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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 reinstituted, 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.

R.L.E.

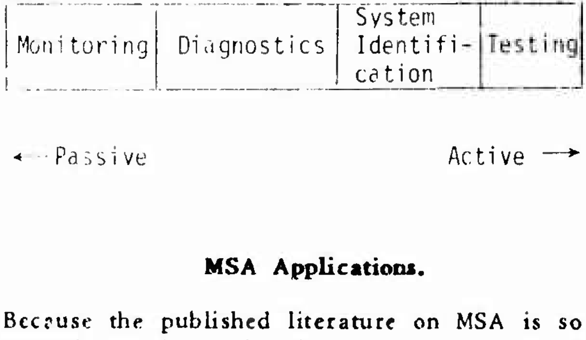
MECHANICAL SIGNATURE ANALYSIS

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.



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

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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 reverberent 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

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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.

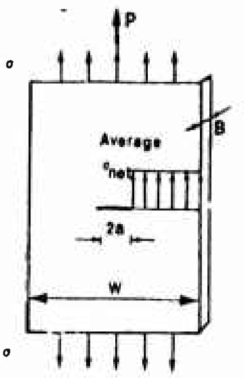
FRACTURE ANALYSIS — A REVIEW

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.



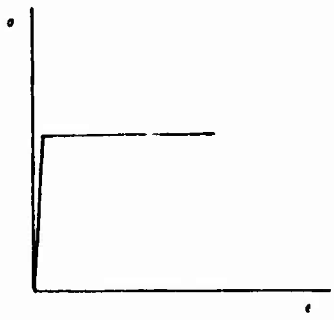


Figure 1. Maximum Load Carrying Capacity Reached at Net Section Yield for Ideally Plastic Material.

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, σ_{ys}, the limit load, P_{lim} of a plate of width W and thickness B with a center crack of size 2a is:

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

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:

$$\sigma_{fmax} = \frac{W - 2a}{W}\sigma_{ys} \tag{2}$$

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

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

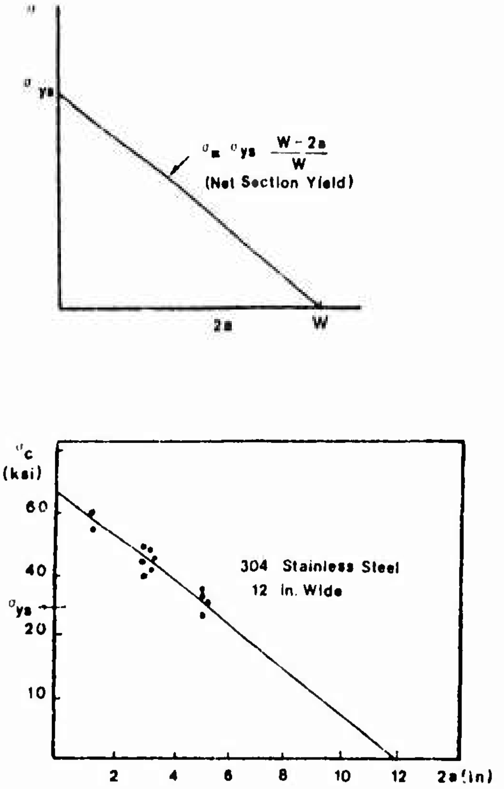

Figure 2. Net Section Yield and Net Section Collapse.

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 σ_{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

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

and

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

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; σ_{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].

$$\sigma_x = \frac{K}{\sqrt{2\pi x}} \tag{5}$$

where σ_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.

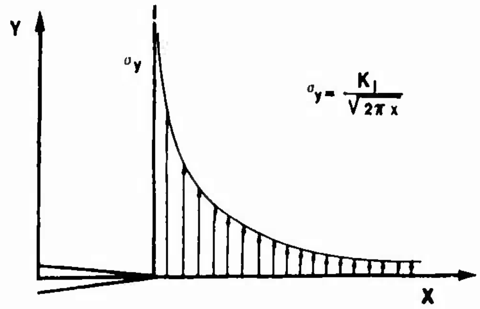

Figure 3. Crack Tip Stresses.

Because equation (5) is for an arbitrary case, it is valid for any and all crack tips. Crack tip stress apparently depends only on the parameter K, called the stress intensity factor. Equation (5) is for elastic stress; hence σ_y must be proportional to the applied stress σ. Crack tip stress also depends upon crack size. For equation (5) to have the proper dimension, σ_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

$$K = C\sigma\sqrt{a} \tag{6}$$

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 β, with $\beta = C/\sqrt{\pi}$. This leads to equation (7).

$$K = \beta\sigma\sqrt{\pi a} \quad \text{with } \beta = f(a/L) \tag{7}$$

From equation (6) and equation (7) the crack tip stresses are known completely if β is known for the geometry at hand. Handbooks [6-8] for β exist; any of many procedures [9] can be used to determine β 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 σ_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_c, the fracture criterion is that fracture occurs if

$$K \geq K_c \tag{8}$$

The critical value K_c 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_c 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

$$\beta\sigma_f\sqrt{\pi a} = K_c \tag{9}$$

where σ_f is the applied stress. Thus, the stress at fracture is

$$\sigma_f = \frac{K_c}{\beta\sqrt{\pi a}} \tag{10}$$

The fracture condition is given by equation (10) whether or not the fracture toughness K_c is known. If the toughness is not known, fracture stress σ_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.

$$F - U = 0 \tag{11}$$

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

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

or

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

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:

$$G = R \tag{14}$$

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

$$\frac{K^2}{E} \quad R \tag{15}$$

or

$$\frac{\beta^2 \sigma^2 \pi a}{E} \quad R \tag{16}$$

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 Δa [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

$$\frac{dG}{da} \quad \frac{dR}{da} \tag{17}$$

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 $G = K^2/E \quad \beta^2\sigma^2\pi a/E$, 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 $\sigma \quad \sigma_i$, proceeds stably from a_i to a_c, and becomes unstable at σ_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.

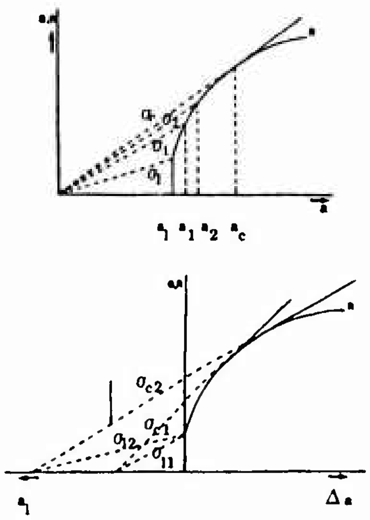

Figure 4. Energy Conservation Criterion for Fracture.

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

$$\left.\begin{array}{l} K \quad K_R \\ \frac{dK}{da} \quad \frac{dK_R}{da} \end{array}\right\} \tag{18}$$

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

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

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

$$\frac{H \sigma^{n+1} a}{F} = J_R \tag{23}$$

H is a geometric parameter similar to β, 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 σ_0 is called the flow stress and $\epsilon_0 = \sigma_0 / E$. The stress σ_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 σ_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 σ_0 were the collapse stress, but, because σ_0 is arbitrary, P_0 is a fictitious limit load. It is trivial that c, P_0, and P are related to a, σ_0, and σ 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

$$G + J = J_R \tag{27}$$

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 Δ_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

$$r_p = \frac{K_c^2}{b^2 \pi \sigma^2} \tag{28}$$

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

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

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

$$\sigma_f \sqrt{(a + K_c^2 / \pi \sigma_u^2)} = K_c \tag{30}$$

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 / σ_{ys}^2

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

The quantities in the equation are then given new symbols

$$T \geqslant T_{material} \tag{32}$$

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.

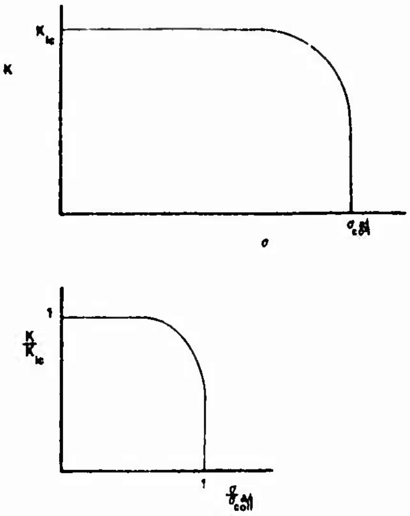

Figure 5. Fracture analysis Diagram [21].

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 , 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].

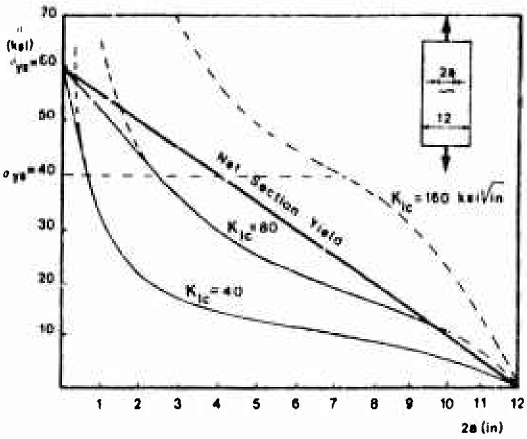

Figure 6. Cases of Elastic Fracture and Collapse.

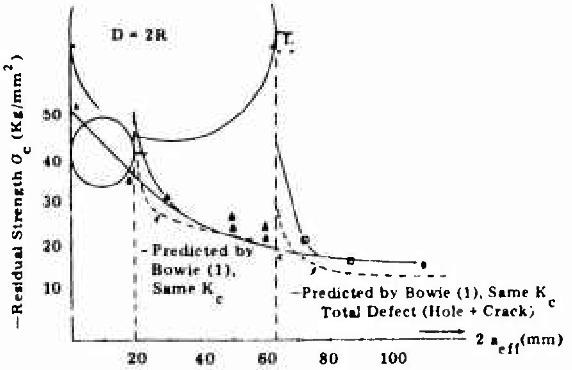

Figure 7. Predictions of Fracture Stress for Cracks at Holes and Test Data [25].

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 β 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.

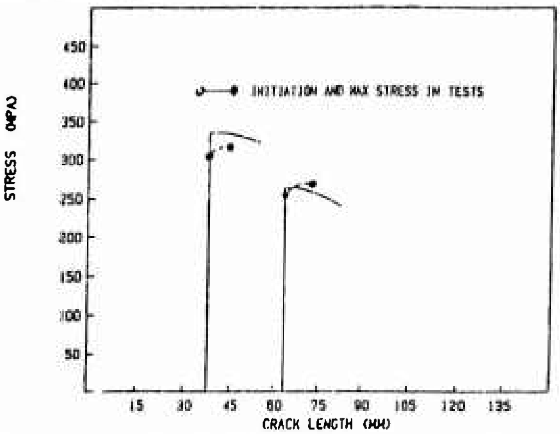

Figure 8. Elastic-Plastic Fracture Predictions [15] and Test Results [4].

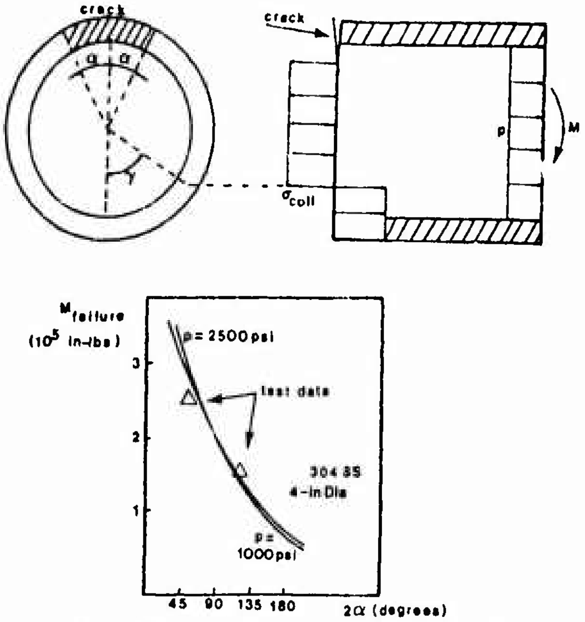

Figure 9. Failute by Collapse of Cracked Stainless Steel Pipe [1].

a. Collapse analysis model
b. 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.

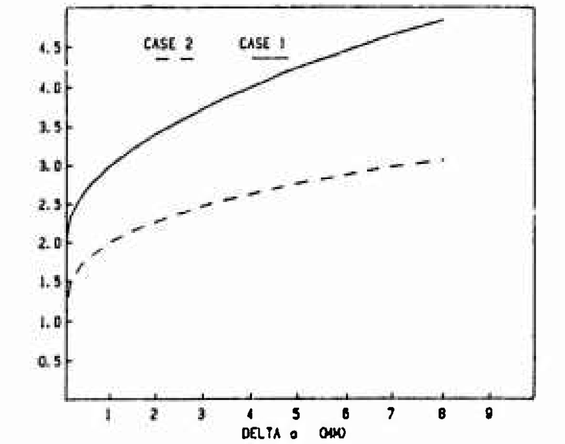

Figure 10. JR-Curves for Stainless Steel.

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. LEFM toughness values typically scatter by 15%. Therefore the 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.

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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, Flouquet 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.

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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.

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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, compressors, 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. Lehnes 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 or 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

AVAILABILITY OF PUBLICATIONS ABSTRACTED

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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 substructives. 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 FRF data were experimentally obtained by impact testing during customer acceptance tests. The FRF 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 or 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 space 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, anistropic 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
Bently 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, Frieburg, 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 behavior 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 workpiece 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 constructural 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 assemblege 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 by 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
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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

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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

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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 analysis 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

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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

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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

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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

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National Taiwan Univ., Taipei, Taiwan, Rep. China
Intl. 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

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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 esitmated 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

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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 is 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

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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 Aerospatiales (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 requirement, 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

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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

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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

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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 qualify 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. Lapierre, 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

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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 by 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 Nonlinear 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

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"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 representative 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

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"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
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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

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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

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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

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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

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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

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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

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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

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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

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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)

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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)

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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)

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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

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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

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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

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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

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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

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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 stresres which raise natural frequencies and are subjected to significant 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

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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

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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

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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

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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

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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

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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)

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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 acceleration 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

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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

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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

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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

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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, F. 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)
DA8606165

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

Cable stay vibration data was obtained from the cable-stayed 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

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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

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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

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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

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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

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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

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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

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Bull. JSME, 29 (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

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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

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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

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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

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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

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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

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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

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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 expression 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. Cattano
Rome Univ., Italy
Intl. Modal Analysis Conf., Proc. of the 4th, Los Angeles, CA, Feb 3-6, 1986, Vol. 2, pp 1367-1369, [illegible] 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

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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
Intl. 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

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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 mode 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 Mechanique 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 Ludwieg 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 Ludwieg 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

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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

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German Space Operations Center, Wesslsing, 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 (19.4)

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

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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

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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., <u>80</u> (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

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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, FREQRES, 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

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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

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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

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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

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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

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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

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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

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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

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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
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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
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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. Oliver, 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
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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
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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
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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
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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
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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
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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
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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

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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

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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 structural 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

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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

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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

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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

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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

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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

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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

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"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

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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

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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

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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

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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 contest 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

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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

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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_S 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

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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

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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

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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 IES Modal Test Structure

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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

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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 apriori 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

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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

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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

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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

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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

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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

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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

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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

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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

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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, Multipoint 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

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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 online.

86-2560

Investigating into the Effective Use of Structural Modification

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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 issued 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

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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

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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

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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

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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

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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 comparision and model improvement using passive structural elements.

86-2566

Combination of Structural Modification Techniques and Acoustic Radiation Models

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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

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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

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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

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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

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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

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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

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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

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"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

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"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

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"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

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"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 down load 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

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"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

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"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

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"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

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"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

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"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 microcomputer control system.

86-2583

Two Input-Single Output Simulation

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"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

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"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 compare 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

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"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

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"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

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"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

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"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

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"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

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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

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"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

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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 Exited 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

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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

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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

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"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 of 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

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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

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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

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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

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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' 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. ; 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 statistical 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.

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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 AIIAA/SAE/ASME/ASEE 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

AHS	American Helicopter Society 1325 18 St. N.W. Washington, D.C. 20036
AIAA	American Institute of Aeronautics and Astronautics 1633 Broadway New York, NY 10019
ASA	Acoustical Society of America 335 E. 45th St. New York, NY 10017
ASCE	American Society of Civil Engineers United Engineering Center 345 E. 47th St. New York, NY 10017
ASLE	American Society of Lubrication Engineers 838 Busse Highway Park Ridge, IL 60068
ASME	American Society of Mechanical Engineers United Engineering Center 345 E. 47th St. New York, NY 10017
ASTM	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103
ICF	International Congress on Fracture Tohoku University Sendai, Japan
IEEE	Institute of Electrical and Electronics Engineers United Engineering Center 345 E. 47th St. New York, NY 10017
IES	Institute of Environmental Sciences 940 E. Northwest Highway Mt. Prospect, IL 60056
IMechE	Institution of Mechanical Engineers 1 Birdcage Walk, Westminster London SW1, UK
IFToMM	International Federation for Theory of Machines and Mechanisms U.S. Council for TMM c/o Univ. Mass., Dept. ME Amherst, MA 01002
INCE	Institute of Noise Control Engineering P.O. Box 3206, Arlington Branch Poughkeepsie, NY 12603
ISA	Instrument Society of America 67 Alexander Dr. Research Triangle Pk., NC 27709
SAE	Society of Automotive Engineers 400 Commonwealth Dr. Warrendale, PA 15096
SEM	Society for Experimental Mechanics (formerly Society for Experimental Stress Analysis) 7 School Street Bethel, CT 06801
SEE	Society of Environmental Engineers Owles Hall Buntingford, Hertz. SG9 9PL, England
SNAME	Society of Naval Architects and Marine Engineers 74 Trinity Pl. New York, NY 10006
SPE	Society of Petroleum Engineers 6200 N. Central Expressway Dallas, TX 75206
SVIC	Shock and Vibration Information Center Naval Research Laboratory Code 5804 Washington, D.C. 20375-5000

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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., 7 (7), pp 97-106 (July 1975).
2. Bisplinghoff, R.L., Ashley, H., and Halfman, R.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:

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THE SHOCK AND VIBRATION DIGEST

Volume 18, No. 12 December 1986

EDITORIAL

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