity analysis the size of the considered modifications is limited to approximately ten percent. The use of the method is illustrated by three examples.

**86-2564**

**Effect of Boundary Conditions on the Response of a Structure**

M.S. Hundal

Univ. of Vermont, Burlington, VT

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1476-1481, 9 figs, 1 table, 11 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques, Boundary condition effects, Finite element technique, Natural frequencies

Among the input data for the finite element model of a structure, boundary conditions are most difficult to quantify precisely. These are also potentially the source of significant errors in the results. This paper discusses the finite element modeling and experimental modal analysis of a simple structure. The effect of boundary conditions used in the FEM model on the natural frequencies is investigated.

**86-2565**

**Structural Modifications Using Active and Passive Structural Elements**

G.D. Shepard, J.C. O'Callahan, P. Avitabile  
Univ. of Lowell, Lowell, MA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1187-1193, 7 figs, 7 refs

**KEY WORDS:** Structural modification techniques, Experimental modal analysis

Structural modifications to a complex system can be separated into two types -- active and passive modifications. Passive modification refers to the addition of passive structural elements such as beams and plates which have mass, damping and stiffness properties. Active modification refers to the addition of active structural elements such as actuators driven by electronic systems and feedback control signals. In the common application where a structure is to be positioned by a high speed actuator, both active and passive structural elements may be utilized to improve system performance. As an example, a structural system is evaluated using an experimental modal data base and a large order system model which is reduced to an equivalent system suitable for experimental modal model comparison and model improvement using passive structural elements.

**86-2566**

**Combination of Structural Modification Techniques and Acoustic Radiation Models**

P. Van de Ponsele, P. Sas, R. Snoeys  
Kath. Univ., Leuven, Belgium  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 943-951, 5 figs, 4 tables, 11 refs

**KEY WORDS:** Modal analysis, Structural modification techniques, Sound waves, Wave radiation

Using modal analysis techniques in combination with local structural modification techniques makes it possible to estimate the shifts in the dynamic properties due to local modifications of

the structure, and consequently they result in a decreased number of prototypes needed for design purposes, thereby generating a serious profit for the user. It is, however, not possible to estimate the impact of such modification on the sound power generated by the structure. This paper deals with a sound optimization strategy where this link is realized. The paper reviews the strategy of the implemented method and reports in detail on the results of calculations and measurements.

**86-2567**

**Modal Control of Flexible Structures Using Modal Residualization Technique**

Chang Jin, Gu Yi  
Northwestern Polytechnical Univ., Xi'an, China  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1653-1658, 3 figs, 8 refs

**KEY WORDS:** Experimental modal analysis, Modal control technique, Structural modification techniques, Elastic systems, Modal residualization technique

A new method of modal residualization is presented. It is based on a closed-loop model and can reduce the order of a structure by using a minimization procedure to search for the parameters of the reduced model. This procedure minimizes the deviations of transfer matrix of the reduced model from the transfer matrix of the structure. The control law of the structure is synthesized by using the optimal quadratic theory: the outputs of the reduced model with practical control law then approximate the outputs of the structural system with optimal control law.

**86-2568**

**On Changing Boundary Conditions in Structural Dynamics**

B.P. Wang, F.H. Chu  
Univ. of Texas, Arlington, TX  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1547-1552, 4 figs, 2 tables, 5 refs

**KEY WORDS:** Experimental modal analysis, Boundary condition effects, Structural modification techniques

Efficient formulations of computing the eigenvalues and forced harmonic responses of a system with boundary condition changes are developed. This is accomplished by using the modal information of the original structure and reanalysis

formulation. The boundary condition changes considered include addition of rigid or elastic restraints, removal of restraints as well as change of rigid supports to elastic supports. Two numerical examples are included to illustrate the formulation.

**86-2569**

**Bond-Graph Modelling — A New Approach to the Structural Dynamics Problem**

P.K. Sen, D. Chandra

Engrg. Services Intl. Private Limited, Calcutta, India

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1564-1571, 12 figs, 6 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques, Bond graph technique, Mathematical models

Bond-graph modeling is one of the several methods of modeling possible for a dynamic system. A bond-graph depicts salient aspects of a time-dependent system having discrete elements, such as mass, spring, dashpot, etc., in a conventional manner using only a few characteristic elements. This paper shows how the bond-graph technique can be applied to solve problems involving dynamical behavior of structures encountered in civil engineering. To show the versatility and generality of bond-graph, a typical problem of biomechanics has also been adopted and solved by this method.

**86-2570**

**Active Structural Modification Using Multivariable Feedback Design Technique**

G.D. Shepard

Univ. of Lowell, Lowell, MA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1636-1639, 3 figs, 8 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques, Active structural modification

Design of actuated structures requires the simultaneous consideration of structural modification, both active and passive, and feedback control. To aid this design process a design approach is presented which combines the efficient matrix techniques used by structural dynamicists with feedback design techniques taken from the field of automatic control.

**86-2571**

**Optimal Redesign of Dynamic Structures Via Sequential Linear Programming**

K.B. Lim, J.L. Junkins

Virginia Polytechnic Institute and State Univ., Blacksburg, VA

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1615-1620, 3 tables, 6 refs

**KEY WORDS:** Modal analysis, Structural modification techniques, Linear programming, Optimization

A sequential linear programming approach for optimal placement/constrained optimization of eigenvalues and eigenvectors of linear dynamical systems is presented. As an example, the total mass of a structure is minimized while the natural frequencies for selected modes are gradually driven to desired values. The above approach appears computationally suitable for redesign of high-dimensioned, complex dynamical systems. Numerical examples are included to demonstrate the practical merit of this approach.

**86-2572**

**An Investigation of Structural Modification Using an H-Frame Structure**

S.M. Crowley, M. Javidinejad, D.L. Brown

Structural Dynamics Research Corp., Milford, OH

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1268-1278, 20 figs, 4 tables, 9 refs

**KEY WORDS:** Experimental modal analysis, Structural modification techniques, Frames

Improvements in data acquisition and modal parameter extraction techniques in recent years, have led to a renewed interest in using a modal model to predict the behavior of a structure subjected to design changes. The ability to quickly evaluate the feasibility of a minor modification to a structure by using a modal database can be quite beneficial. This paper examines the use of structural modification to predict the results of a simple mass and stiffness modification to an H-FRAME structure. Several aspects of the analysis procedure are investigated including the building of an accurate modal model, the contribution of rotational degrees-of-freedom, and the effects of inaccuracies in the estimation of mode shape coefficients on the outcome of a structural modification.

## DYNAMIC TESTS

86-2573

### **Data Acquisition/Control/Analysis Systems for Large-Scale Acoustic Testing Facilities**

S. Smith

Lockheed Palo Alto Res. Lab., Palo Alto, CA  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 163-169, 1 fig, 2 refs

KEY WORDS: Acoustic tests, Test facilities

A new generation of computerized data acquisition systems has been developed that provides practical solutions for the needs of large scale acoustic testing facilities. A system that acquires 200 channels with a data bandwidth of 12 kHz for six minutes has been built and is operational. Advances in hardware design in the areas of large, low cost, removable-media disks and digitally-oriented data acquisition front ends will make these systems less expensive and more flexible in the next few years.

86-2574

### **Martin Marietta Aerospace New High Intensity Acoustic Test Facility**

S.M. Rossi

Martin Marietta Denver Aerospace, Denver, CO  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 152-154, 5 figs, 1 table

KEY WORDS: Acoustic tests, Test facilities, Spacecraft, Space shuttles

This paper describes a new high intensity acoustic test facility to meet the needs of system level acoustic testing for shuttle payloads. The features and design considerations of the facility, as well as measured facility performance, are presented.

86-2575

### **Design and Performance of a Low Cost Vibration Test Facility**

S.M. Rossi, J.F. Barthell

Engineering Dynamics, Inc., Englewood, CO  
"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 386-391, 3 figs, 1 table

KEY WORDS: Vibration tests, Test facilities, Shakers

An inexpensive design of a complete hydraulic shaker table control and testing system is presented. The shaker table is a single axis system which may be configured to provide excitation along three orthogonal axes. The test table excitation includes user definable test sequences in addition to pre-programmed inputs including swept sine, damped sine, random and shock. The test system was designed and constructed with commercially available hardware components.

86-2576

### **An Implemented Approach to Host Computer Control (HCC) of a Digital Random Vibration Control System**

E.A. Andress

Scientific-Atlanta, Inc., San Diego, CA  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 338-345, 4 figs

KEY WORDS: Testing techniques, Vibration tests, Shakers, Computer-aided techniques, Vibration control

An implemented approach to host computer control of a digital random vibration control system's CPU via RS-232 is discussed. A simplified format permitting the host to download instructions, react to responses from the system, and call for and accept/store selected test data from the slave system, is shown.

86-2577

### **Personal Computers in Environmental Test Laboratories -- In Perspective**

D.B. Page

Hughes Aircraft Co., El Segundo, CA  
"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 469-472, 5 refs

KEY WORDS: Vibration tests, Personal computers

Personal computers (PCs) are appearing in more and more applications supporting environmental test laboratories. Connected to data loggers, controllers, voice synthesizers, spectrum analyzers, and other instruments, PCs analyze data, monitor alarm limits, and control tests. This paper puts the application of PCs to environmental test labs in perspective. Results from a small survey of PC users are annotated by the author's experiences. Applications, system costs, user experiences, unexpected benefits, safety, and other subjects are discussed.

86-2578

**Updating Rail Impact Test Methods**

R.A. McKinnon

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 254-262, 5 figs, 2 tables, 10 refs

**KEY WORDS:** Testing techniques, Impact tests, Railroad trains

The primary objective of this study was to develop a realistic and repeatable method for conducting rail impact tests. This was due to the existence of several different methods plus the need for repeatable results. This new procedure was developed by examining existing rail impact test procedures, analyzing their purposes, and reviewing actual railroad procedures. All of the variables were taken into account individually and collectively and were examined.

86-2579

**A Proposed Technique for Ground Vehicle Loose Cargo Vibration Simulation**

W.H. Connon, III

U.S. Army Combat System Test Activity, Aberdeen Proving Ground, MD

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 242-253, 12 figs, 11 tables, 12 refs

**KEY WORDS:** Testing techniques, Vibration tests, Cargo transportation, Simulation, Military vehicles

A technique is described for measuring the actual field environment for loose cargo transported in various military ground vehicles and developing a procedure for realistic laboratory simulation of this environment.

86-2580

**A Multiexciter Dynamic-Testing Control, Data-Acquisition, and Analysis System for Railroad Vehicle Evaluation and Environmental Simulation**

L. L. Cackovic, F. Irani, P. Welik

Assoc. of American Railroads, Pueblo, CO

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 363-367, 5 figs

**KEY WORDS:** Railroad cars, Test facilities

In Pueblo, Colorado, the Association of American Railroads (AAR) Transportation Test Center (TTC) boasts a unique testing facility. This is

the Vibration Test Unit (VTU). It is located in the test center's Rail Dynamic Laboratory (RDL). Dynamic tests on railroad vehicles for environmental simulations and for vehicle evaluations can be performed with the VTU. These tests are done utilizing the VTU's twelve hydraulic actuators (eight vertical and four lateral). The VTU Control System (VTUCS), designed by Synergistic Technology Incorporated (STI) provides the VTU with command-generation, data acquisition, and analysis capabilities. This system allows AAR engineers to perform a wide variety of tests which are needed to help continue the advancement of railroad technology. This paper presents a description of a vibration test unit and its control system, as well as a typical VTU test sequence. Discussed are the mechanical and electrical components of the VTU; the VTU control system hardware design, software design, and performance; and VTU test procedures, data acquisition, and analysis.

86-2581

**Swept Sine on Random Testing Using Swept Sampling Rates**

J.M. Cies

Hewlett-Packard Co., Paramus, NJ

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 346-352, 6 figs, 1 table, 5 refs

**KEY WORDS:** Vibration tests, Random vibrations, Testing techniques, Swept sine-wave excitation

A simpler approach to swept sine on random (SSOR) and swept narrow band random on random (SNBROR) vibration testing is proposed. Both SSOR and SNBROR are used to represent the combined effects of random vibration and strong periodic excitation. The key to this method involves varying the sample rate of the analog to digital converter which in turn sweeps the entire frequency band of the test spectrum. The currently available approaches to satisfying this test requirement are summarized and compared to the proposed method. Considerations involved in setting up a test as well as optimizing the control strategy are detailed.

86-2582

**Automated MTBF Test System**

C.B. Hoskins, V.M. Stone

Naval Weapons Ctr., China Lake, CA

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 330-337, 4 figs, 4 tables

**KEY WORDS:** Test facilities, Computer aided techniques, Microcomputers

This paper describes an approach taken to automate combined environment reliability testing through the use of a full-time supervisory micro-computer control system.

**86-2583**

**Two Input-Single Output Simulation**

R.G. Merritt

Naval Weapons Ctr., China Lake, CA

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 275-294, 20 figs, 3 refs

**KEY WORDS:** Random response, Testing techniques, Simulation

Several aspects of laboratory simulation of field measured responses based upon a model framework where the field and laboratory models are dissimilar are examined. The model dissimilarity plays a major role in how well the laboratory model can be fit to the field measured model. In general, locally optimum model fits can be found but these fits may not be able to faithfully reproduce the field measurements in the laboratory. Laboratory simulation must be used with care and limitations in the reproduction of field measured environments recognized.

**86-2584**

**Equivalence of Fatigue Damage Caused by Vibrations**

J. DeWinne

Atomic Energy Commission

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 227-234, 10 figs, 1 ref

**KEY WORDS:** Swept sine wave excitation, Random tests, Fatigue tests

Materials are subjected in their real environment to vibrations of various kinds (random or sinusoidal) and different types of mechanical shocks. During the design or development of a product, it may be necessary to compute the effects of different kinds of vibration on the material. In this paper an experimental validation of a method of determining equivalence (fatigue damage spectra) between swept sine and random vibration tests on circuit boards using various types of technology is proposed.

**86-2585**

**Some Thoughts on the Vibration Testing of Helicopter Equipment in the UK**

J.C. Barker, H. Goldberg

Westland Helicopters, Somerset, England

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 420-430, 11 figs, 1 ref

**KEY WORDS:** Vibration tests, Testing techniques, Helicopter equipment

The paper gives a condensed history of airworthiness requirements in the United Kingdom and briefly describes the helicopter's vibration sources and environment. It also covers the results of a data survey, discusses the issues involved, and offers a description of possible procedures with examples of their use.

**86-2586**

**C.A. Fixture Design**

E. Elmalah

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 416-419, 4 figs, 38 refs

**KEY WORDS:** Vibration tests, Testing instrumentation, Computer programs, Design techniques

The goal of this article is to encourage the use of standard computer codes used in mechanical design to improve fixture design and lead to savings in time and money. An example is included which compares designs by traditional methods and design and analysis using the SAP6-3 code. Natural frequencies, mode shapes and excitation responses are determined. Several design improvements are presented.

**86-2587**

**Computer Aided Vibration Testing Program Design**

Z. Sherf, J. Zelicovici, E. Katz, E. Elmalah

Ada-Rafael, Haifa, Israel

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 411-415, 7 figs, 3 refs

**KEY WORDS:** Vibration tests, Testing techniques, Computer programs

Accurate simulation of the vibration environment of military equipment necessitates measurement and analysis of the environment and conversion

of the analysis results into a vibration simulation program. The paper presents a computer code written to simplify the construction of testing programs. Included are the principles on which the program is based and a description of the program structure and operation mode. Examples of the different options of the program are presented: building of a stationary testing program, of a non-stationary testing program and evaluation of the program with respect to the real environment using extremum statistics and fatigue damage analysis.

**86-2588**

**An Implementation of a Taped Random Vibration System for Cert**

E.A. Szymkowiak

Westinghouse Electric Corp., Baltimore, MD  
"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 524-527, 4 figs, 1 table, 2 refs

KEY WORDS: Vibration tests, Random vibration, Test facilities

Development and usage of a taped random vibration system as applied to a CERT facility are described. The need to consider spectrum repeatability, product safety, and matching of thermal history are emphasized. Results for a number of boundary conditions are presented.

**86-2589**

**Laboratory Simulation of Field Measured Environments**

R.G. Merritt

Naval Weapons Ctr., China Lake, CA  
"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 512-523, 9 figs, 1 ref

KEY WORDS: Vibration tests, Simulation

Frequently field measured mechanical vibration environments must be simulated in the laboratory. The laboratory inputs causing the vibration response are often dissimilar from those measured in the field. This paper considers the laboratory simulation of a field measured vibration environment that can be modeled as a two input/single output model. The laboratory simulated inputs are assumed to be dissimilar from those in the field. A rationale for judging the effectiveness of the simulation at the output point is provided.

**86-2590**

**A Dual-Shaker Random Vibration Testing Control System**

D. Lehmann

ADA-RAFAEL, Haifa, Israel

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 507-511, 8 figs, 4 refs

KEY WORDS: Shakers, Vibration tests, Random vibration, Computer aided techniques

Special vibration testing problems such as large system testing led to the necessity for dual-shaker testing. Advanced vibration testing systems are controlled with the aid of mini-computers. A special control algorithm was implemented on existing hardware. The algorithm uses a pre-calculated compensation matrix to correct the drive signals which are applied to the shaker amplifiers. This method thus enables the simultaneous operation of the two shakers within the required testing specifications.

**86-2591**

**Closed-Loop Digital Control of Multiaxis Vibration Testing**

G.A. Hamma, R.C. Stroud

Synergistic Technology Inc., Cupertino, CA

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 501-506, 9 figs, 2 refs

KEY WORDS: Vibration tests, Digital techniques

This paper describes the application of multi-exciter closed-loop control systems to multi-exciter sinewave-vibration testing. When the exciters are arranged to be mutually perpendicular, spatial as well as frequency sweeps are achievable. Objectives and results of early applications are compared.

**86-2592**

**Method for Establishing Specifications from Real Environment**

J. De Winne

Atomic Energy Commission

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 458-468, 14 figs, 2 refs

KEY WORDS: Specifications, Shock tests, Vibration tests

In their real environment, materials are subjected to a variety of mechanical shocks and vibrations. A method is proposed for establishing simple specifications, possibly of reduced duration, with the same severity as in a complex vibratory environment made up of vibrations of different origins, or of mechanical shocks to which the material is subjected in the course of its working lifetime. The experimental work undertaken to validate the criterion of equivalence between real environment and specifications that was chosen is described.

**86-2593**

**The Comprehension and Use of MIL-STD-810D**  
Z. Sherf, M. Shaked, G. Ostrovski, E. Elmalah  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 268-274, 16 figs, 8 refs

KEY WORDS: Vibration tests, Military standards

MIL-STD-810D, which replaced 810-C in July 1983, constitutes the basis for important conceptual changes in the planning and performance of environmental testing. Implementation of the new standard is strongly influenced by its interpretation. The paper presents the interpretation given in the author's laboratory to the new standard. Implementation of the new concepts is exemplified in the planning of the vibration testing program for air (unmanned aeroplane) and ground (special trailer) transported systems. The examples stress the use of tailoring concepts (the use of data measured for the systems in their operating environment and for similar systems or similar conditions).

**86-2594**

**Vibration Response on Assemblies or Components in a Fixed System**

M.B. Dumelin  
Defence Technology and Procurement Agency, Switzerland  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 224-226, 6 figs

KEY WORDS: Testing techniques, Standards and codes

The possible differences are shown which may exist between standards, customer-specification and actual measurements as the test spectrum for an entire system. The behavior of rigidly mounted assemblies or items is illustrated. It is

explained that the response values may be up to 15 times the input value. Other examples show the reaction of an assembly mounted on shock absorbers. Experience indicates that there is a typical behavior for such setups.

**86-2595**

**Variable Rate Gunfire Vibration Testing on a Digital Vibration Control System**

J.M. Cies  
"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 491-494, 6 figs, table, 1 ref

KEY WORDS: Vibration tests, Digital techniques, Gunfire effects

Test specifications that define a line spectrum, such as gunfire spectra, are a perfect match for digital vibration control systems. A limitation is encountered, however, when it is desired to simulate the variation of the firing rate over a narrow frequency band caused by the nonconstant rotating speed of the gun barrels. A technique has been implemented that overcomes this limitation by fooling the control system into seemingly performing a constant rate test when in reality the fundamental frequency and all harmonics are being swept over a narrow frequency band. The focus of this effort is to further describe the details of this method.

**86-2596**

**Accelerometers for Pyroshock Measurements**

J.S. Wilson, Tustin Institute of Technology, Santa Barbara, CA  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 263-267, 1 table, 8 refs

KEY WORDS: Accelerometers, Pyrotechnic shock environment

Unique characteristics which make accelerometer measurements of pyroshock difficult are discussed. Accelerometer characteristics of special concern when measuring pyroshock are enumerated. Recommendations for accelerometer performance specifications for pyroshock are presented. Tabulated results of a survey of available accelerometers are shown.

**86-2597**

**Back to Basics about the Original Meaning of Vibration-Tests**

K.-H. Hansen

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 431-434, 9 figs

**KEY WORDS:** Vibration tests, Shock tests, Fatigue life, Strains

Today's environmental engineering uses many specifications for vibration tests and shock tests. They are written mainly in terms of acceleration and frequency (sine-testing) or acceleration density and frequency spectra (random vibration testing). Shock tests are written usually in terms of maximum acceleration and time history of the shocks (pulse shape). In addition, shock spectra may help to describe these tests in more detail. However, it is not the acceleration, but stress which causes fatigue in materials. To understand the specifications and their implications for a test object, we must think in terms of stress and strain - namely in terms of their peak probability distributions.

**86-2598**

**Development of a Personal Computer Based Data Acquisition and Analysis System for Shock Testing**

D.P. Roach

Sandia National Labs., Albuquerque, NM

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 318-329, 16 figs, 11 refs

**KEY WORDS:** Shock tests, Computer aided techniques, Personal computers, Testing techniques

This paper discusses a specialized use of personal computers in the environmental test lab to accommodate the following needs: provide low cost data acquisition and analysis capabilities for shock testing; allow shock testing in remote test areas; and develop experimental methods which take advantage of the expanding personal computer technology.

**86-2599**

**An On-Line Implementation of MIL-STD-810D Transportation, Helicopter and Gunfire Simulation**

A.C. Keller

Scientific-Atlanta, Inc., San Diego, CA

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 353-362, 16 figs, 4 refs

**KEY WORDS:** Testing techniques, Computer aided techniques, Computer programs, Helicopter vibration, Gunfire effects

A software package entitled ATAGS+ has been developed which is designed to operate on a digital vibration control system. It simulated virtually all of the test methods outlined in MIL-STD-810D including transportation, helicopter, propeller, gunfire, external stores, burn-in and others. Examples of the use of this software are given together with comments on several aspects of control strategies.

**86-2600**

**Characterization of Nonstationary Random Processes**

T.L. Paez

Sandia Natl. Labs., Albuquerque, NM

"Improve Your Odds With Sound Basic Sci. and Creative Engrg.," Proc. 31st Ann. Tech. Mtg., Inst. of Env. Sci., Las Vegas, NV, Apr 30-May 2, 1985, pp 495-500, 8 figs, 3 tables, 4 refs

**KEY WORDS:** Shock tests, Random excitation, Stochastic processes

Current methods for shock test specification and shock testing treat the shock environment as a deterministic source. The present study proposes to treat shock sources as nonstationary random processes. A model for a realistic nonstationary random process shock source is specified, and the effect of variation of parameters in the shock source is shown. A method for estimating the parameters of the random process is established, and some numerical examples show that the method yields reasonable results. The use of this model in shock testing is discussed.

**86-2601**

**Minimum Drive Requirements for a Multiple Input Output Linear System**

D.O. Smallwood, T.D. Woodall, E.J. Buksa

Sandia Natl. Labs., Albuquerque, NM

"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 295-301, 4 figs, 5 refs

**KEY WORDS:** Shakers, Test facilities, Random vibration tests

The application of multiple random inputs used to drive a single test item in vibration tests is becoming more common. A test of this nature requires the complete specification of the cross spectral density matrix of all the control points.

If the cross spectra are not specified, they can be chosen to minimize the drive requirements for the test. A set of control point cross-spectra are derived which will minimize the total drive power. The result has a more general application for any linear system with N inputs and N responses. If the auto (power) spectra of the N responses are specified, a set of response cross-spectra which will minimize or maximize the total input power are derived. The method has also been extended to include sine inputs where the desire is to maximize or minimize the drive power while maintaining the input motion at specified amplitudes. The method has been implemented on Sandia's multiple input random vibration control system.

## SCALING AND MODELING

86-2602

### On the Dynamic Similitude Laws in Vibrational Modal Analysis of Structures

Li Dabao

Tsinghua Univ., Beijing, China

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1582-1585, 2 refs

KEY WORDS: Experimental modal analysis, Simulation, Scaling

In order to ensure the quality of the dynamic behavior of a large structure, it is advisable to identify the modal parameters of its scale model in advance. Using prediction equations the measured quantities carried on the model are converted to that of prototype and the dynamic behavior of the real structure are predicted. This paper gives a brief review of dynamic similitude principles. The main purpose is to derive the design equations and the prediction equations of the scaled model used in vibrational modal analysis. The conversion relationships of the modal parameters between model and prototype are deduced.

## DIAGNOSTICS

86-2603

### Eigenparameter Analysis of Beams with Different End Conditions

M.M.F. Yuen

Univ. of Hong Kong, Hong Kong

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1572-1576, 8 figs, 12 refs

KEY WORDS: Diagnostic techniques, Experimental modal analysis, Structural modification techniques, Beams

The eigenvalue and eigenvector of a structure will change when damage is inflicted on the structure. The change should be related to the location and the extent of damage. The eigenparameter, defined as the difference between the damaged and the undamaged case of the vector obtained by dividing the mass orthonormalized eigenvector by the corresponding eigenvalue, can be used as a means of locating the damage and as a measure of its significance.

86-2604

### Computer Aided Fault Diagnosis in Turbo-Compressors Using Vibration Measurements

A. El Khatib, A. El Sayed

Alexandria Univ., Alexandria, Egypt

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1403-1409, 8 figs, 7 tables, 10 refs

KEY WORDS: Experimental modal analysis, Diagnostic techniques, Turbomachinery, Rotatory compressors, Computer aided techniques

The main objective of this paper is to introduce a comprehensive diagnostic computer system based on recording and analyzing vibration spectra of running turbo-compressors to indicate their incipient failure. The proposed diagnostic system automatically warns of faults, enables diagnosis of the cause, and trends the historical data to predict ultimate breakdowns.

## BALANCING

86-2605

### Turbomachinery Incipient Failure Dynamic Detection Indicators and Analysis

D.R. Faby, R.L. Smith, J.L. Frarey

Shaker Res. Corp., Latham, NY

Rept. No. NASA-CR-178739, 54 pp (Aug 1985)  
N86-21857/5/GAR

KEY WORDS: Diagnostic techniques, Failure detection, Ball bearings, Balls

Tape recorded signals from case-mounted accelerometers are examined to determine the feasibility of detecting spalls on bearing balls in the liquid oxygen pump in the space shuttle main engine. The nonperiodic nature of the spall impact on inner and outer bearing races caused traditional techniques to be unsuccessful. A

technique involving statistical techniques and spectra ratios was used to review available pump test tapes.

## MONITORING

**86-2606**

### **Modal Frequency Method in Diagnosis of Fracture Damage in Structures**

F.D. Ju, M. Mimovich  
Univ. of New Mexico, Albuquerque, NM  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1168-1174, 10 figs, 4 tables, 8 refs

**KEY WORDS:** Diagnostic techniques, Beams, Fracture properties, Damage detection

The present paper used the modal frequency method to diagnose the fracture damage experimentally in simple structures, based on the analytic theory of the spring-loaded fracture-hinge. It is illustrated that the damage geometry uniquely defines the spring constant of the fracture hinge, which is therefore independent of the damage location. The experiment also measures the changes in modal frequencies to locate the damage on the beam. The locations of the damages can be predicted to within an accuracy of three percent of the length.

**86-2607**

### **The Calculation of Modal Balance Weights for Rotating Machinery**

W.C. Foiles  
Bently Nevada Corp., Broomall, PA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1518-1522, 6 refs

**KEY WORDS:** Experimental modal analysis, Balancing techniques, Rotating machinery

The relation between conventional balance weights and distributed balance weights is examined, with some discussion on equivalent sets of balance weights given. A mini-max algorithm is presented to calculate approximate modal forcing functions; in particular, modal balance weights. This algorithm is described as a linear programming problem.

**86-2608**

### **Application of Modal Analysis to the Balancing of Rotating Machines**

R. Bigret

Institut Supérieur des Matériaux et de la Construction Mécanique, France

Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1523-1530, 3 figs, 4 refs

**KEY WORDS:** Experimental modal analysis, Balancing techniques, Rotating machinery, Modal balancing technique, Influence coefficient method

A rotating machine includes a rotor, links and a structure. Its vibratory behavior is characterized by eigenvalues and by right and left eigenvectors which generally depend on the speed of rotation. The study of states with imposed forces enables to draw the principles of the modal method and the influence coefficient method for balancing. The relations between those two methods are expressed. The balancing, by means of two correcting unbalances, of a rotor which cannot be deformed and of a rotor in a rigid state is discussed.

**86-2609**

### **A Comparative Study of Vibration Monitoring Techniques for Rolling Element Bearings**

M.A. Elbestawi, H.J. Tait  
Ontario Hydro Research Division Toronto, Ontario, Canada  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1510-1517, 8 figs, 19 refs

**KEY WORDS:** Experimental modal analysis, Monitoring techniques, Rolling contact bearings, Vibration signatures, Signature analysis

Various vibration signature analysis techniques involving time, frequency and statistical methods are available for defect detection in rolling element bearings. This paper presents the results of an experimental investigation utilizing a bearing rig, evaluating the performance of some of these techniques in defect detection. Various defects were artificially induced in the tested bearings, and the resulting vibrations monitored using a piezoelectric accelerometer mounted on the bearing housing. A minicomputer system, interfaced with the test rig, was used to process the vibration signal. The paper presents data obtained at low and medium speeds and discusses the results.

# ANALYSIS AND DESIGN

## ANALYTICAL METHODS

86-2610

### Comments on Curve Veering in Eigenvalue Problems

N.C. Perkins, C.D. Mote, Jr.  
Univ. of California, Berkeley, CA  
J. Sound Vib., 106 (3), pp 451-463 (May 8, 1986)  
12 figs, 1 table, 16 refs

KEY WORDS: Eigenvalue problems

The dependence of eigenvalues on a system parameter is frequently illustrated by a family of loci. When two loci approach each other, they often cross or abruptly diverge. The latter case, called curve veering, has been observed in approximate solutions associated with discretized models. The influence of discretization in producing curve veering has raised doubt on the validity of many approximate solutions. The existence of curve veering in continuous models is illustrated by presenting the exact solution of an elementary eigenvalue problem. Veering is then examined in a general eigenvalue problem. Criteria are established to distinguish veerings from crossings in both continuous and discretized models. The application of the criteria is illustrated by examples.

86-2611

### The Reflection Function $r(t)$ : A Matrix Approach Versus $FFT^{-1}$

J. Agullo, A. Barjau  
Universitat Politecnica de Catalunya, Barcelona, Spain  
J. Sound Vib., 106 (2), pp 192-201 (Apr 22, 1986) 8 figs, 1 table, 2 refs

KEY WORDS: Matrix methods, Fast fourier transform

The equation of a linear unidimensional acoustic system, expressed by means of the convolution integral relating pressure and velocity can be transformed into an equivalent equation. The equation is more convenient than the original equation because  $r(t)$  decays to zero faster than  $h(t)$ . If the  $FFT^{-1}$  algorithm is used to obtain  $r(t)$  a large number  $N^1$  of points is required in order that the time interval be small; if the frequency interval is not to be too large. A matrix method is presented that allows one to compute  $r(t)$  for any value of  $t$ , and which, to

obtain an array of points  $r(t)$ , compares favorably with  $FFT^{-1}$ . This method can be faster than  $FFT^{-1}$  if only a small number of modes are to be considered. If the damping is small modal coupling can be neglected, which leads to an approximate solution that greatly reduces the required computer capacity and time.

## NUMERICAL METHODS

86-2612

### A Numerical Technique for Nonlinear Eigenvalue Equations with Complex Roots and Its Application to Fluidelastic Vibration

T.T. Wu  
Westinghouse Electric Corp., Pittsburgh, PA  
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1577-1581, 3 figs, 7 refs

KEY WORDS: Fluid-structure interaction, Eigenvalue problems, Numerical methods

A sophisticated analytical model for fluidelastic vibration introduces the equations of fluid motion in addition to customary equations for structural motion. This results in a set of nonlinear eigenvalue equations with complex roots. The standard methods for eigenvalue and eigenvector extraction are not applicable mainly because of nonproportional damping and the dependency of the dynamic characteristics of the fluid-structure system on the flow velocity. This paper presents a numerical technique for solving nonlinear eigenvalue equations with complex roots.

## PARAMETER IDENTIFICATION

86-2613

### Parameter Estimation and Error Analysis in Environmental Modeling and Computations

E.E. Kalmaz  
Johnson Space Center, Houston, TX  
"Environmental Tech--Coming of Age", Proc. 32nd Ann. Tech. Mtg., Inst. of Env. Sci., Dallas/Ft. Worth, TX, May 6-8, 1986, pp 40-45, 2 figs, 12 refs

KEY WORDS: Parameter identification technique, Error analysis, Least squares method

One most important application of parameter estimation of system dynamics and the model development for environmental impact assessments is the provision of reliable estimates of parameters which can be used by means of sta-

tistical analysis. In most environmental modeling, parameter estimations and computational problems in pollutant clearance, elimination, half-life peaktime and concentration estimate can be obtained by curve fitting or structural modeling. This paper presents a method for the estimation of parameters and error analysis of the development of nonlinear modeling for environmental impact assessments studies. Modeling and least squares estimation techniques are used to define a model for association of error with experimentally observed data.

## COMPUTER PROGRAMS

86-2614

**EURDYN-1D: A Computer Code for the One-Dimensional Non-Linear Dynamic Analysis of Structural Systems. Description and Users' Manual (Release 1)**

F. Casadei, J.P. Halleux

Commission of the European Communities, Luxembourg

Rept. No. EUR-10115-EN, 198 pp (1985) PB86-189487/GAR

**KEY WORDS:** Computer programs, Dynamic structural analysis

The goal of the present report is to provide for a comprehensive users' manual describing the capabilities of the computer code EURDYN-1D. It includes information and examples about the

type of problems which can be solved with the code and explanation on how to prepare input data and, how to interpret output results. The field of application of EURDYN-1D is the one-dimensional dynamic analysis of general structural systems. The code is particularly suited for fast transient events involving propagation of longitudinal mechanical waves (subsonic) in structures.

## GENERAL TOPICS

### USEFUL APPLICATIONS

86-2615

**Vibrating-Chamber Levitation Systems**

M.B. Barmatz, D. Granett, M.C. Lee

NASA Pasadena Office, Pasadena, CA

U.S. Patent - 4 549 435, 6 pp (Oct 1985)

**KEY WORDS:** Levitation, Vibratory techniques

Systems are described for the acoustic levitation of objects, which enable the use of a sealed rigid chamber to avoid contamination of the levitated object. The apparatus includes a housing forming a substantially closed chamber, and means for vibrating the entire housing at a frequency that produces an acoustic standing wave pattern within the chamber.

PERIODICALS SCANNED

**ACTA MECHANICA**  
(Acta Mech.)

Springer-Verlag New York, Inc.  
175 Fifth Ave.  
New York, NY 10010

**ACTA MECANICA SOLIDE SINICA**  
(Acta Mech. Solida Sinica Chinese  
Soc. Theo. Appl. Mech.)

Chinese Society of Theoretical  
and Applied Mechanics  
Guoji Shudian  
P.O. Box 2820  
Beijing, China

**ACUSTICA**  
(Acustica)

S. Hirzel Verlag, Postfach 347  
7000 Stuttgart 1  
Fed. Rep. Germany

**AERONAUTICAL JOURNAL**  
(Aeronaut. J.)

Royal Aeronautical Society  
4 Hamilton Pl.  
London W1V 0BQ, UK

**AEROSPACE AMERICA**  
(Aerospace Amer.)

American Institute of Aeronautics  
and Astronautics  
1633 Broadway  
New York, NY 10019

**AEROSPACE ENGINEERING**  
(Aerospace Engrg.)

Society of Automotive Engineers  
400 Commonwealth Drive  
Warrendale, PA 15096

**AIAA JOURNAL**  
(AIAA J.)

American Institute of Aeronautics  
and Astronautics  
1633 Broadway  
New York, NY 10019

**AMERICAN SOCIETY OF CIVIL ENGINEERS,  
PROCEEDINGS**  
(ASCE, Proc.)

ASCE  
United Engineering Center  
345 E. 47th St.  
New York, NY 10017

**JOURNAL OF ENGINEERING MECHANICS**  
(ASCE J. Engrg. Mech.)

**JOURNAL OF STRUCTURAL ENGINEERING**  
(ASCE J. Struc. Engrg.)

**AMERICAN SOCIETY OF LUBRICATION  
ENGINEERS, TRANSACTIONS**  
(ASLE, Trans.)

ASLE  
838 Busse Highway  
Park Ridge, IL 60068

**AMERICAN SOCIETY OF MECHANICAL ENGI-  
NEERS, TRANSACTIONS**  
(Trans. ASME)

ASME  
United Engineering Center  
345 E. 47th St.  
New York, NY 10017

**JOURNAL OF APPLIED MECHANICS**  
(J. Appl. Mech., Trans. ASME)

**JOURNAL OF DYNAMIC SYSTEMS, MEA-  
SUREMENT AND CONTROL**  
(J. Dynam. Syst., Meas. Control,  
Trans. ASME)

**JOURNAL OF ENERGY RESOURCES TECH-  
NOLOGY**  
(J. Energy Resources Tech., Trans.  
ASME)

**JOURNAL OF ENGINEERING FOR INDUSTRY**  
(J. Engrg. Indus., Trans. ASME)

**JOURNAL OF ENGINEERING FOR GAS  
TURBINES AND POWER**  
(J. Engrg. Gas Turbines Power,  
Trans. ASME)

- JOURNAL OF MECHANISMS, TRANSMISSION AND AUTOMATION IN DESIGN**  
(J. Mech., Transm., Autom. in Des. Trans. ASME)
- JOURNAL OF PRESSURE VESSEL TECHNOLOGY**  
(J. Pressure Vessel Tech., Trans. ASME)
- JOURNAL OF TURBOMACHINERY**  
(J. Turbomachinery, Trans. ASME)
- JOURNAL OF TRIBOLOGY**  
(J. Trib., Trans. ASME)
- JOURNAL OF VIBRATION, ACOUSTICS, STRESS, AND RELIABILITY IN DESIGN**  
(J. Vib., Acoust., Stress, Rel. Des., Trans. ASME)
- APPLIED ACOUSTICS**  
(Appl. Acoust.)  
Elsevier Applied Science Publishers, Ltd.  
Crown House, Linton Road  
Barking, Essex, IG11 8JU, UK
- ASTRONAUTICS AND AERONAUTICS**  
(Astronautics and Aeronautics)  
1633 Broadway  
New York, NY 10019
- AUTOMOBILTECHNISCHE ZEITSCHRIFT**  
(Automobiltech. Z.)  
Franckh'sche Verlagshandlung  
W. Keller & Co., Postfach 640  
Pfizerstrasse 5-7  
D-700 Stuttgart 1  
Fed. Rep. Germany
- AUTOMOTIVE ENGINEER (UK)**  
(Auto. Engr. (UK))  
Mechanical Engineering Publications Ltd.  
P.O. Box 24  
Northgate Ave., Bury St. Edmunds  
Suffolk IP32 6BW, UK
- AUTOMOTIVE ENGINEERING (SAE)**  
(Auto. Engrg. (SAE))  
Society of Automotive Engineers, Inc.  
400 Commonwealth Dr.  
Warrendale, PA 15096
- BALL BEARING JOURNAL** (English Edition)  
(Ball Bearing J.)  
SKF (UK) Ltd.  
Luton, Bedfordshire  
LU3 3BL, UK
- BROWN BOVERI REVIEW**  
(Brown Boveri Rev.)  
Brown Boveri and Co., Ltd.  
CH-5401, Baden, Switzerland
- BULLETIN OF JAPAN SOCIETY OF MECHANICAL ENGINEERS**  
(Bull. JSME)  
Japan Society of Mechanical Engineers  
Sanshin Hokusei Bldg.,  
H-9, Yoyogi 2-chome, Shibuya-ku  
Tokyo, 151, Japan
- BULLETIN OF SEISMOLOGICAL SOCIETY OF AMERICA**  
(Bull. Seismol. Soc. America)  
P.O. Box 826  
Berkeley, CA 94705
- CHARTERED MECHANICAL ENGINEER**  
(Chart. Mech. Engr.)  
Institution of Mechanical Engineers  
P.O. Box 24  
Northgate Ave., Bury St. Edmunds  
Suffolk IP32 6BW, UK
- CHINA SCIENCE AND TECHNOLOGY ABSTRACTS**  
(China Sci. Tech. Abstracts)  
International Information Service Ltd.  
P.O. Box 24683  
ABD Post Office, Hong Kong
- COMPRESSED AIR**  
(Compressed Air)  
253 E. Washington Ave.  
Washington, NJ 07882-2495
- COMPUTERS AND STRUCTURES**  
(Computers Struc.)  
Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**COMPUTERS IN MECHANICAL ENGINEERING  
(Computers Mech. Engrg.)**

Springer-Verlag New York, Inc.  
175 Fifth Ave.  
New York, NY 10010

**DESIGN NEWS**

**(Des. News)**

Cahners Publishing Co., Inc.  
221 Columbus Ave.  
Boston, MA 02116

**DIESEL PROGRESS**

**(Diesel Prog.)**

Diesel and Gas Turbine Publications  
13555 Bishop's Ct.  
Brookfield, WI 53005-6286

**EARTHQUAKE ENGINEERING AND STRUCTURAL  
DYNAMICS**

**(Earthquake Engrg. Struc. Dynam.)**

John Wiley and Sons Ltd.  
Baffins Lane  
Chichester, Sussex PO19 1UD, Eng-  
land

**ELECTRONIC PRODUCTS**

**(Electronic Prod.)**

Hearst Business Communications,  
Inc.  
P.O. Box 730  
Garden City, NY 11530

**ENGINEERING STRUCTURES**

**(Engrg. Struc.)**

Butterworth Scientific, Ltd.  
P.O. Box 63  
Westbury House, Bury Street  
Guildford, Surrey GU2 5BH, UK

**ENGINEERING WITH COMPUTERS**

**(Engrg. Computers)**

Springer-Verlag New York, Inc.  
175 Fifth Avenue  
New York, NY 10010

**EXPERIMENTAL MECHANICS**

**(Exptl. Mech.)**

Society for Experimental Mechanics  
Experimental Mechanics  
7 School Street  
Bethel, CT 06801

**EXPERIMENTAL TECHNIQUES**

**(Exptl. Tech.)**

Society for Experimental Mechanics  
Experimental Techniques  
7 School Street  
Bethel, CT 06801

**FEINGERÄTE-TECHNIK**

**(Feingerätetechnik)**

VEB Verlag Technik  
Berlin,  
German Dem. Rep.

**FEINWERKTECHNIK UND MESSTECHNIK**

**(Feinwerktech. u. Messtech.)**

Carl Hanser Verlag  
Kolbergerstr. 22  
D-8000 München 80  
Fed. Rep. Germany

**FINITE ELEMENTS IN ANALYSIS AND DESIGN**

**(Finite Elements Analysis Des.)**

Elsevier Science Publishers  
(North Holland)  
P.O. Box 1991  
1000 BZ Amsterdam  
The Netherlands

**FORSCHUNG IM INGENIEURWESEN**

**(Forsch. Ingenieurwesen)**

Verein Deutscher Ingenieur, GmbH  
Postfach 1139, Graf-Recke Str. 84  
4 Düsseldorf 1,  
Fed. Rep. Germany

**GEC JOURNAL OF RESEARCH**

**(GEC J. Res.)**

Marconi Res. Ctr.  
West Henningfield Rd.  
Great Baddow, Chelmsford  
Essex CM2 8HN, UK

**GUMMI FASERN KUNSTSTOFFE**

**(Gummi Fasern Kunstst.)**

Alfons W. Gentner Verlag GmbH and Co. KG  
ForstraBe 131, Postfach 688  
7000 Stuttgart 1  
Fed. Rep. Germany

**HEATING/PIPING/AIR CONDITIONING**

**(Heating/Piping/Air Cond.)**

1111 Chester Avenue  
Cleveland, OH 44114

**HIGH TECHNOLOGY****(High Tech.)**

High Technology Pub. Corp.  
1642 Westwood Blvd.  
Los Angeles, CA 90024

**HYDRAULICS AND PNEUMATICS****(Hydraul. Pneumat.)**

Penton/IPC, Inc.  
614 Superior Ave. West  
Cleveland, OH 44113

**HYDROCARBON PROCESSING****(Hydrocarbon Processing)**

Gulf Publishing Co.  
P.O. Box 2608  
Houston, TX 77001

**IBM JOURNAL OF RESEARCH AND DEVELOPMENT****(IBM J. Res. Dev.)**

International Business Machines  
Corp.  
Armonk, NY 10504

**INDUSTRIAL LUBRICATION AND TRIBOLOGY****(Indus. Lubric. Trib.)**

Peterson Publishing Co. Ltd.  
Peterson House, Northbank,  
Berryhill Industrial Estate  
Droitwich, Worcs WR9 9BL, England

**INDUSTRIE-ANZEIGER****(Industrie-Anz.)**

Verlag W. Girardet, Girardetstr. 2  
Postfach 101365  
4300 Essen, W. Germany

**INGENIEUR-ARCHIV****(Ing.-Arch.)**

Springer-Verlag New York, Inc.  
44 Hartz Way  
Secaucus, NJ 07094

**INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, PROCEEDINGS****(IEEE, Proc.)**

IEEE  
United Engineering Center  
345 E. 47th St.  
New York, NY 10017

**INSTITUTION OF MECHANICAL ENGINEERS, PROCEEDINGS, PART C: MECHANICAL ENGINEERING SCIENCE****(IMechE, Proc. Part C: Mech. Engrg. Sci.)**

Institution of Mechanical Engineers  
1 Birdcage Walk, Westminster,  
London SW1H 9JJ, UK

**INSTRUMENT SOCIETY OF AMERICA, TRANSACTIONS****(ISA, Trans)**

Instrument Society of America  
67 Alexander Dr.  
Research Triangle Park, NC 27709

**INSTRUMENTATION TECHNOLOGY****(Instrum. Tech.)**

Instrument Society of America  
67 Alexander Dr.  
P.O. Box 12277  
Research Triangle Park, NC 27709

**INTERNATIONAL JOURNAL OF ANALYTICAL AND EXPERIMENTAL MODAL ANALYSIS****(Intl. J. Analyt. Exptl. Modal Analysis)**

Society for Experimental Mechanics,  
Inc.  
7 School Street  
Bethel, CT 06801

**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCE****(Intl. J. Engrg. Sci.)**

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**INTERNATIONAL JOURNAL OF FATIGUE****(Intl. J. Fatigue)**

Butterworth Scientific Ltd.  
Journals Div.  
P.O. Box 63, Westbury House, Bury  
St.  
Guildford GU2 5BH, Surrey, UK

**INTERNATIONAL JOURNAL OF IMPACT ENGINEERING****(Intl. J. Impact Engrg.)**

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**INTERNATIONAL JOURNAL OF MACHINE TOOL DESIGN AND RESEARCH****(Intl. J. Mach. Tool Des. Res.)**

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**INTERNATIONAL JOURNAL OF MECHANICAL SCIENCES****(Intl. J. Mech. Sci.)**

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**INTERNATIONAL JOURNAL OF NONLINEAR MECHANICS**

(Intl. J. Nonlin. Mech.)

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**JOURNAL OF AIRCRAFT**

(J. Aircraft)

American Institute of Aeronautics  
and Astronautics  
1633 Broadway  
New York, NY 10019

**INTERNATIONAL JOURNAL FOR NUMERICAL AND ANALYTICAL METHODS IN GEOMECHANICS**

(Intl. J. Numer. Anal. Methods Geomech.)

John Wiley and Sons Ltd.  
Baffins Lane  
Chichester, Sussex PO19 1UD, England

**JOURNAL OF COMPOSITES AND TECHNOLOGY RESEARCH**

(J. Comp. Tech. Res.)

ASTM-CTR  
1916 Race Street  
Philadelphia, PA 19103

**INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGINEERING**

(Intl. J. Numer. Methods Engrg.)

John Wiley and Sons Ltd.  
Baffins Lane  
Chichester, Sussex PO19 1UD, England

**JOURNAL OF ENVIRONMENTAL SCIENCES**

(J. Environ. Sci.)

Institute of Environmental Sciences  
940 E. Northwest Highway  
Mt. Prospect, IL 60056

**INTERNATIONAL JOURNAL OF SOLIDS AND STRUCTURES**

(Intl. J. Solids Struc.)

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**JOURNAL OF THE FRANKLIN INSTITUTE**

(J. Franklin Inst.)

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**INTERNATIONAL JOURNAL OF VEHICLE DESIGN**

(Intl. J. Vehicle Des.)

Interscience Enterprises Ltd.  
World Trade Center Building  
110 Avenue Louis Casai,  
Case Postale 306  
CH1215 Geneva-Aéroport,  
Switzerland

**JOURNAL OF LOW FREQUENCY NOISE AND VIBRATION**

(J. Low Freq. Noise Vib.)

Multi-Science Publishing Co.,  
107 High Street  
Brentwood, Essex CM14 4RX  
England

**ISRAEL JOURNAL OF TECHNOLOGY**

(Israel J. Tech.)

Weizmann Science Press of Israel  
Box 801  
Jerusalem, Israel

**JOURNAL DE MÉCANIQUE THÉORIQUE ET APPLIQUÉE**

(J. de Mécanique Théor. Appl.)

Gauthier-Villars  
C.D.R. - Centrale des Reues  
11, rue Gossin, 92543 Montrouge,  
Cedex, France

**JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA**

(J. Acoust. Soc. Amer.)

American Institute of Physics  
335 E. 45th St.  
New York, NY 10017

**JOURNAL OF PETROLEUM TECHNOLOGY**

(J. Pet. Tech.)

Society of Petroleum Engineers  
222 Palasades Creek Drive  
Richardson, TX 75080

**JOURNAL OF SHIP RESEARCH**

(J. Ship Res.)

Society of Naval Architects and  
Marine Engineers  
One World Trade Center  
Suite 1369  
New York, NY 10048

**JOURNAL OF SOUND AND VIBRATION  
(J. Sound Vib.)**

Academic Press Inc. (London)  
Limited  
Oval Road  
London NW1 7DX UK

**JOURNAL OF SPACECRAFT AND ROCKETS  
(J. Spacecraft Rockets)**

American Institute of Aeronautics  
and Astronautics  
1633 Broadway  
New York, NY 10019

**JOURNAL OF STRUCTURAL MECHANICS  
(J. Struc. Mech.)**

Marcel Dekker, Inc.  
270 Madison Ave.  
New York, NY 10016

**KONSTRUKTION**

**(Konstruktion)**

Springer-Verlag  
Heidelberger Platz 3, D-1000  
Berlin 33  
Fed. Rep. Germany

**LUBRICATION ENGINEERING**

**(Lubric. Engrg.)**

American Society of Lubrication  
Engineers  
838 Busse Highway  
Park Ridge, IL 60068

**MACHINE DESIGN**

**(Mach. Des.)**

Penton/IPC, Inc.  
Penton Plaza,  
1111 Chester Ave.  
Cleveland, OH 44114

**MASCHINENBAUTECHNIK**

**(Maschinenbautech.)**

VEB Verlag Technik  
Oranienburger Str. 13/14  
1020 Berlin,  
German Dem. Rep.

**MECCANICA**

**(Meccanica)**

Pitigora Editrice  
Via Zamboni 57  
Bologna, Italy  
C.C.P. 17396409

**MECHANICAL ENGINEERING**

**(Mech. Engrg.)**

American Society of Mechanical  
Engineers  
United Engineering Center  
345 E. 47th St.  
New York, NY 10017

**MECHANICS RESEARCH COMMUNICATIONS**

**(Mech. Res. Comm.)**

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**MECHANISM AND MACHINE THEORY**

**(Mech. Mach. Theory)**

Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**MICROTECNIC**

**(Microtecnic)**

Agifa Verlag  
Universitatstrasse 94  
P O. Box 257  
CH-8033 Zurich, Switzerland

**MTZ MOTORTECHNISCHE ZEITSCHRIFT**

**(MTZ Motortech. Z.)**

Franckh'sche Verlagshandlung  
Pfizerstrasse 5-7  
D-7000 Stuttgart 1,  
Fed. Rep. Germany

**NAVAL ENGINEERS JOURNAL**

**(Naval Engr. J.)**

American Society of Naval Engi-  
neers, Inc.  
1452 Duke Street  
Alexandria, VA 22314

**NONDESTRUCTIVE TESTING INTERNATIONAL**

**(NDT Intl.)**

Butterworth Scientific Ltd.  
Journals Div.  
P.O. Box 63, Westbury House, Bury  
St.  
Guildford, Surrey GU2 5BH, UK

**NOISE CONTROL ENGINEERING JOURNAL**

**(Noise Control Engrg. J.)**

P.O. Box 2306, Arlington Branch  
Poughkeepsie, NY 12603

**NOISE & VIBRATION CONTROL**  
(Noise & Vib. Control)  
The Trade & Technical Press Ltd.  
Crown House  
Morden  
Surrey, SM4 5EW, England

**NUCLEAR ENGINEERING AND DESIGN**  
(Nucl. Engrg. Des.)  
North-Holland Publishing Co.  
P.O. Box 1000 AC  
Amsterdam, The Netherlands

**OCEAN ENGINEERING**  
(Ocean Engrg.)  
Pergamon Press Inc.  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**PAPER TECHNOLOGY AND INDUSTRY**  
(Paper Tech. Indus.)  
3, Plough Place, Fetter Lane  
London EC4A 1AL, UK

**PHYSICS TODAY**  
(Physics Today)  
American Institute of Physics  
500 Sunnyside Blvd.  
Woodbury, NY 11797

**PLANT ENGINEERING**  
(Plant Engrg.)  
Technical Publishing Co.  
1301 S. Grove Ave.  
Barrington, IL 60010

**POWER**  
(Power)  
McGraw-Hill, Inc.  
1221 Ave. of Americas  
New York, NY 10020

**POWER TRANSMISSION DESIGN**  
(Power Transm. Des.)  
Penton IPC/Inc.  
1111 Chester Ave.  
Cleveland, OH 44114

**REVUE ROUMAINE DES SCIENCES TECH-**  
**NIQUES, SERIE DE MECANIQUE APPLIQUEE**  
(Rev. Roumaine Sci. Tech., Mecanique  
Appl.)  
Editura Academiei  
Republicii Socialiste de Romania  
125, Calea Victoriei, 79717  
Bucarest, Romania

**SAE TECHNICAL LITERATURE ABSTRACTS**  
(SAE Tech. Lit. Abstracts)  
Society of Automotive Engineers  
400 Commonwealth Dr.  
Warrendale, PA 15086

**SCIENTIFIC AMERICAN**  
(Scientific American)  
Scientific American, Inc.  
415 Madison Ave.  
New York, NY 10017

**SHOCK AND VIBRATION DIGEST**  
(Shock Vib. Dig.)  
Shock and Vibration Information  
Center  
Naval Research Laboratory, Code  
5804  
Washington, DC 20375

**SIAM JOURNAL ON APPLIED MATHEMATICS**  
(SIAM J. Appl. Math.)  
Society for Industrial and Applied  
Mathematics  
1400 Architects Building  
117 S. 17th St.  
Philadelphia, PA 19103

**SIEMENS RESEARCH AND DEVELOPMENT**  
**REPORTS**  
(Siemens Res. Dev. Repts.)  
Springer-Verlag New York Inc.  
175 Fifth Ave.  
New York, NY 10010

**STROJNICKY ČASOPIS**  
(Strojnický časopis)  
83606 Bratislava  
ul. Febr. vitazstva 75  
Czechoslovakia

**S/V, SOUND AND VIBRATION**  
(S/V, Sound Vib.)  
Acoustic Publications, Inc.  
27101 E. Oviatt Rd.  
P.O. Box 40416  
Bay Village, OH 44140

**TAPPI JOURNAL**  
(Tappi J.)  
Technical Association of the Pulp  
and Paper Industry  
15 Technology Park South  
Norcross, GA 30092

**TECHNICAL REVIEW (BRUEL and KJAER)**  
**(Tech. Rev. (B and K))**  
Bruel and Kjaer  
185 Forest St.  
Marlborough, MA 01752

**TECHNISCHE MITTEILUNGEN KRUPP,  
FORSCHUNGSBERICHTE**  
**(Techn. Mitt. Krupp, Forschungsber.)**  
Krupp Gemeinschaftsbetriebe,  
Fachbücherei,  
Postfach 10 19 52, D-4300 Essen 1,  
Fed. Rep. Germany

**TECHNISCHE MITTEILUNGEN KRUPP,  
WERKSBERICHTE**  
**(Techn. Mitt. Krupp, Werksber.)**  
Krupp Gemeinschaftsbetriebe,  
Fachbücherei,  
Postfach 10 19 52, D-4300 Essen 1,  
Fed. Rep. Germany

**TECHNISCHES MESSEN-TM**  
**(Techn. Messen-TM)**  
R. Oldenbourg Verlag GmbH  
Rosenheimer Strasse 145,  
D-8000 München 80,  
Fed. Rep. Germany

**TEST**  
**(Test)**  
Mattingley Publishing Co., Inc.  
3756 Grand Ave.  
Suite 205  
Oakland, CA 94610

**TRIBOLOGY INTERNATIONAL**  
**(Trib. Intl.)**  
Butterworth Scientific Ltd.  
Journals Div.  
P.O. Box 63,  
Westbury House, Bury St.  
Guildford, Surrey GU2 5BH, UK

**TURBOMACHINERY INTERNATIONAL**  
**(Turbomachinery Intl.)**  
270 Madison Ave.  
New York, NY 10016

**VDI BERICHTE**  
**(VDI Ber.)**  
Verein Deutscher Ingenieur GmbH  
Postfach 1139, Graf-Recke Str. 84,  
4 Düsseldorf 1,  
Fed. Rep. Germany

**VDI FORSCHUNGSHEFT**  
**(VDI Forsch.)**  
Verein Deutscher Ingenieur GmbH  
Postfach 1139, Graf-Recke Str. 84,  
4 Düsseldorf 1,  
Fed. Rep. Germany

**VDI ZEITSCHRIFT**  
**(VDI Z.)**  
Verein Deutscher Ingenieur GmbH  
Postfach 1139, Graf-Recke Str. 84,  
4 Düsseldorf 1,  
Fed. Rep. Germany

**VERTICA**  
**(Vertica)**  
Pergamon Press  
Maxwell House, Fairview Park  
Elmsford, NY 10523

**VIBRATIONS**  
**(Vibrations)**  
Vibration Institute  
101 W. 55th Street  
Suite 206  
Clarendon Hills, IL 60514

**VIBROTECHNIKA**  
**(Vibrotechnika)**  
Kauno Polytechnikos Institutas  
2 Donelaicio g-ve 17  
233000 Kaunas,  
Lithuanian SSR

**WAVE MOTION**  
**(Wave Motion)**  
Elsevier Science Publishers B.V.  
Molenwerf 1, P.O. Box 1991  
1000 BZ Amsterdam,  
The Netherlands

**WEAR**  
**(Wear)**  
Elsevier-Sequoia S.A.  
P.O. Box 851  
1001 Lausanne 1,  
Switzerland

**ZEITSCHRIFT FÜR FLUGWISSEN-  
SCHAFTEN UND WELTRAUMFORSCHUNG**  
**(Z. Flugwiss. Weltraumforsch.)**  
DFVLR  
D-3300 Braunschweig  
Flughafen, Postfach 3267,  
Fed. Rep. Germany

**SECONDARY PUBLICATIONS SCANNED**

**DISSERTATION ABSTRACTS INTERNATIONAL  
(DA)**

University Microfilms International  
300 N. Zeeb Rd.  
Ann Arbor, MI 48106

**GOVERNMENT REPORTS ANNOUNCEMENTS AND  
INDEX  
(GRA)**

National Technical Information  
Service  
U.S. Department of Commerce  
5285 Port Royal Rd.  
Springfield, VA 22161

**PROCEEDINGS SCANNED**

**INTERNATIONAL MODAL ANALYSIS  
CONFERENCE**

(Intl. Modal Anal. Conf.)  
Union College  
Schenectady, NY 12308

**INTER-NOISE PROCEEDINGS, INTERNATIONAL  
CONFERENCE ON NOISE CONTROL ENGINEERING**

(Inter-Noise)  
Noise Control Foundation  
P.O. Box 3469, Arlington Branch  
Poughkeepsie, NY 12603

**INSTITUTE OF ENVIRONMENTAL SCIENCES  
PROCEEDINGS**

(Inst. Environ. Sci.)  
950 East Northwest Highway  
Mount Prospect, IL 60056

**MACHINERY VIBRATION MONITORING AND  
ANALYSIS MEETING, PROCEEDINGS  
(Mach. Vib. Monit. Anal., Proc.)**

The Vibration Institute  
101 W. 55th St., Suite 206  
Clarendon Hills, IL 60514

**NOISE CONTROL PROCEEDINGS, NATIONAL  
CONFERENCE ON NOISE CONTROL ENGINEERING**

(Noise Control)  
Noise Control Foundation  
P.O. Box 3469, Arlington Branch  
Poughkeepsie, NY 12603

**THE SHOCK AND VIBRATION BULLETIN,  
UNITED STATES NAVAL RESEARCH LABORATORIES,  
ANNUAL PROCEEDINGS  
(Shock Vib. Bull., U.S. Naval Res. Lab., Proc.)**

Shock and Vibration Information  
Center  
Naval Research Lab., Code 5804  
Washington, DC 20375

**TURBOMACHINERY SYMPOSIUM  
(Turbomachinery Symp.)**

Gas Turbine Labs.  
Texas A and M University  
College Station, TX 77843

# ABSTRACT CATEGORIES

## MECHANICAL SYSTEMS

Rotating Machines  
Reciprocating Machines  
Power Transmission Systems  
Metal Working and Forming  
Isolation and Absorption  
Electromechanical Systems  
Optical Systems  
Materials Handling  
Equipment

## STRUCTURAL SYSTEMS

Bridges  
Buildings  
Towers  
Foundations  
Underground Structures  
Harbors and Dams  
Roads and Tracks  
Construction Equipment  
Pressure Vessels  
Power Plants  
Off-shore Structures

## VEHICLE SYSTEMS

Ground Vehicles  
Ships  
Aircraft  
Missiles and Spacecraft

## BIOLOGICAL SYSTEMS

Human  
Animal

## MECHANICAL COMPONENTS

Absorbers and Isolators  
Springs  
Tires and Wheels

Blades  
Bearings  
Belts  
Gears  
Clutches  
Couplings  
Fasteners  
Linkages  
Valves  
Seals  
Cams

## STRUCTURAL COMPONENTS

Strings and Ropes  
Cables  
Bars and Rods  
Beams  
Cylinders  
Columns  
Frames and Arches  
Membranes, Films, and Webs  
Panels  
Plates  
Shells  
Rings  
Pipes and Tubes  
Ducts  
Building Components

## ELECTRIC COMPONENTS

Controls (Switches,  
Circuit Breakers  
Motors  
Generators  
Transformers  
Relays  
Electronic Components

## DYNAMIC ENVIRONMENT

Acoustic Excitation  
Shock Excitation

Vibration Excitation  
Thermal Excitation

## MECHANICAL PROPERTIES

Damping  
Fatigue  
Elasticity and Plasticity  
Wave Propagation

## EXPERIMENTATION

Measurement and Analysis  
Dynamic Tests  
Scaling and Modeling  
Diagnostics  
Balancing  
Monitoring

## ANALYSIS AND DESIGN

Analogs and Analog  
Computation  
Analytical Methods  
Modeling Techniques  
Nonlinear Analysis  
Numerical Methods  
Statistical Methods  
Parameter Identification  
Mobility/Impedance Methods  
Optimization Techniques  
Design Techniques  
Computer Programs

## GENERAL TOPICS

Conference Proceedings  
Tutorials and Reviews  
Criteria, Standards, and  
Specifications  
Bibliographies  
Useful Applications

## FEATURE ARTICLES

	ISSUE	PAGES
Caseiro, C.A. <b>Behavior of Elastomeric Materials under Dynamics Load — IV</b>	1	3-6
Stadelbauer, D.G. <b>Dynamic Balancing with Micro Processors</b>	2	3-6
Laura, P.A.A. <b>The Computer Age And The Usefulness of Old Ideas</b>	3	3-5
Spanos, P.D. and Lutes, L.D. <b>A Primer of Random Vibration Techniques in Structural Engineering</b>	4	3-9
Gupta, A.K. <b>Finite Element Analysis of Vibration of Tapered Beams</b>	5	3-6
Mukherjee, A. and Mukhopadhyay, M. <b>A Review of Dynamic Behavior of Stiffened Plates</b>	6	3-8
Greif, R. <b>Substructuring and Component Mode Synthesis</b>	7	3-9
Rades, M. <b>System Identification Using Real Frequency-Dependent Modal Characteristics</b>	8	3-10
deSilva, C.W., Henning, S.J., and Brown, J.D. <b>Random Testing with Digital Control — Application in the Distribution Qualification of Microcomputers</b>	9	3-13
deSilva, C.W. <b>The Digital Processing of Acceleration Measurements for Modal Analysis</b>	10	3-10
Silva, M.A.G. and Krajcinovic, D. <b>Impact Strength of Concrete</b>	11	3-6
Hundal, M.S. <b>Mechanical Signature Analysis</b>	12	3-10

# LITERATURE REVIEWS

	ISSUE	PAGES
France, D. <b>Rotor Instability in Centrifugal Pumps</b>	1	9-13
Sankar, T.S. and Samaha, M. <b>Research in Rail Vehicle Dynamics — State of the Art</b>	2	9-18
Rao, S.S. <b>Optimization of Structures Under Shock and Vibration Environment</b>	3	7-15
Al-Mousawi, M.M. <b>Theoretical Studies on Flexural Wave Propagation in Beams: A Comprehensive Review — Part I: Historical Background</b>	4	11-18
Al-Mousawi, M.M. <b>Theoretical Studies on Flexural Wave Propagation in Beams: A Comprehensive Review — Part II: Transient Response of Timoshenko Beams</b>	5	9-21
Al-Mousawi, M.M. <b>Theoretical Studies on Flexural Wave Propagation in Beams: A Comprehensive Review — Part III: Wave Propagation in Beams with Discontinuities of Cross Section</b>	6	11-18
Beltzer, A.I. <b>Wave Propagation in Random Composite Materials</b>	7	11-15
Done, G.T.S. <b>Helicopter Vibration Control — Recent Advances</b>	8	13-17
Adeli, H., Amin, A.M., and Sierkowski, R.L. <b>Earth Penetration by Solid Impactors</b>	9	15-22
Nicholson, D.W. <b>Stable Response of Damped Linear Systems — III</b>	10	13-19
Trainor, P.G.S., Popplewell, N., Shah, A.H., and Wong, C.K. <b>Static and Dynamic Behavior of Mechanical Components Associated with Electrical Transmission Lines — II</b>	11	9-17
Broek, D. <b>Fracture Analysis — A Review</b>	12	13-22

## BOOK REVIEWS

Brebbia, C.A., Telles, J.C.F., Wrobel, L.C., Boundary Element Techniques, Springer-Verlag, New York and Berlin, 1984; Reviewed by H. Saunders, SVD, 18 (9), pp 23-24 (Sept 1986).

Bulson, P.S., Buried Structures. Static and Dynamic Strength, Chapman and Hall/Methuen, Inc., New York, NY, 1985; Reviewed by S.A. Kiger, SVD, 18 (4), p 20 (Apr 1986).

Chandra, J. and Scott, A.C., Coupled Nonlinear Oscillator, North-Holland Publishing Company, Amsterdam, 1983; Reviewed by R.A. Ibrahim, SVD, 18 (7), pp 17-18 (July 1986).

Chen, P.Y. and Grimes, C.J., Eds., Seismic Events Probabilistic Risk Assessments, American Society of Mechanical Engineers, New York, NY, 1984; Reviewed by H. Saunders, SVD, 18 (8), p 18 (Aug 1986).

Cheremisinoff P.N. and Ellerbusch, F., Guide for Industrial Noise Control, Butterworth Publishers, Ann Arbor Science, Ann Arbor, MI, 1982; Reviewed by R.J. Peppin, SVD, 18 (8), pp 18-19 (Aug 1986).

Crocker, T.W. and Leis, B.N., eds., Corrosion Fatigue, ASTM Pub STP 801, ASTM, Philadelphia, Pa, 1985; Reviewed by H. Saunders, SVD, 18 (4), pp 21-20 (Apr 1986).

Datta, S.K., ed., Earthquake Source Modelling, Ground Motion and Structural Response, ASME Pub., 1984; Reviewed by H. Saunders, SVD, 18 (9), pp 24-25 (Sept 1986).

Dowding, C.H., Blast Vibration Monitoring and Control, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1985; Reviewed by W.E. Baker, SVD, 18 (1), p 14 (Jan 1986).

D'Souza, A.F. and Garg, V.K., Advanced Dynamics -- Modelling and Analysis, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1984; Reviewed by H. Saunders, SVD, 18 (7), pp 16-17 (July 1986).

Englekirk, R.E., Hart, G.C., and Concrete Masonry Assoc. of California and Nevada, Prentice Hall, Inc., Englewood Cliffs, NY, 1982; Reviewed by S.E. Benzley, SVD, 18 (12), p 24 (Dec 1986).

Fahy, F., Sound and Structural Vibration: Radiation, Transmission and Response, Academic Press, London, 1985; Reviewed by R.J. Peppin, SVD 18 (11), pp 18-19 (Nov 1986).

Gough, W., Richards, J.P.G., and Williams, R.P., Vibrations and Waves, Halsted Press, New York, NY, 1983; Reviewed by R.A. Scott, SVD, 18 (10), p 22 (Oct 1986).

Guckenheimer, J. and Holmes, P., Review of Nonlinear Oscillations, Dynamical Systems, And Bifurcations of Vector Fields, Springer Verlag, New York, New York, NY, 1983; Reviewed by R.A. Scott, SVD, 18 (5), p 22 (May 1986).

Ibrahim R.A., Parametric Random Vibration, John Wiley & Sons, Inc., New York, NY, 1985; Reviewed by P.W. Whaley, SVD, 18 (10), pp 22-23 (Oct 1986).

Kabe, A.W., Organizer, Structural Dynamic Testing and Analysis, SAE, Warrendale, PA, 1984; Reviewed by H. Saunders, SVD, 18 (2), pp 20-21 (Feb 1986).

Kramer, E., Maschinedynamik, Springer Verlag, New York, NY, 1984; Reviewed by S.M. Holzer, SVD, 18 (5), pp 22-23 (May 1986).

Lalanne, M., Berthia, P., and der Hagopian, J., Mechanical Vibrations for Engineers, John Wiley & Sons, New York, NY, 1983; Reviewed by H. Saunders, SVD, 18 (1), pp 14-15 (Jan 1986).

Meirovitch, L., Introduction to Dynamics and Control, John Wiley & Sons, New York, NY, 1985; Reviewed by R.A. Ibrahim, SVD, 18 (2), pp 19-20 (Feb 1986).

Nashif, A.D., Jones, D.I.G., and Henderson, J.P., Vibration Damping, John Wiley & Sons, Inc., New York, NY, 1985; Reviewed by V.R. Miller, SVD, 18 (3), pp 16-17 (Mar 1986).

Nayfeh, Ali H., Problems in Perturbation, John Wiley & Sons, New York, NY, 1985; Reviewed by R.A. Ibrahim, SVD, 18 (12), pp 23-24 (Dec 1986).

Oppenheim, A.V., Willsky, A.S., and Young, I.F., Signals and Systems, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1983; Reviewed by H. Saunders, SVD, 18 (6), pp 19-20 (June 1986).

Rao, J.S. and Gupta, K., Introductory Course on Theory and Practice of Mechanical Vibrations, John Wiley & Sons Inc., New York, NY, 1984; Reviewed by W.D. Pilkey, SVD, 18 (3), p 16 (Mar 1986).

Sharpe, R.S., ed., Research Techniques in Nondestructive Testing -- Vol. VII, Academic Press, London, 1984; Reviewed by S.E. Benzley, SVD, 18 (11), p 18, (Nov 1986).

Varanaukas, P.A., Kurtinaitis, A.K., and Ragulskis, K.M., Methods and Means of Experimental Analysis of the Dynamics of Precise Tape Drives, Mokslas Publ., Vilnius Lithuanian SSR, 1982; Reviewed by A. Longinow, SVD, 18 (3), pp 17-18 (Mar 1986).

Walshaw, A.C., Mechanical Vibrations With Applications, Ellis Horwood, Ltd., 1984; Reviewed by T.S. Sankar, SVD, 18 (4), pp 20-21 (Apr 1986).

White, R.G. and Walker, J.G. (editors), Noise and Vibration, Ellis Horwood (John Wiley) Chichester, 1982; Reviewed by R.J. Peppin, SVD, 18 (6), p 19 (June 1986).

# AUTHOR INDEX

- A -

Abascal, R.....	1714	Akbar, H.....	1903
Abbas, B.A.H.....	2182	Akella, S.....	2380
Abdalla, M.H.M.....	2394	Akers, A.....	947
Abdelhamid, M.K.....	1812	Akers, S.....	2536
Abdel-Ghaffar, A.M.....	775, 951, 952	Akita, Tetsuyoshi.....	2376
	984	Akiyama, H.....	407
Abdel-Hamid, A.N.....	1510	Akkas, N.....	1980
Abdel-Rahman, S.....	1890	Aknine, A.....	1624
Abdel-Rohman, M.....	609, 2216	Aksel, N.....	2294
Abdulhadi, M.I.....	59	Aksu, G.....	1583, 1774
Abd-Rabbo, A.....	2480	Aktan, A.E.....	661
Abe, K.....	926, 1725	Aktan, H.M.....	1673
Abe, T.....	1567	Alam, N.....	1429
Abel, J.F.....	625	Alanoly, J.....	2405
Abel, S.G.....	257	Alarcon, L.F.....	1379
Abkowitz, M.A.....	308	Alavandi, B.V.....	1997
Abom, M.....	1614	Albrecht, D.....	978, 1051
Aboustit, B.L.....	525	Albrecht, P.....	545
Abo-Elkhier, M.....	2241	Alexander, J.C.....	1842
Abramovich, H.....	592, 1607	Alexandropoulos, A.....	2210
Abrams, D.P.....	1709	Alfred, J.R.....	1410
Abt, S.R.....	456	Ali, S.A.....	1039, 1599, 1756
Abu-Arish, A.M.....	1346	Alibe, B.....	1722
Achenbach, J.D.....	93, 2202	Allaire, P.E.....	1745
Adachi, Tsutomu.....	1267	Allard, J.F.....	707, 1624
Adachi, T.....	2004	Allemang, R.J.....	904, 1690, 2209
Adali, S.....	118	Allen, B.G.....	2208
Adams, M.L.....	593	Allen, J.J.....	486
Adams, M.M.....	1076	Allison, I.M.....	61
Adamson, T.C., Jr.....	1801	Altman, W.....	1999
Adeli, H.....	672	Alwan, A.D.....	2396
Adeyeye, J.O.....	260	AL-Ansary, M.D.....	2337
Adhami, R.....	1489	Al-Mousawi, M.M....	1760, 1973, 2203
Adin, M.A.....	833	Al-Noury, S.I.....	1039, 1599
Adler, L.....	1787	Al-Sabeeh, A.K.....	281
Aernoudt, E.....	1117	Al-Sulaimani, G.J.....	939
Aggarwal, A.K.....	2191	Amada, S.....	279, 2377
Agrawal, O.P.....	507, 1329	Amber, J.....	286
Agrwal, V.P.....	508	Amer, M.I.M.....	909
Agullo, J.....	2611	Amiet, R.K.....	2271
Ahluwalia, D.S.....	162	Ammerman, W.B.....	2449
Ahmad, S.....	2350	Anand, G.V.....	2495
Ahmadi, A.R.....	1558	Anand, N.M.....	1201
Ahmadi, G.....	1766, 1890, 2233	Anand, S.C.....	150
Ahmadian, M.....	1680	Ananthakrishnan, S.....	1132
Ahola, R.....	218	Ananthanarayana, N.....	702, 2437
Ahuja, K.K.....	567, 568, 569, 570	Andersen, P.....	1422
Ahuja, S.....	501	Anderson, C.W.....	1038, 1440
Aimoto, T.....	446	Anderson, G.D.....	1089
Ajima, T.....	1954	Anderson, G.L.....	821
Akay, A.....	2348	Anderson, G.S.....	1791
		Anderson, I.....	1729
		Anderson, M.J.....	1075, 1077

Anderson, M.S..... 1266, 1417, 1683  
Ando, Tsuneyo..... 2014  
Andrew, E.A..... 2576  
Andrews, G.B..... 2432  
Andrews, J.R..... 1484  
Ang, A.H.-S..... 549, 960, 961  
Ansari, K.A..... 1575, 1578, 1931  
Anton, E..... 537  
Antony, G..... 1569  
Aoki, S..... 458  
Apostolescu, V.I..... 972  
Arakawa, T..... 145  
Araki, Y..... 95, 473, 536, 2089  
Aranha, J.A.P..... 2148  
Arbey, H..... 1612  
Arendts, J.G..... 2242, 2243  
Argyris, J..... 1098  
Ariaratnam, S.T..... 2238  
Arndt, R.E.A..... 1456  
Arnold, J.M..... 1661  
Arnold, L..... 2101  
Arnold, P..... 770  
Arnold, R.R..... 509  
Arnold, W..... 985  
Arpaci, A..... 2226  
Arros, J.K..... 853  
Artuso, J.W..... 2444  
Arya, A.S..... 1522  
Arzoumanidis, S.G..... 1175  
Asami, T..... 1653  
Asfar, K.R..... 1966  
Asfura, A..... 1794  
Ashraf Ali, M..... 1472  
Ashwill, T.D..... 1704  
Ashworth, D.A..... 1249  
Asnani, N.T..... 392, 1429  
Aspragathos, N..... 1749  
Assadi, M..... 829  
Astaneh-Asl, A..... 603  
Atadan, A.S..... 262  
Atallah, G.C..... 1347  
Atkin, R.J..... 436  
Attenborough, K..... 434, 442  
Aubert, A.C..... 1406  
Austin, E.M..... 1105  
Austin, M.A..... 842, 2110  
Au-Yang, M.K..... 990, 2010  
Avanessian, V..... 1441, 1896  
Avitabile, P..... 2300, 2565  
Avram, J..... 976  
Axelrad, V..... 178, 1454  
Ayabe, Takashi..... 1539  
Ayabe, T..... 366  
Azar, J.J..... 1173  
Azayem, K.M..... 2337  
Azizinamini, A..... 370

- B -

Babcock, C.D..... 1195

Baber, T.T..... 892, 1982  
Babott, F..... 2264  
Babu, C.R..... 2205  
Baca, T.J..... 1831  
Bachmann, H..... 1814  
Badawy, E.M..... 2378  
Badrakhan, F..... 692  
Baeder, J.D..... 1743  
Baetz, W..... 1736  
Baganoff, D..... 2259  
Bagley, R.L..... 471  
Bahar, L.Y..... 886  
Baharlou, B..... 1430  
Bai, Jing..... 870  
Baier, H..... 2167  
Baik, Joo Hyun..... 300  
Bailey, T..... 1040  
Bainum, P.M..... 1132, 1233  
Bai-ling, Zhou..... 1158  
Bajkowski, J..... 1467  
Baker, A..... 802  
Baker, M..... 2069  
Baker, W.E..... 1195  
Bakewell, H..... 872  
Balasubramaniam, R..... 2152  
Baldwin, G.R..... 246  
Baldwin, J.F..... 1127  
Balena, F.J..... 39  
Balendra, T..... 112, 617, 1183, 1524  
Balfour, J.A.D..... 2136  
Balmer, H.A..... 1908  
Balon, K..... 1816  
Bamberger, Y..... 14  
Banaszak, D.L..... 1338  
Banerjee, B..... 2000  
Banerjee, J.F..... 1264  
Banerjee, J.R..... 827, 1045  
Banerjee, P.K..... 1385, 2350  
Baniotopoulos, C.C..... 1577  
Banks, H.T..... 830  
Banon, H..... 29  
Banu, H..... 649  
Bapat, C.N..... 1478  
Barclay, D.W..... 145, 854  
Barietta, R..... 1238  
Barjau, A..... 2611  
Barker, J.C..... 2585  
Barksy, M..... 427  
Barlow, J..... 140  
Barmatz, M.B..... 2615  
Baron, J..... 1433  
Baroncelli, A..... 142  
Barrett, L.F..... 1937, 2371  
Barta, D.A..... 1075  
Barter, N.F..... 601  
Barthelet, B..... 987  
Barthell, J.F..... 2575  
Baruh, H..... 936  
Bar-shalom, Y..... 1732  
Bassani, R..... 142

Basu, P.....	1935	Berry, J.E.....	2336
Basu, T.K.....	703	Bert, C.W.....	1279, 1445
Bates, S.....	2272	Bertero, V.V.....	661
Bathe, K.J.....	134	Bertram, A.L.....	1440
Batis, J.H.....	1770	Bertrand, B.P.....	875
Batra, N.K.....	1142	Beskos, D.E.....	1763
Batterson, J.G.....	2407	Bessler, W.....	215
Bauer, H.F.....	800	Betteridge, D.....	223
Baumeister, K.J.....	1626, 2030	Bettles, R.W.....	1409
Bavendiek, R.....	749	Beucke, K.E.....	685
Baxter, B.J.....	1971	Bevan, B.G.....	601
Baxter, L.....	157	Beyer, T.B.....	999
Baxter, N.L.....	1129	Bezler, P.....	1294
Beards, C.F.....	897, 1403	Bhaskara, K.....	1285
Beattie, K.R.....	337	Bhaskara, K.V.....	2372
Bebermeier, J.....	1921	Bhat, R.B.....	369, 540, 846, 1940
Berchert, W.....	1469	.....	2121, 2373
Beck, C.J.....	686, 1012	Bhatia, K.G.....	43
Beck, J.L.....	285	Bhattacharya, A.P.....	2214
Becker, P.....	2106	Bhattacharya, M.C.....	2468
Behring, A.G.....	2208	Bhattacharya, R.C.....	83, 101
Beig, H.G.....	1806	Bhave, S.K.....	2290
Beiner, L.....	1984	Bi, Q.....	1124
Beissner, K.....	429	Bickford, W.B.....	539, 650, 1446
Belchamber, R.M.....	223	Biehn, K.....	1617
Belingardi, G.....	2481	Bielak, J.....	1114, 1557, 2060
Beliveau, J.-G.....	728, 2363, 2524	.....	2284, 2285
Bellman, R.....	1807	Bielawa, R.L.....	173
Bellvin, W.K.....	411, 1546	Bieniek, M.P.....	2175
Belytschko, T.....	637	Bigret, R.....	2374, 2608
Belytschko, T.B.....	1194	Bijlani, M.....	1283
Bendat, J.S.....	2401	Bilazarian, P.....	439
Bendixsen, O.O.....	1932, 2128	Bily, M.....	1854
Bendimerad, M.F.....	1387	Binder, M.C.....	2449
Benedetti, G.A.....	417	Bingham, B.L.....	2503
Benedettini, F.....	2454	Birdsall, T.G.....	160
Bengisu, M.T.....	2348	Birman, V.....	123, 825, 1587
Benham, R.A.....	327	Birnbaum, G.....	867
Bennett, J.G.....	1179, 1195, 2085	Bishop, D.E.....	572
Lennett, R.H.....	1348	Bishop, R.E.D.....	91, 2059
Bennett, R.M.....	791	Biswas, S.....	1496
Benson, D.J.....	988, 2038	Black, J.D.....	1033
Benson, M.W.....	1071	Blacker, T.D.....	1831
Bentley, D.E.....	1342, 2379	Blakney, D.F.....	570
Bentley, S.B.....	529	Bland, S.R.....	679
Bentsman, J.....	737, 1807	Blanding, J.M.....	1861
Benz, A.D.....	1705	Blech, J.J.....	1322
Bergman, L.A.....	65, 264, 890, 1312	Blessen., D.A.....	2224
.....	1416, 1425, 1468	Block, P.J.W.....	797
Bergman, L.A.....	890	Bloemhof, H.....	350, 1625
Berktay, H.O.....	628	Boarer, L.J.....	2083
Berman, A.....	575, 1357, 1503	Boden, H.....	1614
Berman, A.S.....	1365	Bodlund, K.....	954
Bernal, M.J.M.....	260	Boentgen, R.R.....	2208
Bernard, J.E.....	1695	Bofilios, D.A.....	2410, 2502
Bernard, P.....	1783	Bogy, D.B.....	2292, 2293
Bernasconi, O.....	1696	Bohlender, D.A.....	2264
Berner, D.E.....	561	Bohn, M.P.....	989
Bernhard, R.J.....	431, 2127, 2549	Boisson, C.....	1055, 2392
Bernitsas, M.M.....	30, 1540, 2151	Boisvert, J.E.....	467



Carr, I.....	1455	Chen, C.R.....	1564
Carr, W.E.....	993	Chen, D.....	99
Casadei, F.....	2614	Chen, Huai.....	2193
Caseiro, C.A.....	1395	Chen, H.Q.....	1717
Casey, N.F.....	1674	Chen, Jay-Chung.....	323
Cassenti, B.N.....	898, 2509	Chen, J.....	503
Castagna, J.....	2258	Chen, J.C.....	1008
Castelli, R.....	280	Chen, J.K.....	406, 422
Castner, W.L.....	232	Chen, J.-W.....	1645
Cathers, B.....	2272	Chen, Kecheng.....	2301
Cawley, P.....	1664	Chen, L.C.....	1238
Cazier, F.W.....	1726	Chen, Meng Luo.....	2338
Celep, Z.....	731, 1270	Chen, Ping.....	2512
Cempel, Cz.....	917	Chen, P.C.T.....	836
Cerv, J.....	3	Chen, Qinghua.....	1656
Cha, J.H.....	1292	Chen, R.T.N.....	38
Chadmail, J.F.....	756	Chen, Shao-ting.....	1654
Chakrabarti, A.....	773	Chen, Shoei-Sheng.....	644
Chakrabarti, S.K.....	562, 646	Chen, Su-huan.....	2302
Chalhoub, B.G.....	2184	Chen, S.S.....	52, 651, 856, 2245
Chambless, D.....	129	Chen, T.-Y.....	2556
Chamis, C.C.....	94	Chen, Wen-Hwa.....	510
Chan, A.H.C.....	1773	Chen, W. J.....	1867
Chan, K.S.....	80	Chen, W.-H.....	1328
Chan, R.K.....	2195	Chen, Yen-Sen.....	577
Chandra, B.....	1522	Chen, Y.Y.....	1124
Chandra, D.....	2569	Chen, Zhongyi.....	2518
Chandrasekaran, K.....	399	Cheng, A.H.-D.....	2144
Chandrasekharappa, G.....	2463	Cheng, Chii-Ming.....	291
Chang, C.H.....	608	Cheng, C.....	1684
Chang, I.C.....	2355	Cheng, C.A.....	1365
Chang, I.-J.....	1448, 2252, 2266	Cheng, F.Y.....	1889
Chang, Jin.....	2515, 2567	Cheng, Fiang-sheng.....	1602
Chang, K.T.....	1717	Cheng, Yaodong.....	2360
Chang, Liang-Wey.....	822	Cheng, Yu-ren.....	201
Chang, P.C.....	1177	Cheng, Y.W.....	203, 1116
Chang, Shyue-Bin.....	815	Chenoweth, J.M.....	2008, 2009
Chang, S.B.....	68	Cherfaoui, M.....	207
Chang, Tai-Ping.....	1380	Cherng, J.-S.....	1328
Chang, Y.M.....	557	Chester, C.V.....	184
Chang, Y.W.....	297	Cheu, T.C.....	2349
Chang-ying, Du.....	1191	Cheng, Y.K.....	141, 614, 615, 1773
Chao, A.W.....	24	Chi, Cheng-Ching.....	887
Chapman, D.A.....	1409	Chi, M.....	543
Chapman, D.M.F.....	1304	Chia, C.Y.....	848, 1056
Chapman, J.....	1957	Chia, Tien-Li.....	1504
Chapman, J.R.....	831	Chiba, M.....	1443
Charek, L.T.....	1026	Chijiwa, K.....	542
Chargin, M.....	509, 1356	Childs, D.W.....	85, 1754, 1961
Charlie, W.A.....	456	.....	2452, 2453
Charnley, T.....	649	Childs, M.E.....	660
Charron, F.....	2416	Chilson, G.F., Jr.....	2166
Chaskelis, H.H.....	1142	Chim, E.S.-M.....	697, 2064, 2291
Chattopadhyay, A.K.....	1941	Chino, Akira.....	1313
Chaturvedi, S.K.....	1110	Chiriacescu, S.T.....	1021
Chawla, A.....	2256, 2519	Chitu, D.....	981
Cheema, R.A.....	1554	Chiu, A.N.L.....	763
Chen, A.T.F.....	766	Cho, D.....	1238
Chen, Cheng-Hsing.....	551	Choi, DooWhan.....	33
Chen, C.....	745	Chona, R.....	271



Dakoulas, P.....	1534	Demirbilek, Z.....	147
Dakoulas, P.C.....	1391	Denham, R.N.....	1631
Dalamangas, A.....	630	Denisenko, N.....	452
Dalan, G.A.....	994	Denman, E.D.....	1394
Dallriva, F.D.....	2041	Denman, H.H.....	508
Dalton, E.C.....	1101	Deobald, L.R.....	1106, 2223
Danek, O.....	269, 1824	Der Hagopian, J.....	274
Daniel, I.M.....	1481	der Kiureghian, A.....	940
Daniel, J.....	1891	Derham, C.J.....	809
Daniel, J.I.....	2026	Dermitzakis, S.N.....	1460
Daniel, W.J.T.....	1799	DeRuntz, J.A.....	682
Daniels, E.F.....	999, 1215	Deruyttere, A.....	1117
Darbre, G.R.....	1532	Desai, C.S.....	1529
Dardano, R.....	2481	Desai, P.V.....	7019
Dardy, H.D.....	158, 1287	DeSanto, D.F.....	556
Darts, J.....	1226, 1227	Desaulnier, W.E., Jr.....	2449
Das, A.....	1005	Desrochers, A.A.....	1738
Das, B.....	2220	Desse, J.M.....	880
Dass, W.C.....	1899, 1900	DeVor, R.E.....	949
Dat, R.....	2411	deV Batchelor, B.....	1659
Date, C.G.....	1043	DeWilde, W.P.....	2464
Datta, B.N.....	2385	DeWinne, J.....	2584
Datta, S.K.....	1108, 1447	Dexter, R.J.....	1120
Daugherty, R.H.....	304	De-jun, Wan.....	1158
Dauphin-Tanguy, G.....	514	Dhar, B.....	174
Davani, D.....	2508	Dhar, D.....	2371
David, E.A.....	170	Dhoopar, B.L.....	824
David, J.W.....	272, 1862	Di Paola, M.....	1088
David, M.....	980	Di Sciuva, M.....	1990
Davidson, D.L.....	1120	Diarra, C.M.....	1132, 1233
Davie, N.T.....	495	Diaz-Jimenez, A.....	729
Davies, H.G.....	1466	Dideron, D.....	468
Davies, P.....	1663	Diebold, J.W.....	840, 1710
Davis, B.C.....	1462	Dietmann, H.....	474
Davis, L.C.....	157	Dietz, C.P.....	13
Davis, M.R.....	2262	Dill, J.F.....	2444
Davy, J.L.....	2316	DiMaggio, F.L.....	135, 1207
Day, A.H.....	2150	Dimarogonas, A.D.....	1749, 2186
Day, W.B.....	275	Dimas, D.J.....	2280
De, S.....	107	Ding, Kui-yuan.....	2370
de Azevedo, J.J.R.T.....	457	Ding, Shi.....	1177
de Billy, M.....	1759	Dion, J.L.....	2032
de Pater, A.D.....	813	Dirr, B.....	67
de Silva, C.W.....	721	Dirusso, E.....	1753
De Vis, D.....	2546	Ditlevsen, O.....	1766
De Winne, J.....	2592	Dmytrow, D.A.....	9
Deane, G.B.....	869	Dobbs, N.....	461
Dearth, D.R.....	714	Dobson, B.J.....	229, 2525
DebChaudhury, A.....	891	Doctor, S.R.....	780
DeBejar, L.A.....	1382	Doege, E.....	339
DeBondt, M.....	1117	Dogan, M.....	595
Decha-Umphai, K.....	127, 1046	Dohr, G.....	1352
Dede, M.....	461	Doi, Masahiro.....	1170, 1518, 1875
Deepak, D.....	2437	Dokanish, M.A.....	653
DeHoff, B.S.....	526	Domaszewski, M.....	388
DeJong, R.G.....	368	Dominguez, J.....	1714
Delage, P.....	707	Dominic, R.J.....	278, 314
Delgado-Saavedra, H.E.....	1482	Don, C.G.....	177
Delinic, K.....	2428	Done, G.T.S.....	743
Demetriu, S.....	971	Dong, S.B.....	1441, 1896

Dongping, L.....	1986	Eichenlaub, J.A.....	470
Donnelly, R.P., Jr.....	1915	Eidinger, J.M.....	803
Dooley, W.T.....	2478	Eischen, J.W.....	1662
Doorly, D.J.....	1244	Eisenberger, M.....	833
Dornfeld, D.A.....	253, 916	Ejezie, S.U.....	294
Dossing, O.....	2318, 2522	Ejiri, H.....	46
Dove, R.C.....	1179, 2085	Eken, F.....	2455
Dowell, E.H.....	610, 1054, 1559	Ekhelikar, R.K.....	1767
	1764, 2283, 2466	El Khatib, A.....	2170, 2314, 2435
Dowling, M.J.....	1186		2604
Downes, J.....	662	El Sayed, A.....	2604
Downs, B.....	1976	El Shahawi, M.....	1659
Doyle, G.R., Jr.....	1728	El Shahawi, M.A.-H.....	1265
Doyle, J.F.....	77, 1096	Elbestawi, M.A.....	2609
Dragos, L.....	794, 884	Elgamal, A.-W.M.....	774, 775, 984
Draisey, S.....	2363	Elia, A.....	785
Drake, M.L.....	314, 472, 684	Elishakoff, I.....	825, 1808
	1002, 1113	Ellen, C.H.....	866
Dressman, J.B.....	85	Eller, A.I.....	165, 166
Drew, M.....	695	Ellinas, C.P.....	563
Dreyer, W.....	2313	Ellingwood, B.....	755, 1378
Driels, M.R.....	183	Elliott, L.....	1698, 2185
Drumm, E.C.....	674, 1529	Elliott, S.J.....	662
Du, Qingxuan.....	485	Ellis, D.D.....	1304
Duan, Z.P.....	1662	Ellison, B.....	1633
Dubey, R.N.....	2184	Ellison, J.F.....	1231, 1726
Dubigeon, S.....	2117	Ellyin, F.....	1925
DuBois, T.....	756	Elmadany, M.M.....	2241
Dufour, R.....	274	Elmalah, E.....	2586, 2587, 2593
Duke, J.C., Jr.....	1777	Elmer, K.....	941
Dumanoglu, A.A.....	15	Elrod, D.....	2453
Dumelin, M.B.....	2594	Ely, R.A.....	997
Dumir, P.C.....	1066, 1182, 1281	Elzanowski, M.....	1464, 2037
	1603, 1604, 1776	El-Raheb, M.....	136, 137, 1286
	2215	El-Wardany, T.I.....	2535
Dunavant, D.A.....	1684	Eman, K.F.....	948
Dunwoody, W.E.....	1179	Embling, L.V.....	1252
Dupuis, C.....	144	Endebrock, E.G.....	1179
Dusseau, R.A.....	1884	Endo, Mitsuru.....	1871
Dwyer, R.F.....	37	Endo, M.....	2122, 2477
Dyer, R.....	1090	Engblom, J.J.....	632
Dykhuisen, R.C.....	986	Engel, Z.....	1872
Dyrbye, C.....	1887	Engelke, V.H.....	758
Dzhupanov, V.A.....	654	Engelstad, M.....	129
Dzielski, J.E.....	784	Engja, H.....	517
D'Spain, G.L.....	1790	Enke, N.F.....	208
		En-Sheng, Chen.....	1146
		Epstein, M.....	1464, 2037
		Erasmus, P.J.....	1622
		Ercoli, L.....	1052, 1427, 1433
			1995
Eakes, R.G.....	2171	Erhard, A.....	1817
Eastwood, P.G.....	241	Ericsson, L.E.....	1125
Ebeling, K.J.....	1305	Eriksson, L.J.....	2028
Ebert, K.....	1734	Ertas, A.....	310
Ebrahimi, N.D.....	2118	Ertepinar, A.....	1980
Eckblad, D.M.....	326	Ertugrul, M.G.....	161
Edberg, D.L.....	1919	Eshleman, R.L.....	1129, 1143
Edelstein, W.S.....	856, 2245	Esin, A.....	1118
Edwards, J.W.....	679	Eslambolchi, H.....	488
Edwards, P.R.....	1226, 1227		
Ehsani, M.R.....	1590, 1591		

- B -

Esparza, E.D..... 2040  
 Esposito, E..... 2250  
 Etison, I..... 1037, 1408, 1962  
 ..... 2451  
 Ettema, R..... 1723  
 Etter, C.L..... 340  
 Eugen, L..... 976  
 Evensen, H..... 2306  
 Everett, W.D..... 318  
 Eversman, W..... 574, 1463, 1784  
 ..... 2030  
 Everstine, G.C..... 1609  
 Evrensel, C.A..... 1319  
 Ewans, K.C..... 437  
 Ewing, R.D..... 287  
 Eydeland, A..... 266

- F -

Fabunmi, J.A..... 688, 2414  
 Faby, D.R..... 2605  
 Fafitis, A..... 455  
 Fahmy, M.N..... 718  
 Fahs, A.A..... 1493  
 Falk, S..... 90  
 Fallou, S.N.B..... 1202  
 Fan, Yong-Fa..... 777  
 Fancher, M.F..... 675  
 Fang, Dan Ping..... 2397  
 Fang, M.C..... 1212  
 Fang, Tong..... 1688  
 Fang, T..... 2304  
 Fanous, F..... 28  
 Farassat, F..... 1742  
 Farley, G.L..... 1053  
 Fathi, A.M..... 1263  
 Faulkner, M.G..... 2310  
 Favaloro, S.C..... 1344, 1835  
 Favour, J.D..... 1832  
 Feijoo, R.A..... 1067  
 Feit, D..... 110, 169  
 Felsen, L.B..... 111, 1661  
 Fenech, H..... 1596, 1769  
 Feng, N.S..... 2052  
 Feng, W.Q..... 499, 2303, 2307  
 Feng, Zhendong..... 2387  
 Fenves, G..... 295, 553, 982  
 ..... 983  
 Ferrari, G..... 280  
 Ferri, A.A..... 610, 1810  
 Ferro, G..... 788  
 Fiedler, K..... 1562  
 Fields, D..... 2257  
 Fields, J.M..... 333, 336  
 Figueroa, L..... 768  
 Filippi, P..... 259  
 Filippou, F.C..... 1580  
 Finch, R.D..... 1343  
 Fink, R.G..... 158, 1287  
 Firestein, G.J..... 565

Fischer, F.J..... 33  
 Fischer, U..... 2111  
 Fisher, J.W..... 1036  
 Fitzmorris, D.J..... 348  
 Fitzpatrick, J.A..... 415  
 Fitzpatrick, M..... 55  
 Flaherty, J.E..... 836  
 Flanigan, C.C..... 2313  
 Flashner, H..... 1822  
 Fleeter, S..... 1029, 2375  
 Fleischer, F..... 57  
 Fleischer, H..... 178, 1454  
 Fleischman, T.S..... 211  
 Fleming, D.P..... 1323, 1573, 2445  
 Foiles, W.C..... 2607  
 Fok, Ka-Lun..... 1389, 1718  
 Foley, M.J..... 2126  
 Foltz, J.V..... 1440  
 Fomo, K..... 2139  
 Fontana, R.R..... 360  
 Foote, K.G..... 168  
 Forouhar, F..... 1444  
 Forster, N.H..... 2444  
 Forys, A..... 2200  
 Fournay, W.L..... 271  
 Fox, C.H.J..... 95, 850  
 Fox, N..... 436  
 France, D..... 1366  
 France, D.M..... 986  
 Francois, E..... 1642  
 Franklin, D.E..... 2199  
 Frarey, J.L..... 2605  
 Fratello, D.J..... 173  
 Freed, A.D..... 208  
 Freedman, M.I..... 48  
 Freestone, J.W..... 239  
 Frehlich, R.G..... 261  
 Freund, L.B..... 2217  
 Friberg, P.O..... 828  
 Friedmann, P..... 1228  
 Friedrich, G..... 1402  
 Friesel, M.A..... 506  
 Fritzen, C.-P..... 1691  
 Frohrib, D.A..... 521  
 Froriep, R..... 2413  
 Fu, Chung C..... 1200  
 Fu, Hao-Jen..... 1370  
 Fuchs, H..... 1817  
 Fuh, J.S..... 1503  
 Fuhua, Ling..... 1648  
 Fujii, S..... 1560  
 Fujii, T..... 1568  
 Fujikawa, T..... 511, 2533  
 Fujimoto, Ichiro... 1246, 1247, 1248  
 Fujimoto, Toshiro..... 1516  
 Fujita, Katsuhisa..... 1781  
 Fujiwara, M..... 282  
 Fujiwara, T..... 243  
 Fukahori, M..... 1572  
 Fukano, T..... 2123



Goss, P.C. .... 2472  
 Gottlieb, H.P.W. .... 1424  
 Gould, P.L. .... 963, 1472  
 Goyal, S.K. .... 2290  
 Grace, N.F. .... 844  
 Gracewski, S.M. .... 717, 2292, 2295  
 Gradov, O.M. .... 1811  
 Graf, P.A. .... 314  
 Granberg, R.H. .... 1071  
 Granda, J.J. .... 528  
 Grandhi, R.V. .... 1689, 1848  
 Granett, D. .... 2615  
 Granneman, G. .... 2025  
 Grassie, S.L. .... 776  
 Green, I. .... 1037, 1408, 1962  
 ..... 2451  
 Green, P.L. .... 1013  
 Green, R.E., Jr. .... 234  
 Greenhalgh, R. .... 2020  
 Greenhill, L.M. .... 539  
 Greenwald, S.E. .... 145  
 Gregory, D.L. .... 1805, 2465, 2548  
 Greif, R. .... 2288  
 Greimann, L. .... 28  
 Greitzer, E.M. .... 1508  
 Gridley, D. .... 1786  
 Griefahn, B. .... 1920  
 Griffin, J.H. .... 1114, 1361, 1557  
 ..... 1929, 1935, 2060  
 ..... 2284, 2285  
 Griffin, M.J. .... 584  
 Griffin, O.M. .... 1262  
 Griffiths, P.J. .... 582  
 Grigoriu, M. .... 1722, 2039, 2095  
 Grindrod, K.J. .... 1249  
 Grinfogel, L. .... 1411  
 Grinnell, S.E. .... 1462  
 Grivas, D.A. .... 2105  
 Grochla, J. .... 2111  
 Grootenhuis, P. .... 1432  
 Groper, M. .... 78, 79  
 Gros, E. .... 1920  
 Grossi, R.O. .... 1052, 2473  
 Gruenberger, H.S. .... 2491  
 Gruhl, S. .... 1617  
 Grunseit, Z. .... 463  
 Gu, Jialiu. .... 1868  
 Gu, Song-Nian. .... 2550  
 Gu, Xue Min. .... 855  
 Gu, Yi. .... 2515, 2567  
 Guan, Bo Liang. .... 1258  
 Guan, Fei. .... 2512  
 Guang-fu, Wang. .... 1169  
 Gudmundson, P. .... 2563  
 Guedel, A. .... 668  
 Gueraud, R. .... 806  
 Guerra Rosa, L. .... 1115  
 Guha, S.K. .... 1942  
 Guicking, D. .... 1305  
 Guo, Xing-Huie. .... 2212

Guohao, Li. .... 1177  
 Gupta, A.D. .... 26  
 Gupta, A.K. .... 125, 1420, 1782  
 ..... 1903, 1970, 1974  
 ..... 2489  
 Gupta, B.K. .... 1396  
 Gupta, N.K. .... 373, 938, 1637  
 Gupta, P.C. .... 824  
 Gupta, P.K. .... 2444  
 Gupta, U.S. .... 1282, 1436  
 Gurgoze, M. .... 1041, 1977  
 Guruswamy, G.P. .... 795  
 Gutierrez, R.H. .... 397, 847, 1057  
 Guttalu, R.S. .... 930  
 Guyader, J.L. .... 1055, 2392  
 Guyomar, D. .... 1789  
 Gvildys, J. .... 297  
 Gyori, I. .... 2021  
 Gysin, H. .... 2554

- H -

Haas, E. .... 860  
 Habault, D. .... 258, 663  
 Habermeyer, J.A. .... 2173  
 Hac, A. .... 586, 2176  
 Hadaegh, Y. .... 740  
 Haddow, J.B. .... 2108  
 Hadjian, A.H. .... 804, 1633  
 Haftka, R.T. .... 228, 1031, 1689  
 ..... 1848  
 Hagedorn, P. .... 1994  
 Hagita, A. .... 1582  
 Hagiwara, N. .... 357, 1242  
 Hahn, E.J. .... 196, 693, 2052  
 Hahn, G.T. .... 902  
 Hai, Y. .... 106, 1203  
 Haines, D.W. .... 1133  
 Haisty, B.S. .... 237  
 Hajela, P. .... 2157  
 Hakala, M.K. .... 1208  
 Hale, A.L. .... 264  
 Hall, A. .... 53  
 Hall, J.F. .... 1186, 1715  
 Hall, M. .... 1788  
 Hall, R.L. .... 767  
 Hallauer, W.L., Jr. .... 228, 689, 2057  
 Halle, H. .... 2008, 2009, 2247  
 Halleux, J.P. .... 2614  
 Halliwell, D.G. .... 70  
 Halliwell, N.A. .... 241, 414, 2328  
 Hallquist, J.O. .... 988, 2038, 2112  
 ..... 2113  
 Halpern, M.R. .... 1892  
 Halvorsen, T. .... 147  
 Hamazaki, Y. .... 2533  
 Hamdan, S.M. .... 256  
 Hamdi, M.A. .... 2249  
 Hamed, M.A. .... 225  
 Hamelink, J. .... 78, 79

Hamilton, R.F.....	1750	Hawkins, G.F.....	233
Hamma, G.A.....	2591	Hawong, J.S.....	213
Hammond, J.K.....	296, 1537, 1663	Hayashi, K.....	1274, 1647
	1907, 2149, 2279	Hayden, R.E.....	1791
	2315	Hayes, C.D.....	2423
Hammond, T.A.....	578	Haynes, F.D.....	1904
Hamrock, B.J.....	1744	Hays, W.D., Jr.....	1909
Hamstad, M.A.....	1785	Hayward, J.....	64
Han, D.C.....	2132	Hayward, J.L.....	39
Han, Erh-Chung.....	2212	He, Chang-An.....	2550
Hanawa, T.....	50	Head, R.E.....	361
Hancock, R.N.....	493	Heap, N.W.....	434
Handleton, R.T.....	451	Hebbale, K.V.....	819
Handy, C.R.....	726, 727	Heckl, M.....	2016
Hannover, G.E.....	1921	Hedrick, J.K.....	784, 787, 1238
Hansen, H.S.....	2237	Hegr, J.....	2197
Hansen, J.S.....	254	Heidebrecht, A.C.....	23, 1197
Hansen, K.-H.....	2597	Heins, C.P.....	1177
Hanson, D.B.....	11	Heitkamper, W.....	1275
Hanson, R.D.....	603	Heitman, K.E.....	1541
HaQuang, N.....	864, 1471, 2353	Heitzig, J.H.....	1921
	2486	Helfrich, T.M.....	318
Hara, F.....	375	Hellman, R.P.....	581
Harajli, M.H.....	618	Helsel, R.....	2306
Haran, S.....	1343	Hemphill, R.R.....	340
Hardie, D.J.W.....	850	Hendricks, S.L.....	1512, 1866
Harding, R.....	1005	Heng, R.B.W.....	448
Hardy, C.....	2287, 2490	Henkel, F.-O.....	782
Hardy, S.J.....	89	Henricks, W.....	331
Harichandran, R.S.....	1635	Heppler, G.R.....	1439
Hariharan, S.I.....	2496	Herklotz, G.....	155, 665, 666
Harmanny, A.....	1310	Hernried, A.G.....	185, 2109
Harnchoowong, S.....	2450	Herrmann, G.....	1662
Haroun, M.A.....	852	Herron, D.L.....	286
Harris, R.E.....	653	Hersey, J.B.....	157
Harris, T.A.....	73	Herting, D.N.....	1330
Harrison, J.H.....	2400	Hess, R.W.....	317
Harrison, R.F.....	296, 1537, 1907	Hews-Taylor, K.J.....	2262
	2149	Heylen, W.....	2326
Hart, G.C.....	2425	Hibner, D.H.....	818
Hartt, W.H.....	1721	Hicks, J.....	2536
Harwood, N.....	270	Hidayetoglu, T.....	2348
Hasegawa, Eiji.....	1772	Hiei, Makoto.....	1511
Hasegawa, E.....	1989	Higashi, M.....	1506
Hasegawa, Mitsuhiro.....	1192, 1193	Hildebrandt, J.G.....	2018
Hasegawa, M.....	1713	Hill, D.E.....	1918
Hashimoto, Hiroyuki.....	1316, 1317	Hill, E.v.K.....	826
Hashimoto, H.....	1254, 1443	Hilmy, S.I.....	625
Haskell, R.....	2426	Hinchey, M.J.....	564
Haslim, L.A.....	2438	Hindson, W.S.....	38
Haslinger, K.H.....	1829	Hinga, S.....	1926
Hassiotis, S.....	2505	Hino, J.....	702
Hastrup, O.F.....	1852	Hintergraber, M.....	778
Hata, O.T.....	152	Hiramatsu, T.....	2044
Hatake, S.....	2072	Hirata, T.....	154
Hatamura, Y.....	542	Hireath, M.S.....	525
Hattori, K.....	1567	Hiramoto, D.....	210
Haug, E.J.....	2046, 2104, 2174	Hirose, S.....	245
	2356	Hisada, T.....	18
Hauser, J.A.....	602	Hisley, D.M.....	875





Ju, F.D.....	2606
Juan, Y.C.....	608
Juang, J.N.....	1418
Juckenack, D.....	2382
Judd, J.E.....	2537
Junger, M.C.....	438
Junkins, J.L.....	2571
Jun-Hua, Chen.....	1168

-K-

Kaas, P.....	859
Kaatzsch, U.....	1371
Kaba, S.A.....	424
Kabe, A.M.....	1156
Kainins, A.....	1319
Kaji, S.....	69
Kajita, T.....	1778
Kaladi, V.....	1072
Kalaroutis, A.....	2261
Kalmaz, E.E.....	2613
Kalra, S.P.....	986
Kamada, O.....	367, 2447
Kamegai, M.....	877
Kamga, T.....	2139
Kamil, H.....	757
Kamle, S.....	77, 1096
Kammer, D.C.....	2313
Kammer, N.....	1509
Kampfe, W.R.....	327
Kanai, Eriya.....	1313
Kanda, Hiroshi.....	2551
Kanda, H.....	2209, 2312
Kaneta, M.....	1572
Kang, B.S.J.....	213
Kania, N.....	1618
Kanik, U.....	835
Kapania, R.K.....	1438
Kapoor, S.G.....	949, 1876
Kar, R.C.....	1585
Karakostas, C.Z.....	1577
Karamchandani, A.....	2239
Karamcheti, K.....	2259
Kareem, A.....	753, 754
Kariotis, J.C.....	287
Karius, D.....	733
Karnopp, D.....	426
Karthaus, W.....	1310
Kashefi, I.....	1883
Kashimura, H.....	2484
Kathiresan, K.....	1121
Kato, D.J.....	2253
Kato, Masayoshi.....	1163
Kato, M.....	1864, 1885
Kato, Yoshio.....	1192, 1193
Katsura, S.....	642
Katyl, R.H.....	1821
Katz, E.....	2587
Katz, J.....	998
Kauffman, R.R.....	322

Kaufman, A.....	355
Kausel, E.....	1385
Kawagoe, H.....	657, 2017
Kawai, M.....	1647
Kawai, Tatsuo.....	1267
Kawase, H.....	1712
Kawaroe, Yoshihiko.....	1167
Kaza, K.R.V.....	12, 591, 1027
Kearley, V.C.....	1235
Keefe, R.T.....	329
Keer, L.M.....	386, 1897
Kehoe, M.W.....	1231, 1726
Keith, W.L.....	734
Kekridis, M.S.....	2151
Kekridis, N.S.....	1540
Kelkel, K.....	1994
Keller, A.C.....	2599
Keller, E.E.....	1917
Keller, J.B.....	1796
Keller, Y.....	1616
Kelley, H.L.....	361
Kelley, N.D.....	340
Kelly, J.M.....	587, 685, 803
	809, 1240, 2424
Kelly, T.E.....	2431
Keltie, R.F.....	1780
Keming, Sun.....	1902
Kennedy, D.....	827
Kennedy, J.B.....	844
Kennedy, J.M.....	1194
Kenner, V.H.....	1141
Kensinger, S.G.....	1705
Kerley, J.....	1009
Kern, D.....	332
Kern, W.....	716
Kerong, Li.....	1579
Kersey, A.D.....	219
Kerstens, J.G.M.....	1058
Kerwin, E.M.....	1111
Kesavan, S.K.....	1458
Keshavarzian, M.....	149
Keskinen, R.P.....	1073
Kessler, E.....	1597
Khan, F.....	160
Khan, N.U.....	1575, 1578
Khatri, K.N.....	1066, 1281, 1603
Khouri, B.R.....	522
Khulief, Y.A.....	1457, 1651, 2345
Khvingia, M.V.....	2045
Kibblewhite, A.C.....	437
Kiefer, J.E.....	263
Kiefling, L.....	1165
Kielb, R.E.....	403, 1600, 1840
	1929, 1930
Kienholz, D.A.....	1105
Kiger, S.A.....	459, 2041
Kikuchi, K.....	2
Kikuchi, T.....	46
Kikushima, Y.....	63, 588, 2433
	2434

Kikushima, Yoshihiro.....	1879	Kojima, H.....	532, 2115
Kim, Chul Jung.....	483	Kokarakis, J.E.....	30
Kim, C.....	1752	Kolitsch, H.J.....	475
Kim, C.H.....	1212	Koller, M.G.....	2002
Kim, H.W.....	2179	Kolsch, I.....	2167
Kim, KiBong D.....	2369	Kolsky, H.....	1271, 1640
Kim, K.B.....	1865	Kondou, Takahiro.....	1516
Kim, K.S.....	2204	Kondou, T.....	366, 2093
Kim, K.-S.....	1122	Kong, Fannien.....	1666
Kim, R.Y.....	217	Konishi, T.....	146
Kim, S.H.....	2234	Kopff, P.....	2543
Kim, S.S.....	2351, 2352	Korenev, B.G.....	1024
Kim, Y.D.....	534	Korpert, K.....	338
Kim, Y.-H.....	1576	Kosawada, T.....	372, 1289
Kimura, K.....	412	Koss, L.L.....	748
Kimura, M.....	2114	Kot, C.A.....	1196
Kimura, T.....	2092	Kotera, Tadashi.....	1269
Kirchman, E.J.....	2419	Kotera, T.....	192, 2044
Kiryu, K.....	1407	Kothari, L.S.....	2213
Kishi, T.....	657, 2017	Kounadis, A.....	2210
Kishima, A.....	922	Kounadis, A.N.....	1981
Kiso, M.....	1676	Koung, R.T.F.....	2530
Kitano, Y.....	371	Kouvaritakis, B.....	1846
Kitaoka, S.....	482	Kovacevic, M.....	2340
Kitis, L.....	1636	Koval, L.R.....	574
Kitsios, E.E.....	1094, 1095, 1610	Kowalczyk, W.....	748
Kiureghian, A.D.....	1794	Kramer, T.....	2558
Kjell, G.....	1793	Kramer, E.....	1126
Kjellberg, A.....	342	Krause, W.....	1051
Klahs, J.W.....	2289	Krause, W.....	155, 665, 666
Klamecki, B.E.....	883		978, 1051
Klauer, A.....	1486	Krauss, H.....	1543
Klein, L.S.....	877	Krauthammer, T.....	17
Klein, R.....	2408	Krawinkler, H.....	613
Klein, S.K.....	1816	Kreitlow, H.....	67
Kleine-Tebbe, A.....	908	Kriegsmann, G.A.....	162, 172
Kliman, V.....	2063	Kristensson, G.....	1435
Klit, P.....	2443	Kross, D.A.....	329
Kloster, K.....	2033	Krothapalli, A.....	2259
Kluesener, M.F.....	1112	Kruger, W.E.....	1051
Knapp, A.E.....	559	Kruger, W.-D.....	978
Knauf, W.....	352	Krupka, R.M.....	529
Knepper, R.A.....	2253	Kruppa, P.....	1523
Knight, N.F., Jr.....	710	Kruse, B.J.....	602
Ko, Ching Long.....	1016	Krutul, J.....	786
Ko, Wen-Jiunn.....	2406	Krutzik, N.J.....	756, 757, 758
Kobayashi, A.S.....	213, 900	Krutzik, N.J.....	770, 876
Kobayashi, H.....	814	Ku, C.H.....	2286, 2547
Kobayashi, K.....	1450	Kubo, S.....	2089
Kobayashi, Y.....	849, 2229, 2529	Kubomura, K.....	1144
Koch, R.A.....	440	Kubota, Y.....	2466
Kocur, J.A.....	1745	Kucuk, N.C.....	1938
Koga, T.....	1407	Kucukay, F.....	2187
Koh, Aik-Siong.....	552	Kujath, M.....	2342
Kohgo, O.....	375	Kulak, R.F.....	299
Kohler, H.....	598	Kulp, C.R., Jr.....	216
Kohler, W.E.....	2036	Kumagai, Y.....	532, 2017
Kohno, T.....	357	Kumar, A.S.....	2344
Koide, T.....	1256, 1257, 1568	Kumar, Ch..R.....	1182, 1776
Koizumi, T.....	1676	Kung, L.E.....	1026, 2180, 2181



Kuno, T.....	1582
Kunquan, Zhu.....	1159
Kuramitsu, M.....	931
Kurdila, A.J.....	1327
Kuribayashi, Yutaka.....	1547
Kurtz, R.J.....	505, 915
Kurtze, G.....	1297
Kurz, A.....	1908
Kurze, U.J.....	175, 1190
Kurzweil, L.G.....	894
Kusama, H.....	638
Kuttruff, H.....	179
Kvinge, T.....	2033
Kwan, K.H.....	104
Kwatny, H.G.....	886
Kyle-Little, J.....	53

- L -

La Fontaine, R.F.....	148, 664, 861
LaBouff, G.A.....	1251
Lackney, J.....	1681
LaFlamme, T.E.....	2449
LaFontaine, R.F.....	421
Lagnese, T.J.....	1035
LaGraff, J.E.....	1249
LaGreca, P.D.....	1109
Lai, D.C.....	1584
Lai, Hsin-Yi.....	2389
Lai, Shyh-Shiun.....	1390
Laithier, B.E.....	2479
Lal, R.....	1282, 1436
Lalanne, M.....	274
Lally, R.W.....	230, 2327
Lam, D.K.Y.....	398
Lambe, P.C.....	912
Lambert, R.G.....	2493
Lan, Nghiem-Phu.....	159, 164
Lan, Yuanhong.....	2189
Langan, J.R.....	1063
Lange, C.G.....	724, 725
Lange, Yu..V.....	1139
Langley, R.S.....	558, 2226
Lapierre, H.....	2416
LaSala, K.J.....	2172
Lashkari, B.....	2239
Lasota, H.....	435
Laspesa, F.S.....	330
Lau, S.L.....	614, 615
Lauffer, J.P.....	2124, 2228
Laura, P.A.....	2467
Laura, P.A.A.....	397, 847, 1052
.....	1057, 1427, 1433
.....	1498, 1552, 1595
.....	1598, 1858, 1995
.....	2459, 2467, 2469
.....	2473
Lavigne, P.....	2287
Lawrence, C.....	1930
Lawrence, F.V., Jr.....	81

Lawrence, M.W.....	163
Lawrence, S.J.....	2488
Lawton, B.....	248
Lawton, R.A.....	1484
Lax, R.....	2523
Leatherwood, J.D.....	798
Lebrun, M.....	418, 514
Lecce, L.....	2154
LeChatelier, C.....	2250
Lecointre, C.....	2267
Ledbetter, H.M.....	1108
Lee, B.H.K.....	188, 267
Lee, B.S.....	2150
Lee, B.T.....	1110
Lee, C.K.....	307
Lee, C.W.....	534, 1694
Lee, F.H.....	2331
Lee, G.F.....	1038
Lee, H.S.....	2132
Lee, Jang Moo.....	2384
Lee, J.C.....	386
Lee, J.H.....	174
Lee, J.M.....	2132, 2234
Lee, J.P.....	2499
Lee, Moon Hee.....	479
Lee, M.C.....	2615
Lee, Shaw-Cuang.....	881
Lee, S.H.....	1956
Lee, S.J.....	949, 1876
Lee, S.L.....	1524
Lee, S.M.....	181
Lee, S.W.....	49
Lee, S.Y.....	2132
Lee, U.....	687, 1100
Lee, You Yub.....	2281
Lee, Y.....	873
Lee, Y.A.....	331
Lees, A.W.....	383
Lefebvre, D.....	200
Lehmann, D.....	2590
Lehmann, G.....	744
Leimbach, K.R.....	758
Leipholz, H.H.E.....	2216
Leissa, A.W.....	403, 1049, 1600
.....	2232
Leister, P.....	782
Lekoudis, S.G.....	2251
LeMaster, R.L.....	253, 916
Lembregts, F.....	2312, 2517
.....	2546, 2551
Lemieux, P.....	728
Lemire, G.R.....	447
Leon, R.L.....	250
Leonard, F.....	2319, 2321
Leonard, J.W.....	522, 1720, 1757
Lepicovsky, J.....	569
Lepik, U.....	376
Lepore, F.P.....	27, 2383
Lepschy, A.....	927
Leroy, Y.....	200

Maddocks, J.H.....	1964	Massoud, M.....	2524
Madigosky, W.....	1128	Massouros, G.....	2186
Maekawa, I.....	481	Mastata, V.I.....	979
Maekawa, Z.....	433	Mastorakos, J.....	1069
Mahan, J.R.....	40, 1544	Masuda, T.....	1567
Mahin, S.A.....	236, 712, 764	Masuko, Masami.....	1170, 1518, 1875
	1859, 2110	Masumoto, Hiroki.....	1188, 1189
Maine, R.E.....	524	Maszynska, A.....	1342
Maison, B.F.....	546	Mathews, T.....	2264
Majewski, T.....	1950	Matkowsky, B.J.....	680
Majima, O.....	1274	Matscholl, P.....	1817
Major, C.S.....	1104	Matsuda, Satoshi.....	1267
Majumdar, B.C.....	1941	Matsuhisa, H.....	747
Makovicka, D.....	970	Matsui, Y.....	1765
Malahy, R.C.....	1392	Matsuiishi, M.....	1723
Malcolm, G.N.....	792	Matsumoto, H.....	1639, 2004
Malik, M.....	1947	Matsumoto, S.....	1407
Malik, S.N.....	2023	Matsunaga, T.....	282
Mallik, A.K.....	1421	Matsushita, Mikio.....	1772
Malthan, J.A.....	152	Matsuuchi, Kazuo.....	1267
Malvern, L.E.....	122	Matteucci, M.....	452
Mammola, C.G.....	102	Matysiak, S.J.....	2066
Manderscheid, J.M.....	355	Matzen, V.C.....	255
Mann, J.Y.....	796, 1221	May, R.A.....	2082
Mannion, L.F.....	1048	Mayes, M.J.....	1787
Manolis, G.D.....	1239, 1377	Mayes, R.L.....	1340, 2430
Manos, G.C.....	139	Mayes, W.H.....	1215
Mansour, A.E.....	788	Maymon, G.....	190
Manu, C.....	1682	Maynard, J.D.....	873
Mar, J.W.....	1099	Mayne, R.W.....	2254, 2255
Maragakis, E.A.....	2141	Mazziotti, P.J.....	4
March, J.K.....	362	Mazzoni, A.....	2158
March, P.A.....	2240	McCammon, D.F.....	430
March-Leuba, J.....	779, 2145, 2146	McConnell, K.G.....	100, 198, 199
Margolis, D.L.....	516, 1070	McConnell, K.G.....	1812
Marin, P.....	976	McCormick, M.A.....	1911
Mark, W.D.....	597	McCoy, D.E.....	2159
Marks, C.H.....	99	McCroskey, W.J.....	1743
Markus, S.....	382, 2003	McCullough, M.K.....	2104, 2174
Marlow, I.....	1928	McDevitt, J.B.....	678
Martineau, Gh.....	967	McFadden, P.D.....	244, 600, 1138
Marshall, A.....	2485		1494, 1953
Marsteller, J.W.....	795	McGrath, M.T.....	56
Martens, M.J.M.....	443	McGuckin, W.J.....	252
Martin, H.R.....	2338, 2343	McHugh, J.D.....	943
Martin, J.B.....	105, 1638	McKay, J.T.....	1698, 2185
Martin, M.R.....	502	McKenna, H.E.....	340
Martin, V.....	2483	McKenna, J.....	1268
Martinez, D.R.....	486, 1828, 2228	McKillip, R.M., Jr.....	363
Martinovic, Z.N.....	228	McKinnon, R.A.....	2578
Marukawa, T.....	1254	McLean, L.J.....	196
Marulo, F.....	2154	McVay, M.....	769
Maskey, B.....	393	Mead, D.J.....	382, 1419, 1991
Maslov, L.J.....	1811	Mechel, F.P.....	2260
Maslowstet, A.....	786	Meckl, P.H.....	681
Mason, P.J.....	1946	Mediratta, S.R.....	202
Masopurt, R.....	980	Medury, Y.....	1393
Masri, S.F.....	152, 937	Medwin, H.....	1790
Massey, I.C.....	1703	Meeks, C.R.....	74, 75
Massmann, H.....	2192	Meerkov, S.M.....	1807

Mehl, J.B.....	156	Miura, H.....	1356
Mehta, N.P.....	231, 1396, 1939	Miura, R.M.....	724, 725
Mei, Chuh.....	1415, 1771	Mixson, J.S.....	1541
Mei, C.....	127, 1046	Miyachi, T.....	1934
Mei, C.C.....	1202	Miyachika, K.....	1256, 1257, 1568
Meier, G.E.A.....	1613	Miyagawa, Hiroomi.....	1324
Meijer, J.J.....	1731	Miyao, K.....	481
Meijer, S.....	2412	Miyashita, Y.....	372
Meirovitch, L.....	691, 936, 1004	Miyazaki, M.....	2526
Melcher, K.J.....	945	Miyazaki, N.....	2012, 2013
Mellor, M.....	2504	Miyazono, S.....	2012
Mendes Maia, N.M.....	2362	Mizuno, M.....	1256
Menglin, Lou.....	1902	Mizuno, Eiji.....	1050
Menq, Chia-Hsiang.....	1245	Mizuno, K.....	1621
Menq, C.-H.....	1557, 2060, 2284	Mizuno, M.....	1582, 1864
	2285	Mizusawa, T.....	1778, 2222
Mercer, C.D.....	105	Moe, G.....	2237
Merkle, D.H.....	1899, 1900	Moehle, J.P.....	840, 1379, 1710
Merritt, P.H.....	518	Moes, H.....	72, 1250
Merritt, R.G.....	2583, 2589	Mohammadi, J.....	288, 460, 1308
Mertens, M.....	2354	Mohrle, W.....	1817
Merz, K.L.....	2426	Mohsiul, A.....	1870
Metwalli, S.M.....	2175	Moitinho de Almeid, J.P.B.....	623
Metwally, H.M.....	2378	Molent, L.....	1729
Meyer, P.....	1252	Molnar, A.J.....	750
Meyer, R.A.....	233	Molnar, J.....	2382
Meyers, G.E.....	1309	Molusis, J.A.....	1732
Miao, G.P.....	25	Monaco, R.....	879
Michaels, J.E.....	1672	Monk, P.....	1303, 2031
Michalopoulos, A.P.....	806	Montalvao e Silva, J.M.....	2362
Michalopoulos, D.....	1749	Montgomery, R.C.....	1003, 1326
Michaltsos, G.....	2210	Moodie, T.B.....	145, 854
Michon, J.C.....	2117	Mook, D.T.....	864, 1471, 2353
Mickens, R.E.....	2100		2486
Mikasinovic, M.....	419	Mookerjee, P.....	1732
Miksad, R.W.....	33	Moore, F.K.....	1508
Miles, J.W.....	138, 645	Moore, G.B.....	187
Miles, R.N.....	1000, 1655	Moore, T.....	2388
Millarke, P.R.....	2427	Moore, T.N.....	1369
Miller, A.K.....	1828	Morcl, J.....	2169
Miller, D.F.....	51	Morishita, E.....	1701, 1702
Miller, D.S.....	44	Morissette, J.C.....	2032
Miller, G.F.....	1213	Morita, Nobuyoshi.....	1258
Miller, J.D.....	671	Morris, P.J.....	180, 571
Miller, R.H.....	359	Morton, D.W.....	2541
Miller, R.K.....	404, 720	Moser, M.....	2016
Miller, V.R.....	313, 1002	Moses, F.....	544
Millot, P.....	2392	Mosquera, J.M.....	1271, 1640
Mimovich, M.....	2606	Mostaghel, N.....	2109
Minca, I.....	965, 969	Mote, C.D., Jr.....	88, 596, 2440
Mines, R.A.W.....	498		2610
Min-hua, Zheng.....	1302	Mottershear, J.E.....	2282
Mioduchowski, A.....	533, 2310	Mottier, F.M.....	2078
Mirza, S.....	1283	Mouth, T.A.....	2536
Mischke, J.....	782	Mountain, R.D.....	867
Misra, M.S.....	1109	Mourelatos, Z.P.....	1400
Mitchell, L.D.....	605, 905, 1862	Mourjopoulos, J.....	669
Mitchell, P.J.....	722	Mouroutsos, S.G.....	523
Mitchell-Dignan, M.....	2280	Mu, Ting-rong.....	132
Mitropolsky, Yu..A.....	923	Muckenthaler, T.V.....	325

Mueller, K.....	1297
Mukherjee, A.....	515, 928, 1501
.....	2219
Mukherjee, K.....	646
Mukhopadhyay, M.....	2219
Muki, R.....	1441, 1896
Mulcahy, T.M.....	2247
Muller, G.....	860
Muller, R.....	816
Muramoto, Y.....	1442
Murata, M.....	482
Murin, J.....	1959
Murkami, Yasunori.....	1157
Murphy, C.E.....	255
Murphy, M.W.....	2199
Murri, W.J.....	1123
Murty, A.S.R.....	2385
Murty, A.V. Krishna.....	612
Muscolino, G.....	1088
Musson, B.G.....	2534
Muszynska, A.....	895, 2379
Muthuswamy, V.P.....	838
Muthuveerappan, G.....	402
Muto, T.....	1293
Myllyla, R.A.....	218

- N -

Naaman, A.E.....	618
Nadolski, W.....	533
Nagabhushan, B.L.....	1230
Nagabhushana, G.R.....	604
Nagai, K.....	2471
Nagai, T.....	768
Nagamatsu, A.....	1692, 2074
Nagamatsu, H.T.....	1090
Nagaraja, K.S.....	43
Nagata, H.....	1647
Nagaya, K.....	106, 380, 532
.....	1052, 1052, 1276
.....	2177, 2471
Nagy, P.B.....	1787
Nair, R.S.....	1983
Naitoh, M.....	1641
Nakagiri, S.....	18
Nakahira, N.....	126
Nakai, E.....	50
Nakai, Mikio.....	1300
Nakai, M.....	371
Nakai, S.....	1712, 1713
Nakamichi, J.....	46
Nakamoto, R.T.....	763
Nakamura, A.....	2474
Nakamura, K.....	445
Nakamura, T.....	759, 1701, 1702
Nakamura, Y.....	282
Nakao, T.....	2114
Nakasako, N.....	445
Nakata, Y.....	2177
Nakayama, I.....	2474

Nakazumi, A.....	950
Nakra, B.C.....	392
Nalini, V.N.....	773
Namachchivaya, N.S.....	2238
Namba, M.....	1450
Nandlall, D.....	1466
Napadensky, H.....	1206
Napadensky, H.S.....	460, 1308
Narayanan, V.....	2391
Narita, Y.....	113, 1060, 1064
.....	2473
Naruoka, M.....	126
Naruse, J.....	154
Narvaez, G.....	1119
Nasser, A.....	2170, 2314, 2435
Nastasa, G.....	1025
Nataraj, C.....	1863
Nath, Y.....	851, 1065
Natke, H.G.....	933, 941, 1023
.....	1490, 2305, 2358
Natsuaki, Y.....	126
Nava, L.C.....	1427
Navidi, P.K.....	2293
Nayak, A.P.....	2057
Nayfeh, A.H.....	1147, 1346, 1966
.....	2275
Nedwell, J.....	2034
Neishlos, H.....	450
Nelson, C.C.....	84, 2453
Nelson, C.E.....	2452
Nelson, H.D.....	539, 1863, 1867
Neriya, S.V.....	369
Neto, E.L.....	1999
Neuss, C.F.....	546
Neuwerth, G.....	816
Newman, D.L.....	145
Newman, J.S.....	337
Newnham, J.....	1957
Nezu, K.....	1639
Ng, D.S.....	2067
Ng, K.O.....	74
Ng, S.S.F.....	398, 2220
Nicholas, J.C.....	1937, 2371
Nicholls, C.....	2091
Nicholson, J.W.....	1312, 1416
.....	1425, 1468
Nicks, C.....	2452, 2453
Nicolas, J.....	447
Niedbal, N.....	1830, 2160
Nieh, C.D.....	2246
Nigm, M.M.....	390
Nikolaidis, E.....	1363
Nilakantan, G.R.....	942
Nilsson, N.A.....	7, 10
Nishida, M.....	2484
Nishida, Shin-ichi.....	1188, 1189
Nishimoto, T.S.....	1006
Nishiwaki, H.....	1560
Nisitani, Hironobu.....	1324
Nissim, E.....	1031

Nitescu, G.....	277
Nixon, D.....	1798
Njock Libii, J.....	2458
No, M.....	787
Noel-Leroux, J.-P.....	806
Nogami, T.....	19, 21, 1044
Noguchi, T.....	45, 1374
Nolte, K.G.....	193
Nonami, K.....	1506, 2445
Noori, M.N.....	892
Nordmann, R.....	2192, 2244
Norman, T.....	358
Norris, A.N.....	93, 172
Norris, M.A.....	1004
Norton, M.P.....	2020
Noutry, J.....	2490
Novak, S.....	261
Nowinski, J.L.....	1606
Nozawa, N.....	2461
Nurhadi, I.....	1401
Nyman, W.E.....	544

- O -

Ochoa, O.O.....	632
Oda, S.....	1256, 1256, 1257
	1568
Officer, C.B.....	157
Ogawa, K.....	2092
Oh, B.H.....	1658
Oh, Jae Eung.....	1517, 2281, 2460
Oh, K.P.....	71
Ohanchi, D.C.....	605
Ohayon, R.....	2022
Ohkami, Y.....	50
Ohkawara, K.....	532
Ohlrich, M.....	2274
Ohlsson, S.....	583, 2137
Ohmata, K.....	2058
Ohno, K.....	2462
Ohta, H.....	154
Ohta, M.....	445, 1628
Ojalvo, I.U.....	2324
Okada, I.....	1589
Okada, Y.....	346, 466
Okamura, Haruo.....	1758
Okigami, T.....	2500
Okrouhlik, M.....	2198
Okubo, N.....	2526
Okumura, K.....	922
Okuno, A.F.....	678
Olausson, H.L.....	2125
Oldfield, M.L.G.....	1244
Oliver, D.E.....	2521
Olsen, J.J.....	531
Olsen, N.L.....	2520
Olsson, M.....	2457
Olsson, P.....	1301
Om, D.....	660
On, F.J.....	2419

Ono, K.....	500
Ookuma, M.....	1692, 2074
Oonishi, Masataka.....	1507
Opschoor, G.....	1310
Orthwein, W.C.....	1746
Ortiz, K.....	698
Ory, H.....	2415
Osaki, S.....	433
Osorio R., J.A.....	729
Ostachowicz, W.....	1762
Ostendarp, H.....	6
Ostrovski, G.....	2593
Oswald, B.....	1358
Ota, Hiroshi.....	1163, 1864
Ottens, H.H.....	1914
Ousset, Y.....	1792
Out, J.M.M.....	1036
Overvik, T.....	2237
Ovunc, B.A.....	560, 1278
Owen, D.R.J.....	1594
Oyadiji, S.O.....	1078, 1079
Ozawa, K.....	126
Ozguven, H.N.....	2256, 2436, 2456
O'Callahan, J.C.....	2300, 2530, 2565
O'Connell, M.....	332
O'Connell, M.R.....	321
O'Donoghue, P.E.....	2418
O'Hara, G.J.....	1465
O'Leary, P.M.....	1447
O'Neill, M.W.....	1044
O'Regan, S.D.....	902

- P -

Pacejka, H.B.....	284, 301
Padovan, J.....	924, 1081
Paez, T.L.....	1805, 2051, 2600
Page, D.B.....	1337, 2577
Paidoussis, M.P.....	143, 2011, 2479
Paipetis, S.A.....	347, 2055
Pak, Chan-Gi.....	2384
Pak, R.Y.S.....	1384
Pal, T.....	1825
Palamas, J.....	14
Paliwal, D.N.....	1605
Palluzzi, V.H.....	1598
Palmatier, G.E.....	1342
Palylyk, R.A.....	2199
Pan, H.H.....	2302
Panagiotopoulos, P.D.....	1577
Panayotounakos, D.E.....	607
Pandit, M.....	1486
Pandit, S.M.....	231, 2306
Panesar, A.....	1288
Panossian, H.V.....	2162
Pao, Y.-H.....	1672
Papa, L.....	2475
Papadopoulos, D.P.....	2027
Papadrakakis, M.....	622
Papanicolaou, G.....	444, 2101

Papastavridis, J.G.....	1470	Pfeiffer, F.....	2187
Papoulias, F.A.....	1540	Phan, N.D.....	114
Pappalardo, M.....	452	Piaggio, R.....	2158
Pardoen, G.C.....	2224, 2280, 2425	Pickering, C.J.D.....	2328
Pardue, E.F.....	2341	Pielorz, A.....	533
Pariseanu, G.....	837	Pierre, C.....	1054
Park, Jun Chul.....	2460	Piersol, A.G.....	2401
Park, T.W.....	2356	Piety, K.R.....	2341
Park, Young-Ji.....	547, 960, 961	Pih, H.....	1124
Park, Y.P.....	88	Pike, J.....	599
Parker, R.....	8, 1488	Pilkey, W.D.....	303, 466, 1636
Parnes, R.....	925		2094
Parrott, T.L.....	1786	Pillot, C.....	468
Parthasarathy, G.....	636, 1996	Pinkus, O.....	1565
Pastor, M.....	964, 1184	Pinnington, R.J.....	2225
Patamapongs, N.....	256	Pinsky, M.A.....	2102
Patel, M.H.....	743, 2400	Piombo, B.....	2481
Patil, S.P.....	555	Piotrowski, J.....	1364
Patrick, G.B.....	2320	Pires, J.....	1719
Patrikalakis, N.M.....	97, 1588	Pisarenko, G.S.....	1927
Patt, J.....	210	Pistek, V.....	1551
Patz, G.....	1311	Pister, K.S.....	842, 2110
Paul, D.B.....	1771	Pitimashvili, I.A.....	2045
Paul, H.S.....	194	Pitman, K.E.....	260
Paule, D.W.....	2555	Piziali, R.L.....	2204
Paulson, S.K.....	21	Pizzamiglio, M.....	2158
Paunescu, M.....	973	Planat, M.....	1642
Pavese, M.....	2481	Planchard, J.....	652, 781
Pavic, G.....	704, 705	Plante, R.L.....	58
Pavlin, V.....	503	Plaut, R.H.....	626, 864, 1592
Payne, R.C.....	1213		2353, 2486
Pazargadi, S.....	2235	Plesha, M.E.....	1686
Pazsit, I.....	918	Plint, A.G.....	1092
Pearson, D.....	1556, 1739	Plint, M.A.....	1092
Pearson, L.H.....	1341	Plunkett, R.....	86, 1412
Pech, W.....	1667	Poinsot, T.....	2250
Pecknold, D.A.....	1528	Poland, J.B.....	2327
Pedersen, P.....	1978	Polidor, B.....	1103
Pedersen, P. Ternd.....	789	Polizzotto, C.....	1660
Pedersen, P.C.....	870	Poltorak, K.....	1276, 1426
Peek, R.....	1080	Pombo, J.L.....	1552
Peeken, H.....	1569	Pook, L.P.....	701
Pekau, O.A.....	16, 958	Poole, L.A.....	423
Peleg, K.....	1926	Pope, L.D.....	999
Pell, R.A.....	1221	Popinceanu, N.G.....	899
Pellegrino, E.....	2402	Popov, E.P.....	764
Peng, Zemin.....	2298	Popplewell, N.....	2256, 2519
Penland, C.....	868	Popson, M.J.....	13
Perez, R.B.....	2145, 2146	Porat, I.....	944
Perkins, J.....	2332	Porter, M.B.....	176
Perkins, N.C.....	2610	Poterasu, V.F.....	805
Perrin, R.....	649	Potesil, A.....	1795
Perry, B.....	42	Pototzky, A.S.....	1727
Perry, B., III.....	1727	Powell, C.A.....	336, 999, 2035
Perz, P.....	1483	Powell, C.D.....	13
Pesce, C.P.....	2148	Power, J.....	640, 641, 643
Petrick, L.J.....	1705	Powers, E.J.....	33
Petrovich, A.....	215, 1545	Powers, J.....	1789
Pettigrew, M.J.....	1069	Prabhu, B.S.....	1943, 1944
Pezeshki, C.....	1764	Prabhu, M.S.S.....	328

Prakash, B.G.....	328
Pramono, E.....	957
Prasad, M.G.....	432
Prashad, H.....	1496
Prater, G., Jr.....	1475
Prathap, G.....	2205
Prats, D.J.....	1737
Preumont, A.....	462
Prevost, J.H.....	775, 984
Price, S.J.....	2011
Price, S.M.....	2127, 2549
Price, W.G.....	91, 2059
Prikyrl, K.....	214
Pritz, T.....	2168
Privitzer, E.....	343
Prosser, W.H.....	234
Providakis, C.P.....	1763
Provo Kluit, J.C.....	206
Prucz, J.....	820
Prucz, J.C.....	1404
Prucz, Z.....	62
Prydz, R.A.....	39
Pumplin, J.....	226
Purasinghe, R.....	741
Pust, L.....	1849
Putcha, N.S.....	1428

- Q -

Qamaruddin, M.....	1522
Qian, Z.W.....	1452
Qiou, Yang.....	2211
Qiu, Xiangjun.....	2183
Qu, J.....	2202
Quan-Sheng, Xie.....	1209
Quek, S.T.....	1524
Quinn, R.D.....	1004
Qun-Chao, Zhu.....	1209

- R -

Radcliffe, C.J.....	489
Rades, M.....	711, 2075
Radon, J.C.....	1115
Radziminski, J.B.....	370
Ragab, A.....	1200
Raghavan, T.....	838
Rahman, M.....	751, 2134, 2391
Rahman, Z.....	2099
Rahnejat, H.....	594
Rainer, J.H.....	2079
Raisinghani, S.C.....	2153
Rajalingham, C.....	1943, 1944
Rajamani, A.....	2207
Rajan, M.....	1867
Rakheja, S.....	683, 732, 2405
Rama Rao, P.....	202
Ramachandran, J.....	1285
Ramaiyan, G.....	399
Ramakrishna, D.S.....	2152

Ramaswamy, V.....	202
Ramulu, M.....	900
Rand, O.....	374, 1740
Rand, R.H.....	734
Randolph, M.F.....	20, 1901
Rao, B.M.....	393
Rao, B.V.A.....	448
Rao, D.K.....	476, 2559
Rao, J.S.....	1160, 2372
Rao, K.V.....	1627
Rao, S. Nagaraja.....	633
Rao, S.N.....	1775
Rao, S.S.....	579, 1857
Rapacki, G.R.....	1102
Raptis, A.C.....	1291
Rashed, A.A.....	771
Rashidi, M.....	593
Rasmussen, E.A.....	993
Rasmussen, G.....	2540
Raspet, R.....	1623
Rastogi, P.K.....	1497
Rathe, E.J.....	171
Rausche, F.....	903
Rautenberg, M.....	1509
Ravindra, M.K.....	29
Razzaq, Z.....	1767
Reason, J.....	504
Rebello, C.J.....	1777
Rechard, R.P.....	1340
Reddy, A.....	820
Reddy, A.S.S.R.....	1132
Reddy, C.V.R.....	636, 1996
Reddy, E.S.....	650, 1421, 1446
Reddy, J.N.....	114, 1428
Reddy, V.R.....	2130, 2390
Reed, A.T.....	1913
Rees, I.G.....	177
Reese, R.T.....	2082
Rega, G.....	2454
Regan, R.....	598
Rehak, M.L.....	1207
Rehfield, L.....	820
Rehfield, L.W.....	190
Reibold, R.....	428, 2538
Reich, M.....	1719, 2398
Reid, R.E.....	1495
Reif, Z.....	2388
Reinberg, E.....	47
Reinhall, P.G.....	1655
Reinhorn, A.....	62
Reinhorn, A.M.....	1239
Reinig, K.D.....	1738
Reiss, E.L.....	162, 172, 176
	513, 1843
Reiss, R.....	2346
Remillard, R.L.....	919
Remington, P.J.....	1204
Remmerswaal, J.A.M.....	284
Remseth, S.....	1906
Ren, L.X.....	621

Renganathan, K.....	194
Renkey, E.J.....	1075
Rentz, R.R.....	117
Rentz, T.R.....	401
Revell, J.D.....	39
Reyer, K.....	716
Reznicek, M.E.....	238
Rhode, D.L.....	1754
Riaz, B.....	1459
Ribner, H.S.....	1082
Rice, E.J.....	1299
Rice, J.M.....	520
Rice, R.B.....	1102
Rich, R.B.....	1101
Richards, E.J.....	541, 1174, 1354 1455, 1474, 2263 2510
Richards, T.L.....	434
Richardson, M.H.....	2308
Ricketts, R.H.....	317
Riddell, R.A.....	556
Rieger, N.F.....	351, 1030, 1670 2090
Riggs, H.R.....	765
Rihal, S.S.....	2025
Ringermacher, H.I.....	720
Risitano, A.....	606
Rivin, E.I.....	862, 1553, 1571
Roach, D.P.....	2598
Roberson, R.E.....	1145
Roberts, J.B.....	34, 35, 1946 2050
Roberts, J.W.....	1414
Robertson, D.K.....	1761
Robinson, R.R.....	288, 1206
Roblee, J.W.....	1397
Roblyer, S.P.....	920
Rocha, S.M.....	1343
Rocklin, G.T.....	2317
Rockwood, W.B.....	368
Rodeman, R.....	2325
Rodriguez, O.....	880
Roeder, C.W.....	829
Roesems, D.....	1543
Roessett, J.M.....	939
Roger, M.....	1612
Rogers, J.C.....	181
Rogers, J.D.....	198, 199
Rogers, L.....	1148, 1149
Rogers, L.C.....	470
Rogers, R.J.....	1351
Roget, J.....	207
Rohlf, D.....	576
Rollwage, M.....	1305
Rorres, C.....	870
Rosati, V.I.....	220
Rosch, D.....	2086
Rosen, A.....	374, 592, 1740
Rosen, I.G.....	384
Rosenberg, R.....	929

Rosenberg, R.M.....	887
Rosenhouse, G.....	1083, 1616, 1992
Rosenkilde, C.E.....	877
Ross, C.A.....	122
Ross, T.J.....	613
Rossi, G.A.....	1988
Rossi, S.M.....	2574, 2575
Rossing, T.....	649
Rost, R.W.....	2076
Rotert, D.....	933
Roure, A.....	1081
Rousselet, J.....	144
Rousselot, J.L.....	1601
Roy, A.K.....	86, 1412
Roy, F.....	703
Roy, R.H.....	1229
Roy, R.P.....	986
Rubin, C.A.....	902
Rubin, M.B.....	1650
Rubin, S.....	1675
Rubio, P.....	1350
Rudd, J.L.....	1121
Rudd, M.J.....	1819
Rudder, F.F.....	425
Ruhlin, C.L.....	43
Ruiz, C.....	498
Russell, D.L.....	739
Russell, L.T.....	1084
Russell, S.S.....	235
Rutenberg, A.....	23
Ryan, J.E.....	2172
Ryan, R.J.....	1542
Ryland, G.....	691

- S -

Saberi, H.A.....	1229
Sabol, T.A.....	1375
Sabuncu, M.....	1032
Sackman, J.L.....	185
Sadek, E.A.....	103, 1272
Sadek, M.M.....	390, 1706
Sadler, G.G.....	945
Sahinkaya, M.N.....	1, 1938
Sahli, A.H.....	545
Saigal, S.....	133, 2179, 2476
Saiidi, M.....	2141
Saito, S.....	538
Saito, Takashi.....	1871
Saito, T.....	2122, 2477
Sakata, M.....	412
Sakawa, Y.....	950
Salikuddin, M.....	2248
Salman, F.K.....	2378
Samaha, M.....	1538
Samali, B.....	761, 956, 1865
Samanta, B.....	515, 928, 1501
Sambasiva Rao, M.....	328
Samejima, Makoto.....	1166
Samoilenko, A.M.....	923

Sampson, R.C.....	249	Schmidtberg, R.....	1825
Samp-Staniskawska, E. M.....	388	Schmitt, J.....	484
Samra, B.S.....	1211	Schneider, D.....	31
San Andres, L.....	2053	Schneider, M.E.....	1105
Sanchez Sarmiento, G.....	1433, 1595	Schnobrich, W.C.....	149
Sandberg, L.B.....	901	Schober, K.....	716
Sandford, M.C.....	317	Schollhorn, H.-D.....	863
Sandhu, R.S.....	525	Schomer, P.....	305
Sandi, H.....	975	Schoof, C.C.....	673
Sandler, I.S.....	1207	Schramm, E.J.....	252
Sandman, B.E.....	467	Schroeder, E.A.....	2047
Sandor, G.N.....	1259	Schroeder, R.A.....	530
Sankar, B.V.....	182, 683, 732	Schultz, D.L.....	1249
.....	1413, 1478, 2405	Schulz, R.....	1402
Sankar, T.S.....	369, 540, 1538	Schuss, Z.....	680
.....	1940, 2344, 2373	Schwartz, C.W.....	271
Sankaranarayanan, N.....	399	Schwartz, H.W.....	1909
Santos, A.P.....	1967	Schwarz, J.....	1618
Santos, R.D.....	2469	Schweikhard, W.G.....	1834
Santu, I.A.I.....	979	Schwer, M.....	1652
Sarig, Y.....	410	Schwirian, R.E.....	556
Sarigul (Aydin), A. S.....	1583	Scibbe, H.W.....	2446
Sas, P.....	2311, 2566	Sclavounos, P.D.....	36
Sasaki, M.....	381, 1280	Scruby, C.B.....	246
Sathyamoorthy, M.....	619, 634, 1735	Seaman, L.....	1123
Sato, H.....	1968	Seaman, R.L.....	1750
Sato, K.....	367, 2447	Seering, W.P.....	681
Sato, O.....	1255	Segal, D.J.....	56
Sato, S.....	747	Segerlind, J.J.....	410
Sato, T.....	1566, 2448	Sehmi, N.S.....	624
Sato, Y.....	843	Seiler, F.....	1802
Sattar, M.A.....	2056	Seireg, A.....	658
Sattary-Javid, V.....	1972	Sekiguchi, H.....	1621, 1653
Sattleger, J.....	1352	Sekiguchi, Masatoshi.....	1772
Savage, M.....	1033	Selerowicz, W.C.....	1613
Savci, M.....	2226	Sellers, C.D.....	2147
Sawada, Tatsuo.....	1313, 2014	Sen, P.K.....	2569
Sawan, J.....	609	Sen, R.....	1385
Sawyer, J.W.....	1034	Send, W.....	364
Sayhi, N.....	1792	Senda, T.....	245
Sazawal, V.K.....	2023	Serag, S.....	2170, 2435
Scanlan, R.H.....	951, 952	Sergeev, V.I.....	1958
Scarano, G.....	452	Sethna, P.R.....	855
Schanzer, G.....	793	Seto, K.....	344, 345
Scharrer, J.....	2452	Settgast, W.....	1736
Scharrer, J.K.....	1961	Severn, R.T.....	15
Schein, D.B.....	1786	Severud, L.K.....	1077
Schenke, N.....	1014	Severyn, T.P.....	313
Schewe, G.....	387	Shabana, A.....	690
Schick, D.....	155, 665, 666	Shabana, A.A.....	742, 1329, 1457
Schiefferly, C.....	1928	.....	1651, 2345
Schiess, J.R.....	1644	Shah, A.H.....	1447
Schiff, A.J.....	893	Shahrivar, F.....	2335
Schiff, L.B.....	790, 792, 998	Shaked, M.....	2593
Schijve, J.....	206	Shangchow, C.....	2469
Schirmer, P.J.....	326	Shankaran, R.....	409
Schlagheck, J.G.....	2492	Shanmugam, N.E.....	112, 617
Schmidt, A.A.....	329	Shao-ping, S.....	2142
Schmidt, H.....	1150, 1151, 1152	Sharan, A.M.....	501, 1160, 2130
.....	1153, 1154, 1155	.....	2390

Sharan, S.K.....	772, 1349, 2054	Singh, R.....	1475
Sharma, A.M.....	865, 1298	Singleton, N.R.....	556
Shaw, L.M.....	1563	Singnoi, W.N.....	1834
Shaw, S.W.....	87	Sinha, A.....	1361, 1929
Sheen, R.L.....	1010	Sinha, G.L.....	2385
Shen, C.N.....	874, 1499	Sinha, S.N.....	1605
Shen, F.....	469	Sinharay, G.C.....	2000
Shen, Y.....	1993	Sipcic, S.....	48
Shen, Zong Han.....	629	Sivakumaran, K.S.....	1056
Shepard, G.D.....	2417, 2565, 2570	Skidmore, G.R.....	689, 1477
Shepherd, I.C.....	148, 421, 664	Skreiner, K.M.....	2399
	861	Skrikerud, P.E.....	1814
Shepherd, K.P.....	2035	Sladek, J.....	2098
Sherf, Z.....	2408, 2587, 2593	Sladek, V.....	2098
Sherrick, C.E.....	54	Slater, J.E.....	394
Shestopal, V.O.....	2472	Slawson, T.R.....	459, 2041
Shiau, Ting-Nung B.....	365	Slope, R.M., Jr.....	2421
Shibahara, M.....	1765	Smallwood, D.O.....	2465, 2548, 2601
Shibusawa, Shigehiko.....	1845	Smigielski, P.....	1325
Shick, D.V.....	487	Smiley, R.G.....	2320
Shiga, M.....	353	Smith, B.S.....	1708
Shije, S.....	2142	Smith, B.V.....	161
Shilin, Chen.....	1159	Smith, C.E.....	66
Shilkrut, D.....	463	Smith, C.S.....	1615
Shimada, S.....	1885	Smith, D.A.....	2422
Shimoda, H.....	2058	Smith, E.L.....	1491
Shimajima, H.....	1255	Smith, H.W.....	216
Shin, C.S.....	204	Smith, I.....	1235
Shin, Y.S.....	401	Smith, J.D.....	244, 600, 1494
Shing, Pui-Shum B.....	236, 712	Smith, K.S.....	1087
Shinkle, G.A.....	911	Smith, L.C.....	1076
Shiozawa, K.....	481	Smith, P.W.....	1111
Shiu, K.N.....	2026	Smith, P.W., Jr.....	1630
Shizawa, Kazuyuki.....	2014	Smith, R.A.....	82, 204
Shockey, D.A.....	700	Smith, R.L.....	2605
Shoenberger, R.W.....	1015	Smith, S.....	2573
Shoji, F.F.....	926	Smythe, R.C.....	1285
Shteyngart, S.....	1294	Snoeys, R.....	2311, 2354, 2566
Shulemovich, A.....	1611	Snyder, V.W.....	197, 906
Shye, K.Y.....	2399	So, H.....	1564
Siddharthan, R.....	293	Soares, F.R.....	1359, 2120
Sierakowski, R.L.....	672	Soares, W.A.....	298
Silas, G.....	2073	Soares-Filho, W.....	1629
Silas, G.H.....	1243	Soebagio.....	2381
Sill, R.D.....	708	Soedel, W.....	174, 1026, 1410
Simek, J.....	1948		2179, 2180, 2181
Simkova, O.....	2003	Sofue, Y.....	1934
Simmonds, J.G.....	1068	Sohaney, R.C.....	2320
Simonen, F.A.....	780	Sohn, J.L.....	465
Simonian, S.S.....	1104	Sol, H.....	2464
Simons, H.A.....	20, 1901	Solecki, R.....	1444
Simpkins, P.G.....	1268	Sone, A.....	2006
Simulescu, I.....	1502	Song, Jianwei.....	2298
Singer, J.....	825, 1607	Song, J.....	93
Singh, A.....	1396, 1939	Song, T.-X.....	2201, 2303
Singh, B.....	396	Soni, S.R.....	217
Singh, B.P.....	413, 824	Soom, A.....	1645, 2539
Singh, K.....	413	Soong, T.T.....	62
Singh, M.P.....	865, 1298, 1520	Soovere, J.....	1002, 1985
	1533	Sophianopoulos, D.....	1981

Sorge, F.....	1755	Stoneman, S.A.T.....	8, 1488
Sorocky, S.J.....	2416	Storti, D.W.....	1649
Soucy, Y.....	728, 1826, 2363	Stout, R.B.....	1089
Souflis, C.....	2105	Strahle, W.C.....	2251
Soule, S.....	2161	Straub, F.K.....	361
Soundararajan, A.....	735	Stromsta, R.....	2257
Spanos, P.D.....	1804, 2050	Stroud, R.C.....	2163, 2591
Sparis, P.D.....	523	Sturm, A.....	242, 2086
Spencer, B.F.....	2096	St. Balan, F.....	967
Spencer, B.F., Jr.....	65, 890	St. Doltsinis, J.....	1908
Spencer, D.B.....	254	St. John, C.M.....	1185
Sperle, J.O.....	205	Su, Qing-Za.....	777
Spiekermann, C.E.....	489	Suarez, S.A.....	1106
Spieldener, J.P.....	207	Subbiah, R.....	540, 1940, 2373
Spigler, R.....	1345	Subrahmanyam, K.B.....	12, 591, 1027
Spivack, M.....	2513	Subudhi, M.....	1294, 2398
Springer, W.T.....	237, 238	Sudo, Seiichi.....	1316, 1317
Srinivasan, A.V.....	898, 1930, 2509	Sudo, S.....	1443
Srinivasan, G.R.....	1743	Sudou, K.....	2482
Srinivasan, M.G.....	1196	Suemasu, H.....	2064, 2291
Srinivasan, R.S.....	405, 639	Sueoka, Atsuo.....	1166, 1516, 1539
Srirangarajan, H.R.....	2463	Sueoka, A.....	512, 2093
Stachowiak, G.W.....	2368	Sues, R.H.....	29, 549
Stadelbauer, D.G.....	1679	Sugeng, F.....	1562
Stahl, B.....	559	Sugg, F.E.....	232
Stahle, C.V.....	324, 1011	Sugihara, M.....	1701, 1702
Staley, J.A.....	324, 1011	Sugino, Kazuo.....	1188, 1189
Stalnaker, D.O.....	211	Sugita, Hiroshi.....	1163
Stancu, M.....	1022	Sugiura, Kunitomo.....	1050
Stanway, R.....	2282	Sugiyama, Y.....	657, 2017
Stanworth, C.G.....	584	Sullivan, P.A.....	564
Starkey, J.M.....	1695	Sumida, M.....	2482
Starrh, L.I.....	1462	Summa, J.M.....	1224
Stastny, M.....	1028	Sumner, J.B.....	1916
Stathopoulos, T.....	955	Sun, C.T.....	182, 406, 1110 ..... 1413, 1418, 2511
Statnikov, I.N.....	1958	Sun, Fangning.....	2387
Staudacher, K.....	810	Sun, H.B.....	1474, 2510
Stavrindis, C.....	2164	Sun, J.C.....	1354, 1474, 2263 ..... 2510
Steck, J.E.....	1784	Sun, Qinghong.....	2133
Steele, J.M.....	913, 2441	Sun, Wei-Joe.....	454
Steffen, V.....	27	Sun, Yan-jun.....	201
Steffen, V., Jr.....	2383	Sun, Yueming.....	2360
Stehle, C.D.....	1550	Sundarajan, N.....	1003, 1326
Steinwender, F.....	2244	Sundin, K.G.....	706
Stephen, N.G.....	378	Sung, C.K.....	1751
Stephens, J.E.....	1383	Surace, G.....	1434
Stevens, D.S.....	2077, 2329	Sutantra, I.N.....	302
Stevens, J.R.....	2534	Suzuki, K.....	372, 458, 1289 ..... 2006, 2232
Stevens, K.....	1277	Suzuki, S.....	1979
Stevens, K.K.....	131, 1505	Suzuki, S.-I.....	2221
Stewart, R.M.....	251	Suzuki, T.....	2448
Stiefel, W.....	78, 79	Suzuyama, T.....	357
Stillman, D.W.....	988	Svoboda, R.....	1838
Stimpfling, A.....	1325	Swaddiwudhipong, S.....	1524
Stimpson, G.J.....	1174, 2263	Swalley, J.C.....	1699
Stirnemann, A.....	171	Swansson, N.S.....	1344
Stoessel, J.C.....	2426	Swinson, W.....	129
Stokes, A.N.....	1451		
Stone, B.J.....	2277		
Stone, V.M.....	2582		

Swinstra, S..... 1748  
 Syamal, P.K..... 16, 958  
 Symonds, P.S..... 1047, 1271, 1640  
 Syvertsen, K..... 1906  
 Szafir, D.R..... 818  
 Szemplinska-Stupnicka, W..... 1467  
 Szeri, A.Z..... 1949  
 Szrom, D.B..... 1678  
 Szumowski, A.P..... 1613  
 Szwedowicz, D..... 1762  
 Szymkowiak, E.A..... 2491, 2588

- T -

Ta, K.D..... 1351  
 Tadakawa, T..... 50  
 Tadjbakhsh, I.G..... 807, 823, 1018  
 Taesiri, Y..... 769  
 Tait, H.J..... 2609  
 Tait, R.J..... 2108  
 Takada, H..... 2462  
 Takagami, T..... 1923  
 Takahagi, Toshio..... 1300  
 Takahashi, D..... 871, 1894, 1895  
 Takahashi, K..... 1293  
 Takahashi, M..... 635  
 Takahashi, S..... 372, 1289  
 Takamatsu, Y..... 2123  
 Takase, F..... 931  
 Takatsu, N..... 367, 2447  
 Takatsubo, J..... 2029  
 Takeda, H..... 926  
 Takeda, K..... 1560  
 Takeda, S..... 2177  
 Takewaki, I..... 759  
 Takita, Y..... 344  
 Tallin, A..... 755, 1378  
 Tallin, A.G..... 290  
 Talmadge, R.D..... 1338  
 Tam, C.K.W..... 571  
 Tamura, Akiyoshi..... 1507  
 Tamura, A..... 76, 1809  
 Tamura, Hideyuki... 1166, 1516, 1539  
 Tamura, H..... 366, 512, 2093  
 Tamura, T..... 1713  
 Tan, Ming-yi..... 2562  
 Tan, S.A..... 1386  
 Tanahashi, Takahiko..... 1313, 2014  
 Tanaka, Hideo..... 1246, 1247, 1248  
 Tanaka, Nobuo..... 1879  
 Tanaka, N..... 63, 282, 588  
 ..... 2433, 2434  
 Tanaka, Y..... 657  
 Tang, D.M..... 1559  
 Tang, D.T..... 1135  
 Tang, Renzhong..... 2360  
 Tang, Xiujin..... 1171, 2309  
 Tang, Y..... 2005  
 Tani, J..... 1443  
 Taniguchi, R..... 1676

Taniguchi, S..... 1653  
 Tanna, H.K..... 180, 567  
 Tappert, F..... 159, 164  
 Tarter, J.H..... 1909  
 Tassoulas, J.L..... 1531  
 Tatomir, S..... 981  
 Tauriainen, D.G..... 60  
 Tayel, M.A..... 852  
 Taylor, D.L..... 1706, 1945  
 Taylor, H.M., Jr..... 2041  
 Taylor, J.L..... 1674  
 Taylor, R.L..... 1898  
 Taylor, T.T..... 780  
 Tee, L.B..... 253, 916  
 Teixeira de Freitas, J.A..... 623  
 Tellbuscher, E..... 1873  
 Teodoro, E.B..... 2383  
 Tesar, A..... 647, 2227  
 Tezuka, Atsushi..... 1518  
 Thaller, R.E..... 2420  
 Tham, L.G..... 1773  
 Thambiratnam, D.P.. 1183, 1965, 2194  
 Theissen, J..... 6  
 Thiede, R..... 941, 1023  
 Thinner, G.L..... 2242, 2478  
 Thiruvengadam, V..... 153  
 Thiruvengkatachari, V..... 405, 639  
 Thoma, J.U..... 2365  
 Thomas, A.G..... 809  
 Thomas, D.L..... 383  
 Thomas, H.-M..... 1140  
 Thomas, M..... 2524  
 Thomas, P..... 2169  
 Thomas, R.S.D..... 116  
 Thompson, A.R..... 1791  
 Thompson, B.S..... 1751  
 Thompson, D.O..... 1339  
 Thompson, R.A..... 1877, 1878  
 Thompson, R.B..... 1339  
 Thornhill, L..... 2019  
 Thrane, H.W..... 723  
 Thuestad, T..... 1906  
 Thummler, J..... 155, 665, 666  
 Tichy, J..... 423  
 Tichy, J.A..... 1398  
 Tier, C..... 680  
 Tiernego, M.J.L..... 519, 932  
 Tiersten, H.F..... 1285, 2077, 2329  
 Tilly, G.P..... 212  
 Tindle, C.T..... 869  
 Tischler, V.A..... 1091  
 Tjong, Jimi Sauw-Yoeng..... 2388  
 Tlusty, J..... 1874  
 To, C.W.S..... 1072, 2357  
 Tobak, M..... 316  
 Tobler, R.L..... 1116  
 Tobler, W.E..... 283  
 Todo, I..... 1290  
 Toffer, H..... 920  
 Tohyama, M..... 2498

Tokuhashi, H.....	1809
Toledo, E.M.....	1067
Tomar, J.S.....	125
Tominaga, T.....	2557
Tomita, K.....	521
Tomita, Y.....	1979
Tomlinson, G.R.....	1078, 1079, 2331
Tondl, A.....	896, 1697
Tong, Zhongfang.....	2360
Tongue, B.H.....	1225
Torby, B.J.....	2125
Torii, T.....	1574, 1963
Torkamani, M.A.M.....	957, 1521
Torngren, L.....	1912
Toro, G.R.....	1847
Torvik, P.J.....	471
Toshimitsu, K.....	18
Totani, T.....	1506
Touratier, M.....	2190
Townley, G.E.....	2289
Townsend, D.P.....	2446
Tozzi, J.T.....	1608
Trachsler, T.....	2539
Trethewey, M.W.....	2323
Tretiak, O.J.....	870
Triantafyllidis, T.....	1893
Triantafyllou, M.S.....	1261, 1411
Trochides, A.....	391, 444, 1273
	2261
Troeder, C.....	1569
Trogdon, S.A.....	115
Tromp, J.H.....	1069
Trossbach, R.....	1638
Trubert, M.....	323
Trudell, R.W.....	820
Trum, A.....	1201
Truman, K.Z.....	1373, 1889
Trummer, D.....	2506
Trundle, C.C.....	2166
Tsai, Pwu.....	510
Tsai, T.....	503
Tsakonas, S.....	422
Tsang, S.H.L.....	1071
Tsangaris, S.....	857
Tseng, K.....	48
Tseng, W.S.....	804
Tso, W.K.....	1197, 1634, 1888
Tsuda, Yoshihiro.....	1166
Tsuda, Y.....	512
Tsui, Y.T.....	2278
Tsujiuchi, N.....	2116
Tsukahara, Y.....	2477
Tsuto, T.....	1725
Tsutsumi, Masaomi.....	1157, 1172
Tu, C.V.....	866
Tu, Son.....	1843
Tuah, H.....	1757
Tucker, M.D.....	2228
Tucker, R.....	632
Tung, C.C.....	1314

Tunna, J.M.....	699
Turczyn, M.T.....	1724
Turek, F.....	1838
Turner, J.....	129
Turnock, D.L.....	527
Tustin, W.....	715, 910, 1818
Tyagi, D.K.....	396
Tzavelis, C.A.....	389
Tzou, H.S.....	893

- U -

Uddin, W.....	554
Udwadia, F.E.....	550
Ueda, Shuzo.....	858
Ueda, S.....	2013
Uhl, T.....	1856
Uhlemann, S.....	242, 2086
Ujishashi, S.....	2004
Ukrainetz, P.R.....	2195
Ulbrich, H.....	537
Ulm, S.C.....	2560
Ulriksson, B.....	1485
Ulsoy, A.G.....	1881
Umaretiya, J.R.....	1431
Umezawa, K.....	1566, 1954, 2448
Ungar, E.E.....	894
Unlusoy, Y.S.....	2178
Urashima, Chikayuki.....	1188, 1189
Uscinski, B.J.....	2513
Utjes, J.C.....	1595, 1598
Utsumi, M.....	412
Uzuner, B.....	1118

- V -

Vaicaitis, R.....	109, 573, 1214
Vaicaitis, R.....	2156, 2165, 2410
Vaidya, P.G.....	659
Vail, J.A.....	1816
Vakakis, A.F.....	347, 1237, 2055
Valdya, N.R.....	2429
Valero, N.A.....	1932
Valsgard, S.....	563
Van Campen, D.H.....	1021
Van de Ponsele, P.....	2566
Van der Auweraer, H.....	2311, 2354
	2517, 2546
van der Heijden, L.A.M.....	443
van der Linden, H.H.....	1955
van der Merwe, G.J.J.....	1622
van der Tempel, L.....	72, 1250
Van Karsen, C.....	227
Van Khang, Nguyen..	738
Van Overmeire, M.....	2464
van Rens, W.J.J.M.....	443
van Vliet, M.....	732
van Zyl, B.G.....	1622
Vanbeest, J.....	2268
Vance, J.M.....	2053

Vanderplaats, G.N. .... 1356  
 Vanderploeg, M.J. .... 2351, 2352  
 Vandiver, J.K. .... 1576  
 Vanek, R. .... 338  
 Vanherck, P. .... 2311, 2354  
 Vanmarcke, E.H. .... 1635  
 Varadan, V.K. .... 2514  
 Varadan, V.V. .... 2514  
 Vasilakis, J.D. .... 836  
 Vasile, I. .... 966  
 Vaswani, J. .... 392  
 Veletsos, A.S. .... 907, 2005  
 Veluswami, M.A. .... 402  
 Venkatesh, V.C. .... 2134, 2391  
 Venkatraman, V. .... 2254, 2255  
 Venkayya, V.B. .... 1091  
 Ventura, C.E. .... 907  
 Ventura Z., C.E. .... 1480  
 Verma, A.N. .... 2213  
 Verma, C.P. .... 1282, 1436  
 Verpoest, I. .... 1117  
 Vestroni, F. .... 889, 2454  
 Vianna, M.L. .... 1629  
 Viaro, U. .... 927  
 Vigneron, F.R. .... 1671, 1826, 2068  
 ..... 2363  
 Vijayakumar, P.S. .... 2152  
 Villaverde, R. .... 1527, 2140  
 Ville, J.M. .... 2249  
 Vincent, R. .... 2169  
 Virgin, L.N. .... 189  
 Virtuoso, F.B.E. .... 623  
 Vlad, I. .... 971  
 Vlutters, A.M. .... 206  
 Vogt, E. .... 67  
 Vokurka, K. .... 2501  
 Vold, H. .... 2070, 2544  
 Volker, E. .... 2343  
 von Flotow, A.H. .... 2487  
 von Kerczek, C.H. .... 1608  
 Von Winkle, W.A. .... 872  
 Vossoughi, J. .... 543  
 Vu, B.Q. .... 119  
 Vullo, V. .... 102, 2402  
 Vuong, I. .... 2169

- W -

Waas, G. .... 765  
 Wacker, K. .... 656  
 Wada, B.K. .... 1008  
 Wada, H. .... 96, 1581  
 Wada, S. .... 1254  
 Wagner, P. .... 136, 137, 1286  
 Walker, R.A. .... 1229  
 Walker, W.J. .... 686, 1012  
 Walkington, N.J. .... 1463  
 Wallace, C.E. .... 108  
 Wallace, P. .... 1957  
 Waller, H. .... 2106

Walley, R.A. .... 1987  
 Walls, F.L. .... 1820  
 Walthaus, H.H.J. .... 443  
 Walz, J.E. .... 1266  
 Wambsganss, M.W. .... 651, 1292, 2008  
 ..... 2009, 2247  
 Wang, B.P. .... 466, 2094, 2556  
 ..... 2568  
 Wang, B.-J. .... 2539  
 Wang, C.Y. .... 655, 1295, 2236  
 Wang, D. .... 1399  
 Wang, I.C. .... 2218  
 Wang, Jin-Wen. .... 777  
 Wang, L.R. .... 2015, 2142  
 Wang, Pei-Chung. .... 480  
 Wang, Pin. .... 2366  
 Wang, Qizheng. .... 1181  
 Wang, Shen. .... 1910  
 Wang, S.S. .... 2064, 2291  
 Wang, T.L. .... 1176, 1707  
 Wang, Weiji. .... 2297  
 Wang, Xintian. .... 1593  
 Wang, Y.K. .... 1294  
 Wang, Y.L. .... 1205  
 Wang, Y.Z. .... 1555  
 Wang, Zhen-ni. .... 1688, 2304  
 Wang, Zhifan. .... 2516  
 Wang, Zhijun. .... 2386  
 Wang, Z. .... 1869  
 Warburton, G.B. .... 96  
 Ward, C. .... 31  
 Ware, A.G. .... 1074, 2242, 2243  
 Warnaka, G.E. .... 423  
 Warner, P.C. .... 368  
 Warren, G.E. .... 247  
 Washburn, K.B. .... 1514  
 Washio, S. .... 146  
 Wasserman, J.F. .... 2423  
 Watanabe, K. .... 1657  
 Watanabe, T. .... 69  
 Waterhouse, R.V. .... 169  
 Waters, J.P. .... 2078  
 Watkinson, P.S. .... 2265  
 Watson, A.P. .... 434  
 Watsor, L.T. .... 1689, 1848  
 Wattar, F. .... 545  
 Watts, G.R. .... 335  
 Wawa, J.C. .... 135  
 Weaver, D.S. .... 653, 2480  
 Weaver, H.J. .... 2506  
 Weaver, W., Jr. .... 841  
 Webber, W.R.S. .... 2521  
 Webster, J.J. .... 89  
 Wechsler, M.B. .... 616  
 Weck, M. .... 863  
 Weese, W. .... 2111  
 Wei, J.-C. .... 2218  
 Wei, M.L. .... 2209, 2218  
 Weiger, G. .... 716  
 Weihua, Tai. .... 1579





# SUBJECT INDEX

- A -

- Absorbers (equipment)  
1554, 1555,
- Absorbers (materials)  
707
- Acceleration measurement  
229, 903, 1820
- Accelerometers  
708, 2327, 2537, 2540, 2596
- Acoustic absorption  
324, 391, 395, 580, 585, 627 664, 707, 1081, 1297, 1299,  
1450, 1617, 2018, 2260, 2261
- Acoustic emission  
207, 223, 232, 233, 242, 243, 246, 253, 427, 483, 505, 506,  
720, 915, 916, 1341, 1498, 1785, 1811, 1821, 2497
- Acoustic excitation  
108, 136, 137, 465, 1296, 1771, 2029
- Acoustic fatigue  
314, 997, 2534
- Acoustic holography  
158, 873
- Acoustic imaging  
1911
- Acoustic impedance  
395, 442, 443, 2262
- Acoustic insulation  
954, 1523, 1628, 1886, 2138, 2168
- Acoustic intensity method  
171, 489, 670, 994, 1086, 1287, 1620, 1622, 1625, 1631,  
1668, 2071, 2256, 2265, 2460
- Acoustic linings  
69, 421, 659, 1273, 1297, 1617
- Acoustic measurement  
707
- Acoustic properties  
181, 431, 663, 1614, 1624
- Acoustic resonances  
1291
- Acoustic resonators  
156
- Acoustic response  
669, 1780, 1786, 1985, 2166
- Acoustic scattering  
167, 168
- Acoustic signatures  
1343
- Acoustic tests  
686, 1139, 1626, 2419, 2420, 2421, 2422, 2499, 2573, 2574
- Acoustic waves  
2483
- Active attenuation  
664, 2028
- Active control  
62, 761, 1855, 2216
- Active damping  
469, 689, 956, 1040, 1477, 1915
- Active flutter control  
689, 1730
- Active force control  
63, 2433, 2434
- Active isolation  
346, 537, 683, 1238
- Active noise control  
664, 1081, 1786, 2028
- Active structural modification  
2570
- Active vibration control  
228, 346, 363, 586, 588, 689, 744, 1239, 1738, 1879, 1880,  
2057, 2162, 2176, 2413, 2432, 2437, 2445
- Active vibration isolation  
1923
- Actuators  
426, 2254, 2255, 2277
- Added mass effects  
25
- Adhesives  
901, 1035
- Aerodynamic characteristics  
790, 791, 792, 1028, 1247, 1248, 1733
- Aerodynamic coefficients  
1246

**Abstract**

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 18**

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Aerodynamic damping**  
352, 814

**Aerodynamic loads**  
44, 311, 312, 317, 356, 358, 387, 393, 491, 578, 678, 793, 795, 817, 991, 998, 1216, 1217, 1219, 1249, 1357, 1731, 1743

**Aerodynamic stability**  
880, 1740, 2375

**Aerodynamics characteristics**  
313

**Aeroelasticity**  
743, 1231, 1704

**Agricultural machinery**  
27, 1191

**Air bags (safety restraint systems)**  
315

**Air blast**  
1206, 2504

**Air conditioning equipment**  
13, 1081, 1701, 1702

**Air launched missiles**  
2420

**Aircraft engines**  
1545, 1741

**Aircraft fuselages**  
1541

**Aircraft noise**  
39, 41, 337, 567, 568, 569, 570, 571, 572, 573, 574, 575, 582, 1000, 1001, 1213, 1214, 1215, 1544, 1783, 1911, 2410, 2412

**Aircraft propellers**  
797, 1560

**Aircraft vibration**  
311, 312, 319, 2411

**Aircraft wings**  
42, 43, 44, 45, 46, 317, 393, 579, 794, 795, 796, 995, 1216, 1217, 1219, 1220, 1221, 1730, 1731, 2408, 2409

**Aircraft**  
40, 47, 48, 313, 314, 316, 530, 576, 577, 578, 790, 791, 792, 793, 817, 994, 996, 997, 998, 999, 1002, 1218, 1222, 1336, 1338, 1542, 1644, 1726, 1727, 1728, 1729, 1912, 1913, 1930, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2407, 2463

**Airfoils**  
188, 364, 678, 679, 884, 1090, 1563, 1731, 2271

**Airports**  
582

**Alignment**  
2, 1364

**Aluminum**  
199, 206, 207, 208, 479, 696, 1038, 1053, 1919, 1928, 2165

**Amplitude attenuation**  
681

**Amplitude measurement**  
1325, 1821, 2079

**Analog simulation**  
1467

**Annular plates**  
399, 639, 1282, 1436, 1775

**Antennas**  
411, 1546, 2159, 2211, 2357

**Anthropomorphic dummies**  
31

**Approximation methods**  
303, 430, 462, 508, 1663, 1907, 1993, 2447

**Arch dams**  
1186, 1717, 1718

**Arches**  
619, 626, 1983

**Articulated vehicles**  
601, 777

**Artillery fire**  
1623

**Asymmetric structure**  
1634

**Asymptotic approximations**  
170, 513, 1411, 2056, 2065, 2101, 2036

**Asymptotic series**  
2102

**Audio frequencies**  
1038

**Automobile bodies**  
1543, 2403

**Automobile engines**  
801, 1553

**Automobile noise**  
2402

**Automobiles**  
783, 798, 1236, 1954, 2062, 2386, 2552

**Autoparametric response**  
1414

**Abstract**

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 18**

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Autoregressive/moving average models  
1688, 2406

Averaging techniques  
1467

Axial excitation  
89, 189, 274, 300, 850, 1050, 1202, 1269, 1270

Axial force  
1041, 1260, 1980

Axial vibration  
2, 1572

Axial vibrations  
2108

Axisymmetric vibrations  
1436, 1068, 1182, 1282, 1776

- B -

Backlash effects  
1809

Baffles  
107, 259, 585, 651, 2498

Balancing machines  
502

Balancing techniques  
501, 534, 719, 1258, 1838, 1839, 1840, 2089, 2090, 2607,  
2608

Ball bearings  
74, 75, 366, 538, 594, 1158, 1511, 1746, 2383, 2444, 2605

Ball screw type dampers  
2058

Balls  
2605

Band saws  
596, 1881, 2440

Bars  
372, 373, 606, 607, 608, 799, 825, 1384, 1580, 1581, 1641,  
1960, 1966, 1981, 2196, 2197, 2198

Base excitation  
540, 762, 840, 1195, 1480, 1870, 1975, 2363

Base isolation  
65, 587, 685, 807, 808, 809, 810, 811, 812, 1018, 1240,  
1374, 1924, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431

Beams  
86, 87, 88, 90, 91, 93, 237, 238, 345, 376, 377, 378, 379,  
380, 381, 382, 383, 384, 385, 386, 417, 539, 610, 611, 612,  
613, 614, 615, 616, 618, 619, 620, 631, 702, 704, 705, 827,  
828, 831, 832, 833, 841, 844, 1000, 1003, 1041, 1042,  
1044, 1045, 1046, 1047, 1162, 1263, 1264, 1265, 1266,  
1412, 1413, 1414, 1415, 1416, 1418, 1419, 1420, 1583,  
1587, 1615, 1643, 1655, 1656, 1659, 1760, 1761, 1762,

Beams (cont'd.)  
1763, 1765, 1828, 1880, 1902, 1925, 1967, 1968, 1969,  
1970, 1971, 1972, 1973, 1974, 1976, 2202, 2203, 2204,  
2205, 2206, 2209, 2256, 2283, 2380, 2436, 2456, 2457,  
2458, 2479, 2603, 2606

Beam-columns  
370, 767, 1043, 1584, 1978, 2191

Beam-plate systems  
1100

Bearings  
1396, 1400, 1747, 1748, 1937, 2185, 2343, 2445

Bellows  
2019

Bells  
649, 2234

Belt conveyors  
1570, 1881

Belts (moving)  
596

Bending  
1971

Berger theory  
1605

Bernoulli-Euler method  
88, 830, 1264, 1739, 1765

Bibliographies  
7, 10, 311, 312, 416, 449, 713, 991, 1236, 1320, 1860,  
1922, 2061, 2087, 2497

Bicycles  
1537

Bifurcation theory  
189, 262, 265, 316, 734, 1842, 1843, 1844, 1945

Biot theory  
1624, 1892

Bird impact  
1934

Bispectral Analysis  
33

Blade loss dynamics  
1562, 1870

Bladed disks  
276, 278, 353, 476, 1361, 1557, 1933, 1935, 2183

Blades  
69, 92, 350, 357, 591, 1031, 1032, 1242, 1243, 1246, 1247,  
1248, 1558, 1563, 1929, 1932, 2060, 2182, 2440

Blade-vortex interaction  
815

Abstract  
Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Blast effects  
2040

Blast excitation  
456

Blast resistant structures  
184, 459, 460, 461, 1194, 1306, 1307, 1309, 1310, 1597,  
2041

Blast response  
26, 408, 1308, 1439

Blowdown response  
2013

Blowers  
7

Bodies of revolution  
1441, 1589

Boilers  
1535

Bolted joints  
78, 79, 212, 2191

Bolts  
1956, 1957, 2450

Bond graph technique  
283, 284, 301, 418, 426, 514, 515, 516, 517, 519, 528, 928,  
929, 932, 1070, 1501, 2569

Booster rockets  
329

Boundary condition effects  
606, 617, 1285, 1430, 1944, 1988, 1995, 2218, 2470, 2564,  
2568

Boundary element technique  
520, 1385, 1532, 1712, 1713, 1763, 2106, 2350, 2394

Boundary integral equation method  
2418

Boundary value problems  
260, 432, 724, 725, 1426, 1764, 1893

Bounded structures  
1286

Box beams  
126

Box type structures  
684

Braces  
603

Brakes (motion arresters)  
1909

Bridges  
14, 212, 285, 543, 544, 545, 720, 953, 1177, 1178, 1372,  
1658, 1882, 1883, 1884, 1885, 2137, 2430

Bridge-vehicle interaction  
1176

Bubble dynamics  
1316, 2501

Buckling  
114, 189, 1592

Buffeting  
2010

Buildings  
16, 17, 79, 255, 286, 287, 547, 548, 584, 587, 754, 755,  
756, 757, 758, 759, 760, 807, 809, 954, 955, 957, 958, 959,  
960, 961, 962, 1179, 1240, 1308, 1373, 1374, 1375, 1376,  
1377, 1378, 1379, 1380, 1381, 1382, 1383, 1388, 1522,  
1523, 1524, 1525, 1526, 1708, 1709, 1710, 1711, 1886,  
1888, 1889, 1972, 2138, 2392, 2424, 2425, 2426, 2430, 2431

Burst random technique  
1336

Busboxes  
2490

Buses  
2387

Business equipment  
1737

Cable stayed structures  
2137, 2455

Cables  
417, 604, 619, 824, 1039, 1261, 1262, 1409, 1410, 1411,  
1498, 1575, 1576, 1577, 1578, 1674, 1756, 1757, 1758,  
2454, 2455

Calibrating  
497, 708, 1818

Cantilever beams  
12, 95, 96, 591, 829, 1040, 1048, 1049, 1528, 1585, 1805,  
1975, 1977, 2121, 2201

Cantilever blades  
92

Cantilever plates  
129, 403, 1064, 1283, 1600

Cantilever shells  
1443

Cantilevers  
1492, 1524, 1638, 1829, 2017, 2245, 2532

Caps  
1603, 1604

- C -

Abstract  
Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Carbon 233	Clearance effects 2123
Cardan shafts 4	Clearance effects 2192, 2348
Cargo ships 309, 788, 789, 1209	Clutches 748
Cargo transportation 1134, 2579	Coanda effect 414
Cascades 69, 352, 358, 1028, 1029, 1031, 1561, 1562, 1563, 2128	Coefficient of friction 1749
Case histories 1677, 1678, 1747, 2008, 2159, 2172, 2208, 2235, 2242, 2243, 2258, 2287, 2290, 2339	Coherence function technique 518, 1150, 1151, 1152, 1153, 1154, 1155, 2544, 2549
Catenaries 1261	Collision research (ships) 31, 55, 56, 303, 786, 1908, 563
Cavitation 451, 1207, 1744, 1797, 2052, 2092	Columns 25, 621, 622, 1050, 1051, 1269, 1270, 1766, 1767, 1891, 1980
Centrifugal compressors 1509, 1510	Combined systems 510
Centrifugal forces 2089	Combustion engines 174, 716
Centrifugal pumps 1366, 1703	Combustion excitation 2253
Centrifuges 946 1365	Combustion noise 2250
Cepstrum analysis 2518	Compaction equipment 27, 985
Ceramics 382	Complex modulus 1035, 1079, 1128, 1148, 1149
Chains 824, 1516	Complex structures 1501
Chatter 751, 1170, 1874, 1875, 1877, 1878, 2132, 2187	Component mode analysis 610, 841, 1329, 2526
Chimneys 291, 1891	Component mode synthesis 486, 1330, 1331, 1521, 1827, 1828, 1902, 2069, 2072, 2074, 2125, 2257, 2370, 2512, 2533
Circuit boards 2491, 2492, 2494	Composite beams 94
Circular bars 1582	Composite materials 233, 234, 697, 1053, 1106, 1108, 1109, 1110, 1223, 1473, 1662, 1777, 1785, 1997
Circular cylinders 98, 99, 387, 644, 645, 813, 834, 835, 836, 838, 1267, 1647	Composite structures 45, 46, 106, 121, 132, 153, 406, 632, 1052, 1061, 1062, 1128, 1133, 1279, 1430, 1440, 1919
Circular plates 131, 132, 397, 404, 1060, 1061, 1062, 1182, 1280, 1281, 1437, 1776, 1994, 2215, 2471, 2472, 2473, 2474, 2502	Compressor blades 814, 1532, 1741
Clays 294	

Abstract  
Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Compressors  
8, 282, 1125, 1508, 1699, 1700, 1701, 1702, 2127, 2128

Computer aided design  
2170, 2435

Computer aided techniques  
712, 721, 842, 1793, 1951, 2582, 2590, 2598, 2599, 2604

Computer graphics  
625

Computer programs  
45, 55, 188, 270, 271, 286, 295, 325, 393, 401, 525, 526, 527, 528, 529, 530, 534, 560, 565, 575, 599, 655, 656, 671, 741, 742, 743, 815, 835, 836, 914, 945, 988, 1063, 1098, 1159, 1243, 1295, 1356, 1357, 1359, 1360, 1386, 1423, 1524, 1667, 1704, 1705, 1718, 1728, 1746, 1761, 1816, 1834, 1860, 1863, 1904, 1908, 1913, 1987, 2001, 2013, 2038, 2051, 2103, 2111, 2112, 2113, 2129, 2164, 2223, 2268, 2340, 2365, 2389, 2407, 2435, 2444, 2547, 2557, 2558, 2559, 2561, 2586, 2587, 2599, 2614

Computer storage devices  
154

Computer systems hardware  
2256, 2519

Computerized simulation  
283, 284, 416, 877, 1071, 1728

Computer-aided techniques  
236, 251, 719, 1337, 2110, 2334, 2499, 2576

Concentric structures  
146, 410, 1781

Concrete  
295, 407, 424, 455, 553, 554, 672, 977, 981, 1146, 1186, 1462, 1482, 1529, 1658, 1709, 1814, 1967

Conformal mapping  
1052, 1427

Conical bodies  
539

Constitutive equations  
674, 1146, 1148, 1899, 1900

Constrained structures  
87, 742, 1350, 1504, 1651

Constraint function technique  
1695

Constraint modes method  
1328, 1898, 2011, 2557

Construction industry  
448

Contact stresses  
1253

Contact vibration  
1188, 1189, 1645

Containment structures  
561, 1719

Continuous beams  
830

Continuous parameter method  
516, 739, 924, 1040, 1097, 1233, 2346

Continuous systems  
191

Continuum mechanics  
1123

Control simulation  
1853

Control systems  
1732, 2027

Cooling towers  
963, 1438

Coriolis forces  
591, 1931

Correlation techniques  
2199, 2324, 2528

Corrosion fatigue  
481

Cosserat point  
1650

Coulomb damping  
685, 1959

Coulomb friction  
152, 155, 278, 629, 733, 896, 897, 898, 1007, 1114, 1245, 1361, 1478, 1762, 1810, 1915, 1929, 2060, 2283, 2284, 2285, 2509

Coupled response  
95, 272, 328, 369, 465, 944, 1032, 1286, 1862, 2108, 2318, 2457

Coupled systems  
1414

Couplings  
1571

Crack detection  
245, 247, 717, 718, 915, 1141, 1142, 1953, 2337

Crack propagation  
80, 203, 204, 206, 213, 215, 246, 247, 477, 478, 479, 482, 483, 506, 698, 900, 915, 1115, 1116, 1120, 1121, 1187, 1221, 1226, 1324, 1657, 1813, 1814, 2217

Cracked media  
217, 1181, 1444, 1481, 1579, 1659, 1765, 1815, 1863, 2098

Abstract  
Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Cranes (hoists)  
950, 1192, 1193, 2136

Crankshafts  
801, 1164

Crash research (aircraft)  
756, 757, 770, 860, 876, 1223

Crash victim simulation  
55, 56

Crashworthiness  
988

Critical damping  
1097, 2056

Critical excitation method  
676

Critical loads  
1584

Critical speeds  
785, 787, 1037, 1165, 1166, 1602, 1867, 1868, 1869, 1937,  
1945, 2374, 2376

Critical stress identification  
1689

Cryogenic systems  
561

Curve fitting  
2308, 2322

Curved beams  
1445, 1764, 2177

Curved pipes  
2482

Cutting  
253, 948, 1875, 1876, 2131

Cyclic loading  
59, 89, 104, 294, 355, 370, 388, 561, 602, 603, 622, 638,  
768, 769, 964, 1020, 1146, 1482, 1529, 1580

Cylinders  
97, 100, 101, 102, 147, 654, 837, 1212, 1268, 1291, 1421,  
1422, 1512, 1588, 1589, 1641, 1979, 2011, 2260

Cylindrical bearings  
1252, 2184

Cylindrical bodies  
843

Cylindrical shells  
136, 137, 138, 139, 140, 142, 499, 543, 640, 641, 642, 643,  
850, 1288, 1443, 1444, 1606, 1607, 1780, 1871, 1986, 1997,  
2003, 2004, 2122, 2230, 2231, 2232, 2233, 2475, 2477, 2502

Dam bearings  
1939

Damage detection  
2606

Damage prediction  
457, 547, 878, 1375

Damped modes  
933

Damped structures  
865, 887, 1065, 1331, 1432, 1480, 1503, 1869, 1991, 2020,  
2226, 2256, 2284, 2285, 2288, 2456

Damped systems  
886

Damper locations  
1554

Dampers  
326, 683, 888, 1000, 1479, 2058, 2287

Damping characteristics  
818, 1099

Damping coefficients  
20, 84, 99, 199, 320, 371, 375, 550, 593, 595, 688, 693,  
768, 805, 894, 895, 909, 934, 935, 936, 952, 1002, 1019,  
1030, 1069, 1074, 1075, 1077, 1172, 1254, 1294, 1335,  
1348, 1396, 1397, 1398, 1422, 1429, 1565, 1596, 1654,  
1691, 1692, 1748, 1767, 1940, 1944, 1946, 1949, 2017,  
2124, 2129, 2191, 2192, 2242, 2243, 2281, 2282, 2371,  
2385, 2391, 2472, 2494, 2510

Damping effects  
18, 25, 197, 277, 347, 357, 611, 636, 692, 1009, 1055,  
1170, 1656, 1704, 2280, 2378, 2381

Damping  
684, 2054

Dams  
295, 454, 553, 771, 772, 773, 774, 775, 982, 983, 984,  
1187, 1389, 1390, 1391, 1534, 1715, 1716, 1902, 2144,  
2395, 2396

Data dependent systems  
231, 2306

Data processing  
303, 504, 518, 1491, 2307, 2317, 2318, 2319, 2320, 2321,  
2322, 2323, 2542, 2543, 2544, 2545, 2546, 2547, 2548,  
2549, 2550, 2551

Data recorders  
1338

Deconvolution technique  
1711, 2318

Design sensitivity analysis  
2302

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Design techniques**  
 6, 286, 325, 422, 461, 472, 658, 684, 699, 746, 754, 820, 863, 972, 996, 1002, 1006, 1009, 1012, 1099, 1165, 1309, 1453, 1505, 1943, 1951, 1952, 2125, 2130, 2404, 2586

**Detectors**  
 1130, 1131, 2535

**Diagnostic instrumentation**  
 252, 1342, 1343

**Diagnostic techniques**  
 237, 238, 239, 240, 241, 242, 243, 244, 246, 247, 499, 913, 914, 990, 1136, 1137, 1138, 1342, 1493, 1494, 1674, 1675, 1676, 1677, 1678, 1835, 1836, 1837, 1885, 2086, 2088, 2335, 2336, 2337, 2338, 2603, 2604, 2605, 2606

**Diesel engines**  
 57, 201, 239, 240, 241, 248, 541, 1167, 1363, 1725

**Difference equations**  
 2525

**Digital filters**  
 1486, 1487

**Digital techniques**  
 225, 1487, 1953, 2028, 2499, 2536, 2581, 2595

**Direct computational method**  
 72

**Direct integration technique**  
 1868, 2136

**Discontinuity-containing media**  
 237, 238, 474, 602, 838, 1096, 1181, 1324, 1433, 1773, 2203, 2292, 2295

**Discrete Fourier transform**  
 907, 1480

**Disk drives**  
 2257, 2258

**Disks**  
 279, 747, 913, 1059, 1160, 1435, 1545, 2377, 2383, 2462, 2472

**Displacement analysis**  
 1728, 2357

**Displacement measurement**  
 60, 225

**Dissipation factor**  
 1943

**Donnell's theory**  
 2233

**Doors**  
 184, 1306, 1307

**Doubly asymptotic approximation**  
 135, 682

**Drag coefficients**  
 100, 1576

**Drilling platforms**  
 559, 1675, 1720, 1722, 1723, 2136, 2335, 2400

**Drilling**  
 1548, 1549, 1873

**Drills**  
 605, 1173, 1665

**Driveline vibrations**  
 2386, 2387

**Drop tests (impact tests)**  
 1455

**Ducts**  
 148, 176, 421, 422, 423, 659, 660, 664, 861, 1081, 1296, 1448, 1449, 1450, 1451, 1612, 1613, 1614, 1769, 2023, 2024, 2123, 2150, 2248, 2249, 2250, 2251, 2252, 2253, 2483, 2484

**Duffing oscillators**  
 261, 1345, 1466, 1764, 2315

**Duffings differential equation**  
 267, 2093

**Duhamel integral**  
 2273

**Dynamic absorbers**  
 344, 345

**Dynamic balancing**  
 1679

**Dynamic buckling**  
 385, 603, 1060, 1066, 1603, 1891

**Dynamic calibration**  
 491

**Dynamic coefficients**  
 2443, 2452, 2453

**Dynamic condensation technique**  
 501, 2530, 2130

**Dynamic plasticity**  
 1643

**Dynamic properties**  
 1440

**Dynamic relaxation**  
 2129

**Dynamic stability**  
 123, 779, 1050, 1192, 1193, 1443, 1585, 1947

**Dynamic stiffness method**  
 191

**Abstract**  
 Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1880 1881-2114 2115-2388 2389-2615

**Volume 18**

**Issue:** 1 2 3 4 5 6 7 8 9 10 11 12

Dynamic stiffness  
103, 828, 895, 1035, 1264, 1377, 1397, 1893

Dynamic structural analysis  
531, 2614

Dynamic tests  
184, 968, 2025, 2082

Dynamic vibration absorption (equipment)  
800, 1025

Dynamometers  
716

- B -

Fers  
1016

Earthquake damage  
139, 187, 457, 547, 1375, 2105, 2142

Earthquake prediction  
673

Earthquake resistant structures  
1709, 1859, 2026

Earthquake response  
412, 458

Earthquake simulation  
975

Eddy current probes  
1140

Effective eccentricity  
1888

Eigenvalue problems  
103, 257, 260, 637, 728, 845, 929, 1394, 1502, 1683, 1684,  
1824, 1850, 1851, 1867, 2094, 2346, 2610, 2612

Ejection seats  
315, 343

Elastic foundations  
130, 833, 847, 851, 1058, 1182, 1282, 1587, 1604, 1763,  
2181, 2194, 2214, 2215, 2370, 2461

Elastic half space  
1639

Elastic media  
513, 1464, 1642, 2037, 2066

Elastic medium  
1043

Elastic plastic properties  
268, 1047, 1271, 1593, 1640, 1660, 1768, 2065, 2293

Elastic properties  
114, 376, 507, 621, 623, 825, 965, 976, 1019, 1020, 1103,  
1482, 1964, 2454

Elastic restraints  
730, 1285, 1584, 1776, 1778

Elastic supports  
381, 386, 397, 535, 657, 1280, 1365, 1978, 2037

Elastic systems  
190, 1348, 1766, 2046, 2567

Elastic waves  
717, 718, 731, 921, 1268, 1351, 2203, 2292, 2295, 2310

Elastodynamic response  
83, 128, 256, 1579, 2198

Elastohydrodynamic properties  
71, 72, 142, 1748

Elastomeric dampers  
1103

Elastomers  
59, 66, 209, 210, 211, 347, 806, 809, 973, 1019, 1020,  
1237, 1260, 1395, 1748, 1962, 2062, 2424, 2430, 2439, 2451

Electric components  
876

Electric motors  
1136, 1137

Electrodynamic shakers  
2520

Electrohydraulic shakers  
2333

Electromagnetic damping  
687, 1100

Electromagnetic exciters  
2045

Electromagnetic properties  
1137

Electronic instrumentation  
715, 1821, 1833, 2449, 2492, 2493

Electronic test equipment  
2173

Elevated railroads  
1204

Elevators  
893

Enclosures  
179, 1297, 1786, 2410, 2485

Energy absorption  
373, 1223, 1928, 2191, 2438

Energy dissipation  
776, 784, 885, 886, 1474, 1927

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Energy methods  
50, 399

Energy transfer  
2508, 2539

Energy transmission  
1055

Engine mounts  
1553

Engine noise  
1618

Engine vibration  
574

Environment simulation  
1013

Environmental effects  
1833

Equations of motion  
507, 736, 947, 1132

Equipment mounts  
324

Equipment response  
1135, 1197, 1633

Equipment-structure interaction  
185, 940, 1087, 1240, 1527, 1794, 2140, 2426, 2489

Equivalent linearization method  
404, 685, 1374, 1380, 1434, 1502, 1982

Equivalent plate analysis method  
2409

Equivalent viscous damping  
79

Error analysis  
96, 529, 598, 1150, 1151, 1152, 1153, 1154, 1155, 1614,  
1669, 2079, 2107, 2265, 2317, 2323, 2374, 2536, 2547,  
2554, 2613

Euler equation  
1964

Euler-Lagrange equation  
1499

Exact methods  
646

Excavators  
2397

Excitation techniques  
2240

Exhaust systems  
280, 475, 2481

Expansion joints  
974, 1178

Experimental data  
39, 117, 121, 157, 202, 249, 278, 285, 304, 305, 332, 356,  
361, 401, 443, 459, 570, 580, 601, 689, 763, 840, 934, 935,  
951, 952, 1179, 1188, 1271, 1299, 1306, 1307, 1376, 1379,  
1558, 1560, 1563, 1572, 1632, 1710, 2008, 2009, 2040,  
2057, 2124, 2152, 2331, 2406, 2414, 2444, 2452, 2453

Experimental modal analysis  
131, 229, 230, 711, 904, 1007, 1008, 1010, 1159, 1331,  
1334, 1335, 1336, 1338, 1705, 1825, 1826, 1828, 1904,  
2068, 2070, 2075, 2076, 2135, 2137, 2147, 2152, 2154,  
2160, 2161, 2162, 2167, 2172, 2208, 2212, 2218, 2224,  
2228, 2234, 2235, 2240, 2242, 2257, 2258, 2281, 2287,  
2290, 2305, 2311, 2313, 2323, 2326, 2327, 2334, 2339,  
2354, 2359, 2363, 2370, 2371, 2372, 2373, 2374, 2379,  
2383, 2384, 2387, 2390, 2396, 2399, 2405, 2406, 2410,  
2411, 2414, 2416, 2417, 2424, 2425, 2426, 2427, 2428,  
2464, 2465, 2466, 2475, 2478, 2481, 2490, 2494, 2512,  
2517, 2518, 2520, 2521, 2522, 2523, 2524, 2525, 2526,  
2529, 2530, 2531, 2534, 2535, 2536, 2539, 2540, 2541,  
2542, 2543, 2545, 2546, 2548, 2549, 2550, 2552, 2553,  
2554, 2555, 2556, 2557, 2558, 2560, 2561, 2562, 2563,  
2564, 2565, 2567, 2568, 2569, 2570, 2572, 2602, 2603,  
2604, 2607, 2608, 2609

Experimental test data  
1933

Expert systems  
1816

Explosion effects  
461, 968, 2040, 2268, 2503, 2504

Explosives  
1800

Extensional deformation effects  
650

Extensional waves  
1111, 1128

External damping  
691

Extremum principles  
925

- F -

Failure analysis  
238, 1836

Failure detection  
246, 503, 1138, 1139, 1140, 1492, 1493, 1494, 1674, 1785,  
2335, 2339, 2605

Fan blades  
70, 1557, 1741, 1840, 1933, 1934

Fan noise  
2123

Abstract  
Numbers: 1-271 272-531 532-742 743-842 843-1156 1157-1357 1358-1505 1506-1695 1696-1880 1881-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Fans  
7, 357, 1514, 1677, 1705

Fast fourier transform  
178, 905, 1071, 1096, 1485, 1488, 1664, 1759, 1852, 2611

Fasteners  
1955, 2450

Fatigue life  
47, 52, 73, 80, 81, 82, 108, 200, 201, 202, 203, 204, 206, 207, 208, 209, 210, 211, 212, 214, 215, 246, 350, 351, 355, 474, 478, 479, 480, 481, 482, 483, 503, 544, 545, 558, 559, 602, 695, 696, 697, 698, 699, 796, 899, 902, 955, 1033, 1034, 1036, 1113, 1115, 1116, 1117, 1118, 1120, 1121, 1138, 1176, 1180, 1227, 1253, 1256, 1265, 1324, 1363, 1481, 1494, 1513, 1545, 1657, 1658, 1659, 1746, 1811, 1812, 1813, 1906, 1936, 1955, 1956, 1957, 2019, 2023, 2062, 2063, 2064, 2195, 2289, 2290, 2291, 2446, 2449, 2481, 2491, 2512, 2597

Fatigue tests  
81, 205, 216, 475, 476, 477, 618, 701, 901, 1116, 1119, 1189, 1221, 1226, 1256, 1721, 1729, 2062, 2446, 2584

Feedback control  
2027

Fiber composites  
632, 1048, 1106, 1109, 1124, 1429, 1873, 2064, 2165, 2291, 2502, 2511, 2514

Fiber optics  
1132, 2535

Fiberglass  
2330

Field test data  
2173

Fifth wheel couplings  
601

Finite difference method  
1259, 1313

Finite difference technique  
421, 577, 1144, 1296, 1352, 1448, 1583, 1599, 1803, 2153, 2448, 2468, 2551

Finite element techniques  
18, 22, 45, 49, 71, 81, 102, 127, 129, 256, 268, 271, 281, 310, 383, 390, 398, 404, 406, 413, 431, 518, 522, 525, 539, 558, 614, 633, 653, 671, 690, 702, 730, 731, 741, 772, 836, 859, 913, 979, 1026, 1032, 1046, 1067, 1097, 1098, 1101, 1104, 1105, 1112, 1114, 1146, 1168, 1171, 1175, 1208, 1251, 1271, 1283, 1328, 1330, 1349, 1351, 1354, 1359, 1377, 1392, 1396, 1400, 1413, 1415, 1423, 1428, 1432, 1438, 1439, 1476, 1492, 1502, 1528, 1530, 1531, 1581, 1590, 1591, 1594, 1595, 1598, 1609, 1670, 1681, 1684, 1687, 1704, 1705, 1716, 1735, 1737, 1745, 1756, 1757, 1762, 1777, 1784, 1799, 1803, 1814, 1834, 1855, 1858, 1863, 1876, 1896, 1901, 1908, 1915, 1925, 1974, 1999, 2013, 2022, 2023, 2030, 2103, 2106, 2111, 2112, 2113, 2120, 2129, 2132, 2139, 2164, 2181, 2182, 2188, 2198, 2205, 2208, 2218, 2223, 2224, 2227, 2234, 2244, 2245,

Finite element techniques (cont'd)  
2257, 2270, 2272, 2300, 2302, 2313, 2345, 2380, 2396, 2404, 2405, 2441, 2457, 2490, 2530, 2553, 2564, 309

Flexibility coefficients  
5, 1675

Flexible foundations  
552, 765, 1869

Flexible rotors  
1, 196, 500, 534, 719, 1943, 2116, 2117

Flexible shafts  
2383

Flexural stiffness  
41, 604

Flexural vibrations  
19, 113, 115, 119, 120, 278, 369, 396, 398, 500, 596, 614, 630, 634, 831, 832, 848, 944, 1045, 1052, 1057, 1058, 1059, 1060, 1061, 1062, 1064, 1256, 1256, 1257, 1263, 1274, 1278, 1384, 1426, 1431, 1507, 1568, 1582, 1586, 1598, 1751, 1762, 1763, 1881, 1960, 1973, 1976, 1993, 2115, 2121, 2210, 2214, 2384, 2387, 2459, 2467, 2469

Flexural waves  
77, 86, 1096, 1111, 1412, 1760, 2203

Flight simulation  
206

Flight tests  
1125

Flight vehicle equipment response  
38, 1134

Floating ring journal bearings  
1947

Floating structures  
835, 1207, 2148

Floors  
152, 583, 865, 940, 1235, 1298, 1555, 1616, 1794, 2489

Floquet theory  
362

Flow measurement  
569

Flow-induced vibration  
98

Flügge's shell theory  
1986

Fluid elastic instability  
1069

Fluids  
881, 1320

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Fluid-filled bearings  
1399

Fluid-filled containers  
138, 144, 145, 156, 309, 417, 535, 536, 611, 620, 645, 657,  
800, 854, 855, 1072, 1316, 1317, 1318, 1365, 1443, 1609,  
1734, 1781, 1800, 2002, 2064, 2005, 2006, 2016, 2017,  
2022, 2235, 2238, 2245, 2479

Fluid-filled media  
525, 1512

Fluid-film bearings  
1, 943, 1160, 1564, 1940, 2370, 2372, 2373, 2379

Fluid-induced excitation  
48, 52, 97, 110, 144, 192, 193, 259, 291, 300, 310, 380,  
415, 416, 417, 536, 556, 620, 644, 651, 652, 653, 654, 656,  
679, 794, 814, 816, 834, 856, 857, 880, 884, 896, 918, 986,  
990, 1069, 1072, 1073, 1082, 1093, 1094, 1095, 1201, 1222,  
1242, 1262, 1288, 1290, 1319, 1451, 1469, 1508, 1509,  
1510, 1564, 1562, 1576, 1588, 1608, 1611, 1613, 1741,  
1769, 1770, 1979, 1989, 2008, 2009, 2010, 2011, 2016,  
2019, 2022, 2230, 2238, 2241, 2245, 2246, 2247, 2271,  
2278, 2462, 2471, 2480, 2482

Fluid-structure interaction  
141, 299, 394, 450, 467, 556, 557, 655, 682, 781, 1016,  
1194, 1198, 1199, 1291, 1349, 1754, 2047, 2054, 2164,  
2236, 2270, 2612

Fluid-structure  
1208

Flutter  
43, 45, 46, 70, 188, 527, 677, 821, 995, 1029, 1031, 1218,  
1219, 1220, 1231, 1280, 1361, 1542, 1563, 1731, 1840,  
1929, 1984, 2017, 2128, 2158, 2375

Flywheels  
239

Foams  
1624, 2171

Follower forces  
88, 1585

Footings  
25, 1714

Force measurement  
222, 903, 1242, 1672, 1754, 2040

Force prediction  
1728, 1754

Force transmission  
1406

Forced vibrations  
379, 838, 923, 1516, 1844, 2274

Force-state mapping technique  
1406

Forcing function  
681, 2415

Forging machinery  
339, 1517, 1706, 1879

Fossil power plants  
914

Foundations  
551, 767, 1183, 1388, 1531, 1532, 1892, 1893

Four bar mechanisms  
823, 1258, 1751, 2348

Fourier analysis  
1454, 2133

Fourier series  
379, 1485

Fourier transformation  
1489, 1666, 2071

Fracture detection  
2342

Fracture properties  
217, 271, 498, 673, 700, 780, 900, 993, 1048, 1122, 1123,  
1265, 1341, 2065, 2606

Framed structures  
103, 388, 389, 425, 1200, 1272, 1423, 1526, 1887, 1890,  
1981, 1982

Frames  
104, 105, 153, 390, 624, 625, 839, 840, 841, 842, 1271,  
1768, 1974, 2168, 2193, 2209, 2210, 2211, 2212, 2572

Free vibration  
1773

Freight cars  
1205, 1707

Frequency analysis  
637, 1674, 2092

Frequency analyzers  
905

Frequency domain method  
37, 48, 240, 273, 485, 711, 881, 986, 1005, 1333, 1387,  
1485, 1685, 1810, 1826, 1835, 2049, 2075, 2325, 2347,  
2358, 2364, 2503, 2517, 2550

Frequency response functions  
1663, 1664, 1726, 2076, 2163, 2299, 2320, 2544, 2209,  
2312, 2364, 2388, 2546, 2558, 2559

Frequency response  
526, 530, 927, 1150, 1151, 1152, 1153, 1154, 1155, 1846,  
1913, 2093, 2159

Friction bearings  
2186

**Abstract**

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 18**

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Friction excitation  
76

Friction  
1260, 1796

Functional analysis  
881

Fundamental frequency  
397, 466, 632, 1427, 1433, 1592, 1800, 1950, 1995, 2459,  
2469, 1977

Fundamental modes  
1424

- G -

Galerkin method  
396, 1274, 1427, 1431, 1524, 1968, 2005, 2122, 2220

Galloping  
677, 1093

Gas bearings  
1397

Gauss-Newton method  
2153

Gear boxes  
722, 1033, 1138, 1954, 2083, 2187

Gear couplings  
2

Gear drives  
1507, 1678

Gear noise  
1567

Gear teeth  
1138, 1402, 1678, 2188

Gears  
76, 272, 282, 367, 368, 369, 532, 597, 598, 599, 1255,  
1401, 1494, 1570, 1749, 1750, 1835, 1861, 1862, 1952,  
1953, 2189, 2447

Gear-induced vibration  
575

Geometric effects  
591, 664, 1055, 1210, 1592, 1682, 2458, 2465

Geometric imperfection effects  
14, 400, 825, 1399

Gimbals  
2553

Glass reinforced plastics  
223

Gliders  
1231

Global fitting method  
2308, 2529

Global identification technique  
269, 2163, 2517

Grain silos  
1528

Granular materials  
195, 473

Graphic methods  
489, 625, 1026, 1364

Graphite  
694, 1038, 1107

Green function  
48, 259, 1422, 1425

Grids (beam grids)  
617, 2208

Grids (beams)  
1417

Grillage method  
112

Grinding machinery  
1877, 1878, 2135

Gross spectral method  
482

Ground effect machines  
305

Ground motion  
759, 1387, 1635

Ground resonance  
1225, 1559

Ground shock  
2505

Ground surface  
442, 443, 663, 1084, 1791

Ground vehicle equipment response  
1134

Ground vehicles  
301, 302, 346, 991, 1206, 1537, 1907, 2149, 2512

Ground vibration  
63, 456, 588, 1190, 2005, 2433, 2434

Guideways  
992

Gun mounts  
2172

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Gunfire effects  
2595, 2599

Guyed structures  
763, 1546, 1891

Gyroscopes  
691

- H -

Half-space  
2294

Hamiltonian functions  
736

Hamiltonian principle  
266, 1470, 2210

Hammers  
390

Hardened installations  
460

Harmonic analysis  
703, 1852

Harmonic balance method  
262, 272, 379, 512, 538, 610, 726, 727, 1054, 1968

Harmonic excitation  
127, 191, 552, 747, 924, 966, 1043, 1046, 1126, 1322,  
1346, 1347, 1443, 1792, 1810, 1894, 1895, 1966, 1993,  
2001, 2098

Harmonic response  
120, 137, 850, 891, 1432, 1444, 1468, 1718, 1892, 2043,  
2102

Harmonic waves  
1662, 2031, 2204

Head (anatomy)  
343, 2423

Heat exchangers  
415, 416, 1290, 1292, 2008, 2009, 2246, 2247

Heat generation  
59

Heat shields  
232

Heaviside functions  
1597

Helical gears  
1256, 1256, 1257, 1567, 2448

Helical springs  
1556, 1739, 2178, 2428

Helicopter blades  
1740

Helicopter equipment  
2159, 2585

Helicopter noise  
37, 336, 575, 815

Helicopter rotors  
273, 319, 359, 361

Helicopter vibration  
744, 2413, 2414, 2599

Helicopters  
38, 68, 318, 359, 360, 362, 363, 365, 722, 743, 816, 942,  
1125, 1162, 1224, 1225, 1226, 1227, 1228, 1229, 1230,  
1368, 1559, 1732, 1733, 1743

Helmets  
2423

Helmholtz integral method  
390, 2106

Helmholtz resonators  
174

Hertzian contact  
379, 1645, 2002

High frequency excitation  
2427

High frequency resonance technique  
1496

High frequency response  
1901

Hole-containing media  
205, 1324, 1598, 1779, 1987, 1996, 2024, 2467, 2475

Holographic techniques  
67, 129, 713, 1325, 1483, 1497, 2550

Holzer method  
1887

Honeycomb structures  
108, 580, 684 1928, 1985

Hopkinson bar technique  
496, 708, 1458

Hospitals  
13

Household appliances  
284

Hugoniot equation  
26

Human hand  
54, 341, 1017, 1548, 1549

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Human response  
53, 66, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342,  
581, 582, 583, 584, 798, 1014, 1015, 1235, 1548, 1549,  
1920

Human spine  
343

Hunting motion  
785, 787, 1167

Hydraulic dampers  
1921

Hydraulic equipment  
146

Hydraulic servomechanisms  
2254, 2255

Hydraulic systems  
526, 656, 1832, 2385

Hydraulic turbines  
2208

Hydrodynamic coefficients  
308

Hydrodynamic excitation  
36, 147, 465, 772, 773, 872, 1212

Hydrodynamic loads  
92

Hydrodynamic lubrication  
1250, 1251

Hydrodynamic response  
2112, 2236

Hysteretic damping  
760, 774, 889, 890, 891, 892, 958, 959, 984, 1018, 1049,  
1580, 1648, 1815, 2003, 2059, 2279, 2436

- I -

Ibrahim time domain technique  
1823, 2319

Ice  
1723

Impact dampers  
195, 473, 1478

Impact excitation  
835, 923, 1263, 1275, 1593, 1664, 1965, 2002, 2098

Impact hammer tests  
230, 718

Impact limiters  
2171

Impact noise  
446, 1174, 1300

Impact response  
74, 75, 111, 122, 182, 268, 343, 376, 386, 410, 609, 621,  
671, 672, 756, 757, 770, 836, 860, 876, 1413, 1457, 1641,  
1707, 1723, 1765, 1796, 1967, 1968, 1971, 2038, 2196,  
2231, 2294

Impact tests  
304, 327, 329, 1053, 1462, 1934, 2334, 2539, 2578

Impedance technique  
663, 2225

Impulse response  
102, 372, 452, 643, 662, 669, 1286, 1458, 1638, 2004,  
2221, 2417, 2461

Impulse testing  
1110, 1795

Incipient failure detection  
2088

Indentation  
182

Industrial facilities  
175, 338, 339, 447, 449, 458, 585, 941, 1377

Inertial forces  
100, 735, 1946, 1948, 2053, 2118, 2192, 2293

Infinite element technique  
2047

Inflatable structures  
2179, 2396

Influence coefficient method  
1160, 1377, 2608

Initial deformation effects  
189, 1032, 1041, 1042

Instrumental variable method  
1691

Instrumentation  
155, 1667

Intake systems  
1837

Integral equations  
258

Integration methods  
2325

Integration  
2356

Integrodifferential equation  
2202

Interface: solid-fluid  
1787

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Interface: solid-solid  
717

Interferometers  
219

Interferometric techniques  
67, 129, 707, 1325, 1497, 1821

Interior noise  
39, 40, 41, 573, 574, 575, 798, 994, 999, 1000, 1001, 1214,  
1215, 1541, 1544, 2402, 2410

Intermittent motion  
1651, 2046

Internal combustion engines  
1168, 280

Internal damping  
41, 247, 1237, 2229, 2511

Internal forces  
136, 137, 1402

Internal pressure  
1903

Internal resonance  
138, 864, 1414, 1467, 1471, 2353, 2376

Isolators  
1237, 2175

Iteration  
522, 2349, 2530

- J -

Jet engines  
1114, 1834

Jet noise  
180, 414, 567, 568, 569, 570, 571, 2259

Joints  
77, 370, 820, 897, 901, 1034, 1181, 1186, 1340, 1403,  
1404, 1405, 1406, 1958, 1959, 2190, 2449

Journal bearings  
71, 72, 593, 1250, 1251, 1399, 1564, 1565, 1676, 1698,  
1744, 1745, 1941, 1942, 1943, 1944, 1945, 2443

Jump phenomena  
367

- K -

Kron method  
624

Kryloff-Bogoliuboff method  
16, 726

- L -

Lagrange equations  
510, 1064, 1289, 1578, 1898, 2038, 2241, 2355

Laplace transformation  
347, 532, 1581, 2098

Large amplitude vibrations  
2463

Lasers  
234, 241, 1165, 1819, 2078, 2328

Laser-Doppler method  
2262

Lateral response  
755, 840, 2488

Lateral vibrations  
1163, 1864, 1981

Lathes  
1157, 2132

Launch vehicles  
328, 2415

Launching response  
330

Launching  
1011

Layered damping  
636, 997, 1111, 1112, 1775, 1996, 2286

Layered materials  
94, 118, 119, 122, 123, 167, 216, 217, 382, 399, 400, 614,  
615, 629, 673, 799, 912, 1056, 1139, 1141, 1276, 1277,  
1385, 1413, 1421, 1428, 1429, 1430, 1431, 1432, 1481,  
1655, 1713, 1751, 1990, 1991, 2003, 2032, 2502

Least squares method  
1326, 1335, 1681, 1823, 1848, 2190, 2358, 2528, 2529,  
2557, 2613

Levitation  
2615

Lifeline systems  
2142

Limit cycle analysis  
257, 734, 837, 2145, 2146

Line source excitation  
1894, 1895

Linear programming  
1636, 2571

Linear systems  
907, 1327, 1685, 2095

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Linearization methods  
508, 732, 2552

Linings  
1450

Linkages  
821, 822, 823, 1259, 1751, 1960, 2277

Linking analysis and test  
2154, 2190, 2199, 2207, 2256, 2257, 2324, 2325, 2326,  
2399, 2439, 2456, 2458, 2464, 2475, 2478, 2552, 2553,  
2554, 2555, 2556

Liquid rocket propellants  
1734, 1806

Longitudinal response  
1966

Longitudinal vibrations  
115, 1650, 1762, 606, 1950

Longitudinal waves  
1447, 1619

Loosening  
2450

Loss factors  
885, 1354, 1474, 1996, 2020, 2225, 2510, 2559

Lubrication  
71, 72, 1753, 2186, 2446

Lumped mass method  
1259

Lumped parameter method  
262, 438, 516, 1097, 1680, 2306

Lyapunov functions  
1766

Lyapunov's method  
1680

Machine diagnostics  
2336, 2342

- M -

Machine foundations  
63, 969, 976, 971, 972, 973, 974, 975, 976, 977, 979, 980,  
981, 1019, 1024, 1025, 1103, 1555, 2435

Machine tools  
253, 916, 1021, 1169, 1170, 1171, 1172, 1518, 1665, 1873,  
1876, 2130, 2131, 2132, 2133, 2134, 2389, 2390, 2391,  
2535, 2547

Machinery noise  
665, 666, 1453, 1620, 2263

Machinery vibration  
1552, 1816, 1872

Machinery-induced vibrations  
588, 967, 2433, 2434

Machines  
2356

Machining  
751, 949

Magnetic bearings  
537, 819, 1738

Magnetic tapes  
1881, 1930

Magnets  
24

Marine engines  
368, 1363, 1400

Marine risers  
30, 97, 147, 310, 1588

Masonry  
150, 287, 1522, 2488

Mass additive technique  
2209

Mass coefficients  
934, 935, 936, 1422, 1691

Mass matrices  
1420, 1692, 1855, 2326

Mass participation factors  
255

Mass-beam systems  
384, 1585, 2115, 2121

Mass-plate systems  
2473

Matched asymptotic expansion technique  
2202

Material damping  
198, 468, 470, 472, 694, 1001, 1002, 1010, 1107, 1108,  
1109, 1110, 1133, 1919, 2511

Materials handling equipment  
752, 1371

Mathematical models  
174, 283, 284, 301, 328, 343, 385, 516, 517, 518, 519, 571,  
688, 742, 822, 932, 950, 977, 998, 1094, 1108, 1123, 1157,  
1233, 1234, 1352, 1387, 1503, 1854, 1856, 2126, 2179,  
2367, 2423, 2442, 2569

Matrix methods  
828, 833, 1264, 1362, 1691, 1692, 1914, 2611

Matrix reduction methods  
2390, 2554

---

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1506 1506-1695 1696-1860 1861-2114 2115-2388 2389-2615

Volume 18

---

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

---

Maximum entropy spectral analysis  
 296

Maximum likelihood method  
 530

Mean square response  
 1066

Measurement techniques  
 147, 428, 484, 694, 768, 903, 1095, 1107, 1108, 1116,  
 1150, 1151, 1152, 1153, 1154, 1155, 1213, 1287, 1484,  
 1614, 1665, 1723, 2114, 2156, 2265, 2382, 2518, 2519,  
 2534, 2546

Measuring instruments  
 218, 221, 222, 1733, 2156, 2264, 2535, 2536, 2537, 2539,  
 2541, 224, 241, 429, 490, 492, 706, 708, 1128, 1130, 1131,  
 1818, 1819, 1820, 2081

Mechanical admittance  
 155

Mechanical components  
 876, 2104

Mechanical drives  
 283, 475

Mechanical impedance  
 155, 706, 1994, 2212

Mechanical systems  
 458, 507, 925

Membranes  
 106, 107, 162, 172, 627, 843, 1052, 1424, 2179, 2213

Metal working  
 542, 1369, 1875, 2129

Metals  
 1638, 1919

Method of superposition  
 1849, 2476

Microcomputers  
 1423, 1495, 1779, 1852, 2582

Microphones  
 662, 1550

Military standards  
 2593

Military vehicles  
 2289, 2579

Milling (machinery)  
 2389

Milling (machining)  
 1370, 1874, 2388

Mindlin theory  
 677, 639, 845, 1965

Mines (excavations)  
 1570

Minimization technique  
 2133

Minimum weight design  
 1984

Mining equipment  
 143

Missiles  
 326, 1013

Mixed element technique  
 1428

Mobility functions  
 2178

Mobility method  
 2274, 2277

Modal analysis  
 109, 197, 227, 231, 383, 390, 418, 499, 540, 686, 747, 758,  
 783, 905, 906, 1070, 1126, 1268, 1312, 1327, 1369, 1505,  
 1533, 1612, 1636, 1646, 1670, 1671, 1688, 1690, 1693,  
 1782, 1789, 1823, 1824, 2049, 2072, 2080, 2117, 2118,  
 2125, 2127, 2131, 2132, 2133, 2134, 2139, 2141, 2153,  
 2163, 2166, 2169, 2173, 2178, 2183, 2184, 2190, 2193,  
 2199, 2201, 2207, 2209, 2211, 2223, 2239, 2241, 2243,  
 2253, 2256, 2269, 2273, 2279, 2280, 2289, 2296, 2298,  
 2299, 2300, 2301, 2302, 2303, 2304, 2306, 2307, 2309,  
 2314, 2315, 2317, 2318, 2319, 2320, 2321, 2322, 2324,  
 2325, 2337, 2345, 2349, 2355, 2360, 2361, 2362, 2364,  
 2365, 2366, 2367, 2389, 2397, 2402, 2404, 2415, 2439,  
 2440, 2441, 2445, 2456, 2457, 2458, 2483, 2515, 2516,  
 2519, 2527, 2528, 2532, 2533, 2544, 2547, 2551, 2566, 2571

Modal balancing technique  
 500, 2608

Modal confidence method  
 2545

Modal constraint method  
 1058

Modal control techniques  
 51, 1916, 1917, 2567, 1326, 2445

Modal coupling  
 2454

Modal damping  
 322, 610, 1005, 1007, 1008, 1654

Modal energy reallocation method  
 882

Modal filters  
 148

Modal methods  
 710

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Modal models**  
 229, 1671, 1825, 2068

**Modal residualization technique**  
 2567

**Modal strain energy method**  
 292, 1101, 1104

**Modal superposition method**  
 509, 1073, 1480, 1660, 1682, 2072, 2136

**Modal synthesis**  
 709, 777, 1191, 1328, 1822, 1827, 2269, 2297, 2387, 2403, 2404, 2527

**Mode acceleration method**  
 1298, 1520

**Mode displacement method**  
 1520

**Mode response on trace method**  
 2542

**Mode shapes**  
 24, 67, 91, 95, 121, 153, 229, 230, 522, 612, 617, 648, 719, 771, 795, 833, 849, 1026, 1064, 1169, 1177, 1191, 1243, 1283, 1289, 1410, 1411, 1416, 1423, 1424, 1442, 1445, 1468, 1589, 1638, 1665, 1761, 1774, 1930, 1983, 1987, 1988, 2000, 2079, 2088, 2120, 2188, 2213, 2229, 2232, 2308, 2310, 2312, 2314, 2368, 2395, 2465, 2542, 2559

**Model strain energy method**  
 1105

**Model testing**  
 273, 304, 361

**Monitoring techniques**  
 248, 249, 250, 251, 252, 253, 254, 504, 505, 506, 720, 721, 722, 723, 915, 916, 917, 918, 919, 920, 990, 1143, 1344, 1495, 1496, 1497, 1498, 1841, 2091, 2341, 2343, 2609

**Monitoring**  
 2342

**Monte Carlo method**  
 109, 453, 1802, 1847, 1982, 2485

**Moorings**  
 1575, 1578, 2148

**Motor vehicle engines**  
 1705

**Motor vehicles**  
 1725, 2187

**Mountings**  
 64, 799, 1922

**Mounts**  
 2405, 2540

**Moving loads**  
 14, 409, 555, 616, 702, 747, 769, 1175, 1176, 1602, 1707

**Moving strips**  
 2206

**Multi degree of freedom systems**  
 133

**Multibeam systems**  
 2207

**Multibody systems**  
 1145, 1329, 1457, 1619, 2345, 2348, 2351, 2352

**Multifrequency excitation**  
 1147

**Multiphase-step-sine method**  
 2070

**Multiplane balancing techniques**  
 2340

**Multiple scale method**  
 1346, 1966, 2108

**Multiple shakers**  
 1331

**Multipoint excitation techniques**  
 244, 1336, 1845, 2161, 2307, 2558, 904

**Multireference method**  
 2551

**Multistorey buildings**  
 15, 104, 288, 289, 290, 546, 549, 550, 753, 761, 762, 956, 1520, 1521, 1887, 1890, 2139, 2140, 2141, 2507

**Multi-degree-of-freedom systems**  
 289, 344, 887, 1459, 1711, 1808, 1845, 2048, 2051, 2055, 2093, 2508, 2527

**Musical instruments**  
 371, 2458

**Myklestad method**  
 1887

- N -

**Natural frequencies**  
 67, 91, 95, 106, 113, 114, 118, 121, 125, 131, 153, 185, 189, 238, 353, 357, 381, 396, 402, 405, 522, 591, 607, 617, 624, 633, 639, 648, 771, 824, 833, 844, 846, 849, 970, 977, 1026, 1060, 1064, 1158, 1191, 1256, 1257, 1280, 1283, 1289, 1350, 1402, 1410, 1411, 1416, 1417, 1424, 1425, 1428, 1430, 1442, 1445, 1446, 1468, 1556, 1568, 1586, 1587, 1589, 1595, 1605, 1616, 1650, 1683, 1739, 1761, 1774, 1805, 1808, 1858, 1871, 1930, 1978, 1981, 1983, 1987, 1988, 1996, 2000, 2021, 2124, 2207, 2213, 2222, 2228, 2232, 2237, 2244, 2246, 2308, 2314, 2318, 2385, 2462, 2465, 2477, 2542, 2559, 2564

**Natural modes**  
 1127

**Near-field region**  
 110

**Abstract**  
 Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Newmark method  
96, 126, 1581, 1887

Newton-Raphson method  
71, 72

Noise analyzers  
226

Noise barriers  
1623

Noise control  
41, 449, 1204, 1909

Noise generation  
7, 11, 180, 334, 339, 340, 415, 446, 448, 597, 749, 866, 872, 1300, 1369, 1401, 1456, 1514, 1560, 1769, 1979, 2149, 2253

Noise measurement  
305, 332, 338, 339, 360, 798, 861, 1213, 1570, 1783, 1911, 2081, 2412

Noise prediction  
280, 445, 447, 541, 1174, 1214, 1567, 1742, 2388, 2485

Noise reduction  
9, 13, 39, 40, 53, 155, 281, 414, 423, 572, 585, 665, 666, 748, 752, 862, 999, 1000, 1001, 1168, 1453, 1455, 1541, 1544, 1617, 1620, 1621, 1622, 1623, 1706, 1725, 1952, 2127, 2155, 2169, 2258

Noise source identification  
427, 994, 1517, 1784, 2256, 2267, 2460, 2518

Noise tolerance  
333, 581, 1014

Noise transmission  
2156, 2410, 2502

Noncontacting probes  
219

Nondestructive tests  
233, 234, 713, 780, 1132, 1139, 1339, 1607

Nonlinear damping  
35, 1559, 1905

Nonlinear response  
21, 400, 614, 615, 702, 775, 1046, 1593, 1599, 1709, 2145, 2146, 2255, 2531

Nonlinear springs  
1511

Nonlinear stiffness  
190

Nonlinear systems  
265, 267, 729, 737, 881, 887, 1073, 1313, 1470, 1515, 1807, 2093, 2099, 2141, 2304, 2353, 2354

Nonlinear theories  
133, 134, 261, 275, 619, 623, 930, 1016, 1042, 1345, 1434, 1776, 2248, 2355, 2476

Nonproportional damping  
197

Nonsynchronous vibration  
1414

Normal density functions  
462, 1847

Normal mode method  
1304, 1312, 1581, 2330

Normal modes  
96, 176, 440, 441, 516, 649, 673, 826, 868, 933, 1646, 1830, 2272

Notched structures  
1971

Nozzles  
414, 862, 2248, 2259

Nuclear containment structures  
1195, 1196, 1903

Nuclear explosion effects  
184, 221, 326, 1439, 2041, 2506

Nuclear fuel elements  
781, 782, 918, 988

Nuclear power plants  
28, 29, 300, 458, 756, 757, 758, 778, 803, 804, 806, 808, 811, 858, 860, 989, 1179, 1196, 1197, 2147, 2398, 2399, 2428

Nuclear powered ships  
32

Nuclear reaction safety  
989

Nuclear reactor components  
2236, 249, 297, 505, 556, 780, 781, 920, 1074, 1076, 1080, 1241, 2012, 2143, 2398

Nuclear reactor containment  
28, 1075, 2023

Nuclear reactor safety  
299

Nuclear reactors  
298, 506, 557, 655, 765, 779, 915, 986, 987, 1194, 1198, 1199, 1536, 1719, 2145, 2146, 2399

Nuclear waste depositories  
671, 782

Nuclear weapons effects  
2463

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Numerical methods  
266, 267, 520, 738, 2106, 2107, 2267, 2356, 2464, 2469,  
2484, 2538, 2612

- O -

Oceans  
1757, 2495

Off-highway vehicles  
2405

Off-shore structures  
25, 141, 143, 203, 558, 559, 560, 561, 562, 563, 764, 1200,  
1201, 1392, 1575, 1584, 1675, 1720, 1721, 1722, 1723,  
1757, 1904, 1906, 2136, 2237, 2335, 2400, 2401

Oil dampers  
1653

Oil film bearings  
1400, 1706, 1941, 1942, 2116

Openings  
1083

Opening-containing media  
2026

Optical probes  
219

Optimization  
75, 119, 728, 937, 1031, 1091, 1214, 1228, 1272, 1356,  
1373, 1592, 1636, 1857, 1858, 2157, 2175, 2301, 2391,  
2494, 2511, 2571

Optimum control theory  
325, 586, 1091

Optimum design  
376, 579, 801, 807, 1021, 1166, 1370, 1689, 1695, 1735,  
2135

Orthotropism  
844, 851

Oscillation  
564, 646, 1051, 2148, 2501

Oscillators  
680, 891, 1648, 1649, 2096

- P -

Packaging  
1737, 1926

Panels  
108, 391, 392, 393, 394, 628, 1053, 1141, 1273, 1592,  
1615, 1984, 1985, 1986, 2166, 2488

Paper products  
218, 2114

Parabolic bodies  
1045

Parallelepiped bodies  
1650, 1998

Parameter identification techniques  
524, 663, 739, 740, 934, 935, 936, 937, 938, 1003, 1004,  
1171, 1327, 1504, 1688, 1690, 1693, 1694, 1823, 1913,  
1938, 2190, 2282, 2309, 2312, 2319, 2321, 2322, 2324,  
2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366,  
2367, 2379, 2395, 2406, 2407, 2516, 2517, 2524, 2525,  
2528, 2529, 2532, 2545, 2550, 2551, 2613, 830, 1156, 1628

Parametric excitation  
1516, 2044, 2050

Parametric resonance  
1511, 2200, 2275

Parametric response  
735, 2015

Parametric vibrations  
1518, 192, 1054

Particular integral method  
2350

Pasternak foundations  
1065, 1605

Pavements  
554, 769, 1658

Penalty technique  
2301

Pendulums  
2057, 2089, 2355

Penetration  
1637

Periodic excitation  
16, 87, 100, 463, 880, 889, 1065, 1269, 1290, 1539, 1574,  
1608, 1963, 2161, 2523

Periodic response  
266, 615, 733, 805, 1408, 1441, 1739, 1772, 1861, 1930,  
2048, 2206, 2273, 2360

Periodic structures  
515, 928, 1412, 1419, 1850, 1851, 2117, 2204, 2274, 2487

Personal computers  
527, 2021, 2577, 2598

Perturbation method  
2183

Perturbation theory  
18, 142, 185, 513, 514, 691, 724, 725, 1347, 1540, 1866,  
1961, 2056, 2296, 2302, 2489, 2562

Phase methods  
2395, 2524

Phase resonance method  
805, 2305

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Phase separation method  
1830, 2305

Photoelastic analysis  
213, 1118

Photographic techniques  
568, 1765

Piers  
1519

Piezoceramics  
194

Piezoelectric transducers  
487, 488

Pile driving  
20, 1386

Pile structures  
19, 21, 903, 963, 1202, 1384, 1385

Piles  
22

Pipe whip restraints  
1080

Pipe whip  
858, 1638, 2012, 2241

Pipelines  
146, 249, 418, 419, 420, 655, 656, 859, 860, 1070, 1072, 1073, 1074, 1075, 1076, 1077, 1201, 1293, 1294, 1295, 1392, 1447, 1609, 1610, 1782, 1794, 2015, 2020, 2021, 2236, 2237, 2239, 2240, 2241, 2243, 2244, 2338

Pipes  
143, 144, 657, 780, 857, 858, 1078, 1079, 1611, 1829, 2013, 2014, 2016, 2017, 2238, 2242, 2479, 2481

Pistons  
452, 947

Pivoted pad bearings  
1949

Plane wave approximation  
135

Planet gears  
600, 1402, 1569

Plates  
46, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 162, 172, 393, 396, 398, 406, 407, 409, 545, 629, 631, 632, 633, 634, 637, 638, 704, 705, 844, 845, 847, 1054, 1055, 1274, 1275, 1276, 1277, 1278, 1279, 1286, 1287, 1300, 1310, 1324, 1372, 1405, 1416, 1419, 1424, 1425, 1426, 1427, 1428, 1429, 1430, 1431, 1432, 1474, 1593, 1594, 1595, 1615, 1643, 1710, 1770, 1772, 1773, 1774, 1777, 1779, 1988, 1989, 1990, 1991, 1998, 2024, 2214, 2216, 2217, 2218, 2221, 2223, 2224, 2225, 2283, 2418, 2459, 2460, 2461, 2462, 2463, 2464, 2470, 2510

Pneumatic dampers  
348

Pneumatic isolators  
589, 1923

Pneumatic lines  
1071

Pneumatic springs  
349, 589, 1022, 1238

Pneumatic tires  
2180, 2181

Pneumatic tools  
1017

Point source excitation  
434, 1790, 2007, 2466, 2474

Poisson's ratio  
1965, 2222

Polymers  
1473, 2061

Polyreference method  
2545

Polyurethane resins  
2171

Porous materials  
434, 442, 707, 1302, 1941, 1942, 1947, 2260

Positioning devices  
681

Power plants (facilities)  
2341

Power plants  
7, 10, 990, 1113, 1535

Power spectra  
453

Power spectral density  
1847, 463, 540, 1150, 1151, 1152, 1153, 1154, 1155, 2515

Power transmission systems  
282, 1368, 1513, 1566, 1750

Prediction techniques  
480, 1115, 2092

Presses  
281, 748, 1174

Prestressed concrete  
561, 618, 1265, 1659, 1707, 1885

Prestressed structures  
406

**Abstract**

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 18**

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Prismatic bodies  
141, 377, 849, 1093

Probability density function  
263, 350, 462, 558, 2095

Probability theory  
294, 2039

Proceedings  
1620

Projectile penetration  
874

Propellant tanks  
2235

Propeller blades  
68, 359, 360, 361, 362, 363, 364, 365, 393, 816, 942, 1215,  
1224, 1559, 1560, 1742, 1743, 1930

Propeller noise  
2030

Propellers  
11, 422, 1225, 1226, 1227, 1784

Proximity probes  
1817, 2521, 2534

Pseudodynamic testing method  
1460, 1673

Pulse combustion devices  
174

Pulse excitation  
62, 1047, 1271, 1484, 1640, 1897, 2191, 2330, 2463, 2474,  
2482

Pumps  
9, 10, 920, 947, 1165, 1241, 1407, 2126, 2384

Perturbation theory  
2100

Pyrotechnic shock environment  
495, 2596

- Q -

Quartz crystals  
220, 1820, 2077, 2329

Quartz  
1285

- R -

Radioactive materials  
988

Railroad bridges  
1176, 1519, 1707

Railroad cars  
1724, 2580

Railroad tracks  
555

Railroad trains  
584, 785, 787, 1238, 1538, 2578

Railroads  
1190

Rails  
1188, 1189

Railway wheels  
718, 813, 1343

Rail-vehicle interaction  
784, 1538

Rail-wheel interaction  
776, 784, 785, 1188, 1189, 1539

Raleigh-Ritz method  
771, 1057

Random decrement technique  
99, 2088

Random excitation  
33, 34, 109, 130, 270, 367, 464, 552, 699, 1466, 1469,  
1646, 1992, 2051, 2063, 2097, 2161, 2447, 2512, 2600

Random parameters  
735, 1348, 2051

Random response  
827, 1656, 1771, 1985, 2043, 2101, 2357, 2360, 2515, 2583

Random tests  
2584

Random vibration tests  
2601

Random vibration  
412, 454, 529, 714, 715, 892, 1312, 1378, 1388, 1459,  
1803, 1804, 1805, 1808, 1865, 1982, 2010, 2049, 2050,  
2096, 2157, 2276, 2304, 2369, 2493, 2507, 2581, 2588, 2590

Rational fraction polynomials  
2308

Rayleigh method  
728, 2094

Rayleigh-Ritz method  
124, 384, 399, 509, 846, 1177, 1598, 2121, 2222, 2223,  
2467

Reciprocating compressors  
517, 1307, 2021

Reciprocating engines  
1367, 1493

---

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1880 1881-2114 2115-2368 2369-2615

Volume 18

---

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

---

Reciprocating machinery  
749

Recording instruments  
224, 1129

Rectangular bars  
826

Rectangular beams  
89, 1586

Rectangular bodies  
2482

Rectangular panels  
1987

Rectangular plates  
123, 124, 125, 126, 127, 128, 129, 130, 397, 400, 408, 635,  
636, 846, 848, 1056, 1057, 1058, 1285, 1285, 1433, 1434,  
1596, 1597, 1598, 1599, 1769, 1771, 1993, 1994, 1995,  
1996, 1997, 2222, 2226, 2465, 2466, 2467, 2468, 2469,  
2534, 2548

Recursive methods  
1845

Reduction methods  
90, 514, 926, 927, 1500

Reentry vehicles  
327

Reinforced concrete  
105, 149, 547, 548, 609, 613, 661, 756, 760, 839, 939, 959,  
960, 961, 1179, 1373, 1376, 1379, 1461, 1594, 1710, 1711,  
1889, 1903, 1972, 2026, 2085, 2141

Reinforced structures  
411, 1078

Reissner method  
2002

Reliability  
294, 389, 460, 493, 494, 1719

Residual compliance matrix  
2074

Resonance bar techniques  
1133

Resonance pass through  
1809

Resonance tests  
198, 1729

Resonant column tests  
966, 967

Resonant frequencies  
273, 307, 392, 652, 888, 1285, 1316, 1335, 1777, 2229

Resonant response  
357, 436, 647, 985, 1402, 1472, 1602, 1759, 1933, 2099,  
2202, 2227, 2381, 2486

Resonators  
220, 1820, 2077, 2329

Response spectra  
23, 940, 1381, 1682, 2067

Response spectral density  
2130

Restoring factors  
1905

Retaining walls  
151

Reverberation chambers  
2316

Reviews  
573, 587, 604, 619, 672, 711, 721, 992, 1130, 1239, 1321,  
1395, 1456, 1498, 1538, 1679, 1804, 1857, 1858, 1974, 2219

Ribs (supports)  
640, 641

Ride dynamics  
302, 777

Rigid body modes  
2317, 2557, 2561

Rigid foundations  
23, 552, 2384

Rigid plastic properties  
1640

Rings  
413, 650, 1445, 1446, 2181, 2213, 2451

Ritz method  
113, 1433, 1467, 1589, 1595, 1998, 2226

Ritz vectors  
1332, 1333

Ritz-Galerkin method  
1049

Riveted joints  
1036

Rivets/joints  
1607

Road roughness  
296, 334, 777, 2149, 2405

Road-vehicle interaction  
1178

Robots  
821, 822, 1880, 1969, 2277, 2355

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Rock foundations**  
 1180, 1717

**Rocket engines**  
 52

**Rocking**  
 23

**Rocks**  
 1181, 1548, 1549, 1686

**Rods**  
 374, 375, 605, 706, 918, 1964, 1965, 2199, 2200

**Roller bearings**  
 1157, 1253, 1676, 1746, 1936

**Rolling contact bearings**  
 73, 243, 244, 254, 723, 1172, 1344, 1496, 2609

**Rolling friction**  
 899, 902

**Rolling motion**  
 34, 35

**Roofs**  
 866, 1410

**Rooms**  
 669, 2485

**Rotating machinery**  
 504, 540, 914, 1166, 1342, 1865, 1937, 2120, 2170, 2369, 2607, 2608

**Rotating structures**  
 12, 374, 888, 1446, 2121, 2122, 2377, 2477

**Rotational degrees of freedom**  
 2300

**Rotational response**  
 49, 730

**Rotatory compressors**  
 2604

**Rotatory inertia effects**  
 119, 130, 608, 621, 634, 639, 650, 1056, 1200, 1259, 1300, 1328, 1362, 1425, 1931, 1960, 1970, 1973, 2206, 2210, 2461

**Rotor blades (turbomachinery)**  
 351, 352, 403, 1027

**Rotor blades**  
 817, 1740

**Rotors**  
 2, 5, 272, 274, 275, 276, 501, 535, 536, 537, 538, 539, 540, 743, 744, 944, 1037, 1123, 1160, 1162, 1359, 1360, 1361, 1362, 1400, 1511, 1512, 1515, 1697, 1698, 1749, 1838, 1861, 1862, 1866, 1867, 1868, 1870, 1871, 1925, 2090, 2115, 2340, 2370, 2371, 2372, 2373, 2374

**R-function method**  
 1426

- S -

**Sand**  
 769, 912, 964, 1474, 1529

**Sandwich panels**  
 109

**Sandwich structures**  
 120, 392, 398, 629, 1279, 1615, 1656, 2166, 2220, 2472

**Scaling**  
 1791, 2085, 2602

**Screening**  
 715, 2212, 2492, 2493

**Seals**  
 84, 85, 901, 1037, 1260, 1407, 1408, 1572, 1573, 1752, 1753, 1754, 1755, 1961, 1962, 2192, 2451, 2452, 2453

**Search techniques**  
 1848

**Seismic analysis**  
 295, 297, 389, 420, 553, 774, 964, 982, 983, 987, 1067, 1184, 1187, 1241, 1379, 1382, 1389, 1391, 1525, 1526, 1633, 1686, 1884

**Seismic design**  
 15, 18, 151, 454, 547, 548, 661, 759, 778, 807, 808, 842, 893, 939, 940, 961, 979, 1077, 1185, 1240, 1373, 1376, 1381, 1708, 1859, 1889, 2109, 2110, 2429

**Seismic excitation**  
 16, 23, 65, 149, 354, 552, 764, 853, 958, 967, 1088, 1180, 1186, 1382, 1387, 1388, 1439, 1635, 1865, 1903, 2023, 2039, 2105, 2144, 2233, 2331

**Seismic isolation**  
 557, 587, 685, 803, 804, 805, 806, 809, 810, 811, 812, 1241, 1374, 1522, 2424, 2425, 2426, 2430, 2431

**Seismic response spectra**  
 453, 865, 939, 1298, 1525, 1526, 1527, 1794, 2109

**Seismic response**  
 28, 29, 79, 105, 150, 152, 153, 185, 255, 285, 287, 288, 289, 298, 407, 412, 424, 455, 457, 492, 546, 549, 551, 638, 760, 761, 762, 766, 773, 775, 782, 839, 840, 852, 860, 878, 933, 959, 960, 962, 963, 989, 1074, 1075, 1087, 1177, 1195, 1197, 1198, 1199, 1203, 1295, 1372, 1376, 1380, 1383, 1390, 1438, 1460, 1461, 1520, 1522, 1533, 1534, 1634, 1710, 1715, 1716, 1718, 1719, 1766, 1781, 1845, 1882, 1883, 1888, 1890, 1972, 2006, 2015, 2085, 2140, 2141, 2142, 2143, 2147, 2239, 2369, 2394, 2507, 2508

**Seismic tests**  
 236, 712, 1022, 1135, 1179, 1196, 1536, 1673, 1793, 2025, 2398

**Seismic waves**  
 186, 1352

**Abstract**  
 Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1880 1881-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Self-excited vibrations  
192, 1225, 2044

Semiactive vibration  
1239

Sensitivity analysis  
1867, 2298

Servomechanisms  
2385

Shafts  
3, 214, 277, 332, 333, 943, 1158, 1159, 1161, 1163, 1363,  
1364, 1506, 1507, 1513, 1583, 1696, 1697, 1738, 1755,  
1839, 1863, 1964, 1869, 2089, 2117, 2118, 2119, 2337,  
2376, 2377, 2378, 2379, 2380, 2381, 2382

Shakedown theorem  
388

Shakers  
910, 975, 1022, 1340, 1831, 2332, 2575, 2576, 2590, 2601

Shear modulus  
470, 768, 909, 2114

Shear strength  
613

Shear vibration  
1650

Shear waves  
1089, 1183, 1447, 1619

Sheet strength  
661

Shells of revolution  
1068, 1999

Shells  
133, 134, 135, 141, 409, 647, 849, 963, 1067, 1438, 1439,  
1440, 1447, 1594, 1601, 1602, 1643, 1781, 1828, 1902,  
2000, 2227, 2228, 2247, 2476

Ship anchors  
1575

Ship hulls  
1209, 2406

Ship noise  
1632

Shipboard equipment response  
32, 1816

Shipping containers  
671

Ships  
33, 34, 35, 36, 203, 306, 308, 394, 565, 566, 993, 1207,  
1208, 1210, 1211, 1212, 1393, 1495, 1540, 2150, 2151

Shock absorbers  
799, 1236, 1555

Shock absorption  
66

Shock excitation  
2128

Shock isolation  
326, 683, 2173

Shock isolators  
348, 589, 1636

Shock resistant design  
1465

Shock response spectra  
1465, 1870

Shock response  
135, 394, 708, 1206, 1724, 1857

Shock tests  
17, 459, 492, 1491, 1831, 1832, 2592, 2597, 2598, 2600

Shock tube testing  
875

Shock wave attenuation  
1306, 1307, 2037

Shock wave propagation  
450, 674, 879, 1089, 1798, 2484

Shock waves  
117, 183, 1244, 1311, 1463, 1464, 1499, 1637, 1642, 1797,  
1799, 1800, 1801, 1802, 2042, 2268

Shock wave-boundary layer interaction  
660, 1090

Shrouds  
422, 1557, 1932, 1933

Siffened plates  
1063

Signal processing techniques  
485, 722, 723, 905, 1140, 1486, 1487, 1488, 1494, 1933,  
2028, 2543, 2549

Signal processing  
2536

Signature analysis  
1676, 1816, 2336, 2497, 2558, 2609

Silencers  
57

Simulation  
453, 949, 1145, 1610, 1876, 1935, 2035, 2356, 2503, 2508,  
2579, 2583, 2589, 2602

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1158 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Sine-dwell technique 1726	Sound attenuation 2024
Single degree of freedom systems 1088, 1147, 1346, 1459, 1472	Sound generation 8, 1872, 2029, 2271
Single point excitation technique 198, 1726, 2307, 2414	Sound insertion noise 438
Sinusoidal excitation 633, 1395, 2282	Sound level meters 177, 490, 1669
Skew plates 402, 630, 1778, 2220	Sound measurement 171, 2033, 2034, 2316
Slabs 609, 613, 1186, 1319	Sound power levels 171, 1086, 2319
Slamming 788	Sound pressure levels 1625
Slider crank mechanisms 1751	Sound pressure 1454
Sliding bearings 1838	Sound propagation 160, 258, 259
Sliding friction 242	Sound transmission loss 159, 164, 425, 444
Sliding supports 1522	Sound transmission 140, 391, 628, 631, 1523, 2392
Sling loads 1230	Sound waves 92, 93, 107, 157, 161, 162, 169, 170, 172, 173, 175, 176, 178, 179, 234, 391, 395, 421, 423, 428, 429, 430, 432, 433, 434, 435, 436, 439, 441, 659, 667, 668, 867, 868, 869, 870, 871, 1082, 1083, 1084, 1085, 1275, 1296, 1301, 1302, 1303, 1304, 1405, 1421, 1435, 1448, 1449, 1451, 1452, 1463, 1514, 1558, 1601, 1627, 1629, 1630, 1632, 1661, 1779, 1780, 1787, 1788, 1789, 1790, 1791, 1792, 2001, 2007, 2018, 2021, 2030, 2031, 2032, 2036, 2106, 2248, 2249, 2251, 2252, 2261, 2263, 2264, 2266, 2495, 2496, 2498, 2500, 2566
Sloshing 139, 297, 307, 557, 1316, 1317, 1318, 1734, 1806, 1918, 2006	Sound 797
Snow 181	Space shuttles 52, 232, 329, 330, 331, 332, 1007, 2419, 2421, 2574
Soils 20, 26, 294, 442, 443, 456, 525, 674, 766, 768, 909, 964, 966, 967, 968, 1184, 1899, 1900, 1901	Space stations 1234, 2165
Soil-foundation interaction 965, 969, 1180, 1711, 2037, 2170, 2435	Spacecraft components 687, 2165, 2166, 2167, 2553
Soil-structure interaction 19, 22, 293, 350, 551, 560, 757, 765, 767, 769, 871, 963, 971, 1043, 1044, 1183, 1384, 1388, 1529, 1530, 1531, 1532, 1712, 1713, 1714, 1719, 1892, 1893, 1896, 1897, 1898, 2005, 2041, 2143, 2394, 2508	Spacecraft equipment response 324, 686
Solar energy 1547	Spacecraft instrumentation responses 1012, 1011
Sommerfeld number 1254	Spacecraft platforms 50, 411, 580, 1011
Sonic boom 2035	
Sonograms 643	

Abstract  
Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Stress amplification factors**  
 2290

**Stress analysis**  
 2188, 2521

**Stress intensity factors**  
 2098, 2217

**Stress waves**  
 1124, 1499, 1639, 1777, 1799

**Strings**  
 93, 371, 1574, 1963, 2194

**Strip method**  
 1183, 1778

**Strips**  
 1579

**Structural damping**  
 1403

**Structural members**  
 212, 267, 424, 474, 543, 710, 863, 864, 1049, 1079, 2486, 2487

**Structural modification techniques**  
 30, 227, 228, 313, 534, 566, 666, 817, 906, 1091, 1127, 1355, 1687, 1694, 1695, 2094, 2172, 2209, 2234, 2244, 2296, 2298, 2299, 2300, 2301, 2391, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2603

**Structural response**  
 1308, 1520, 1533, 2095

**Structural synthesis**  
 264, 1356

**Structure borne noise**  
 281, 573, 574, 1287, 1543, 1619, 2165

**Structure borne vibration**  
 631

**Structure-foundation interaction**  
 65, 1465, 1717

**Structure-ground interaction**  
 1894, 1895

**Struts**  
 1210

**Subharmonic oscillations**  
 864, 512, 922, 1574, 2045, 2376

**Submarine hulls**  
 1910

**Submarines**  
 32, 1577

**Submerged structures**  
 93, 99, 110, 135, 140, 141, 143, 183, 375, 380, 402, 467, 620, 628, 633, 682, 717, 1291, 1313, 1314, 1315, 1759, 1780, 2054, 2202, 2292, 2295, 2400

**Subspace method**  
 2349, 2530

**Substructuring methods**  
 264, 320, 511, 906, 1332, 1333, 1460, 1718, 2073, 2120, 2211, 2277, 2288, 2297, 2403, 2416

**Subsynchronous vibration**  
 745, 943, 1161, 1366, 1703, 2381

**Successive transformation method**  
 2288

**Sum and difference frequencies**  
 1574, 1837

**Summation of forces method**  
 1727

**Superharmonic vibrations**  
 2045

**Supports**  
 24, 1442, 1595, 1669, 1737, 1925, 1937, 1969, 1975, 2244, 2378, 2507

**Surface effect machines**  
 304, 306, 564

**Surface roughness**  
 14, 296, 1537, 1611, 1645, 1790, 1907

**Suspended structures**  
 152

**Suspension bridges**  
 951, 952, 1175, 2455

**Suspension systems (vehicles)**  
 60, 61, 349, 586, 802, 1236, 1238, 1554, 2174, 2175, 2176, 2180, 2437

**Swept sine wave excitation**  
 1774, 1829, 2581, 2584

**Synchronous motors**  
 1358

**Synchronous vibration**  
 1, 943

**Synchrophasing method**  
 2155

**System analysis**  
 2347

**System identification techniques**  
 269, 308, 503, 521, 522, 523, 524, 760, 933, 959, 1326, 1335, 1692, 1856, 1882, 2338, 2368

**Abstract**  
 Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 18**  
 Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Spacecraft**  
 49, 51, 228, 292, 311, 312, 320, 321, 322, 323, 325, 328,  
 469, 730, 800, 820, 1003, 1004, 1005, 1006, 1008, 1009,  
 1010, 1102, 1104, 1132, 1233, 1266, 1394, 1406, 1546,  
 1547, 1734, 1735, 1767, 1806, 1828, 1914, 1915, 1916,  
 1917, 1918, 1919, 2160, 2161, 2162, 2163, 2164, 2313,  
 2339, 2415, 2416, 2417, 2418, 2422, 2574

**Specifications**  
 2592

**Spectrum analysis**  
 226, 250, 1381, 1489, 1517, 1782, 1812, 2067, 2149, 2189,  
 2315, 2455, 2489

**Spheres**  
 273, 2294

**Spherical shells**  
 156, 410, 646, 682, 851, 1065, 1066, 1442, 1604, 1605,  
 2001, 2002, 2229

**Spindles**  
 1157, 1172

**Spline technique**  
 384, 1778, 1848

**Spoilers**  
 880

**Spokes**  
 1446

**Spring constants**  
 965, 1565

**Springs**  
 657, 812, 1966, 2093, 2177, 2438

**Spring-supported foundations**  
 980, 981

**Spur gears**  
 1566, 1567, 1568, 1951, 2446

**Squeeze-film bearings**  
 595, 1398, 1938, 1964

**Squeeze-film dampers**  
 196, 693, 1322, 1323, 1398, 1652, 2052, 2053, 2225

**Stability**  
 265, 316, 362, 513, 535, 593, 626, 925, 1269, 1408, 1512,  
 1680, 1807, 1905, 1939, 1941, 1942, 2116, 2119, 2131

**Stalling**  
 1508, 1509

**Standards and codes**  
 448, 972, 1227, 1367, 1889, 2333, 2540, 2594

**State space approach**  
 231

**Statistical analysis**  
 558, 1088, 1305, 1452, 1628, 1846, 2039, 2124, 2357

**Statistical energy methods**  
 885, 1354, 2263

**Statistical linearization**  
 2304

**Steam hammer**  
 419

**Steam turbines**  
 745, 915, 1030, 2371

**Steel**  
 28, 199, 200, 291, 202, 203, 204, 205, 370, 480, 506, 544,  
 622, 625, 695, 1117, 1195, 1373, 1461, 1889, 1971, 2110

**Step functions**  
 1597

**Step relaxation method**  
 1826

**Stepped-sine excitation**  
 2311

**Stick-slip excitation**  
 1407

**Stick-slip response**  
 883, 1092, 1749

**Stiffened plates**  
 401, 405, 1992, 2219

**Stiffened shells**  
 648

**Stiffeners**  
 1421

**Stiffness coefficients**  
 20, 84, 85, 550, 593, 693, 934, 935, 936, 1254, 1319, 1396,  
 1543, 1573, 1691, 1748, 1863, 1940, 1944, 1945, 2192,  
 2199, 2371, 2385, 2391, 2453, 2511

**Stiffness effects**  
 277, 1542, 1655

**Stiffness matrices**  
 1156, 1420, 1683, 1692, 1850, 1851, 1855, 2326

**Stiffness**  
 2342

**Stochastic processes**  
 18, 289, 350, 586, 698, 918, 1345, 1380, 1635, 1685, 1854,  
 1856, 1982, 2050, 2097, 2130, 2145, 2146, 2162, 2600

**Storage tanks**  
 412, 852, 853, 1918, 2005, 2006, 2478

**Strain gages**  
 704, 705, 2082

**Strains**  
 2303, 2597

**Abstract**

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 19**

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

- Takeoff  
314
- Tanker ships  
307
- Tanks (containers)  
139
- Taylor series  
523, 2051
- Temperature effects  
125, 194, 470, 479, 630, 633, 675, 715, 866, 1059, 1061,  
1062, 1076, 1119, 1321
- Tennis rackets  
2281
- Test equipment  
901, 910, 969, 1189, 1832, 2506
- Test facilities  
318, 444, 476, 477, 531, 716, 792, 875, 908, 1337, 1338,  
1340, 1491, 2084, 2331, 2332, 2419, 2421, 2499, 2520,  
2548, 2573, 2574, 2575, 2580, 2582, 2588, 2601
- Test models  
912, 2313
- Test stands  
1834
- Testing  
911
- Testing instrumentation  
497, 2452, 2586
- Testing techniques  
42, 232, 245, 331, 493, 494, 495, 496, 498, 712, 714, 764,  
909, 969, 1076, 1110, 1132, 1134, 1135, 1341, 1490, 1699,  
1700, 1831, 1833, 2069, 2083, 2411, 2452, 2492, 2493,  
2522, 2523, 2576, 2578, 2579, 2581, 2583, 2585, 2587,  
2594, 2598, 2599
- Textile looms  
1023, 1515, 1958
- Textile spindles  
837
- Textiles  
941
- Thermal damping  
687, 1321
- Thermoelasticity  
235, 1100
- Three-dimensional problems  
655
- Thrust bearings  
818
- Tiles  
232, 1286
- Tilt pad bearings  
1254, 1565, 1948
- Time dependent parameters  
970
- Time domain method  
159, 164, 264, 322, 323, 383, 435, 485, 499, 530, 867, 933,  
986, 1210, 1387, 1476, 1484, 1485, 1532, 1663, 1666, 1685,  
1688, 1690, 1742, 1823, 1835, 2049, 2088, 2303, 2304,  
2306, 2307, 2347, 2360, 2361, 2364, 2365, 2389, 2395,  
2515, 2517, 2528, 2532
- Time integration method  
1144
- Time series analysis method  
223, 1171, 2309
- Time shift frequency domain  
2321
- Time-dependent parameters  
1296, 1848
- Timoshenko theory  
91, 377, 381, 383, 413, 611, 612, 613, 632, 827, 831, 1418,  
1419, 1583, 1586, 1871, 1973, 1976, 1981, 2193, 2479
- Timoshenko  
2380
- Tires  
302, 1026, 2179, 2439, 2476
- Tire-wheel interaction  
590, 2180, 2181
- Titanium  
1142
- Toroidal shells  
136, 137, 1289, 2007
- Torque  
274, 947, 1582, 2382
- Torsional excitation  
3
- Torsional response  
23, 378, 753, 755, 789, 829, 942, 957, 958, 1255, 1634,  
1924
- Torsional vibrations  
12, 277, 282, 369, 500, 533, 750, 944, 1164, 1358, 1359,  
1363, 1506, 1507, 1551, 1696, 2108, 2118, 2120, 2207,  
2386, 2448
- Towed bodies  
1409

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

Towed systems  
1540, 2151, 2432

Towers  
291, 292, 763, 764, 2393

Track roughness  
776

Tracked vehicles  
2174, 2437

Tractors  
777, 1191

Traffic noise  
53, 177, 334, 335, 445, 1620, 1783, 1920

Traffic sign structures  
1590, 1591

Traffic-induced vibrations  
335, 584

Transducers  
492, 1483, 2538

Transfer functions  
662, 1242, 2347, 2366, 2552

Transfer matrix method  
21, 144, 824, 1072, 1868, 2177, 2229, 2344

Transformation techniques  
1348

Transformers  
2080

Transient analysis  
510, 1686, 1860

Transient excitation  
1144, 1490, 1594, 2152

Transient response  
323, 380, 419, 467, 532, 835, 1281, 1293, 1639, 1681, 2043, 2194, 2254

Transient vibrations  
1483, 1925, 2115

Translational inertia effects  
2210

Translational response  
49, 374, 730, 1261, 1367

Transmission lines  
604, 1070, 1071, 1610, 2195, 2278, 2287

Transportation effects  
321, 988, 1926

Transverse shear deformation effects  
114, 118, 119, 130, 608, 612, 621, 634, 639, 650, 1056, 1200, 1300, 1362, 1425, 1931, 1973, 2206, 2461

Triangular bodies  
2470

Truck tires  
590

Trucks  
1192, 1193, 1236, 1928, 2403, 2404

Truncation  
1694

Trusses  
623, 841, 1418, 1768

Tube arrays  
147, 300, 415, 438, 652, 653, 654, 1069, 1290, 1291, 1292, 2008, 2009, 2010, 2011, 2480

Tubes  
80, 145, 416, 417, 611, 651, 854, 855, 856, 1474, 1608, 2016, 2018, 2143, 2245, 2246, 2247, 2479

Tuned frequencies  
2417

Tuning  
230, 973, 1029, 1031, 1932, 1935, 2275, 2375

Tunnels  
770

Turbine blades  
67, 353, 354, 355, 356, 476, 592, 1028, 1030, 1244, 1245, 1600, 1931, 2441, 2442

Turbine components  
2290

Turbine engines  
746, 1113

Turbine rotors  
1249

Turbines  
6, 502, 2125

Turbofan engines  
180, 945

Turbogenerators  
978, 979, 1051, 2169

Turbomachinery  
5, 977, 980, 981, 1165, 1836, 2375, 2604

Turbulence  
98, 173, 354, 358, 365, 577, 578, 660, 677, 793, 956, 1069, 1082, 1201, 1456, 1565, 1745, 1961, 2010, 2053, 2230

Two degree of freedom systems  
586

Two microphone technique  
994, 1086, 1614

Abstract

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

- U -

Ultrasonic techniques  
225, 240, 245, 338, 1142, 1339, 1440, 1817

Ultrasonic vibrations  
2538

Unbalanced mass response  
64, 538, 944, 1160, 1254, 1511, 1868, 1869, 2116, 2444

Uncoupling technique  
2526

Undamped structures  
2273

Underground explosions  
221, 2506

Underground structures  
326, 420, 968, 1183, 1185, 1384, 1447, 1713, 2015, 2041,  
2142, 2143

Underwater explosions  
117, 401, 1063, 1207

Underwater pipelines  
658

Underwater shock waves  
451, 877, 1063

Underwater sound  
157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168,  
437, 438, 439, 440, 441, 869, 1085, 1304, 1305, 1452,  
1629, 1630, 1631, 1632, 1788, 2033, 2034, 2036

Underwater structures  
100, 1202, 1203, 1262, 1422, 1758, 2237

Universal joints  
1864

- V -

Valves  
2092

Van der Pol method  
192, 930, 931, 1649, 2044

Vanes  
358

Variable cross section  
120, 125, 126, 372, 380, 396, 399, 533, 539, 702, 847,  
1045, 1203, 1264, 1274, 1281, 1282, 1283, 1420, 1436,  
1437, 1583, 1776, 1970, 1974, 1976, 2000, 2014, 2232,  
2469, 2484

Variable material properties  
2201, 2345

Variable speed drives  
750

Variational methods  
874, 1470, 2104

Velocity measurement  
241

Velocity  
2357

Vibration absorption (materials)  
801, 1551, 666

Vibration analysers  
914

Vibration analysis  
1735

Vibration control  
4, 13, 69, 154, 220, 228, 319, 344, 345, 422, 583, 658,  
681, 737, 745, 817, 882, 894, 941, 946, 1004, 1091, 1158,  
1209, 1226, 1229, 1239, 1258, 1326, 1394, 1506, 1547,  
1677, 1725, 1732, 1873, 1915, 1927, 2169, 2253, 2400,  
2418, 2433, 2434, 2576

Vibration dampers  
278, 1113

Vibration damping  
324, 468, 666, 746, 820, 1006, 1011, 1012, 1098, 1161,  
1168, 1235, 1273, 1321, 2057, 2061

Vibration detectors  
2078, 2087

Vibration excitation  
342, 1015, 1235, 2423, 2450

Vibration isolation  
537, 588, 683, 980, 1921, 2170, 2173

Vibration isolators  
58, 59, 347, 732, 973, 1019, 1020, 1021, 1022, 1023, 1550,  
1736, 1922, 2055, 2168, 2435

Vibration measurement  
218, 332, 484, 504, 704, 705, 1132, 1758, 1818, 1820,  
1821, 1885, 2374

Vibration meters  
1819

Vibration prediction  
403

Vibration probes  
709

Vibration response spectra  
643

Vibration response  
38, 54, 76, 190, 194, 1017, 1276, 1320, 1429, 1437, 1778,  
1857, 1931, 1935, 1970, 1980, 1998, 1999, 2107, 2179, 2220

Vibration severity  
943

Abstract  
Numbers: 1-271 272-531 532-742 743-942 943-1157 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Vibration signatures**  
1368, 2336, 2609

**Vibration tests**  
235, 306, 714, 908, 911, 969, 1134, 1180, 1218, 1243,  
1490, 1726, 1774, 2073, 2331, 2408, 2411, 2414, 2491,  
2523, 2543, 2575, 2576, 2577, 2579, 2581, 2585, 2586,  
2587, 2588, 2589, 2590, 2591, 2592, 2593, 2595, 2597

**Vibration tolerance**  
1014

**Vibration transfer**  
640, 641, 1078, 1252, 1992

**Vibrators**  
1371

**Vibratory techniques**  
542, 1607, 2114, 2212, 2615

**Vibratory tools**  
27, 341, 1548, 1549

**Vibrometer**  
2328

**Vibro-impact systems**  
2269

**Viscosity effects**  
795

**Viscoelastic core-containing media**  
109, 392

**Viscoelastic damping**  
131, 292, 469, 470, 686, 690, 831, 832, 893, 996, 1002,  
1104, 1105, 1106, 1111, 1277, 1404, 1473, 1476, 1655,  
1656, 1775, 2003, 2286

**Viscoelastic foundations**  
635

**Viscoelastic media**  
186, 966, 1795

**Viscoelastic properties**  
2119, 115, 145, 409, 1035, 1078, 1079, 1149, 1714, 1866,  
2294

**Viscoelasticity**  
1148

**Viscoelastic-core-containing media**  
1655

**Viscoplastic properties**  
1482

**Viscosity effects**  
1293

**Viscous damping**  
471, 605, 610, 615, 685, 812, 1007, 1049, 1101, 1102,  
1312, 1416, 1418, 1475, 1551, 1671, 2055, 2068, 2298, 2439

**Viscous friction**  
2037

**Viscous medium**  
1313

**Vlasov theory**  
377

**Vortex amplifiers**  
1094, 1095

**Vortex shedding**  
8, 68, 543, 677, 1224, 1267, 1288, 1588, 1647, 1769, 2024

**Vortex-induced excitation**  
1093, 1558

**Vortex-induced vibration**  
97, 359, 816, 834, 1262, 1576, 1743

**Vulnerability**  
1206

- W -

**Walls**  
69, 149, 150, 444, 661, 1372, 2025, 2026, 2261, 2488

**Warping**  
12

**Water hammer**  
2004

**Water waves**  
1722, 1906, 1910, 2148, 2150

**Water**  
2478

**Wave attenuation**  
173, 436, 441, 1412, 1452

**Wave diffraction**  
433, 435, 1083, 1311, 1910

**Wave dispersion**  
831

**Wave energy**  
2150

**Wave equation**  
1386, 2014

**Wave forces**  
34, 36, 310, 562, 658, 788, 1202, 1211, 1212, 1314, 1315,  
1393, 2400, 2401

**Wave generation**  
1082, 1405

**Wave propagation**  
83, 101, 116, 146, 157, 163, 165, 166, 169, 176, 178, 179,  
186, 263, 268, 382, 421, 423, 432, 440, 659, 667, 731, 797,  
854, 868, 869, 871, 877, 921, 1084, 1085, 1124, 1128,

**Abstract**

Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

**Volume 18**

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

**Wave propagation (cont'd.)**  
 1268, 1304, 1311, 1331, 1419, 1448, 1449, 1451, 1458,  
 1499, 1601, 1606, 1612, 1627, 1629, 1630, 1632, 1639,  
 1642, 1661, 1662, 1760, 1790, 1791, 1799, 1894, 1895,  
 1965, 1991, 2001, 2016, 2018, 2066, 2101, 2197, 2203,  
 2204, 2248, 2249, 2251, 2252, 2264, 2266, 2274, 2310,  
 2330, 2483, 2487, 2495, 2496, 2500, 2513

**Wave radiation**  
 92, 93, 107, 429, 1275, 1421, 1514, 1558, 1780, 1789,  
 1792, 1910, 2007, 2030, 2263, 2498, 2566

**Wave reflection**  
 77, 430, 718, 854, 1096, 1302, 1800, 1802

**Wave scattering**  
 161, 162, 172, 175, 668, 717, 867, 870, 1301, 1303, 1435,  
 1452, 2031, 2036, 2292, 2295, 2514

**Wave transmission**  
 77, 434, 1083, 1096, 1779, 2032, 2261

**Waveguide absorbers**  
 894

**Waveguide analysis**  
 2483

**Waveguides**  
 2266

**Weapons systems**  
 64

**Wear**  
 1835

**Wedges**  
 433, 1802

**Weighted residual technique**  
 2358, 2527

**Welded joints**  
 80, 81, 82, 245, 545, 602, 1607

**Wheelsets**  
 813

**Whirling**  
 1, 276, 1163, 1365, 1698, 1867, 1942, 2185, 2378

**Wind induced excitation**  
 1644

**Wind tunnel testing**  
 491, 642, 792, 1090, 1125, 1244, 1267, 1562, 1626, 1912,  
 2158

**Wind tunnels**  
 2030

**Wind turbines**  
 340, 354, 667, 1243, 1704, 2124, 2393

**Windows**  
 1309, 1310

**Wind-induced excitation**  
 42, 290, 291, 354, 437, 543, 565, 576, 579, 642, 677, 753,  
 754, 755, 763, 955, 956, 957, 1175, 1211, 1222, 1378,  
 1438, 1472, 1528, 1791, 2095, 2139, 2157, 2195, 2271, 2393

**Wing stores**  
 318, 1730, 2408

**Winkler foundations**  
 1057, 1065

**Wire cloth**  
 1410

**Wire**  
 1117, 1492, 1674

**Wires**  
 1038, 1759

**Wood**  
 373, 425, 2025

**Woodworking machines**  
 2440

**Work pieces**  
 1369

- Y -

**Young modulus**  
 2114

- Z -

**Z-transform**  
 1485, 1666

**Abstract**  
 Numbers: 1-271 272-531 532-742 743-942 943-1156 1157-1357 1358-1505 1506-1695 1696-1860 1861-2114 2115-2368 2369-2615

Volume 18

Issue: 1 2 3 4 5 6 7 8 9 10 11 12

# CALENDAR

1987

## JANUARY

12-15 AIAA 25th Aerospace Sciences Meeting, Reno, NV

## FEBRUARY

24-28 SAE International Congress "Excellence in Engineering," Cobo Hall, Detroit, MI (SAE Engrg. Activities Div., 400 Commonwealth Drive, Warrendale, PA 15096)

## MARCH

10-12 Power Plant Pumps Symposium [Electric Power Research Institute], New Orleans, LA (Electric Power Research Institute, 3412 Hillview Avenue, Palo, Alto CA 94304)

6-9 56th International Modal Analysis Conference [Union College and Imperial College of Science], London, England (IMAC, Union College, Graduate and Continuing Studies, Wells House -- 1 Union Ave., Schenectady, NY 12308)

6-8 AIAA 28th Structures, Structural Dynamics and Materials Conference, Monterey, CA

9-10 AIAA Dynamics Specialist Conference, Monterey, CA

## APRIL

13-16 IEEE Intl. Conf. on Acoustics, Speech, and Signal Processing, Dallas, TX

13-16 IUTAM Symp. on Advanced Boundary Element Methods, San Antonio, TX

28-30 1987 SAE Noise and Vibration Conference, Traverse City, Michigan (SAE, 400 Commonwealth Drive, Warrendale, PA 15086 (412) 776-4841)

## MAY

3-8 33rd International Instrumentation Symposium [Aerospace Industries and Test Measurement Divisions, Instrument Society of America], Las Vegas, NV (33rd International Instrumentation Symposium, 738 W. Larigo Ave., Littleton, CO 80120)

11-15 ASA Spring Meeting, Indianapolis, IN

12-13 International Appliance Technical Conference, Columbus, OH

## JUNE

8-10 AIAA 19th Fluid Dynamics, Plasma Dynamics and Laser Conference

8-10 Noise-Con 87, Pennsylvania State University (Conference Secretariat, NOISE-CON 87, The Graduate Program in Acoustics, Applied Science Building, University Park, PA 16802)

16-18 11th Annual Meeting [Vibration Institute], St. Louis, MO (Dr. Ronald L. Eshleman, Director, Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254)

29-2 AIAA/SAE/ASME/ASBE 23rd Joint Propulsion Conference, San Diego, CA

## AUGUST

31-2 Twentieth Midwestern Mechanics Conference (20th MMC), Purdue University, West Lafayette, IN (Professors Hamilton and Soedel, School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907)

**SEPTEMBER**

**27-30 Vibrations Conference and Other Technical Conferences, Boston, MA**

**NOVEMBER**

**15-19 ASME Winter Annual Meeting, New York, NY**

**16-20 ASA Fall Meeting, Miami, FL**

**CALENDAR ACRONYM DEFINITIONS  
AND ADDRESSES OF SOCIETY HEADQUARTERS**

<b>AHS</b>	American Helicopter Society 1325 18 St. N.W. Washington, D.C. 20036	<b>IMechE</b>	Institution of Mechanical Engineers 1 Birdcage Walk, Westminster London SW1, UK
<b>AIAA</b>	American Institute of Aeronautics and Astronautics 1633 Broadway New York, NY 10019	<b>IFTOMM</b>	International Federation for Theory of Machines and Mechanisms U.S. Council for TMM c/o Univ. Mass., Dept. ME Amherst, MA 01002
<b>ASA</b>	Acoustical Society of America 335 E. 45th St. New York, NY 10017	<b>INCE</b>	Institute of Noise Control Engineering P.O. Box 3206, Arlington Branch Poughkeepsie, NY 12603
<b>ASCE</b>	American Society of Civil Engineers United Engineering Center 345 E. 47th St. New York, NY 10017	<b>ISA</b>	Instrument Society of America 67 Alexander Dr. Research Triangle Pk., NC 27709
<b>ASLE</b>	American Society of Lubrication Engineers 838 Busse Highway Park Ridge, IL 60068	<b>SAE</b>	Society of Automotive Engineers 400 Commonwealth Dr. Warrendale, PA 15096
<b>ASME</b>	American Society of Mechanical Engineers United Engineering Center 345 E. 47th St. New York, NY 10017	<b>SEM</b>	Society for Experimental Mechanics (formerly Society for Experimental Stress Analysis) 7 School Street Bethel, CT 06801
<b>ASTM</b>	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103	<b>SBE</b>	Society of Environmental Engineers Owles Hall Buntingford, Hertz. SG9 9PL, England
<b>ICF</b>	International Congress on Fracture Tohoku University Sendai, Japan	<b>SNAME</b>	Society of Naval Architects and Marine Engineers 74 Trinity Pl. New York, NY 10006
<b>IEEE</b>	Institute of Electrical and Electronics Engineers United Engineering Center 345 E. 47th St. New York, NY 10017	<b>SPE</b>	Society of Petroleum Engineers 6200 N. Central Expressway Dallas, TX 75206
<b>IES</b>	Institute of Environmental Sciences 940 E. Northwest Highway Mt. Prospect, IL 60056	<b>SVIC</b>	Shock and Vibration Information Center Naval Research Laboratory Code 5804 Washington, D.C. 20375-5000

## PUBLICATION POLICY

Unsolicited articles are accepted for publication in the **Shock and Vibration Digest**. Feature articles should be tutorials and/or reviews of areas of interest to shock and vibration engineers. Literature review articles should provide a subjective critique/summary of papers, patents, proceedings, and reports of a pertinent topic in the shock and vibration field. A literature review should stress important recent technology. Only pertinent literature should be cited. Illustrations are encouraged. Detailed mathematical derivations are discouraged; rather, simple formulas representing results should be used. When complex formulas cannot be avoided, a functional form should be used so that readers will understand the interaction between parameters and variables.

Manuscripts must be typed (double-spaced) and figures attached. It is strongly recommended that line figures be rendered in ink or heavy pencil and neatly labeled. Photographs must be unscreened glossy black and white prints. The format for references shown in **Digest** articles is to be followed.

Manuscripts must begin with a brief abstract, or summary. Only material referred to in the text should be included in the list of References at the end of the article. References should be cited in text by consecutive numbers in brackets, as in the following example:

Unfortunately, such information is often unreliable, particularly statistical data pertinent to a reliability assessment, as has been previously noted [1].

Critical and certain related excitations were first applied to the problem of assessing system reliability almost a decade ago [2]. Since then, the variations that have been developed and practical applications that have been explored [3-7] indicate . . .

The format and style for the list of References at the end of the article are as follows:

- each citation number as it appears in text (not in alphabetical order)
- last name of author/editor followed by initials or first name
- titles of articles within quotations, titles of books underlined
- abbreviated title of journal in which article was published (see Periodicals Scanned list in January, June, and December issues)
- volume, issue number, and pages for journals; publisher for books
- year of publication in parentheses

A sample reference list is given below.

1. Platzer, M.F., "Transonic Blade Flutter -- A Survey," Shock Vib. Dig., 2 (7), pp 97-106 (July 1975).
2. Bisplinghoff, R.L., Ashley, H., and Halfman, P.L., Aeroelasticity, Addison-Wesley (1955).
3. Jones, W.P., (Ed.), "Manual on Aeroelasticity," Part II, Aerodynamic Aspects, Advisory Group Aeronaut. Res. Dev. (1962).

Articles for the **Digest** will be reviewed for technical content and edited for style and format. Before an article is submitted, the topic area should be cleared with the editors of the **Digest**. Literature review topics are assigned on a first come basis. Topics should be narrow and well-defined. Articles should be 3000 to 4000 words in length. For additional information on topics and editorial policies, please contact:

Milda Z. Tamulionis  
Research Editor  
Vibration Institute  
101 W. 55th Street, Suite 206  
Clarendon Hills, Illinois 60514

DEPARTMENT OF THE NAVY  
NAVAL RESEARCH LABORATORY, CODE 5804  
SHOCK AND VIBRATION INFORMATION CENTER  
Washington, DC 20375-5000

OFFICIAL BUSINESS  
PENALTY FOR PRIVATE USE \$300

FIRST CLASS MAIL  
POSTAGE & FEES PAID  
USN  
PERMIT No G 9

---

THE SHOCK AND VIBRATION DIGEST

Volume 18, No. 12

December 1986

---

**EDITORIAL**

- 1 **SVIC Notes**
- 2 **Editors Rattle Space**

**ARTICLES AND REVIEWS**

- 3 **Feature Article → Mechanical Signature Analysis**  
M.S. Hundal
- 12 **Literature Review**
- 13 **Fracture Analysis -- A Review**  
D. Broek
- 23 **Book Reviews**

**CURRENT NEWS**

- 25 **Short Courses**
- 28 **Reviews of Meetings**

**ABSTRACTS FROM THE CURRENT LITERATURE ; and**

- 32 **Abstract Contents**
- 33 **Availability of Publications Abstracted**
- 34 **Abstracts: 86-2369 to 86-2615**
- 92 **Periodicals Scanned**
- 100 **Abstract Categories**

**ANNUAL INDEXES**

- 101 **Feature Articles**
- 102 **Literature Review**
- 103 **Book Reviews**
- 105 **Author Index**
- 138 **Subject Index**

**CALENDAR**