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EDITORS RATTLE SPACE

ON THE COSTS AND BENEFITS OF TECHNOLOGY TRANSFER

The recent announcement on the disestablishment of the Shock and Vibration Information Center (SVIC) represents a distressing fact of life that I have observed for some time. Many people do not budget for or expect to pay for technology transfer. It is taken for granted that telephone calls and/or written inquiries to repositories of technical information will be answered without cost. They do not stop to think about who pays for it. Fortunately, SVIC survived up to this time because there were some forward thinking managers who paid their way and more. But in the end nonsupport was partly responsible for the demise of an organization that served members of the shock and vibration community for about forty years. When SVIC is no longer available past users will have to either "reinvent the wheel" or spend endless hours in pursuit of information that would have been readily available. Who is the loser in this situation? Obviously it is the users -- both those who were willing to pay for technology transfer services and those who would not pay for it.

If technology transfer is to be a viable mechanism in the equipment design and development process, a method of funding this type activity is going to have to be evolved. The first step in the establishment of funding is the recognition of the need for the services. A good source of technical information will make any engineer more efficient and the return on investment on his services will increase. Management often hires an engineer with the idea that he is an expert that needs no outside help. They would do better with fewer engineers and more outside help --especially that which is technology transfer oriented. It is not easy to quantify the assistance received from technology transfer nor how to budget for it. It is not constant in return on investment. One year a company will receive a huge return -- the next year they will realize very little. But over the year those who support technology transfer will realize benefits for exceeding the cost -- a high return on investment.

If technology transfer services are to be maintained, it is going to have to be sold to management as a necessary and worthwhile activity. This means managers have to be appraised of its value not only by outside persons but also by engineers using it. Engineers are going to have to forcefully tell management that they need to budget and pay for outside technical information that will increase their efficiency.

R.L.E.

THE DIGITAL PROCESSING OF ACCELERATION MEASUREMENTS FOR MODAL ANALYSIS

C.W. deSilva*

Abstract. In modal testing dynamic responses are usually measured as acceleration signals. The corresponding displacement time histories are obtained through digital computation for subsequent modal analysis. Techniques used in this computation -- data windowing, digital filtering, and double integration are described in this paper. Problems of aliasing distortion, leakage, numerical instability, and complementary-function effect are discussed; methods to reduce their influence are given. Typical results of data analysis are presented.

Experimental modal analysis is a frequency domain technique of model identification. The objective of this method is to determine natural frequencies, modal damping ratios, mode shapes, and a time domain model for a mechanical system from experimentally-determined transfer functions. The introduction of the fast Fourier transform (FFT) algorithm in 1965 [1] was followed by rapid advances of dedicated digital FFT analyzers and microcomputers. Experimental modal analysis has emerged as a powerful and cost-effective tool in dynamic modeling, design development and optimization, control, and qualification of mechanical systems [2].

A typical scheme for experimental modal analysis is shown in Figure 1. The test object is excited by applying a known forcing function along one degree of freedom. The resulting dynamic response along various degrees of freedom is measured using properly mounted accelerometers. Bias toward the accelerometer as a response sensor in modal testing is attributable to its many advantages. They include simplicity, high bandwidth (fast response and wide useful frequency range), high accuracy, low cost, and light weight. High output impedance in piezoelectric accelerometers provides the added advantage of reduced loading effects from connected instrumentation (e.g. signal conditioning and recording devices). Unfortunately, for the same reason, the level of the output signal of the accelerometer is small. A charge amplifier is traditionally used at the output of an accelerometer to increase overall sensitivity and reduce noise problems; e.g. cable capacitance noise.

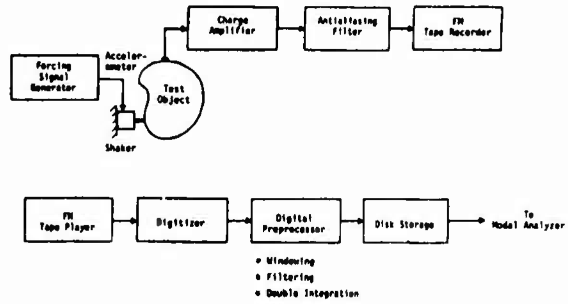

Figure 1. Schematic Representation of Experimental Modal Analysis.

A signal conditioning device in digital processing is the antialiasing filter. It can be a separate unit or part of a single package with the charge amplifier. An antialiasing filter is an analog low-pass filter with a cutoff frequency set slightly above the highest frequency of interest in the Fourier spectrum of the analyzed signal. If a signal is sampled at a certain rate (termed sampling frequency) for digital Fourier analysis, the Fourier spectrum beyond the Nyquist frequency -- equal to one half the sampling frequency -- is lost [3]. This portion of the continuous Fourier spectrum is folded about the Nyquist frequency and added to the remaining portion, which corresponds to the digital Fourier spectrum. The distortion of the spectrum in the neighborhood of the Nyquist frequency is known as aliasing.

Aliasing distortion does not take place if a signal is band limited to less than the Nyquist frequency. An antialiasing filter removes high-frequency components from a signal, in effect band limiting the signal thereby reducing the aliasing distortion. Approximately 20% of a digital spectrum at the high-frequency end of a Nyquist frequency band might have to be discarded if a good antialiasing filter is not used prior to digital Fourier analysis. The conditioned (amplified and filtered) acceleration signals are recorded on multiple track FM tapes for subsequent digital processing.

Displacement responses needed for modal analysis are obtained by double integrating accelera-

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tion signals. In the past this was accomplished using analog integrating amplifiers. This approach possesses all the drawbacks inherent to analog signal processing techniques; e.g., high noise levels, distortion, time variance, bias, and sluggishness. Because modal analysis is performed digitally, it is logical to employ digital techniques to preprocess the acceleration signals. This paper describes some digital preprocessing techniques for modal analysis that have been thoroughly tested by the author. Possible problem areas are discussed and ways to circumvent them are presented. Attention is given to data windowing, digital filtering in the frequency domain, and double integration.

DATA WINDOWS

As indicated in Figure 2, digitized acceleration data are buffered (typical buffer size is 2048 real values) and windowed prior to Fourier analysis. Data buffering is necessary because digital Fourier analysis requires a finite block of data values. Data windowing is accomplished by multiplying each data block by an appropriate weighting function. The objective is to reduce the leakage (or truncation error) due to buffering (truncation) of transient signals. Leakage error manifests itself as end ripples in the Fourier spectrum [2]. These ripples can be suppressed by shaping each data block with a suitable weighting function. The window function assigns relatively low weighting to the end values of data in the buffer. There are thus no severe discontinuities from buffer to buffer.

Windowing has the undesirable effect of reducing the energy content of each data segment. The energy reduction factor associated with a window function w(t) of length T is given by

$$\lambda = \frac{1}{T}\int_0^T w(t)^2\, dt \tag{1}$$

In the discrete-time case the corresponding expression is

$$\lambda = \frac{1}{N}\sum_{n=0}^{N=1} w_n^2 \tag{2}$$

N represents the buffer size; w_n denotes the sampled values of the window function. Each data block (buffer) must be scaled up by a factor of $1/\sqrt{\lambda}$ in order to achieve energy equivalence of windowed data and original data. This can be accomplished directly by scaling the window function itself. Scaling factors for commonly used data windows are given in Table 1.

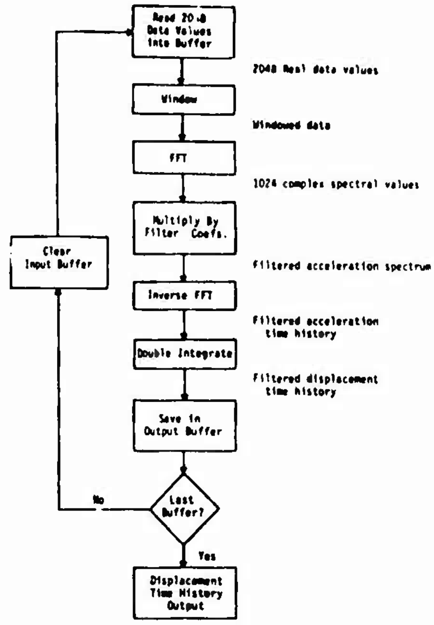

Figure 2. A Flowchart of the Digital Preprocessing Program for Acceleration Signals.

Table 1. Energy Scaling Factors for Common Window Functions

Window	Describing Equation	Scaling Factor $1/\sqrt{\lambda}$
Rectangular	w(t) = 1 for t = 0 to T = 0 elsewhere	1
Flat-Top cosine	w(t) = 0.5 (1 - cos 10πt/T) for t = 0 to T/10 and t = 9T/10 to T = 1 for t = T/10 to 9T/10 = 0 elsewhere	1.07
Bartlett (Triangular)	w(t) = 2t/T for t = 0 to T/2 = - 2t/T + 2 for t = T/2 to T = 0 elsewhere	1.73
Hamming	w(t) = 0.8 + 0.46 (cos 2πt/T) for t = 0 to T = 0 elsewhere	1.59
Hanning (cosine)	w(t) = 0.5 (1 - cos 2πt/T) for t = 0 to T = 0 elsewhere	1.63
Parzen	w(t) = 1 - 6 $(2t/T-1)^2$ + 6$\lvert 2t/T-1\rvert^3$ for t = T/4 to 3T/4 = 2 $(1 - \lvert 2t/T-1\rvert)^3$ for t = 0 to T/4 and t = 3T/4 to T = 0 elsewhere	2.10

Analysis bandwidth is a measure of the frequency resolution in spectral results. If a rectangular window of length T is used, the true nature of periodic signal components having frequencies smaller than 1/T (or period larger than T) is not reflected in each data buffer analyzed. Therefore, the associated analysis bandwidth may be given by 1/T. For other types of windows a further loss of information occurs due to shape distortion. Hence the analysis bandwidth must be increased in order to maintain the accuracy of the rectangular window. Note that, in the context of selecting a data window, leakage error and bandwidth are conflicting parameters. For the modal analysis of heavily damped systems the Hanning window is recommended, provided other characteristics of the signal being analyzed do not favor a different choice of window. For lightly damped systems the Hanning window is generally preferred. Signal type (including system type) is an important consideration in selecting a data window. Some general guidelines are provided in Table 2.

Table 2. Guidelines for Selecting Window Functions.

Signal Type	Window
• Pericdic with period = T • Rapid transients within (0, T)	Rectangular
• Periodic with period ≠ T • Quasi-periodic • Slow transients beyond (0, T) • Nonstationary Random	Flat-Top cosine
• Beat-like signals with period ~ T	Bartlett (Triangular)
• Narrow-Band Random • Stationary Random • Lightly damped systems	Hanning (cosine)
• Important low-level components mixed with widely-spaced high-level spectral components • Broad-Band Random e.g., white noise, pink noise	Parzen
• Heavily damped systems	Hamming

DIGITAL FILTERING

Digital filtering can be performed either in the time domain using a recursive filter algorithm such as the Butterworth filter or the Chebyshev filter [4,5], or in the frequency domain using the Fourier transform method. Recursive digital filters are ideal for real time applications because they employ discrete-time recursive algorithms (difference equations) to compute filter outputs continuously from a few input data values. The point-by-point accuracy of the results, however, might not be satisfactory when real measurements having low signal/noise ratio are filtered by this method. When real time computation is not a requirement, as is the case for recorded data, or, if a finite delay in the output is tolerable, digital filtering in the frequency domain is preferable. Frequency-domain digital filters are more accurate than recursive digital filters in general because an entire batch of data points (e.g., 2048 samples) is processed at one time; furthermore, any arbitrary filter specification can be conveniently incorporated.

As indicated by the flowchart in Figure 2, frequency domain digital filtering is accomplished by computing the Fourier spectrum of the signal using FFT, shaping this spectrum as desired and computing the inverse Fourier transform of the shaped spectrum using the FFT algorithm. Any arbitrary filter, including low-pass, high-pass, band-pass, and notch filters, can be implemented by multiplying the original spectrum by an appropriate shaping function. For instance, band-pass filtering is achieved by retaining the portion within the pass band and blanking out the rest of the spectrum. This process is illustrated in Figure 3 for a filter band of f_1, f_2. Note that the magnitude of the digital Fourier spectrum is symmetric about the Nyquist frequency f_N. The filter should maintain this property. The pass band should also be chosen with care. In some situations very-narrow-band filtering can lead to excessive dither. An example is given in Figure 4. Note that, for the same noisy signal, satisfactory results are obtained with a filter of pass band 45-60 Hz, but excessive dither is present when the pass band is reduced to 45-50 Hz. This rare situation occurs if the dither-suppressing high-frequency components that might be present in the original signal are eliminated by the narrow-band filter. In preprocessing acceleration signals for modal analysis, digital filters are primarily used as antialiasing low-pass filters to supplement the analog antialiasing filters. In this case the cutoff frequency of the filter is set at the Nyquist frequency.

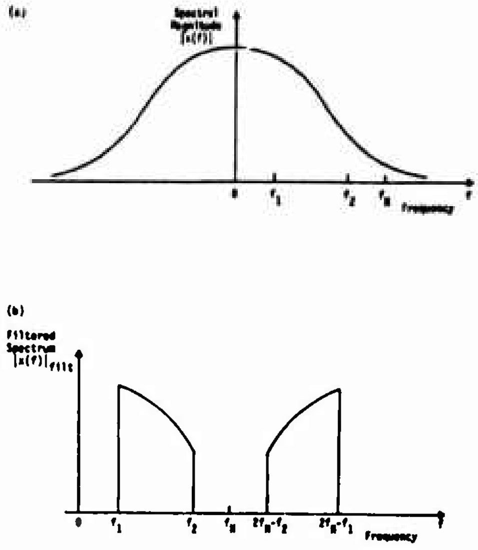

Figure 3. Band-Pass Filtering in the Frequency Domain.

(a) Original Fourier Magnitude Spectrum
(b) Filtered Magnitude Spectrum

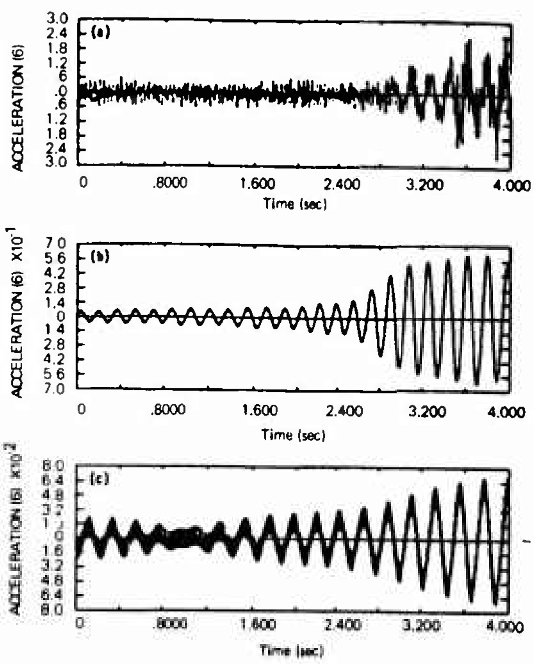

Figure 4. The Effect of Band-Pass Filtering

(a) Raw Signal with Measurement Noise
(b) Signal from a 45-60 Hz Pass
(c) Signal from a 45-50 Hz Pass

DOUBLE INTEGRATION

Digital integration algorithms differ primarily by the method employed for data interpolation. Experience has shown that parabolic integration -- in which each triad of successive data points is fitted onto a quadratic curve (parabola) -- is adequate in signal processing for modal analysis. If the three data points are denoted by x_{k-1}, x_k, and x_{k+1}, it can be shown that the area between the points x_k and x_{k+1} under the quadratic curve that passes through these three points is

$$\delta A = \frac{\Delta T}{12} [5\, x_{k+1} + 8\, x_k - x_{k-1}] \tag{3}$$

in which Δ T denotes the time step for each data sample. It follows that the parabolic integration algorithm is given by

$$y_{k+1} = y_k + \frac{\Delta T}{12} [5\, x_{k+1} + 8\, x_k - x_{k-1}] \tag{4}$$

The discrete transfer function corresponding to this difference equation is obtained using the Z-transform method [4] by representing each time delay of Δ T by z^{-1}; thus

$$\frac{Y(z)}{X(z)} = \frac{\Delta T\ [5 + 8\, z^{-1} - z^{-2}]}{12\ [1 - z^{-1}]} \tag{5}$$

The double-integration transfer function is given by the square of the single-integration transfer function. This can be expressed as

$$\frac{Y(z)}{X(z)} = \frac{\Delta T^2\ [25 + 80\, z^{-1} + 54\, z^{-2} - 16\, z^{-3} + z^{-4}]}{144\ [1 - 2\, z^{-1} + z^{-2}]} \tag{6}$$

The corresponding difference equation is obtained by interpreting z^{-1} as the operator for a time delay of ΔT. Hence the parabolic double-integration algorithm is given by

$$y_{k+1} = 2y_k - y_{k-1} + \frac{\Delta T^2}{144} [25\, x_{k+1} + 80\, x_k + 54\, x_{k-1} - 16\, x_{k-2} + x_{k-3}] \tag{7}$$

Filtering can make a substantial difference in the double-integrated results. In the results presented in Figure 5, for example, measurement noise has introduced a large bias into the displacement signal. This bias is eliminated when the acceleration signal is processed through a 40-70 Hz-pass digital filter prior to double integration.

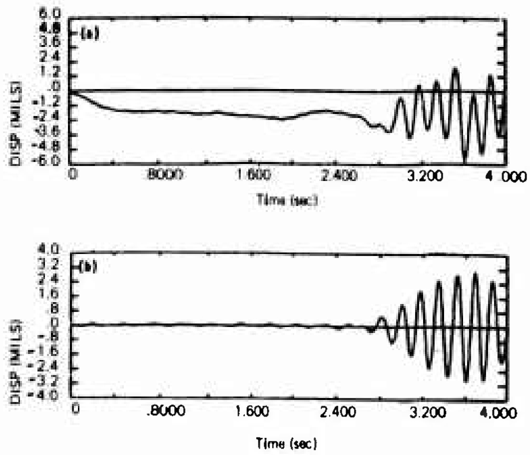

Figure 5. Bias Removal by Digital Filtering Prior to Double Integration.

(a) No Filter
(b) With a 40-70 HZ Pass Filter

COMPUTATIONAL STABILITY

The transfer function of the double-integration algorithm, as given by equation (6), can be written in the form

$$\frac{Y(z)}{U(z)} = \frac{\Delta T^2\,[25\,z^4 + 80\,z^3 + 54\,z^2 - 16\,z + 1]}{144\,z^2\,(z-1)^2} \tag{8}$$

This pole configuration is double poles at the origin and double poles at z = 1 of the complex Z-plane, as shown in Figure 6(a). Stable poles are bounded by the unit circle centered at the origin. It follows that the pair of poles at z = 1 produces a marginally stable integration algorithm; a slight numerical disturbance can lead to numerical instability. A high-frequency signal integrated using the marginally stable algorithm is shown in Figure 7(a). A similar low-frequency example is shown in Figure 8(a). The marginally stable poles must be shifted into the stable region to stabilize the integration algorithm. One way of accomplishing this shift is by using the modified transfer function

$$\frac{Y(z)}{U(z)} = \frac{\Delta T^2\,[25\,z^4 + 80\,z^3 + 54\,z^2 - 16\,z + 1]}{144\,z^2\,(z-a)^2}$$

with $0 < a < 1$

(9)

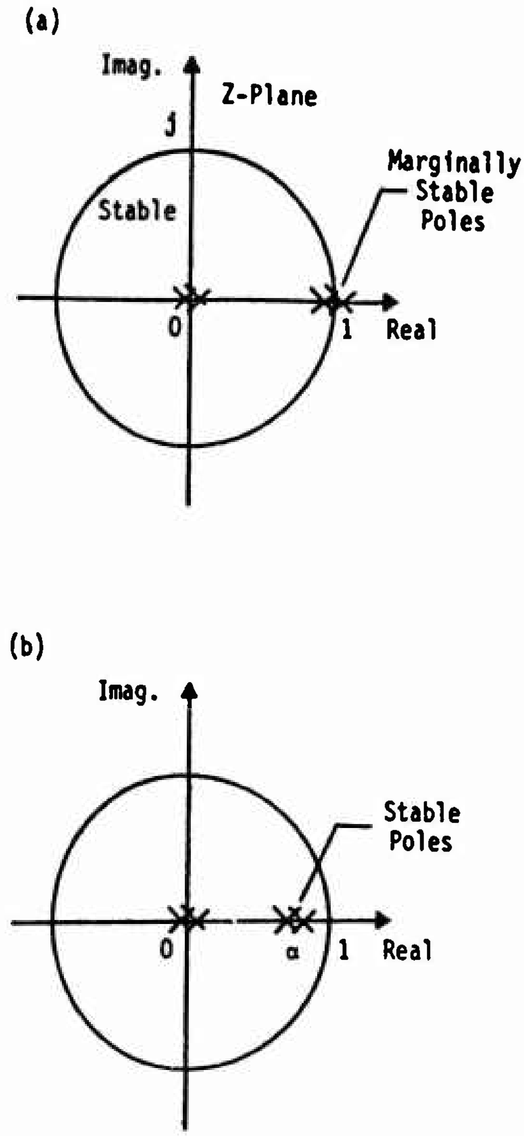

Figure 6. Pole Configuration in the Z-plane for the Parabolic Double Integrator.

(a) Marginally Stable Case
(b) Stabilized Case

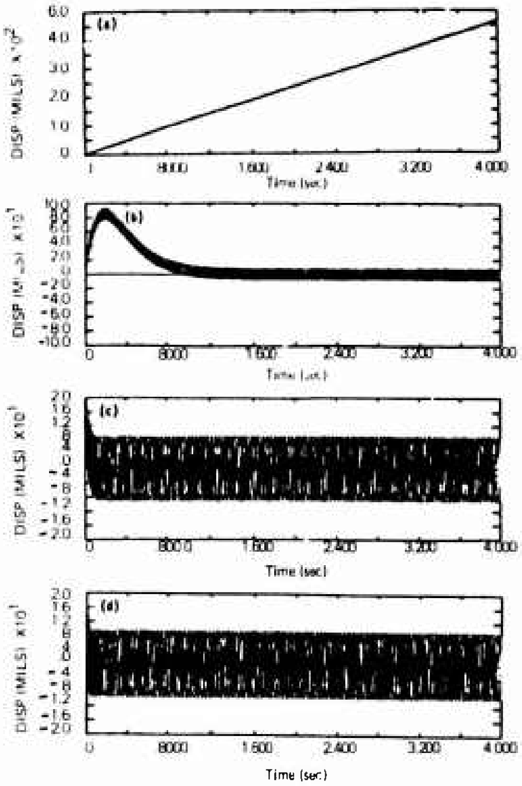

Figure 7. The Effect of the Double-Integrator Stability on a High-Frequency Signal.

(a) Alpha = 1.00
(b) Alpha = 0.99
(c) Alpha = 0.90
(d) Alpha = 0.80

The resulting pole configuration is shown in Figure 6(b). The stabilized algorithm is given by

$$y_{k+1} = 2a\, y_k - a^2\, y_{k-1} + \frac{\Delta T^2}{144} [25\, x_{k+1} + 80\, x_k + 54\, x_{k-1} - 16\, x_{k-2} + x_{k-3}]$$

with $0 < a < 1$. (10)

Figures 7 and 8 provide results showing the effect of decreasing the stability parameter α from the marginal value of unity.

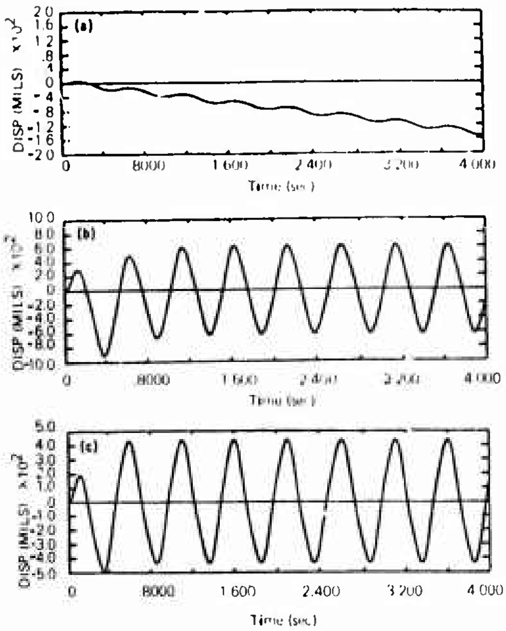

Figure 8. The Effect of the Double-Integrator Stability on a Low-Frequency Signal.

(a) Alpha = 1.00
(b) Alpha = 0.99
(c) Alpha = 0.98

THE COMPLEMENTARY—FUNCTION EFFECT

Because initial displacement and velocity conditions are not known in most cases of modal testing, double integration is done by assuming zero initial conditions. This assumption can lead to an error that originates from the complementary function (or homogeneous solution) of the difference equation. The error is termed the complementary function error. For stable algorithms the complementary function error decays exponentially; the rate of decay is governed by the degree of stability of the algorithm. For example, the initial error present in the results of Figure 7 and Figure 8 decays when the (positive) stability parameter α is less than unity. The smaller the value of α, the faster will be the decay rate of the complementary function error. If α is decreased significantly from unity, however, large integration errors result. Typically a value of α between 0.8 and 0.98 is satisfactory.

It is not possible to completely remove the complementary function error by improving the stability of the integration algorithm. In the scheme shown in Figure 2 each buffer of data is processed separately. Consequently, the complementary function effect will appear in the beginning of each block of processed data. The displacement signal shown in Figure 9(a), for example, was obtained by processing two buffers of data. A noticeable error is present beyond the halfway point of this signal. This type of error can be removed by using overlapped processing.

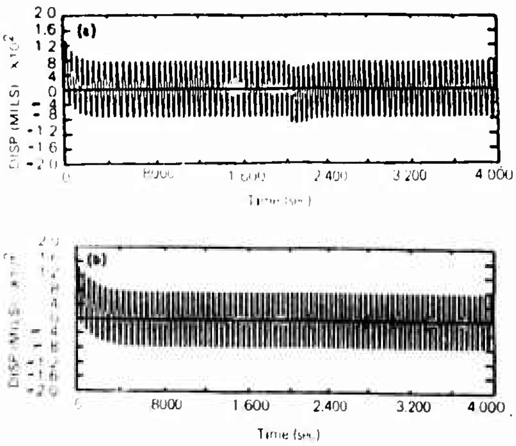

Figure 9. Removal of the Complementary Function Error.

(a) Standard Result
(b) Result Using Overlapped Processing

Overlapped processing is explained in Figure 10 for a 25% overlap. A flowchart for the computer program is given in Figure 11. The first input data buffer is processed as usual and stored in the output buffer. Then the first 75% of the input data buffer is cleared and the remaining 25% of original data is shifted to the left end of the buffer. The empty 75% of the input buffer is filled with new data. This becomes the second input data buffer, which is processed as before. Only the last 75% of the processed data is stored in the output buffer, however. Next, the third input data buffer is generated as before using 25% of the old data and 75% of the new data and processed in the usual manner. This procedure is repeated until the entire acceleration signal is processed. Figure 9(b) shows a double-integrated result obtained in this manner. Observe that the complementary function error in the intermediate segment has been eliminated.

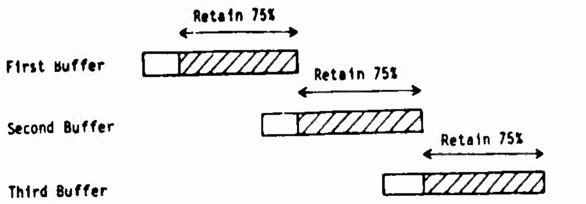

Figure 10. Overlapped Processing with 25% Overlap.

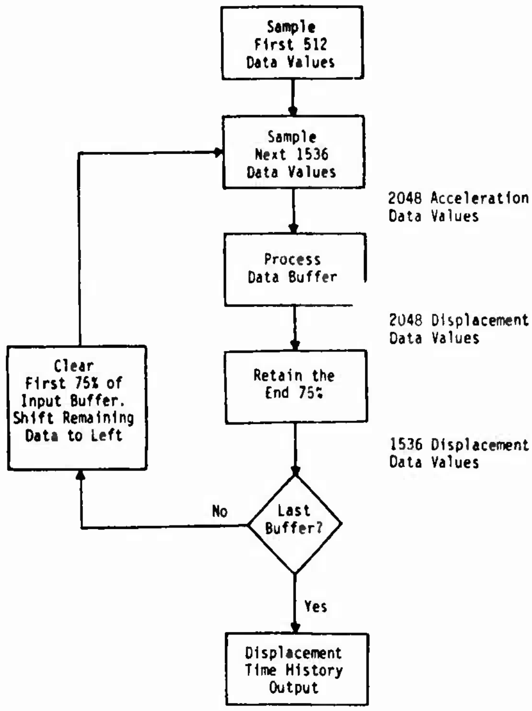

Figure 11. Modified Processing Scheme to Eliminate the Complementary Function Error.

CONCLUSIONS

Displacement responses needed for experimental modal analysis may be obtained by digitally integrating measured acceleration responses. This approach is generally favored for the ease with which accurate acceleration measurements can be made using piezoelectric accelerometers. Several problems are encountered in the associated digital processing, however.

Aliasing distortion can be reduced by employing antialiasing prefilters as well as digital low-pass filters tuned to the Nyquist frequency. Because real-time identification is not a crucial requirement in experimental modal analysis, frequency domain digital filters are preferred over time domain recursive filters. Any arbitrary filter can be implemented with high accuracy by the frequency domain method. Two FFT computations are required for each data buffer. Data windowing is necessary to reduce the leakage error resulting from truncation or buffering of nonperiodic data. System type (damping level in particular) as well as signal type should be considered in selecting a window function. Some guidelines have been provided in this regard. Signal energy reduction due to windowing can be adjusted by upward scaling of the window function. The loss of information from windowing can be accounted for by increasing the analysis bandwidth through the same scaling factor.

Filtering reduces the bias in double-integrated results originating from measurement noise. Very-narrow-band filtering can lead to dither problems, however. Numerical stability of the double integration algorithm can be guaranteed by restricting the poles of the integrator transfer function to within the unit circle in the complex Z-plane. Nevertheless, these poles should not be deviated far from their analytical positions; otherwise, large errors result due to an incorrect integration algorithm. Complementary function error is caused by the inconsistency in the initial values used in double integration. This can be eliminated by using overlapped processing.

REFERENCES

1. Cooley, J.W. and Tukey, J.W., "An Algorithm for the Machine Computation of Complex Fourier Series," Math. Computation, 19, pp 297-301 (Apr 1985).

2. deSilva, C.W., "Techniques and Applications of Experimental Modal Analysis in Modeling and Control," Proc. 1984 American Control Conference, IEEE 84CH2024-8, 2, pp 992-997 (June 1984).

3. deSilva, C.W. Dynamic Testing and Seismic Qualification Practice, D.C. Heath & Co., Lexington, MA (1983).

4. Franklin, G.F. and Powell, J.D., Digital Control of Dynamic Systems, Addison-Wesley Publishing Co., Reading, MA (1980).

5. Rabiner, L.R. and Gold, B. Theory and Applications of Digital Signal Processing, Prentice-Hall, Inc., Englewood Cliffs, NJ (1975).

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.

STABLE RESPONSE OF DAMPED LINEAR SYSTEMS — III

D.W. Nicholson*

Abstract. This article reviews several aspects of the response of discrete time-invariant damped linear mechanical systems governed by the equation $\underline{M}\ddot{\underline{x}} + \underline{C}\dot{\underline{x}} + \underline{K}\underline{x} = \underline{f}(t)$. The focus is on response bounds under several types of excitation. A formal bound is also presented for general time-dependent loads. In addition, the strong relation between system stability and the numerical stability of integration methods for computing system response is described.

In the equation

$$\underline{M}\ddot{\underline{x}} + \underline{C}\dot{\underline{x}} + \underline{K}\underline{x} = \underline{f}(t) \qquad (1)$$

$\underline{x}(t)$ is the n by 1 real displacement vector; f(t) is the n by 1 real vector of applied forces; $\underline{M}$, $\underline{C}$, and $\underline{K}$ are real, n by n, symmetric, positive definite matrices representing inertia, damping, and stiffness respectively. Equation (1) is frequently used as a model equation for multi-degree-of-freedom (mdof) lumped parameter systems. It also frequently arises from finite element analysis of linear viscoelastic structures.

This review updates and to some extent expands two earlier reviews [1,2]. Other recent surveys [3-7], monographs [8-15], and two important classical papers [16,17] are also of interest. A forthcoming book [18] addresses a number of topics relevant to this review, particularly response bounds.

The initial article in this series [1] emphasized conditions on the extreme eigenvalues of $\underline{M}$, $\underline{C}$, and $\underline{K}$ that guarantee asymptotic stability. The second article [2] addressed four topics:

- conditions for asymptotic stability
- conditions for underdamping, critical damping, and overdamping
- bounds on forced response
- localization of system eigenvalues

The current article focuses on response bounds under several types of excitations:

- impulsive loads
- constant step loads
- harmonic loads
- prescribed harmonic base motion

The response bounds examined here are typically expressed in terms of the extreme eigenvalues of $\underline{M}$, C, and K. These eigenvalues and the bounds can typically be calculated with modest computational effort, especially if the system is stiff and has a large spread between the system eigenvalues [19]. Accurate calculation of transients can be difficult for such systems. Further, particularly for stiff systems, the bounds provide information for checking the accuracy of the calculated responses.

Simple response bounds are potentially useful in design because they provide approximate information on the effects of design modifications on dynamic response. Perhaps more importantly, bounds can also be of interest in conjunction with active vibration control, for example in large flexible space structures. Typically, a number of actuators -- small in comparison to the total number of system eigenvalues (poles) -- are used to reduce vibration amplitudes over some excitation frequency range. The actuator gains are chosen to shift the system eigenvalues in a favorable manner relative to the excitation frequencies [20,21]. However, an alternate approach relevant to this review would be to choose gains that minimize response bounds.

The next section contains a brief review of bounds of interest for systems exhibiting classical normal modes [22]. The subsequent sections treat nonclassical systems -- the main concern of this review.

CLASSICAL SYSTEMS

An enormous simplification results in the special but commonly assumed case for which there exists a complete set of orthonormal vectors, $\underline{\Phi}_1, \underline{\Phi}_2, \ldots, \underline{\Phi}_n$ that simultaneously diagonalize $\underline{M}$, C, and K. Introduce the modal matrix $\underline{\Phi}$ by

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$$\underline{\underline{\Phi}} = [\underline{\phi}_1 \quad \underline{\phi}_2 \quad \cdots \quad \underline{\phi}_n] \tag{2}$$

The existence of classical normal modes implies that

$$\underline{\underline{\Phi}}^T \underline{\underline{M}} \underline{\underline{\Phi}} = \text{diag}\,\{m_1, m_2, \ldots m_n\}$$

$$\underline{\underline{\Phi}}^T \underline{\underline{C}} \underline{\underline{\Phi}} = \text{diag}\{c_1, c_2, \ldots c_n\}$$

$$\underline{\underline{\Phi}}^T \underline{\underline{K}} \underline{\underline{\Phi}} = \text{diag}\,\{k_1, k_2, \ldots k_n\}$$

The superscript T implies the transpose. The quantities m_j, c_j, and k_j are called the generalized mass, generalized damping coefficient, and generalized stiffness of the j^{th} mode. It follows that equation (1) is equivalent to n uncoupled single-degree-of-freedom (sdof) systems (modes) governed by equation (3).

$$m_j \ddot{y}_j + c_j \dot{y}_j + k_j y_j = g_j \tag{3}$$

In equation (3)

$$y_j = (\underline{\underline{\Phi}}^T \underline{x})_j \qquad g_j = (\underline{\underline{\Phi}}^T \underline{f})_j$$

Thus the overall system response bounds reduce to the maxima of the sdof bounds.

Equation (3) can be rewritten.

$$\ddot{y}_j + 2\zeta_j \omega_j \dot{y}_j + \omega_{nj}^2 y_j = g_j/m_j \tag{4}$$

Complete solution also required the initial conditions

$$y(o) = y_o \qquad \dot{y}(o) = \dot{y}_o$$

Now ω_{nj} and ζ_j are the undamped natural frequency and the damping factor of the j^{th} mode respectively. The j^{th} mode is under-damped (oscillatory), critically damped, or over-damped according to whether

$$\zeta < 1,\ \zeta = 1,\ \text{or}\ \zeta > 1$$

For simplicity, attention is restricted to under-damping. The general solution of equation (4) is [23]

$$y_j(t) = \exp(-\zeta_j \omega_{nj} t)\left[\cos(\omega_{dj} t) y_{jo} + \frac{\dot{y}_{jo} + \zeta \omega_{nj} y_{jo}}{\omega_{dj}} \sin(\omega_{dj} t)\right] + \frac{\exp(-\zeta_j \omega_{nj} t)}{\omega_{dj}\, m_j} \times \int_o^t \sin(\omega_{dj}(t-\tau)) g_j(\tau)\, d\tau \tag{4.1}$$

in which

$$\omega_{dj} = \omega_{nj} \sqrt{1 - \zeta_j^2}$$

is the damped natural frequency of the j^{th} mode.

Bounds under impulsive loading are obtained using

$$g_j(t) = g_{jo} \delta(t) \qquad y_{jo} = \dot{y}_{jo} = 0$$

and $\delta(t)$ is the Dirac function. Formally, this case is equivalent to $g_j(t) = y_{j0} = 0$ with $\dot{y}_{j0} = g_{j0}/m_j$. The solution is

$$y_j(t) = \exp(-\zeta_j \omega_{nj} t) \times \sin(\omega_{dj} t)\, g_{jo}/\omega_{dj} m_j$$

The modal displacement y_j exhibits an exponentially decaying oscillation.

Bounds under transient response are obtained using

$$g_j(t) = g_{jo}\, H(t) \qquad y_{jo} = \dot{y}_{jo} = 0$$

H(t) is the Heaviside function. The solution is

$$y_j(t) = \frac{g_{jo}}{\omega_{nj}^2 m_j} [1 - \exp(-\zeta_j \omega_{nj} t) \times$$

$$\{\cos(\omega_{dj} t) + \frac{\zeta_j}{\sqrt{1-\zeta_j^2}} \sin(\omega_{dj} t)\}]$$

The function $y_j(t)$ asymptotically settles to a steady-state value $y_{j\infty} = g_{j0}/m_j \omega_{nj}^2$. It first attains the steady-state value at the rise time t_{rj} given by

$$t_{r\gamma j} = \frac{1}{\omega_{dj}} \tan^{-1} (- \frac{\sqrt{1 - \zeta_j^2}}{\zeta_j})$$

Thereafter, $y_j(t)$ overshoots the steady-state value and attains a maximum at the peak time t_{pj}:

$$t_{pj} = \pi / \omega_{dj}$$

The overshoot is measured by

$$\mu_j = (y_j(t_{pj}) - y_{j\infty})/y_{j\infty}$$

$$= \exp(-\zeta_j / \sqrt{1 - \zeta_j^2})$$

Note that increasing the value of ζ_j results in a reduced overshoot (smaller μ_j) but increases the peak time t_{pj}. In design of active control systems for linear vibrations, a common objective is to accelerate attainment of the steady state without simultaneously causing excessive overshoot.

Bounds under harmonic force are obtained using

$$g_j(t) = g_{jo} \exp(i\omega t)$$

$$i = \sqrt{-1}$$

$$y_{jo} = \dot{y}_{jo} = 0$$

The solution is

$$y_j(t) = \frac{g_{jo}}{m_j} Y_j(\omega) \exp(i(\omega t - \phi_j))$$

$$\phi = \tan^{-1} (\frac{\zeta_j \omega_{nj} \omega}{\omega_{nj}^2 - \omega^2})$$

$$Y_j(\omega) = \frac{1}{\omega_{nj}^2} \frac{1}{\sqrt{(\omega_{nj}^2 - \omega^2)^2 + \zeta_j^2 \omega_{nj}^2 \omega^2}}$$

The amplitude function $Y_j(\omega)$ attains its maximum value (over $\omega > 0$) at resonance, for which

$$\omega = \omega_{rj} = \omega_{nj} \sqrt{1 - 2\zeta_j^2}$$

$$Y_j(\omega_{rj}) = \frac{1}{\zeta_j \omega_{nj}^4 \sqrt{1 + 2\zeta_j^2}}$$

The smaller the value of ζ_j, the higher and sharper is the resonance peak.

A possible objective in designing active control systems is to force the closed-loop system resonance frequencies to be outside the range of the excitation frequencies. Passive devices such as dynamic absorbers can also be used in such a manner.

For bounds under prescribed harmonic base motion the underlying model is expressed by the equation

$$\ddot{y}_j(t) + 2\zeta_j \omega_{nj} (\dot{y}_j - \dot{z}_j) + \omega_{nj}^2 (y_j - z_j) = 0$$

$$z_j = z_{jo} \exp(i\omega t) \qquad y_{jo} = \dot{y}_{jo} = 0$$

Here z_j represents the coordinate of nodes at the base for which motion is prescribed. Thus,

$$g_j(t) = [2i\omega\zeta_j \omega_{nj} + \omega_{nj}^2] z_{jo} \exp(i\omega t)$$

This solution is

$$y_j(t) = z_j(\omega) z_{jo} \exp(i\omega t - \psi_j)$$

$$z_j(\omega) = (\omega_{nj}^4 + 4\zeta_j^2 \omega_n^2 \omega^2)^{1/2} \, Y_j(\omega)$$

$$\psi_j(\omega) = \tan^{-1}\left(\frac{2\zeta_j \omega_{nj} \omega}{\omega_{nj}^2 - \omega^2}\right) -$$

$$\tan^{-1}\left(\frac{2\zeta_j \omega_{nj} \omega}{\omega_{nj}^2}\right)$$

The maximum value of the function $z_j(\omega)$ occurs at a frequency ω_{bj}, which is different from ω_{rj}. In particular,

$$\omega_{bj} = \frac{\omega_{nj}}{2\zeta_j} \left[\sqrt{1 + 8\zeta_j^2} - 1\right]^{1/2}$$

As $\zeta \to 0, \omega_{bj} \to \omega_{nj}$ as expected.

Refer to equation 4.1; suppose

$$|g_j(t)| < \gamma_j, \text{ for } t > 0$$

Then formally,

$$|y_j(t)| \le \exp(-\zeta_j \omega_{nj} t) [|y_{jo}| +$$

$$\frac{1}{\omega_{dj}} |\dot{y}_{jo} + \zeta_j \omega_{nj} y_{jo}| + \frac{\gamma_j}{\omega_{dj} m_j} t]$$

This formal general bound is not very helpful in many cases. But recall that potentially useful bounds can be obtained in the special cases described above. Of course, numerical methods, Fourier expansion, and other techniques are also available in the general case.

NONCLASSICAL SYSTEMS

If equation (2) fails, the system does not exhibit classical normal modes. It is thus not possible to decompose the total system response into the uncoupled responses of n independent sdof systems (real modes).

Two broad classes of bounds can be sought for nonclassical systems: (I) bounds based on the n by n second-order system equation in the original form of equation (1) or (II) bounds based on the 2n by 2n first-order system produced by reducing equation (1) to a state form. It is preferable to obtain bounds of the first type, if for no other reason than that n by n matrices are easier to manipulate computationally than 2n by 2n matrices.

Harmonic forcing and harmonic base motion. Bounds of type (I) obtained for prescribed harmonic forces have been reviewed [2]. Recent results based on small deviations from classical normal modes have been reported [24]. Numerical comparisons and earlier bounds have been presented [25]. Bounds have also recently been reported for prescribed harmonic base motion [26]. The relevant equation is

$$\underline{\underline{M}}\ddot{\underline{x}} + \underline{\underline{C}}\dot{\underline{x}} + \underline{\underline{K}}\underline{x} = \underline{\underline{A}}\dot{\underline{y}} + \underline{\underline{B}}\underline{y}$$

The vector y representing the base motion is prescribed as

$$\underline{y} = \underline{y}_o \exp(i\omega t)$$

Unfortunately, the matrices $\underline{\underline{A}}$ and $\underline{\underline{B}}$ need not be either symmetric nor positive definite although they are assumed to be nonsingular.

Suppose $|\underline{x}|$ denotes the Euclidean vector norm of $\underline{x}$. Let $\|\underline{\underline{M}}\|$ denote the corresponding matrix norm of $\underline{\underline{M}}$. Then [26]

$$|\underline{x}|/|\underline{y}_0| \le \max_{\omega > 0} \{ [\omega \|\underline{\underline{A}}\| + \|\underline{\underline{B}}\|] / \Omega(\omega)$$

where $\Omega(\omega)$ is a function of the extreme eigenvalues of M, C, and K. This function has been derived [27]. Simple numerical results that show the expected effects of damping are available [26].

Reduction to state form. Various results have been derived when equation (1) is replaced by the 2n by 2n first order system

$$\frac{dz}{dt} + \underline{\underline{A}}\underline{z} = \underline{g}(t)$$

$$\underline{z} = \begin{Bmatrix} \dot{\underline{x}} \\ \underline{x} \end{Bmatrix} \qquad \underline{\underline{A}} = \begin{bmatrix} \underline{\underline{M}}^{-1}\underline{\underline{C}} & \underline{\underline{M}}^{-1}\underline{\underline{K}} \\ -\underline{\underline{I}} & \underline{\underline{0}} \end{bmatrix}$$

$$\underline{g}(t) = \begin{Bmatrix} \underline{\underline{M}}^{-1}\underline{f}(t) \\ \underline{0} \end{Bmatrix} \qquad \underline{z}(o) = \underline{z}_1 = \begin{Bmatrix} \dot{\underline{x}}_o \\ \underline{x}_o \end{Bmatrix} \tag{5}$$

Without loss, it is assumed that M is the identity matrix. The general solution of equation (5) is

$$\underline{z} = \exp(-\underline{\underline{A}}t)\underline{z}_o + \exp(-\underline{\underline{A}}t)\int_o^t \exp(\underline{\underline{A}}\tau)\underline{g}(t)d\tau \tag{6}$$

Formal bound in general case. A formal bound for z in equation (3) can be obtained using the one-sided Lipschitz constant for the exponential matrix function exp (-At) [19]. In particular,

$$||\exp(-\underline{\underline{A}}t)|| \leq \exp(\nu(\underline{\underline{A}})t)$$

where

$$\nu(\underline{\underline{A}}) = \min_j \lambda_j(-1/2(\underline{\underline{A}} + \underline{\underline{A}}^T))$$

is called the one-sided Lipschitz constant for A.

It has been shown [28] that

$$\exp(-\underline{\underline{A}}t) = \begin{bmatrix} \underline{\underline{I}} & \underline{\underline{0}} \\ \underline{\underline{0}} & \underline{\underline{K}}^{1/2} \end{bmatrix} \exp(-\underline{\underline{B}}t) \begin{bmatrix} \underline{\underline{I}} & \underline{\underline{0}} \\ \underline{\underline{0}} & \underline{\underline{K}}^{-1/2} \end{bmatrix}$$

where

$$\underline{\underline{B}} = \begin{bmatrix} \underline{\underline{C}} & \underline{\underline{K}}^{1/2} \\ -\underline{\underline{K}}^{1/2} & \underline{\underline{0}} \end{bmatrix}$$

Hence

$$\exp(-\underline{\underline{A}}t) \leq \alpha\exp(\nu(\underline{\underline{B}})t)$$

where

$$\alpha = \frac{\max[\lambda_1^{1/2}(\underline{\underline{K}}),1]}{\min[\lambda_n^{1/2}(\underline{\underline{K}}),1]}$$

where $\lambda_j(K)$ are the ordered eigenvalues of K (i.e.,

But

$$\nu(\underline{\underline{B}}) = 0$$

Thus

$$|\underline{z}| \leq \alpha[|\underline{z}_o| + \int_o^t |\underline{g}(\tau)|d\tau] \tag{7}$$

Alternatively, it can be assumed that there exists a nonsingular matrix $\underline{\underline{S}}$ for which

$$\underline{\underline{A}} = \underline{\underline{S}}^{-1}\,\underline{\underline{\Lambda}}\underline{\underline{S}}$$

$$\underline{\underline{\Lambda}} = \text{diag}(\lambda_1(\underline{\underline{A}}),\ldots,\lambda_n(\underline{\underline{A}}))$$

The bound now is

$$|z| \leq \kappa[|\underline{z}_o|e^{-\chi t} + \int_o^t |\underline{g}(\tau)|d\tau] \tag{8}$$

where

$$\chi = \min_j \text{Re}(\lambda_j(\underline{\underline{A}}))$$

and where κ is the spectral condition number of $\underline{\underline{A}}$. The interest in equation (7) as opposed to equation (8) is that equation (7) is expressed in terms of a known matrix $\underline{\underline{K}}$. Equation (8) involves the matrix $\underline{\underline{S}}$, which may be difficult to determine.

Impulse loading. Apparently new results provides a time-dependent bound for impulsive loading. Refer to equation (1). Suppose

$$\underline{f}(t) = \underline{f}_o\delta(t) \qquad \underline{x}(o) = \dot{\underline{x}}(o) = 0$$

Again, suppose without loss that M = I, and let

$$\underline{y}(t) = e^{-\gamma t}\,\underline{x}(t)$$

Equation (1) now implies

$$\underline{\underline{I}}\ddot{\underline{y}} + \underline{\underline{C}}'\dot{\underline{y}} + \underline{\underline{K}}'\underline{y} = \underline{f}_o\, e^{\gamma t}\, \delta(t)$$

$$\underline{\underline{C}}' = \underline{\underline{C}} - 2\gamma\underline{\underline{I}} \qquad \underline{\underline{K}}' = \underline{\underline{K}} - \gamma\underline{\underline{C}} + \gamma^2\underline{\underline{I}} \tag{9}$$

The matrices C' and K' are still positive definite if

$$\gamma > \min[c_n/2,\ c']$$

where

$$c' = \begin{cases} c_n/2 & \text{if } c_1^2 - 4k_n < 0 \\ \frac{1}{2}[c_1 - (c_1^2 - 4k_n)^{1/2}] & \text{if } c_1^2 - 4k_n \geq 0 \end{cases} \tag{10}$$

where c_i and k_i are the ordered eigenvalues of $\underline{\underline{C}}$ and K respectively. Assuming equation (1), equation (9) is now reduced to the state form

$$\dot{\underline{w}} + \underline{\underline{A}}'\underline{w} = \underline{g}_o \exp(\gamma t)\,\delta(t)$$

$$\underline{w} = \begin{Bmatrix} \dot{\underline{y}} \\ \underline{y} \end{Bmatrix} \qquad \underline{\underline{A}}' = \begin{bmatrix} \underline{\underline{C}}' & \underline{\underline{K}}' \\ -\underline{\underline{I}} & \underline{\underline{0}} \end{bmatrix}$$

$$\underline{g}_o = \begin{Bmatrix} \underline{f}_o \\ \underline{0} \end{Bmatrix}$$

A time-dependent bound is readily found as

$$|\underline{w}| \leq \nu(\underline{\underline{A}}')\underline{g}$$

and hence

$$\left\| \begin{Bmatrix} \dot{\underline{x}} - \gamma\underline{x} \\ \underline{x} \end{Bmatrix} \right\| < e^{-\gamma t}\, \nu(\underline{\underline{A}}') \left\| \begin{Bmatrix} \underline{f}_o \\ 0 \end{Bmatrix} \right\|$$

Transient response. Results have recently been reported for constant step loading [28]:

$$\underline{g}(t) = \underline{g}_o\, H(t) \qquad\qquad \underline{z}(o) = \underline{0}$$

For example, a generalized overshoot is defined as

$$\mu = \left\| \begin{Bmatrix} \dot{\underline{x}} \\ \underline{x} \end{Bmatrix} - \begin{Bmatrix} \dot{\underline{x}} \\ \underline{x} \end{Bmatrix}_\infty \right\| \Big/ |\underline{g}_o|$$

The infinity symbol implies the steady state value. A bound on μ is obtained [28] as

$$\mu \leq \alpha'$$

where

$$\alpha' = \frac{\max[\lambda_1^{1/2}(\underline{\underline{K}}'),1]}{\min[\lambda_n^{1/2}(\underline{\underline{K}}'),1]}$$

Other approaches. For the sake of completeness, it should be noted that bounds can be derived by approaches not reviewed here. For example, bounds have been obtained directly using Lyapunov functions [29]. Hamilton's principle of least action has been extended to accommodate varying initial conditions [30].

NUMERICAL STABILITY

The system properties -- for example small damping -- that produce extreme responses such as sharp resonance peaks can also impede accurate numerical integration of the system equations. However, there is often a simple relation between asymptotic stability of the physical system and numerical stability of the integration method used for calculating system response.

Several methods are used for integrating systems such as are described in equation (1) They include: multistep methods [31]; Runge-Kutta methods, extensively discussed in a recent monograph [19]; and matrix polynomial methods, notably including Padé approximations [32-35]. The relation between system stability and numerical stability is best illustrated in conjunction with the calculation of the matrix exponential function; 19 methods have been reviewed [36,37]. Padé methods are described below.

Consider $\exp(\underline{H}t)$ where $\underline{H}$ is Hurwitz; i.e., all of its eigenvalues lie in the right-half plane. If H is the system matrix, say $\underline{H} = -\underline{A}$ in equation (4), the system is asymptotically stable. Such stability is equivalent to

$$||\exp\underline{H}t|| \to 0 \text{ as } t \to \infty \tag{11}$$

$\mathrm{Exp}(\underline{H}t)z_0$ is the exact solution for the system

$$\frac{d\underline{z}}{dt} = \underline{H}\underline{z} \qquad \underline{z}(o) = \underline{z}_o \tag{12}$$

Let h denote the time step in a numerical integration procedure for equation (12) and let Q = Hh. A one-step (t,s) - Padé numerical integration procedure for equation (12) is introduced by the formula

$$\underline{A}(Q)\underline{z}_{n+1} = \underline{B}(\underline{Q})\underline{z}_n \tag{13}$$

where z_n represents the numerical approximation to z at time t = nh. Also

$$\underline{A}(\underline{Q}) = \underline{I} + a_1\underline{Q} + a_2\underline{Q}^2 + \ldots + a_t\underline{Q}^t$$

$$\underline{B}(\underline{Q}) = \underline{I} + b_1\underline{Q} + b_2\underline{Q}^2 + \ldots + b_s\underline{Q}^s$$

The coefficients a_i and b_i are chosen to produce agreement with the Taylor series expansion of exp(Q) up to the highest possible power in Q.

In equation (12)

$$\underline{z}_{n+1} = \underline{A}^{-1}(\underline{Q})\underline{B}(\underline{Q})\underline{z}_n$$

Assume that z_n is the exact solution at nh (z_n = z(nh); the truncation error vector τ is thus defined by [38]

$$\underline{\tau} = [\exp(\underline{Q}) - \underline{A}^{-1}\underline{B}]\underline{z}_n$$

and τ is proportional to $\underline{Q}^{t+s+1}$

For equation (13) to exhibit numerical stability, it is necessary that perturbations of the initial conditions die out as n increases. This is tantamount to

$$||\underline{A}^{-1}\underline{B}|| < 1 \tag{14}$$

The point is that, under certain conditions, the fact that H and hence Q are Hurwitz implies that equation (14) is satisfied. This was proved in a classical paper [39] for the diagonal Pade approximation (t=s). It has more recently been proved [40,41] for the first two subdiagonal Padé approximation (t=s+1, t=s+2). For several types of Padé approximation asymptotic stability implies numerical stability.

In numerical integration of large systems, it is often important to avoid over-stabilizing the numerical integration method by using features that dissipate high-frequency modes. The computations should accurately trace the extreme aspects of the system response. For this purpose, numerical methods with good relative stability, in which the ratio of error to true solution is controlled, are desirable. Apparently, common numerical integration methods such as Newmark, which has been reviewed [31], are primarily designed to control absolute error.

CONCLUSION

This article is the third in a series of reviews focusing on the dynamic response of damped linear systems. Emphasis has been on response bounds under impulse excitation, step force excitation, harmonic force, and harmonic base motion. Both classical and nonclassical systems are discussed. A general bound is also reported using the one-sided Lipschitz constant. Finally, the close relation between system stability and numerical stability has been illustrated using Padé approximations.

REFERENCES

1. Nicholson, D.W., "Stable Response Bounds for Damped Linear Systems," Shock Vib. Dig., 12 (6) (1980).

2. Nicholson, D.W., "Stable Response of Damped Linear Systems," Shock Vib. Dig., 15 (11) (1983).

3. Huseyin, Z., "Vibrations and Stability of Mechanical Systems, Part I," Shock Vib. Dig., 8 (4) (1976).

4. Huseyin, Z., "Vibrations and Stability of Mechanical Systems, Part II," Shock Vib. Dig., 12 (4) (1980).

5. Hill, D. and Moylan, P.J., "Dissipative Dynamical Systems: Basic Input-Output and State Properties," J. Franklin Inst. 309 (1980).

6. Shrivastava, S.K. and Bhat, M.S., "Dissipativeness and Stability of a Class of Distributed Parameter Systems," J. Appl. Mech., Trans. ASME, 52 (1985).

7. Mori, T. and Derese, I.A., "A Brief Summary on the Solution of the Algebraic Matrix Equations in Control Theory," Intl. J. Control, 39 (2) (1984).

8. Müller, P.C., Stabilität und Matrizen, Springer-Verlag (1977).

9. Huseyin, Z., Vibrations and Stability of Multiple Parameter Systems, Sijthoff and Noordhoff (1978).

10. Rouche, N. et al, Stability Theory by Lyapunov's Direct Method, Springer-Verlag (1977).

11. Atherton, D.P., Stability of Nonlinear Systems, Research Studies Press (1981).

12. Müller, P.C. and Schiehlen, W.O., Linear Vibrations, Martinus Nijhoff Publ., The Netherlands (1985).

13. Leipholz, H.H.E. (ed.), Structural Control, Proc. IUTAM Symp. Struc. Control, North-Holland (1980).

14. Aggarwal, J.K. and Vidyasagar, M., Nonlinear Systems: Stability Analysis, Dowden, Hutchinson, and Ross, Inc. (1977).

15. Pusey, et al, An International Survey of Shock and Vibration Technology, Shock and Vibration Information Center (1981).

16. Kalman, R.E. and Bertram, J.E., "Control System Analysis and Design via the 'Second Method' of Lyapunov; I: Continuous-Time Systems," J. Basic Engrg., Trans. ASME, 82 (1960).

17. Kalman, R.E. and Bertram, J.E., "Control System Analysis and Design via the 'Second Method' of Lyapunov; I: Discrete Time Systems," J. Basic Engrg., Trans. ASME, 82 (1960).

18. Inman, D.J., Vibrations: Control, Stability, and Measurement, Prentice-Hall Inc. (to be published).

19. Dekker, K. and Verwer, J.G. Stability of Runge-Kutta Methods for Stiff Nonlinear Differential Equations, Elsevier Scientific Publ., B.V. (1984).

20. Meirovitch, L., "Direct Feedback Control of Distributed Structures," preprint, Soc. Engrg. Sci. (1985).

21. Reinhorn, A.M. and Manolis, G.D., "Current State of Knowledge on Structural Control," Shock Vib. Dig., 17 (1985).

22. Caughey, T. and O'Kelley, M.E.K., "Classical Normal Modes in Damped Linear Dynamic Systems," J. Appl. Mech., Trans. ASME, 32 (1960).

23. Lalanne, M. et al, Mechanical Vibrations for Engineers, J. Wiley and Sons (1983).

24. Kwang, K.H. and Inman, D.J., "Response Bounds for Linear Underdamped System", J. Appl. Mech., Trans. ASME (to be published).

25. Nicholson, D.W., "Free Vibrations of a Large Damped Mechanical System," U.S. Naval Res. Lab., Shock Vib. Bull. No. 52 (1982).

26. Nicholson, D.W., "Response Bounds for Damped Linear Mechanical Systems under Prescribed Base Motion," (to be published).

27. Nicholson, D.W., "Response Bounds for Asymptotically Stable Linear Dynamical Systems," IEEE Trans. Auto. Contr., AC-27 (1982).

28. Nicholson, D.W., "Transient Response Bounds for Damped Linear Mechanical Systems," (to be published).

29. Ahmadian, M. and Inman, D.J., "On the Stability of General Dynamic Systems Using a Liapunov's Direct Method Approach," Computers Struc., 20 (1-3) (1985).

30. Papastavridis, J.G., "An Action-Based Method for the Kinetic Stability of Potential But Nonconservative Systems," J. Appl. Mech., Trans ASME, 52 (1985).

31. Zienkiewicz, O.C., "Finite Elements in the Time Domain," State of the Art Surveys in Finite Element Technology, A.K. Noor and W.D. Pilkey (eds.) ASME (1983).

32. Trujillo, D.M., "The Direct Numerical Integration of Linear Matrix Differential Equations Using Padé Approximations," Intl. J. Numer. Methods Engrg., 9 (1975).

33. Trujillo, D.M. and Busby, H.R., "Investigation of Highly Accurate Integration Formulae for Transient Heat Conduction Analysis Using the Conjugate Gradient Method," Intl. J. Numer. Methods Engrg., 18 (1982).

34. Serbin, S., "On a Fourth Order Unconditionally Stable Scheme for Damped Second Order Systems," Comp. Methods Appl. Mech. Engrg. 23 (1980).

35. Dougalis, V.A. and Serbin, S.M., "On Some Unconditionally Stable Higher Order Methods for the Numerical Solution of the Structural Dynamics Equations," Intl. J. Numer. Methods Engrg., 18 (1982).

36. Golub, G. and Van Loan, C., Matrix Computations, The Johns Hopkins University Press (1983).

37. Moler, C.B. and Van Loan, "Nineteen Dubious Ways to Compute the Exponential of a Matrix,"SIAM Rev., 20 (1978).

38. Brusa, L. and Nigro, L., "A One-Step Method for Direct Integration of Structural Dynamics Equations," Intl. J. Numer. Methods Engrg., 15 (1980).

39. Birkhoff, G. and Varga, R.S., "Discretization Errors for Well-Set Cauchy Problems. I," J. Math. Phys. 44 (1965).

40. Ehle, B.L., "A-Stable Methods and Padé Approximations to the Exponential," SIAM J. Numer. Anal., 5 (1973).

41. Wanner, G., Hairer, E., and Norsett, S.P., "Order Stars and Stability Theorems," BIT, 18 (1978).

BOOK REVIEWS

VIBRATIONS AND WAVES

W. Gough, J.P.G. Richards and R.P. Williams
Halsted Press, New York, NY
1983, 278 pp

This book is intended for beginning physics and engineering students with a knowledge of elementary calculus. A novel treatment is the use of partial differential equations to describe physical phenomena and the introduction of Fourier series and transforms (stated without proofs). I would judge the treatment to be successful, relying as it does on extensive use of physical arguments. A welcome feature is computer programs that are to be used for certain homework problems and for demonstration purposes.

There are eleven chapters and two appendices. The introductory chapter is devoted to intuitive, physical notions on waves. One- and two-dimensional vibrations of a particle are discussed in Chapter 2, as are the normal modes and beating of coupled particles. Damped and forced motions of mechanical and electrical systems are the topics of Chapter 3. Fundamental concepts of one-, two-, and three-dimensional waves are given in Chapter 4. The treatment is somewhat atypical in that wave-like solutions are introduced, and the governing equations are derived from them. In Chapter 5 the equations are derived from fundamental physical laws. Topics are transverse waves in a string, longitudinal waves in a fluid, pressure waves in a gas, and current and voltage waves in an ideal transmission line. Chapter 6 presents a thorough, physically-oriented discussion on wave reflection and transmission, energy flow, and waveguides.

Fourier series and transforms are introduced in Chapter 7. Of interest are the use of the transform of a truncated cosine to illustrate the uncertainty principle and the interpretation of a delta function as a limiting sequence of equal area, rectangular pulses. Addition, similarity, derivative, and convolution theorems are developed in Chapter 8. Such wave phenomena as the Doppler effect, dispersion, and group velocity are analyzed in Chapter 9. A good example on the practical use of the convolution theorem is the treatment of amplitude modulation.

Waves in pipes and strings are analyzed in Chapter 10; musical instruments are the practical applications. The final chapter focuses on electromagnetic waves. Polarization, interference, Huygen's principle, and Fraunhofer diffraction are described. Appendix A is devoted to computer programs that are possibly too system dependent to be of general use. Appendix B contains details of solutions to the differential equations that arise in vibration problems.

The book should be of some value to classroom instructors (it was to me). It also would be useful to engineers who seek a better understanding of vibrations and waves without the purely mathematical detail.

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PARAMETRIC RANDOM VIBRATION

R.A. Ibrahim
Res. Studies Press, Ltd. Distr. by
John Wiley & Sons, Inc., New York, NY
1985, $59.95

Parametric random vibration refers to the vibratory response of dynamic systems and involves randomly fluctuating coefficients. The term random vibration refers to the random response of dynamic systems with deterministic coefficients; random vibration is well developed for linear systems under stationary excitation. However, parametric random vibration is a new technology involving nonlinear systems and non-constant coefficients.

The book offers a coherent and systematic approach to the response of vibrating systems with random parametric variations. The basic considerations of parametric vibrations provide an excellent background for the reader who might be unfamiliar with the theory of random variables. Fundamental concepts in random variables, stochastic processes, and stochastic calculus are clearly defined and applied to engineering problems. The treatment is concise, and a lengthy bibliography allows the reader the opportunity to explore topics in greater detail. Stochastic process theory and stochastic calculus are reviewed. Coverage of the response of vibratory systems includes three main topics. First is the approximation of the statistics of the response by several techniques that lead to a practical application of theory to common engineering problems. Second is the estimation of the stability of the random response by several recent theorems of stochastic parameter stability. A description of the time response of linear and nonlinear systems is also given.

Overall, the book is a clear and concise treatment of an important topic. It will be valuable to graduate students, researchers, and structural engineers involved in analysis of random vibration of engineering structures. The fundamentals of random process theory are presented clearly enough so that prior training is not required although it would be helpful. The book does assume, however, that the reader is well versed in the fundamentals of vibrations of distributed and lumped parameter systems. In addition, some prior training in nonlinear system response will be helpful but is not absolutely essential.

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SHORT COURSES

NOVEMBER

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

Dates: November 3-7, 1986
Place: Orlando, Florida
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.

MACHINERY VIBRATION ANALYSIS I

Dates: November 11-14, 1986
Place: Chicago, Illinois
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.

GENERAL TURBOMACHINERY COURSE

Dates: November 18-21, 1986
Place: Houston, Texas
Objective: This course will cover the following topics: Turbomachinery Specifications, Centrifugal and Axial Flow Machinery, Gas and Steam Turbines, Instrumentation, Rotor Dynamics, Bearings, SEals, and Flexible Couplings. The course is designed to address present market needs, and is aimed at the engineers in plants utilizing turbomachinery. Students are invited to bring up problems for discussions, and practical and usable procedures will be offered.

Contact: Course Director, Boyce Engineering International, Inc., 10555 Rockley Road, Houston, TX 77099 - (713) 933-7210.

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 damp d systems, linear and nonlinear, and emphasize learn ng 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

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

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

NEWS BRIEFS: news on current and Future Shock and Vibration activities and events

CALL FOR PAPERS

33RD INTERNATIONAL INSTRUMENTATION SYMPOSIUM
May 3-8, 1987
Las Vegas, Nevada

The 33rd International Instrumentation Symposium will convene in Las Vegas. This annual symposium is sponsored jointly by the Aerospace Industries and Test Measurement Divisions of the Instrument Society of America. This symposium has become recognized as the outstanding forum for discussion of new and innovative instrumentation techniques, development and applications. Prospective authors are invited to submit papers in the following interest areas:

MEASUREMENTS: Pressure, Flow, Strain, Motion, Force, Vibration, Thermal, Measurement Uncertainty, Metrology, Blast and Shock

DATA SYSTEMS: Data Acquisition Processing, Real Time Systems, Telemetry Systems, Remote Systems, Computer Applications, Software Design/Development

INSTRUMENTATION SYSTEMS: Flight Test and Avionics, Wind Tunnel, Aerospace, Energy, Transportation, Machinery, Special Test Facilities, Reentry Vehicles/Systems

NOISE-CON 87
June 8-10, 1987
Pennsylvania State University
State College, Pennsylvania

The conference will be co-sponsored by the Graduate Program in Acoustics, the Department of Engineering Science and Mechanics, the Department of Mechanical Engineering, The Applied Research Laboratory, and the Institute of Noise Control Engineering. The theme of NOISE-CON 87 will be "High Technology for Noise Control." Emphasis will be placed on active noise and vibration control, acoustic intensity techniques, machinery noise monitoring, computer-aided design for noise control, reduction of turbomachinery noise, office equipment noise control, transportation noise, outdoor noise propagation, and computer-aided data acquisition. Papers in other areas of noise control engineering are also welcome.

In addition to technical sessions, an exhibition of measurement instrumentation, materials, and products for noise control will be held. Laboratory tours in such diverse areas as acoustical holography, acousto-optics, architectural acoustics, bioengineering, ultrasonics, environmental acoustics, and noise reduction will also be arranged.

A Call of Papers for the three-day conference has been issued. Abstracts must be limited to approximately 300 words, and must be submitted to the conference organizers no later than November 7, 1986. Three copies of the abstract are required. Special manuscript paper will be mailed to authors whose papers are accepted, and the final manuscript is due no later than February 1, 1987.

Abstracts and requests for additional information should be mailed to: Conference Secretariat, NOISE-CON 87, The Graduate Program in Acoustics, Applied Science Building, University Park, PA 16802.

ABSTRACTS FROM THE CURRENT LITERATURE

ABSTRACT CONTENTS

AVAILABILITY OF PUBLICATIONS ABSTRACTED

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

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

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

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

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

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

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

When ordering, the pertinent order number should always be included, <u>not</u> the **DIGEST** abstract number.

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

MECHANICAL SYSTEMS

ROTATING MACHINES

86-1861
An Analytical Study and Computer Analysis of Three-Dimensional, Steady-State Vibration of Multishaft Geared-Rotor Systems
J.M. Blanding
Ph.D. Thesis, Virginia Polytechnic Institute and State University, 206 pp (1985) DA8600361

KEY WORDS: Rotors, Gears, Periodic response

A unique multifrequencied transfer matrix method performs three-dimensional harmonic, steady-state response calculations on geared-rotor systems. The full six degrees-of-freedom method includes physical branching to accommodate multiple shafting and frequency branching. Areas of emphasis include development of a modified transfer matrix to handle multiple frequencies and shafting. A description of the time-varying stiffness tensor representing the involute spur gear mesh based on bending, shear, compression, and local contact is given. A computer analysis demonstrates the significance of terms included in the stiffness evaluation as compared with less rigorous treatment in the literature.

86-1862
Linear Dynamic Coupling in Geared Rotor Systems
J.W. David, L.D. Mitchell
North Carolina State Univ., Raleigh, NC
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 171-176 (Apr 1986) 5 figs, 2 tables, 21 refs

KEY WORDS: Gears, Rotors, Coupled response

Accurate analysis of torsional-axial-lateral coupled response of geared systems is the key to the prediction of dynamic gear forces, shaft moments and torques, dynamic reaction forces, and moments at all bearing points. The importance of certain linear dynamic coupling terms on the predicted response of geared rotor systems is addressed. The coupling terms investigated are associated with those components of a geared system that can be modeled as rigid disks. First, the coupled, nonlinear equations of motion for a disk attached to a rotating shaft are presented. The conventional argument for ignoring these dynamic coupling terms is presented and the error in this argument is revealed. It is shown that in a geared system containing gears with more than about 50 teeth, the magnitude of some of the dynamic-coupling terms is potentially as large as the magnitude of the linear terms that are included in most rotor analyses. In addition, it is shown that the dynamic coupling terms produce the multi-frequency responses seen in geared systems. To quantitatively determine the effects of the linear dynamic-coupling terms on the predicted response of geared rotor systems, a trial problem is formulated in which these effects are included. The results of this trial problem shows that the inclusion of the linear dynamic-coupling terms changed the predicted response up to eight orders of magnitude, depending on the response frequency. In addition, these terms are shown to produce sideband responses greater than the unbalanced response of the system.

86-1863
The Dynamics of a Rotor System with a Cracked Shaft
H.D. Nelson, C. Nataraj
Arizona State Univ., Tempe, AZ
J. Vib., Acoust., Stress, Rel Des., 108 (2), pp 189-196 (Apr 1986) 11 figs, 2 tables, 24 refs

KEY WORDS: Shafts, Cracked media, Stiffness coefficients, Finite element technique, Computer programs

A theoretical analysis of the dynamics of a rotor-bearing system with a transversely cracked rotor is presented. The rotating assembly is modeled using finite rotating shaft elements and the presence of a crack is taken into account by a rotating stiffness variation. This stiffness variation is a function of the rotor's bending curvature at the crack location and is represented by a Fourier series expansion. The resulting parametrically excited system is nonlinear and is analyzed using a perturbation method coupled with an iteration procedure. The system equations are written in terms of complex variables and an associated computer code has been developed for simulation studies. Results obtained by this analysis procedure are compared with previous analytical and experimental work presented by Grabowski

86-1864
Lateral Vibrations of an Asymmetrical Shaft Driven by a Universal Joint —Generation of Unstable Vibration and Expansion of Unstable Region by Angular Velocity Fluctuation
H. Ota, M. Kato, M. Mizuno
Nagoya Univ. Nagoya, Japan

Bull. JSME, 29 (249), pp 916-923 (Mar 1986) 12 figs, 10 refs

KEY WORDS: Shafts, Universal joints, Lateral vibrations

Vibrations of a driven shaft with asymmetrical stiffness are governed by simultaneous equations with parametrical excitation. The equations of motion are analyzed by the asymptotic method, and the characteristics of vibration are explained.

86-1865

Random Vibration of Rotating Machines under Earthquake Excitations

B. Samali, K.B. Kim, J.N. Yang
George Washington Univ., Washington, DC
ASCE J. Engrg. Mech., 112 (6), pp 550-565 (June 1986) 12 figs, 40 refs

KEY WORDS: Rotating machinery, Seismic excitation, Random vibrations

Random vibration of rotating machines subjected to seismic excitations is analyzed. Six-component earthquake ground motions are modeled as nonstationary random processes. The method of Monte Carlo simulation is used to simulate the six-component nonstationary earthquake ground motions and to determine the statistics of the response of rotating machines. The significance of seismic base rotations on the overall structural response is examined. A numerical example is worked out to demonstrate the methodology employed.

86-1866

The Effect of Viscoelasticity on the Vibration of a Rotor

S.L. Hendricks
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
J. Appl. Mech. Trans. ASME, 53 (2), pp 412-416 (June 1986) 8 figs, 13 refs

KEY WORDS: Rotors, Viscoelastic properties, Perturbation theory

This paper analyzes the dynamics of a simple rotor mounted on a shaft constructed from a viscoelastic material. The equations are solved using a perturbation technique that is valid whenever viscoelastic time constants are much larger than elastic time constants. Regions of stable and unstable motion are discovered analytically. Several time histories for the rotor motion are presented.

86-1867

Parameter Sensitivity in the Dynamics of Rotor-Bearing Systems

M. Rajan, H.D. Nelson, W.J. Chen
Arizona State Univ., Tempe, AZ
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 197-206 (Apr 1986) 5 figs, 8 tables, 11 refs

KEY WORDS: Rotors, Sensitivity analysis, Whirling, Critical speeds, Eigenvalue problems

When designing a rotor system it is frequently desirable to have at hand a set of design sensitivity coefficients which quantitatively predict a change in specific system characteristics to changes in design parameters. This paper presents eigenvalue sensitivity coefficients for the damped natural frequencies of whirl of general linear rotor system modeled by finite element discretization. In addition, a simple and direct method for calculation of the damped critical speeds is presented, which utilizes the eigenvalue sensitivity with respect to the spin speed. It is shown that the combination of design parameter and spin speed whirl frequency sensitivity coefficients may be used to also evaluate the damped critical speed sensitivity coefficients.

86-1868

An Improved Transfer Matrix-Direct Integration Method for Rotor Dynamics

Jialiu Gu
Northwestern Polytechnical Univ., Xi'an, China
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 182-188 (Apr 1986) 8 figs, 1 table, 10 refs

KEY WORDS: Rotors, Critical speeds, Unbalance mass response, Transfer matrix method, Direct integration technique

A transfer matrix-direct integration combined method is proposed. It employs the transfer matrix method to derive the equations of motion of a characteristic disk, and uses the direct integration method to determine the critical speeds, modes and unbalance response of a rotor-bearing system, and to analyze its stability. An impedance matrix iteration method is proposed to consider the effect of a complicated bearing-supporting system on the rotor dynamics. Two examples are given, and the results agree satisfactorily with the experiments.

86-1869

Application of the Riccati Method to Rotor Dynamic Analysis of Long Shafts on a Flexible Foundation

J.W. Lund, Z. Wang

The Technical Univ. of Denmark, Lyngby, Denmark
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 177-181 (Apr 1986) 1 fig, 9 refs

KEY WORDS: Shafts, Flexible foundations, Damped structures, Critical speeds, Unbalance mass response

A method is described for calculating critical speeds, unbalance response and damped natural frequencies of long rotors on a flexible foundation. The shaft and the foundation are calculated separately and coupled at the bearing through impedance matching. Included in the analysis is a method for representing the shaft response by an expansion in its free-free modes.

86-1870
Shock Spectra Analysis of Rotor-Bearing Systems
A. Mohsiul
Ph.D. Thesis, Arizona State Univ., 156 pp (1985) DA 8602832

KEY WORDS: Rotors, Shock response spectra, Blade loss dynamics, Base excitation

A shock response spectrum procedure is developed to estimate the peak displacement response of linear flexible rotor-bearing systems subjected to a shock load. Blade loss, base acceleration pulse or a step turn maneuver are examples. A response spectrum is established for each of these types of shock loads. The spectrum is established for each of these shock loads. The spectrum for blade loss consists of a progressive and a retrograde part. The blade loss and base acceleration pulse spectra are expressed in a unique nondimensional form. The blade loss spectrum is a function of the modal damping ratio and the ratio of rotor spin speed to modal damped whirl speed. The spectrum associated with a base acceleration pulse is expressed as a function of the modal damping ratio and the ratio of excitation frequency to damped whirl speed.

86-1871
Vibration Analysis of Rotating Cylindrical Shells Based on the Timoshenko Beam Theory
Takashi Saito, Mitsuru Endo
Tokyo Institute of Technology, Tokyo, Japan
Bull. JSME, 29 (250), pp 1239-1245 (Apr 1986) 5 figs, 6 refs

KEY WORDS: Rotors, Cylindrical shells, Timoshenko theory, Natural frequencies

The basic equations for the beam-type vibration of a rotating cylindrical shell are derived by the Timoshenko beam theory. The frequency analysis is presented for three kinds of boundary conditions. The validity of this model is examined by comparing the results with those based on the cylindrical shell theory. It is found that natural frequencies of non-rotating, and rotating cylindrical shells, and for the critical speeds reasonable results can be obtained by solving the problem on the basis of the Timoshenko beam theory.

RECIPROCATING MACHINES

86-1872
Vibroacoustics of Machines -- Problems, Tasks
Z. Engel
Institute of Mechanics and Vibroacoustics, Krakow, Poland
Strojnicky Casopis, 36 (4/5), pp 499-505 (1985) 2 figs, 5 refs (in Slovak)

KEY WORDS: Machinery vibration, Sound generation

The paper formulates the most important tasks of vibroacoustics. It presents a method for determining parameters of an equivalent acoustic source of a station for gas compression reduction.

METAL WORKING AND FORMING

86-1873
Dynamic Stiffening of Long Grinding Mandrels (Dynamische Versteifung langer Schleifdorne)
E. Tellbuscher
Industrie Anz., 29 (11), pp 30-31 (Mar 1986) 5 figs, 6 refs (in German)

KEY WORDS: Drilling, Machine tools, Vibration control, Fiber composites,

During grinding of mandrel a weak spot is often created. Regenerative chatter and unbalance vibrations influence the results. A high degree of damping is obtained with coated grinding mandrels. During grinding very high vibration amplitudes were excited with increasing angular velocity. Carbon fiber reinforced grinding mandrels, because of their small mass, were much more silent and produced much better results.

86-1874
Dynamics of High-Speed Milling
J. Tlusty
Univ. of Florida, Gainesville, FL
J. Engrg. Indus., Trans. ASME, 108 (2), pp 59-67 (May 1986) 18 figs, 4 tables, 7 refs

KEY WORDS: Milling (machining), Chatter

This paper is based on previous work dealing with time domain simulation of chatter in milling, with cutting process damping and with stability lobes. These matters are reevaluated here from the particular point of view of high-speed milling. The derivation of limit of stability of chatter in the frequency domain is recapitulated, and lobes of stability explained. These lobes should lead to substantial increases of stability at high speeds of milling. Corrections to the results of the simple theory using time domain are presented as they are obtained by time domain simulation which takes into account in a very realistic way, all the main aspects of milling. It is shown that in many instances high gains of stability are achievable by determining and using a particular spindle speed such that the cutter tooth frequency nears the frequency of the decisive mode of vibration as measured on the cutter. The usual modes of vibration of a spindle with a long end mill are discussed, and it is shown how a long end mill stabilizes cutting at medium speeds but becomes a flexible element strongly involved in chatter at high speeds. Cutting process damping and typical cases of high-speed face milling of steel and long end milling of aluminum are discussed.

86-1875
Considerations of Chucking Force in Chuck Work
Masahiro Doi, Masami Masuko
Musashi Institute of Technology, Tokyo, Japan
Bull. JSME, 29 (250), pp 1344-1349 (Apr 1986) 10 figs, 1 table, 9 refs

KEY WORDS: Metal working, Cutting, Chatter

Chucking characteristics were investigated experimentally. The chucking force during cutting was measured with a load washer and many advantageous characteristics were ascertained. The results obtained are as follows: fluctuation of the chucking force is generated periodically with the rotation of the main spindle due to the combined effects of the direction orientation of the chucking stiffness and the cutting force; this fluctuation increases with an increase in the applied moment on the chuck-jaw; the chucking force of a three-jaw scroll chuck decreases with an increase in the fluctuation of the chucking force.

86-1876
Cutting Process Dynamics Simulation for Machine Tool Structure Design
S.J. Lee, S.G. Kapoor
Univ. of Illinois, Champaign-Urbana, IL
J. Engrg. Indus., Trans. ASME, 108 (2), pp 68-74 (May 1986) 7 figs, 3 tables, 18 refs

KEY WORDS: Cutting, Machine tools, Finite element technique, Simulation

A methodology to simulate the real cutting process dynamics using a finite element structural model and a mechanistic face milling, force model is proposed. While the finite element structural model provides an analytic way to assess structural dynamic characteristics, the mechanistic face milling force model calculates the time histories of cutting forces taking many cutting process parameters into consideration and acts as forcing functions to the structural model. The methodology is verified through experimentation. The effects of structural parameters and cutting process parameters on the dynamic behavior of the machine tool structure are also studied. The results indicate that the proposed methodology can greatly enhance the machine tool design process.

86-1877
On the Doubly Regenerative Stability of a Grinder: The Mathematical Analysis of Chatter Growth
R.A. Thompson
General Electric Co., Schenectady, NY
J. Engrg. Indus., Trans. ASME, 108 (2), pp 83-92 (May 1986) 12 figs, 1 table, 9 refs

KEY WORDS: Grinding machinery, Chatter

The growth of doubly regenerative chatter in a typical plunge cylindrical grinder is analyzed. The work is based on a mathematical method. Throughout, the physics of double regeneration is explained: the individual contribution to chatter of wheel and workpiece regeneration is illustrated; The wear resistant Borazon wheel, although slightly more chatter prone, is shown to have an advantage over alumina because it requires less frequent dressing; and the best in-process measure of grinding stability is shown to be wheel and workpiece lobe precession. The paper is concluded by showing how the optimum wheel and workpiece speeds are chosen.

86-1878
On the Doubly Regenerative Stability of a Grinder: The Theory of Chatter Growth
R.A. Thompson
General Electric Co., Schenectady, NY
J. Engrg. Indus., Trans. ASME, 108 (2), pp 75-82 (May 1986) 3 figs, 11 refs

KEY WORDS: Grinding machinery, Chatter

A mathematical method is devised to solve for the growth of chatter in grinders. The chatter growth rate is important because the grinding process is generally unstable. As such there is a need to find the conditions which minimize wheel and workpiece wave growth and optimize the time between wheel dressing cycles. The analysis of grinding is complicated by the fact that regenerative feedback from both the wheel and workpiece drive the system.

86-1879
A Study on the Vibrationless Forging Hammer — A Principle of the Vibrationless Forging Hammer
Nobuo Tanaka, Yoshihiro Kikushima
Mechanical Engineering Lab., Ibaraki, Japan
Bull. JSME, 29 (249), pp 935-942 (Mar 1986) 18 figs, 8 refs

KEY WORDS: Forging machinery, Active vibration control

A new method is proposed to develop a vibrationless forging hammer. The principle of the vibrationless forge system is based on the active vibration control method. The principle of the vibrationless forging hammer is presented and characteristics of the system are discussed. Analyzing the vibrationless forge system from the viewpoint of feedforward control, a state equation of the systems is derived. To simulate the system designed by the dynamic compensation method, an analog computer with an input signal of an actual impact force is used. The control effect to suppress the impulse response of the system is shown and an experiment is carried out to verify effectiveness of the system.

MATERIALS HANDLING EQUIPMENT

86-1880
Control of Flexible Robotic Arms — Vibration Control of First and Second Degrees of Freedom Systems
Toshio Fukuda
The Science Univ. of Tokyo, Tokyo, Japan
Bull. JSME, 29 (250), pp 1269-1273 (Apr 1986) 11 figs, 1 table, 4 refs

KEY WORDS: Robots, Beams, Active vibration control

Dynamic characteristics and control methods of a flexible robotic arm of a first degree-of-freedom system are shown modeling a flexible arm as an elastic beam. Vibrations of the arm in positioning can be suppressed by dynamic compensation with consideration of the arm flexibility. A control method of a SCARA type of a second degree-of-freedom system is shown based on the local feedback with variable adaptive gains to suppress vibrations in positioning control. In case of arm collisions against other objects, a control method to recover the state before collision is also shown as an application. The control methods proposed here are not limited to this type of robotic arms, but also applicable in more general cases.

86-1881
Coupling Between Spans in the Vibration of Axially Moving Materials
A.G. Ulsoy
Univ. of Michigan, Ann Arbor, MI
J. Vib., Acoust., Stress, Rel. Des., 108 (2), pp 207-212 (Apr 1986) 8 figs, 16 refs

KEY WORDS: Belt conveyors, Band saws, Magnetic tapes, Flexural vibrations

Axially moving materials (e.g., belts, chains, bandsaws, paper and magnetic tapes, etc.) arise in various mechanical systems, and their vibration and stability are often of engineering significance. Previous work describing the transverse vibration of axially moving materials is extended in this paper to include the elastic coupling between spans. The equations of motion are derived, an approximate solution method is developed and simulation results are presented. The simulation results predict the presence of a beating phenomenon at low transport velocities which is destroyed by higher velocities and/or tension differences in the two spans. The coupling mechanism described could potentially be exploited for vibration control.

STRUCTURAL SYSTEMS

BRIDGES

86-1882
Analysis of the Observed Seismic Response of a Highway Bridge
J.C. Wilson

McMaster Univ., Hamilton, Ontario, Canada
Earthquake Engrg. Struc. Dynam., 14 (3), pp 339-354 (May-June 1986) 10 figs, 6 tables, 24 refs

KEY WORDS: Bridges, Seismic response, System identification techniques

Strong-motion accelerograms obtained on separation bridge during a 1979 California earthquake are used to examine the response of this multiple-span bridge to moderate levels of earthquake loading. Although the bridge was not damaged, the records are of significant engineering interest as they are the first to be recorded on a highway bridge structure in North America. A technique of system identification is used to determine optimal modal parameters for linear models which can closely replicate the observed time-domain seismic response of the bridge. Time variations in frequency and damping in the horizontal response are identified using a moving-window analysis. A three-dimensional finite element model is developed to study the bridge response in detail.

86-1883
Investigation of Earthquake Response of Simple Bridge Structures
I. Kashefi
Ph.D. Thesis, Univ. of Southern California (1985)

KEY WORDS: Bridges, Seismic response

The effects of the oven neglected rotational components of strong earthquake ground motion on the response of two structural models are investigated. The first model approximates a structure by a massless column supporting a concentrated mass at its top and excited by incident plane waves in a homogeneous elastic half-space. The linear and nonlinear analyses are carried out. In the linear analysis, the effects of the vertical ground motion in the frequency term of the differential equation of motion are neglected. The fourth order Runge-Kutta algorithm is employed to solve the nonlinear problem. The linear and nonlinear responses of the model for incident P, SV and Rayleigh wave excitations are studied. The transfer functions of the linear and nonlinear responses are investigated. The effects of rocking and vertical ground motions on the overall response of the model and on the response spectrum amplitudes are discussed. The second model represents a three-dimensional bridge with two spans erected on the elastic half-space and excited by incident body and Rayleigh surface waves. The coupled-system of differential equations of motion is solved by the Runge-Kutta technique. The maximum relative rocking and twisting of the columns and the relative sliding of the girders is studied in the frequency domain. An application of the foregoing theory and examples of the response of a four span bridge model crossing a canyon and excited by transient earthquake excitations is presented.

86-1884
Unequal Seismic Support Motions of Steel Deck Arch Bridges
R.A. Dusseau
Ph.D. Thesis, Michigan State Univ., 394 pp (1985) DA 8603401

KEY WORDS: Bridges, Seismic analysis

Seismic analyses were conducted on two steel deck arch bridges. The analyses consisted of computer modeling using a finite element program called LINSTRUC. The LINSTRUC program performs time history analyses with either equal or unequal seismic support acceleration as input. The bridges were modeled using one-plane models derived by a synthesis of structural properties in the lateral direction. These one-plane models were analyzed under dead and wind loading and the more important of these results were generally within 10% of the values listed in the actual bridge plans.

86-1885
Vibration of PC Bridge During Failure Process
M. Kato, S. Shimada
Nagoya Univ., Nagoya, Japan
ASCE J. Struc. Engrg., 112 (7), pp 1692-1703 (July 1986) 10 figs, 2 tables, 8 refs

KEY WORDS: Diagnostic techniques, Vibration measurement, Bridges, Prestressed concrete

A vibration measurement was carried out on an existing prestressed concrete bridge during its failure test. The vertical and horizontal vibrations were measured based on the ambient vibration method. The change of vibrational characteristics due to deterioration of the bridge during the failure test was obtained. A measured mechanism on the change of vibrational characteristics is discussed and compared with a numerical analysis.

BUILDINGS

86-1886
Sound Insulation of Buildings with Large Slabs
S. Ljunggren

The Royal Institute of Technology, Stockholm, Sweden
Acustica, 60 (2), pp 135-143 (Apr 1986) 12 figs, 8 refs

KEY WORDS: Buildings, Acoustic insulation

A simple analytical model is presented for the air-borne and impact sound insulation of an isotropic plate, which is excited over only a part of its surface. In the first place the impact sound insulation at frequencies well above the critical frequency is studied. The plate is assumed to be so large, that the resonant field of bending vibrations is of less importance than the primary wave from the point of excitation. The air-borne sound insulation is then obtained from a well-known reciprocity relation. In the special case of concrete slabs, a simplified procedure is worked out for the estimation of the sound insulation. For the cases covered by the theory, it is shown that the sound insulation is independent of the loss factor of the plate. On the other hand if two rooms with the same area are separated by a part of a large slab, the sound insulation is dependent on the room area. Field measurements support the model, but show that in practice some allowance must be made for the reflections of the primary wave that are inevitable at the facades of the building.

86-1887
Dynamic Response of Framed Structures
C. Dyrbye
Technical Univ. of Denmark, Lyngby, Denmark
Earthquake Engrg. Struc. Dynam., 14 (3), pp 487-494 (May-June 1986) 6 figs, 4 refs

KEY WORDS: Multistory buildings, Framed structures, Newmark method, Holzer method, Myklestadt method

A method for analyzing plane frames subjected to dynamic forces or to ground motion is presented and illustrated by a numerical example. Numerical integration uses the approximation of constant acceleration in each time interval. In space, calculations are carried out story by story, as in Holzer's or Myklestad's methods in the case of harmonic vibrations.

86-1888
Effective Eccentricity for Inelastic Seismic Response of Buildings
W.K. Tso, Y. Bozorgnia
McMaster Univ., Hamilton, Ontario, Canada
Earthquake Engrg. Struc. Dynam., 14 (3), pp 413-427 (May-June 1986) 15 figs, 3 tables, 8 refs

KEY WORDS: Buildings, Seismic response, Effective eccentricity

The concept of effective eccentricity is generalized for inelastic systems to provide guidelines for estimating the maximum dynamic edge displacement and resisting element deformation of a single mass monosymmetrical system subjected to unidirectional ground excitations. Inelastic responses of three structural models having the same overall elastic responses are compared and the model which generally results in larger edge displacement is chosen as the structural model to be used to evaluate effects of asymmetry. The inelastic effective eccentricity is calculated for different values of the system parameters, based on an ensemble of six ground motion records as input. It is concluded that, except for stiff structures having low yield strength, the elastic effective eccentricity curves developed previously by Dempsey and Tso can provide a relatively conservative estimate for inelastic effective eccentricity. These curves can be used to estimate the edge displacement and element deformation of inelastic eccentric systems.

86-1889
Optimal Design of 3-D Reinforced Concrete and Steel Buildings Subjected to Static and Seismic Loads Including Code Provisions
F.Y. Cheng, K.Z. Truman
Univ. of Missouri, Rolla, MO
Civil Engineering Study - 85-20, 416 pp (June 1985) PB86-168564/GAR

KEY WORDS: Buildings, Steel, Reinforced concrete, Seismic design, Standards and codes

A structural optimization algorithm based upon an optimality criteria approach is presented for three-dimensional statically and dynamically loaded steel and/or reinforced concrete structures. The theoretical work is presented in terms of scaling, sensitivity analyses, optimality criteria, and Lagrange multiplier determination. The structures can be subjected to a combination of static and/or dynamic displacement and stress, and natural frequency constraints. The dynamic analyses are based upon the ATC-03 provisions or multi-component response spectra modal analyses. About 75 design examples are provided to illustrate the rapid convergence and practicality of the presented method as well as the effects of ATC-03 provisions and multicomponent seismic input on the optimal structural parameters.

86-1890
Stability of Elastic Frames Subjected to Earthquake Excitations

G. Ahmadi, S. Abdel-Rahman
Clarkson Univ., Potsdam, NY
Earthquake Engrg. Struc. Dynam., 14 (3), pp 455-474 (May-June 1986) 9 figs, 1 table, 63 refs

KEY WORDS: Multistory buildings, Framed structures, Seismic response

Dynamic stability of elastic multistory frame structures subjected to vertical earthquake ground accelerations is studied. Different stationary, non-stationary, white and non-white random models for earthquake strong motion are considered. The concepts of mean-square and almost-sure stability are reviewed and the corresponding stability theorems are presented. Several general criteria regarding the dynamic stability of the equilibrium state of multistory frames subjected to random excitations are developed. A few examples concerning the stability of single and multi-degree-of-freedom structures under earthquake excitations are presented.

TOWERS

86-1891
Dynamic Buckling of Guyed Stacks, Masts and Columns with Constant Inertia and Algebraic Polynomials Generated by use of Operator T_n Attached to Bessel Functions
J. Daniel
Concordia Univ., Montreal, Quebec, Canada
J. Franklin Inst., 321 (2), pp 95-107 (Feb 1986) 1 fig, 7 refs

KEY WORDS: Chimneys, Guyed structures, Columns, Dynamic buckling

A new method of analysis of the dynamic critical load of columns, guyed stacks and masts with constant inertia, under the combined action of horizontal loads, axial load and uniformly distributed loads along the vertical axis is presented. The integro-differential formulation of the problem leads to fourth- and fifth-order partial differential equations. In addition to the solution of the equation of motion in expansion series, the new method of solution proposed to solve the fifth-order partial differential equation has led to the differential equation of the plate on elastic foundations in the old Winkler hypothesis.

FOUNDATIONS

86-1892
Steady-State Harmonic Response of a Rigid Plate Bearing on a Liquid-Saturated Poroelastic Half-space
M.R. Halpern, P. Christiano
Weidlinger Assoc., New York, NY
Earthquake Engrg. Struc. Dynam., 14 (3), pp 439-454 (May-June 1986)

KEY WORDS: Foundations, Soil-structure interaction, Biot theory, Harmonic response

Soil-structure interaction problems are typically modeled by assuming subgrade behavior to be either elastic or viscoelastic. Compliance functions that may be used to solve soil-structure interaction problems are evaluated by treating the subgrade as a liquid-saturated poroelastic material whose behavior is governed by Biot's theory. The compliances are evaluated for the harmonic rocking and vertical motions of rigid permeable and impermeable plates bearing on a poroelastic halfspace Comparisons are made with elastic solutions which assume the subgrade to be either completely drained or undrained. Solid and fluid contact stresses are reported for the poroelastic case and compared to the solid contact stresses for the elastic cases.

86-1893
Dynamic Stiffness of Rigid Rectangular Foundations on the Half-Space
T. Triantafyllidis
Univ. of Karlsruhe, Karlsruhe, Fed. Rep. Germany
Earthquake Engrg. Struc. Dynam., 14 (3), pp 391-411 (May-June 1986) 4 figs, 29 refs

KEY WORDS: Soil-structure interaction, Foundations, Dynamic stiffness, Boundary value problems

The dynamic soil-structure interaction of a rigid rectangular foundation with the subsoil represents a mixed-boundary value problem. This problem is formulated in terms of a system of coupled Fredholm integral equations of the first kind. The subsoil is modeled by a homogeneous, linear-elastic and isotropic half-space which is perfectly bonded to the rigid, rectangular foundation. An approximate solution for the resultant loads between the foundation and the half-space due to a unit forced displacement or rotation is obtained using the Bubnov-Galerkin method. Using this method the displacement boundary value conditions are exactly satisfied and the contact stress distributions between the foundation and the half-space are approximated by series expansions of Chebyshev polynomials. This method provides a simple means of studying the soil-structure interaction of rectangular foundations with different inertia properties.

86-1894
Wave Propagation in Ground-Structure Systems, Part I: Analysis of the Model with Surface Contact
D. Takahashi
Kyoto Univ., Kyoto, Japan
J. Sound Vib., 105 (1), pp 27-36 (Feb 22, 1986) 1 fig, 17 refs

KEY WORDS: Structure-ground interaction, Wave propagation, Harmonic excitation, Line source excitation

A simple two-dimensional model composed of a structure lying on a viscoelastic half-space (VEHS) with a continuous flexible interface is considered as a ground-structure system. Structural vibration and sound radiation into the closed space of the structure resulting from a harmonic line force applied on the ground surface are investigated theoretically. The structure is modeled as thin plates and the ground-structure interface is assumed to be perfectly bonded in both horizontal and vertical directions. Boundary conditions at the edges of the base plate cannot be expressed in an explicit form, such as free, simply supported or clamped, and so the fundamental modes of vibration also are unknown. Therefore, a modified Fourier series expansion method, which can be applied to problems with arbitrary boundary conditions, is used to obtain an approximate solution to the present problem. Relations between the Fourier component of the displacement and the corresponding stresses are formulated by using the Green function approach in the form of integral equations which can be solved numerically, regardless of the upper structure. Consequently the unknown coefficients of the components can be obtained as a result of the response of the whole system.

86-1895
Wave Propagation in Ground-Structure Systems, Part II: Parametric Survey
D. Takahashi
Kyoto Univ., Kyoto, Japan
J. Sound Vib., 105 (1), pp 37-48 (Feb 22, 1986) 11 figs, 1 table, 2 refs

KEY WORDS: Structure-ground interaction, Wave propagation, Harmonic excitation, Line source excitation

The effect of varying certain parameters concerned in the process of wave propagation in ground-structure systems on the dynamic response is evaluated numerically by using previously established models of the systems. For two types of model having different contact conditions the response resulting from a harmonic line force applied on the ground surface is determined. The results of variation in vibration and sound radiation with varying properties of the ground, contact condition, material and thickness of the structure are presented. It is found that the response strongly depends on both viscosity of the ground and properties of the structure base slab.

86-1896
Axisymmetric Soil-Structure Interaction by Global-Local Finite Elements
V. Avanessian, R. Muki, S.B. Dong
Univ. of California, Los Angeles, CA
Earthquake Engrg. Struc. Dynam., 14 (3), pp 355-367 (May-June 1986) 7 figs, 23 refs

KEY WORDS: Soil-structure interaction, Finite element technique

A version of the global-local finite element method is presented for studying dynamic steady-state soil-structure interaction wherein the soil medium extends to infinity. Axisymmetric behavior is considered. Conventional finite elements are used to model the structure and some portion of the surrounding soil medium considered to be homogeneous and isotropic. A complete set of outgoing waves in the form of spherical harmonics for the entire space is used to represent the behavior in the half-space beyond the finite element mesh and these are termed the global functions. Full traction and displacement continuity is enforced at the finite element mesh interface with the outer region. On the free surface of the half-space in the outer field, traction-free surface conditions are enforced by demanding that a sequence of integrals of the weighted-average tractions must vanish. Numerical examples are presented for the response of different shaped foundations.

86-1897
Antiplane Transient Response of Embedded Cylinder
A.C. Wijeyewickrema, L.M. Keer
Northwestern Univ., Evanston, IL
ASCE J. Engrg. Mech., 112 (6), pp 536-549 (June 1986) 13 figs, 11 refs

KEY WORDS: Soil-structure interaction, Pulse excitation

The antiplane response of a rigid simicircular cylinder embedded in a homogeneous, isotropic half space due to a step function incident stress is considered. A Fourier synthesis technique is used, in which the admittance function is obtained from the corresponding steady state solution. The influence of the angle of incidence and the mass of the cylinder on the interfacial stresses are examined. The studies carried out indicate that for cylinders with a mass density larger than that of the surrounding half space, the interfacial stresses at the first point of contact between the nonvertically incident stress wave and the cylinder attain their maximum value not at the initial moment of impact but at some later time. A cylinder with a higher mass density would develop a higher maximum stress and take a longer time to reach this maximum stress.

86-1898
Methods for Solution of Dynamic Contact Problems
R.L. Taylor
Rept. No. NCEL-CR-86-002, 41 pp (Dec 1985) AD-A163 553/1/GAR

KEY WORDS: Soil-structure interaction, Constraint modes method, Lagrange equations

Methods for treating dynamic soil-structure interaction in large three-dimensional, nonlinear finite element settings are first compared. Frequency domain methods, nonlinear material models without contact models, and constraint methods such as Lagrange multiplier and penalty methods are included in the discussion. Nonlinear material models possessing tension cut-off capability would seem to most easily satisfy the soil-structure interaction requirement. However, such a formulation does not provide for more general requirements involving contact conditions of structural components. Thus the report focuses on constraint-type methods in addressing the spatial aspects of the problem of implementing dynamic contact behavior into large-scale finite element calculations for civil-structural systems. Of the constraint-type methods, one in particular known as the augmented Lagrangian formulation, is deemed most appropriate to the specified class of problems. This method is a combination of the Lagrange multiplier and penalty formulations and aims at retaining only the best characteristics of both methods.

86-1899
Fundamental Properties of Soils for Complex Dynamic Loadings. Development of a Three Invariant Constitutive Model
D.H. Merkle, W.C. Dass
Applied Research Assoc., Inc., Albuquerque, NM
Rept. No AFOSR-TR-85-1232, 104 pp (Apr 22, 1985) AD-A164 206/5/GAR

KEY WORDS: Soils, Constitutive equations

This study sought to develop a general soil stress-strain model which can be used to solve a wide range of soil dynamics problems. The approach used was to review existing soil constitutive models used to predict the response of soil masses to complex dynamic loads, and then formulate a new model for that purpose. Eight existing solid dynamic stress-strain models were studied. The Lade model was selected as the best point of departure for developing a new soil stress-strain model for complex dynamic loading, because of its accuracy and flexibility in representing soil stress-strain behavior, ease of parameter determination, and ease of developing intuition for parameter physical significance and accuracy. The new conic model is so called because its principal mathematical surfaces are conic sections. The computer code used to exercise all nine soil constitutive models under eleven stress and strain paths is called the soil element model. It can be incorporated in large finite difference of finite element codes fc. analyzing the response of soil masses to complex dynamic loads.

86-1900
Fundamental Properties of Soils for Complex Dynamic Loadings, Development of a Three Invariant Constitutive Model. Appendices A-W
D.H. Merkle, W.C. Dass
Applied Research Assoc., Inc., Albuquerque, NM
Rept. No. 5230-APP-A/W, AFOSR-TR-85-1232-APP, 609 pp (Apr 22, 1985) AD-A164 207/3/GAR

KEY WORDS: Soils, Constitutive equations

Topics in these appendices to AD-A164 206 include: stress analysis; Cayley-Hamilton invariant formulations, ochtahedral plane plots; basic equations of elastoplasticity; vector representation of a general stress or strain state; incremental flexibility matrix for stress control; incremental stiffness matrix for strain control; incremental deformation mode logic for stress control; elastic stress-strain equations; special equations for the triaxial test; transient response of a three element viscoelastic model; Young's modulus for a hyperbolic stress-strain curve; a hyperbolic expression for Poison's ratio; hyperbolic model for cyclic simple shear; yield surface violation correction for an elastic-perfectly plastic model; AFWL engineering model incremental plastic response; drained and undrained cap models and computational algorithms; Lade model cross sections and parameter determination; conic model cross sections and parameter determination.

86-1901
Comparison of Transmitting Boundaries in Dynamic Finite Element Analyses Using Explicit Time Integration
H.A. Simons, M.F. Randolph
University Engineering Department, Cambridge, UK
Intl. J. Numer. Anal. Methods Geomech., 10 (3), pp 329-342 (May-June 1986) 9 figs, 8 refs

KEY WORDS: Soils, Finite element technique, High frequency response

Explicit time integration schemes provide an efficient solution to nonlinear dynamic finite element analyses of geotechnical problems especially when high frequency response is important. Such explicit time integration schemes require one of two distinct transmitting boundary formulations to overcome the problem of radiation damping. These are the superposition boundary approach, which involves the cancellation of the reflected waves by combining the solutions of two different boundary conditions, and the viscous boundary approach, which involves the absorption of incident wave energy by frequency independent viscous dashpots. The theoretical justification of these two approaches and their means of implementation are reviewed. The solutions obtained using the two different boundary approaches to the problem of a rigid massless circular footing vibrating on an elastic half-space are compared with an independent theoretical solution. The performance of the boundaries for problems involving step loading is also examined and the implications for any loading pattern with a non-zero time average are discussed.

HARBORS AND DAMS

86-1902
A Strip Mode Synthesis Technique for Dynamic and Static Analysis of Arch Dam and Shell Structures
Lin Gao, Sun Keming, Lou Menglin
Acta Mech. (4), pp 469-477 (1985) 5 figs, 5 refs (in Chinese)

KEY WORDS: Component mode synthesis, Dams, Shells, Beams

A new component mode synthesis approach using arch or beam elements as substructures is developed for the dynamic and static analysis of arch dam and shell structures. It has the advantage of simplicity in the treatment of subsystems, minimizing the numbers of degree-of-freedom of the structure to a great extent and achieving relatively higher precision.

POWER PLANTS

86-1903
Ultimate Behavior of an R.C. Nuclear Containment Subjected to Internal Pressure and Earthquake
H. Akbar, A.K. Gupta
North Carolina State Univ., Raleigh, NC
ASCE J. Struc. Engrg., 112 (6), pp 1280-1295 (June 1986) 9 figs, 1 table, 13 refs

KEY WORDS: Nuclear containment structures, Reinforced concrete, Seismic excitation, Internal pressure

The results of nonlinear analysis of a reinforced concrete nuclear containment vessel subjected to dead load, internal pressure, and earthquake are presented. The membrane reinforcement for the containment is first designed based on the principle of minimum resistance using the stresses from an elastic analysis. The nonlinear analysis shows that the containment is able to achieve 102% of the design pressure and earthquake load along with its dead load. The objective of the research program involved is to understand and establish a relationship between the reinforcement design and the ultimate behavior of concrete shells. A nonlinear finite element program has been developed. The computer program includes a new concrete cracking model which is consistent with the limit state. The program also includes a new selective integration scheme which enables an accurate evaluation of the cracked element's stiffness matrix.

OFF-SHORE STRUCTURES

86-1904
Vibration Analysis of the Yamachiche Lightpier
F.D. Haynes
U.S. Army Cold Regions Res. and Engrg. Lab.
Intl. J. Analyt. Exptl. Modal Analysis, 1 (2), pp 9-18 (Apr 1986) 9 figs, 4 tables, 14 refs

KEY WORDS: Off-shore structures, Experimental modal analysis, Computer programs

The Yamachiche lightpier was instrumented with geophones, accelerometers and an inclinometer.

In order to determine its dynamic characteristics, 15 breakable bolts with failure strengths from 10,000 to 101,000 lb were used to apply a step unloading force on the pier. The damping and stiffness were obtained from the data in the time domain. The natural frequencies and mode shapes were obtained from the data transformed into the frequency domain. A modal-analysis computer program was used to verify the natural frequencies and mode shapes. A mathematical model was developed which includes translation, rotation and shear-beam deformation of the pier.

86-1905

Stability of a Non-Linearly Damped Second-Order System with Randomly Fluctuating Restoring Coefficient

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Intl. J. Nonlin. Mech., 21 (1), pp 1-13 (1986) 1 table, 25 refs

KEY WORDS: Offshore structures, Stability, Restoring factors, Nonlinear damping

In connection with questions concerning possible unstable motion of certain types of marine structures, the non-stationary response of a homogeneous second-order system with randomly fluctuating restoring coefficient and with combined linear and non-linear power-law damping has been studied. New solutions, both in the time-domain and in terms of probability distributions, have been derived for non-stationary response initiated by some disturbance at time zero. The solutions hold asymptotically in the limit of small damping and small random restoring and have been obtained using stochastic averaging techniques and a Fokker-Planck-Kolmogorov equation. The solutions have been used to assess the asymptotic behavior of time-domain realizations of response, and of statistical moments of response as time approaches infinity. It is found that, depending on magnitude and nonlinearity of the damping force, response can decrease to zero, can tend to a stationary state of random finite-amplitude response, or can grow unboundedly as time increases.

86-1906

Effect of Short Crested Waves to Fatigue Damage Calculation

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Rept. No. STF71-A85041, ISBN-82-595-3897-0, 23 pp (Sept 1985) PB86-180627/GAR

KEY WORDS: Fatigue life, Water waves, Offshore structures

The report includes results from an investigation of fatigue damage calculation. The influence on fatigue damage from variation in shortcrestedness of waves is investigated. The example structure considered is a North Sea steel jacket at 150 m water depth. Different formulations of short-crestedness are included. The report is aimed towards the analysis of fixed jacket structures with particular emphasis on the use of short crested waves in wave load calculation and its importance to fatigue damage estimates. The shortcrestedness of the waves has been identified as an important parameter for fatigue damage accumulation.

VEHICLE SYSTEMS

GROUND VEHICLES

86-1907

Approximate, Time Domain, Non-stationary Analysis of Stochastically Excited, Non-linear Systems with Particular Reference to the Motion of Vehicles on Rough Ground

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J. Sound Vib., 105 (3), pp 361-371 (Mar 22, 1986) 3 figs, 12 refs

KEY WORDS: Ground vehicles, Surface roughness, Approximation methods

An approximate state-space method for obtaining the time varying mean and covariance of non-linear systems excited by non-stationary random processes is presented. The class of non-stationarity associated with the motion of a vehicle on rough ground is of interest. The method is based on a technique of modeling the input process as a "shaping filter" in the spatial domain which may be linked to the vehicle dynamic equations through the velocity function. The nonlinear problem is overcome by using the technique of statistical linearization. An example is briefly discussed.

86-1908

Computer Simulation of Crash Phenomena

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Intl. J. Numer. Methods Engrg., 22 (3), pp 497-519 (Mar 1986) 27 figs, 27 refs

KEY WORDS: Collision research (automotive), Finite element technique, Computer programs

The paper summarizes preliminary work on crash analysis performed on an extended finite element model as provided by the nonlinear LARSTRAN program package. The essential methodology is evolved along the natural finite element approach. Also overviewed are solution techniques for the nonlinear equations of motion. The application of a simple folding mechanism is indicated and crashworthiness computations of car structures are described.

SHIPS

86-1909
Brake Noise Analysis: A Systematic Approach
H.W. Schwartz, W.D. Hays, Jr., J.H. Tarter
Auto. Engrg. (SAE), 94 (6), pp 51-58 (June 1986)

KEY WORDS: Brakes (motion arresters), Noise control

Engineers describe their test and analysis methods for preventing brake squeal and creep groan.

86-1910
Motions of a Spherical Submarine in Waves
Shen Wang
Univ. of Miami, Fl
Ocean Engrg., 13 (3), pp 249-271 (1986) 2 figs, 4 tables, 13 refs

KEY WORDS: Submarine hulls, Water waves, Wave radiation, Wave diffraction

The free motions in waves of submerged vehicles with a spherical hull form but different metacentric heights are sought. The problem is analyzed by considering the submerged vehicle as a neutrally buoyant sphere. The solutions to two independent problems, namely the radiation problem and the diffraction problem, are required. lly buoyant spheres are derived and com Nondimensional parameters known as the added mass, damping and diffraction coefficients for neutrally buoyant spheres are derived and computed values of these coefficients are presented in tabulated form. The responses of surge, heave and pitch are explicitly expressed by these coefficients and the metacentric height of the submarine. A spherical submarine is practically motionless relative to the particle movement of waves except at the vicinity of resonant frequency, which is governed by the value of metacentric height.

AIRCRAFT

86-1911
De-dopplerization and Acoustic Imaging of Aircraft Flyover Noise Measurements
G.P. Howell, A.J. Bradley, M.A. McCormick, J.D. Brown
Rolls-Royce Limited, Derby DE2 8BJ, England
J. Sound Vib., 105 (1), pp 151-167 (Feb 22, 1986) 14 figs, 7 refs

KEY WORDS: Aircraft noise, Noise measurement, Acoustic imaging

The technique described in this paper eliminates the Doppler effect from aircraft flyover noise measurements and generates narrow band spectra at required angles. Such a capability allows more accurate interpretation of flight data, and is necessary for a detailed comparison with predictions and static measurements, since 1/3 octave or narrow band levels, before de-Dopplerization, yield limited information on tonal content. The paper explains how a single microphone output is de-Dopplerized, and includes details of aircraft tracking and computer simulation of flyover measurements. The technique is especially relevant to the analysis of noise from counter-rotating propeller driven aircraft, and results are shown for an Avro Shackleton.

86-1912
New Dynamic Testing Techniques and Related Results at FFA
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Aeronautical Research Inst. of Sweden, Stockholm, Sweden
Rept. No. AD-A165 045 (Nov 1985) Proc., Joint Symp. Fluid Dynamics and Flight Mechanics Panels held in Goetingen, Fed. Rep. Germany, May 6-9, 1985, pp 20-1 - 20-14) AD-P005 024/5/GAR

KEY WORDS: Aircraft, Wind tunnel testing

With the advent of the JAS fighter project, a need for improved dynamic testing of wind tunnel models arose at the Aeronautical Research Institute of Sweden both in the subsonic and transonic speed range. Some old rigs have been refurbished and some new ones have been developed. These are all briefly described and in some cases results from tests with different models including the Standard Dynamics Model are shown.

86-1913
Evaluation of a Frequency Response Technique for Aircraft System Identification
A.T. Reed
Air Force Inst. of Tech., Wright-Patterson AFB, OH
Rept. No. AFIT/GAE/AA/85J-2, 108 pp (Oct 1985) AD-A164 367/5/GAR

KEY WORDS: Aircraft, Parameter identification technique, Frequency response, Computer programs

Results of a project which used frequency analysis methods applied to flight test data in order to identify aircraft parameters are presented. Computer programs were developed to generate simulated flight test data so the frequency response programs could be tested using a noise free data source. Once the simulated data programs were complete, the frequency response methods were developed. The frequency response method uses the cross-spectral density technique to generate magnitude and phase information. The program also generates the power spectral density functions. Noise contamination studies were made.

MISSILES AND SPACECRAFT

86-1914
Computational Methods for the Improvement of Dynamic Analytical Models of Aerospace Structures
H.H. Ottens
Natl. Aerospace Lab., Amsterdam, Netherlands
Rept. No. NLR-TR-84126-U, 37 pp (Nov 1984) N86-19320/8/GAR (in Dutch)

KEY WORDS: Spacecraft, Matrix methods

Methods to improve dynamic analytical models are surveyed. Matrix correction methods for the improvement of mass and stiffness matrices and parameter correction methods for the improvement of mass, damping and stiffness submatrices are discussed.

86-1915
Effect of Energy Dissipation Due to Friction at the Joint of a Simple Beam Structure
R.P. Donnelly, Jr.
Air Force Inst. of Tech., Wright-Patterson AFB, OH
Rept. No. AFIT/GAE/AA/85D-5, 81 pp (Dec 1985) AD-A163 975/6/GAR

KEY WORDS: Spacecraft, Vibration control, Active damping, Coulomb friction, Finite element technique

New interest in the development of more stable space structures has increased the need for more detailed knowledge of the behavior of engineering structures under dynamic loading. Interests lie in decreasing the amount of vibration by both passively and actively damping the structure. A means exists to passively damp structures by friction damping resulting from relative slip between joint interfaces. It may be feasible to increase the damping in a structure by allowing more friction damping than is normal and thereby controlling the vibration response. This thesis incorporated friction damping in a one-dimensional model. Finite element techniques are used to accomplish the numerical analysis. A clamped-clamped beam is used as the physical model.

86-1916
Modal Assignment Effects on Decentralized Control of Large Space Structure
J.B. Sumner
Air Force Inst. of Tech., Wright-Patterson AFB, OH
Rept. No. AFIT/GA/AA/85D-9, 158 pp (Dec 1985) AD-A163 977/2/GAR

KEY WORDS: Spacecraft, Modal control technique

The thrust of this thesis is to implement time response output for the nontrivial model and investigate the effect on time response of certain modal assignments by fixed groups to any of the three controllers with another fixed group assigned as residuals. The inclusion of residuals provides in a limited sense a truth model for the analysis of stability and performance. The investigation will involve initially the fixing of certain baseline parameters to allow a parallel comparison of reasonable results. Then line-of-sight pointing and defocus performance will be generated for comparison among various cases. Selected model configuration is described and finite element representation is discussed.

86-1917
Control of a Large Space Structure Using Direct Output Feedback and Modal Suppression
E.E. Keller
Air Force Inst. of Tech., Wright-Patterson AFB, OH
Rept. No. AFIT/GAE/AA/85D-10, 106 pp (Dec 1985) AD-A163 960/8/GAR

KEY WORDS: Spacecraft, Modal control technique

Direct output feedback control using one or two controllers is applied to the NASA Ground Test Facility offset antenna model. This is a test structure designed to have the vibration characteristics associated with large space structures. The control problem is transformed from physical variables into modal variables and reformulated into a first order system. This system is truncated to a reduced order model with residual modes used only in performance evaluation. Optimal linear equadratic regulator techniques are ured to design the gain matrices and full state feedback is approximated by use of generalized inverses of the observation matrices. Spillover is eliminated through the use of transformation matrices. The structure is shown to be controllable with this method. Alternative sensor placement is explored and found to cause improvement in performance.

86-1918

Dynamics and Control of Spin- Stabilized Spacecraft with Sloshing Fluid Stores

D.E. Hill

Ph.D. Thesis, Iowa State Univ., 184 pp (1985) DA 8604472

KEY WORDS: Spacecraft, Storage tanks, Sloshing

Launchings of several of the STAR 48 communications- satellites from the space shuttle have consistently resulted in a nutating motion of the spacecraft. Sloshing fluid stores have been suspected as a source of dynamic instability. A mathematical model of the sloshing fluid motion coupled with the satellite dynamics was developed and the launch phase simulated. The flight simulation shows similar behavior when compared to telemetered flight data. A control law was developed, using the mathematical model, which supresses the nutating motion and may also be used for earth pointing maneuvers. An implementation of the control law was outlined.

86-1919

Material Damping of Simple Structures in a Simulated Space Environment

D.L. Edberg

Stanford Univ., Stanford, CA

J. Spacecraft Rockets, 23 (3), pp 288-296 (May-June 1986) 14 figs, 4 tables, 20 refs

KEY WORDS: Spacecraft, Material damping, Metals, Aluminum, Composite structures

The need for accurate, quantitative knowledge of the vibration dissipation of large space structures is explained. The sources of experimental error in vibrational measurements are detailed. A new method for such testing based on the use of a miniature telemetry system is presented, which allows the testing of structures in a simulated space environment consisting of free-fall inside of a vacuum chamber. Theoretical relations are given for the damping ratios of metals and composites. Measured damping ratios for both aluminum and composite beams and plates, and aluminum planar trusses, are presented. Experimental results are used to evaluate the theoretical damping relations.

BIOLOGICAL SYSTEMS

HUMAN

86-1920

Noise and Sleep at Home, a Field Study on Primary and After-Effects

B. Griefahn, E. Gros

Univ. of Dusseldorf, Dusseldorf, Germany

J. Sound Vib., 105 (3), pp 373-383 (Mar 22, 1986) 5 figs, 1 table, 34 refs

KEY WORDS: Traffic noise, Human response

The sleep of 20 healthy subjects who lived more than one year in streets with high traffic load were recorded during 12 consecutive nights each. In comparison with other variables (age, sex, personality) noise influenced the course of sleep slightly. Small negative effects were found for some physiological, for subjective, and for performance data indicating that there is no (complete) habituation to the usual acoustical environment.

MECHANICAL COMPONENTS

ABSORBERS AND ISOLATORS

86-1921

Hydraulically Damped Bearing Elements for Vibration Isolation (Hydraulisch gedampfte Lagerelemente zur Schwingungsisolation)

J.H. Heitzig, J. Bebermeier, G.E. Hannover

Feinwerktech. u. Messtechnik, 94 (3), pp ZM 56-70 (April 1986) 6 figs (In German)

KEY WORDS: Vibration isolation, Hydraulic dampers

In connection with an increasingly lighter construction and higher specific ratings of machine sets requirements for a more humane working place and heavier demands on comfort have given special significance to the insulation from vibrations and noise in modern mechanical and automotive engineering. In many cases, conventional flexible bearings, such as rubber springs, no longer meet demands. This has led to the development of bearing elements integrating a hydraulic damping unit along with a bearing rubber spring.

86-1922

Antivibration Mountings. 1970-April 1986 (Citations from the Engineering Index Database)

NTIS, Springfield, VA

89 pp (April 1986) PB86-8641212/GAR

KEY WORDS: Mountings, Vibration isolators, Bibliographies

This bibliography contains 133 citations concerning mechanical and fluid antivibration mountings. Topics include vibration damping methods for buildings as well as machinery. New Materials and new methods are discussed in the automotive, machinery, nuclear, and construction industries. Various methods of measuring vibration are also presented.

86-1923

Study of an Active Vibration Isolation System - a Learning Control Method

T. Takagami, Y. Jimbo

Univ. of Tokyo, Tokyo, Japan

J. Low Freq. Noise Vib., 4 (3), pp 104-119 (1985) 16 figs, 3 tables, 7 refs

KEY WORDS: Active vibration isolation, Pneumatic isolators

Improvements of performance of a vibration isolation table supported by an air-spring are attempted. A servo-control mechanism regulates the air in the air-spring so that the table can always remain immobile in spite of the vibrations of the floor. A method of determining an optimal control-signal, which regulates the air in the air-spring, is discussed from a learning control standpoint by a microcomputer. For periodic disturbances, adjustment of control signal for both amplitude and phase is applied. For random disturbances, adjustment of control gain only is applicable.

86-1924

Dynamic Analysis of Base Isolation System

V. Jeng

Ph.D. Thesis, Univ. of California, 146 pp (1984), DA 8524557

KEY WORDS: Base isolation, Torsional response

The objective of this study is to develop a feasible solution scheme for nonlinear dynamic analysis of a base isolation system. The upper structure is elastic. The base isolation devices are 2-D nonlinear and modeled by strain surface plasticity theory. The 3-D mathematical models of the upper structure and base isolation system are constructed separately then combined together for analysis. Individual and simultaneous earthquake inputs are used to study the torsional behavior of the base isolation system with different eccentricities.

86-1925

Transient Response of a Support Structure Excited by an Accelerating Unbalanced Rotor

F. Ellyin, Z. Wolanski

Univ. of Alberta, Edmonton, Alberta, Canada

J. Appl. Mech. Trans. ASME, 53 (2), pp 417-423 (June 1986), 10 figs, 11 refs

KEY WORDS: Supports, Rotors, Beams, Transient vibrations, Finite element technique

The transient vibration of a beam supporting an unbalanced rotor is investigated using finite element discretization techniques.. The rotor speed is time dependent to simulate transients at startup. The beam is low-tuned relative to the rotor operating speed. A rigid rotor shaft mounted in an oil-film bearing is considered. The short-bearing approximation and nonlinear performance of the journal bearing are assumed. The method of solution for transient response is based on direct integration of the system equations of motion using finite element in time formulation. The results of numerical analysis are presented in graphical form and discussed.

86-1926

Transportation Environments of Fresh Produce

K. Peleg, S. Hinga

Technion Israel Institute of Technology, Haifa, Israel

J. Environ. Sci., 24 (3), pp 19-25 (May-June 1986) 7 figs, 12 refs

KEY WORDS: Packaging, Transportation effects

A produce distribution survey was conducted to develop a calculated risk approach to packaging systems design. A database for simulating shock and vibration inputs was derived from two instrumented surveys of typical transport routes of apples and citrus fruit. These comprised spectral envelopes encompassing different truck types and road conditions, and a ship voyage. Intermittent transient accelerations were segregated from continuous steady-state vibration records and presented separately as Fourier spectrum envelopes. Handling shocks sustained by pallet loads during forklift loading and unloading are also reported.

86-1927
General Method for Calculation of Vibrations of Mechanical Systems Considering Energy Dissipation
G.S. Pisarenko
Institute for Problems of Strength, Kijev, USSR
Strojnicky Casopis, 36 (4/5), pp 599-617 (1985) 4 figs, 4 refs (in Russian)

KEY WORDS: Energy dissipation, Vibration control

A generalized nonlinear model for calculation of vibrations of mechanical systems considering arbitrary energy dissipation is presented. The corresponding differential equations describing these vibrations contain experimentally determined decrements of vibrations as functions of their parameters. It is assumed that energy dissipation is small which gives the possibility in the proposed theory to use the asymptonic methods of nonlinear mechanics, based on the solutions in the form of asymptotic series according to the powers of a small parameter.

86-1928
Development of a Lightweight Truck Mounted Attenuator
C. Schiefferly, J. Marlow
California State Dept. of Transportation, Sacramento, CA
Rept. No. REPT-609934, 187 pp (July 1983) PB86-166899/GAR

KEY WORDS: Energy absorption, Aluminum, Honeycomb structures, Trucks

The development of a lightweight truck mounted attenuator (TMA) is described. Aluminum honeycomb material was selected for the energy absorption material. Two sizes of TMA's were developed, one that could be mounted on a medium duty truck and one designed to be mounted on a three quarter or one-ton pickup. Crash tests were conducted.

BLADES

86-1929
Influence of Friction Dampers on Torsional Blade Flutter
A. Sinha, J.H. Griffin, R.E. Kielb
Pennsylvania State Univ., University Park, PA
J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 313-318 (Apr 1986) 12 figs, 2 tables, 12 refs

KEY WORDS: Blades, Coulomb friction, Flutter

This paper deals with the stabilizing effects of dry friction on torsional blade flutter. A lumped parameter model with single degree-of-freedom per blade has been used to represent the rotor stage. The well-known cascade theories for incompressible and supersonic flows have been used to determine the allowable increase in fluid velocity relative to the blade. It has been found that the effectiveness of friction dampers in controlling flutter can be substantial.

86-1930
Dynamic Characteristics of an Assembly of Prop-Fan Blades
A.V. Srinivasan, R.E. Kielb. C. Lawrence
United Technologies Research Center, East Hartford, CT
J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 306-312 (Apr 1986) 13 figs, 2 tables, 9 refs

KEY WORDS: Propeller blades, Aircraft, Periodic response, Natural frequencies, Mode shapes

The object of this paper is to present and discuss the principal results of structural analyses of a five-bladed prop-fan assembly and compare the results with corresponding test data. The test results reported here include both steady deformations and vibratory frequencies and mode shapes of the prop-fan in a vacuum centrifugal environment. Several unique measurement techniques were used during the program including determination of the steady-state deformations by measuring the angular deflections of a laser beam reflected from mirrors bonded to the blades. In addition, direct tip deflection measurements were made with high-speed strobe photography. Use of a piezoelectric crystal excitation system provided smooth sinusoidal blade excitation of the assembly at arbitrary amplitude and interblade phase angle.

86-1931

On the Importance of Shear Deformation, Rotatory Inertia, and Coriolis Forces in Turbine Blade Vibrations

K.A. Ansari
Gonzaga Univ., Spokane, WA
J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 319-324 (Apr 1986) 8 figs, 1 table, 20 refs

KEY WORDS: Turbine blades, Transverse sheer deformation effects, Rotatory inertia effects, Coriolis forces, Vibration response

The significance of the effects of shear deformation, rotatory inertia, and Coriolis forces in the analysis of turbine blade vibrations is studied. Since these are quite pronounced at the high frequency ranges encountered in turbine blade vibration problems, they should not be overlooked although their inclusion paves the way for a complicated nonlinear analysis. An approximate analysis technique is presented which involves an application of the stationary functional method using the normal modes of a discretized model. Numerical results for a typical blade are obtained and discussed. An advantage of this analysis as applied to a lumped parameter model is that nonlinear modes higher than the fundamental can also be easily computed and assessed.

86-1932

Vibration Characteristics of Mistuned Shrouded Blade Assemblies

N.A. Valero, O.O. Bendiksen
Princeton Univ., Princeton, NJ 08544
J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 293-299 (Apr 1986) 14 figs, 15 refs

KEY WORDS: Blades, Shrouds, Tuning

An investigation of the mode localization phenomenon associated with mistuning is presented for shrouded blade assemblies. The calculations are based on a generic finite element model, which permits modeling of arbitrary mistuning and both slipping and nonslipping shroud interfaces. The results presented indicate that interactions occur between mistuning and slip effects, with maximum mode localization occurring when the shrouds slip freely. Certain modes are found to be very sensitive to shroud slip, and in some cases completely change character when slip occurs. Mode localization is most pronounced in the predominantly bending modes, and varies considerably from mode to mode. As the ratio of interblade coupling strength to mistuning strength is increased, the effect of mistuning is observed to decrease significantly. This result has important implications for the flutter problem, since it suggests that the stabilization effect available from mistuning is significantly less for a shrouded rotor as compared to an unshrouded rotor.

86-1933

Characteristics of the Diametral Resonant Response of a Shrouded Fan Under a Prescribed Distortion

R.L. Jay, D.W. Burns
Allison Gas Turbine Div. of General Motors, Indianapolis, IN.
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 125-131 (Apr 1986) 14 figs, 6 tables, 11 refs

KEY WORDS: Fan blades, Shrouds, Resonant response, Experimental test data, Bladed disks

A comprehensive controlled study of the resonant vibratory structural response of a shrouded fan blade/disk due to known excitation was performed. A full circumferential definition of the inlet velocity field was obtained at five radial locations for three axial spacings and for four unique patterns of distortion and three mass flow rates. Harmonic analyses of the velocity patterns were used to establish a gust perturbation velocity normal to the blade chord. From these spanwise perturbation velocities, a normalized force parameter was established.

86-1934

Fundamental Investigation on the Impact Strength of Hollow Fan Blades

T. Ikeda, T. Miyachi, Y. Sofue
Natl. Aerospace Lab., Tokyo, Japan
Rept. No. NAL-TR-879, 23 pp (Sept 1985) N86-19657/3/GAR (in Japanese)

KEY WORDS: Fan blades, Impact tests, Bird impact

Models of hollow fan blades were made and tested to prove that their strength is sufficient for use in real engines. The hollow blades were fabricated by diffusion bonding of two titanium

alloy plates, one of which had three spanwise stiffeners and the other being a flat plate. The model was a non-twisted tapered blade. Impact tests were carried out on the hollow fan blade models in which the ingestion of a 1.5 pound bird was simulated. Solid blades with the same external form were also tested by similar methods for comparison. The results of these tests show that properly designed hollow blades have sufficient stiffness and strength for use as fan blades in the turbo-fan engine.

86-1935

The Effect of Limiting Aerodynamic and Structural Coupling in Models of Mistuned Bladed Disk Vibration

P. Basu, J.H. Griffin

Carnegie-Mellon Univ., Pittsburgh, PA.

J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 132-139 (Apr 1986) 10 figs, 14 refs

KEY WORDS: Bladed disks, Tuning, Simulation, Vibration response

A model has been developed for studying the effect of mistuning on bladed disk vibration. Its unique feature is the extent of aerodynamic and structural interaction which it simulates can be readily varied from full coupling of all blades on the disk to coupling of each blade with only its nearest neighbors. Simulations utilizing the resulting algorithm shows that limited coupling models may be used to predict the statistical distribution of blade amplitudes that characterizes the mistuning effect, which in turn determines stage durability. This approach is used to study the effect of changing various system parameters on amplitude scatter. Gas density, the number of blades on the disk, disk stiffness, and the engine order of the excitation are considered. The results are used to draw some conclusions about how to improve laboratory tests and component design.

BEARINGS

86-1936

Effect on Interference Fits on Roller Bearing Fatigue Life

H.H. Coe, E.V Zaretsky

NASA, Lewis Res. Ctr., Cleveland, OH

Rept. No. NASA-TM-87165, 24 pp (Jan 1986) N86-19616/9/GAR

KEY WORDS: Roller bearings, Fatigue life

Analysis was performed to determine the effects of inner-ring speed and press fits on roller bearing fatigue life. The effects of the resultant hoop and radial stresses on the principal stresses were considered. The maximum shear stresses below the Hertzian contact were determined for different conditions of inner-ring speed and load, and were applied to a conventional roller bearing life analysis. The effect of mean stress was determined using a Goodman diagram approach. Hoop stresses caused by press fits and centrifugal force can reduce bearing life by as much as 90 percent. Use of a Goodman diagram predicts life reductions of 20 to 30 percent. The depth of the maximum shear stress remains virtually unchanged.

86-1937

The Effectr of Bearing Support Flexibility on Critical Speed Prediction

J.C. Nicholas, L.E. Barrett

Turbodyne-Dresser, Wellsville, NY

ASLE, Trans., 29 (3), pp 329-338 (July 1986) 13 figs, 5 tables, 13 refs

KEY WORDS: Bearings, Supports, Rotating machinery, Critical speeds

This paper shows that if the bearing support flexibility is considered, accurate critical speed predictions are possible without reducing the bearing damping. The equations for the equivalent support stiffness and damping are given for a flexible support spring, mass, and damper in series with the fluid film stiffness and damping properties of a tilting-pad bearing. These equations can easily be incorporated with any synchronous response and/or stability computer program. Examples of test stand results for four production rotors are shown illustrating the accuracy of this method.

86-1938

Modeling of Oil-Film Forces in Squeeze-Film Bearings

C.R. Burrows, M.N. Sahinkaya, N.C. Kucuk

Univ. of Strathclyde, Glasgow, Scotland

J. Trib., Trans. ASME, 108 (2), pp 262-269 (Apr 1986)

KEY WORDS: Squeeze-film bearings, Parameter identification technique

The role played by bearings in determining the dynamic characteristics of rotor-bearing systems is well known. This has led to various attempts to model oil-film force coefficients in terms of linearized stiffness and damping elements. The inadequacy of these theoretical coefficients to predict performance under certain conditions has led some authors to propose the use of nonlinear models. An alternative philosophy, developed in this paper, is to retain a linear model structure and seek to determine optimized coefficient values using modern parameter estimation techniques. It is shown that these estimated linearized parameters predict system performance more accurately than the theoretical linear coefficients, particularly when the rotor is operating near a critical speed.

86-1939

Stability Analysis of Finite Offset-Halves Pressure Dam Bearing

N.P. Mehta, A. Singh
Regional Engrg. College, Kurukshetra, India
J. Trib., Trans ASME, 108 (2), pp 270-274 (Apr 1986) 9 figs, 10 refs

KEY WORDS: Dam bearings, Stability

Cylindrical pressure dam bearings are manufactured in two halves. This paper analyzes the dynamic behavior of a cylindrical pressure dam bearing having centers of both halves displaced. It is observed that stability of a cylindrical pressure dam bearing can be increased many times by displacing the centers of two halves. The bearing so obtained is superior even to elliptical and half-elliptical pressure dam bearings in stability. A simple and inexpensive method of increasing stability of cylindrical pressure dam bearings is analyzed.

86-1940

Rotational Stiffness and Damping Coefficients of Fluid Film in a Finite Cylindrical Bearing

R. Subbiah, R.B. Bhat, T.S. Sankar
Concordia Univ., Montreal, Quebec, Canada
ASLE, Trans., 29 (3), pp 414-422 (July 1986) 14 figs, 2 tables, 11 refs.

KEY WORDS: Fluid-film bearings, Stiffness coefficients, Damping coefficients

The dynamic behavior of flexible rotors supported on fluid-film bearings is studied including the rotational stiffness and damping coefficients of the oil film. The rotational stiffness and damping coefficients are evaluated for a finite cylindrical fluid-film bearing by solving the appropriate Reynolds equation for the oil film, using the finite difference method. The resulting critical speeds and the unbalance response for a single-disk flexible-rotor system modeled by the finite element method are compared with those obtained using a short bearing approximation.

86-1941

On the Stability of a Rigid Rotor in Finite Porous Journal Bearings With Slip

A.K. Chattopadhyay, B.C. Majumdar
Indian Inst. of Tech., Kharagpur, India
J. Trib., Trans. ASME, 108 (2), pp 190-194 (Apr 1986) 5 figs, 3 tables, 20 refs

KEY WORDS: Journal bearings, Oil film bearings, Porous materials, Stability

The stability characteristics of oil filled porous journal bearings of finite length and with velocity slip are investigated. The stability curves are drawn for different slip parameters, eccentricity ratios, slenderness ratios, and in the absence of any experimental data, the theoretical results for the solid bearings obtained by this analysis are compared with the available results of solid bearings.

86-1942

Study of Conical Whirl Instability of Externally Pressurized Porous Oil Journal Bearings With Tangential Velocity Slip

S.K. Guha
Indian Inst. of Tech., Kharagpur, India
J. Trib., Trans. ASME, 108 (2), pp 256-261 (Apr 1986) 7 figs, 10 refs

KEY WORDS: Oil film bearings, Journal bearings, Porous materials, Stability, Whirling

The conical whirl instability of unloaded hydrostatic porous oil journal bearings with tangential velocity slip on the bearing film interface is studied. The effect of various parameters on stability is also investigated.

86-1943

The Dissipation Coefficient and its Application to Flexible Rotor-Bearing System Design

C Rajalingham, N. Ganesan, B.S. Prabhu
Indian Inst. of Tech., Madras, India
Wear, 107 (4), pp 343-354 (Feb 15, 1986) 6 figs, 6 refs

KEY WORDS: Journal bearings, Flexible rotors, Dissipation factor, Design techniques

Information on the design of journal bearings for use in high speed rotating machinery to minimize the energy dissipation due to the out-of-balance of the flexible rotor is provided. The results are presented in the form of design charts for full journal bearings, where the dissipation coefficient must be selected to be as small as possible at operating and critical speeds.

86-1944
The Effect of Modified Inlet Boundary Conditions on the Stiffness and Damping Characteristics of Finite Hydrodynamic Journal Bearings
C. Rajalingham, N. Ganesan, B.S. Prabhu
Indian Inst. of Tech., Madras, India
Wear, 108 (3), pp 203-211 (Apr 1986) 5 figs, 7 refs

KEY WORDS: Journal bearings, Stiffness coefficients, Damping coefficients, Boundary condition effects

The well-known solutions for the pressure distribution in the lubricating film of a hydrodynamic journal bearing, satisfying the Reynolds boundary conditions, show a sudden change in the pressure gradient at the position of maximum film thickness, which is possible only if the lubricant is supplied precisely at this location. Since the pressure develops smoothly because of hydrodynamic action, a correction in the boundary conditions is applied and a modified solution for the pressure distribution is obtained. The stiffness and damping characteristics of a finite hydrodynamic journal bearing using the new boundary conditions are compared with the well-known characteristics incorporating the Reynolds boundary conditions.

86-1945
Hopf Bifurcation to Limit Cycles in Fluid Film Bearings
P. Hollis, D.L. Taylor
Cornell Univ., Ithaca, NY 14853
J. Trib., Trans ASME, 108 (2), pp 184-189 (Apr 1986) 9 figs, 2 tables, 8 refs

KEY WORDS: Journal bearings, Critical speeds, Bifurcation theory

The nonlinear response of a cylindrical journal bearing operating close to the critical speed stability boundary is studied. Using linear stability theory, the value of the critical variable (usually speed) at the point of loss of stability is obtained and shown to agree with results of previous researchers. Using Hopf bifurcation analysis, parameters for determining the behavior close to this point are obtained. Analytically, these parameters prove that the system can exhibit stable limit cycles for speeds above the critical speed. Such supercritical limit cycles exist only for a narrow range of values of modified Sommerfeld number. In other cases, subcritical limit cycles are predicted. The results are supported by numerical simulation.

86-1946
Estimation of Squeeze-Film Damping and Inertial Coefficients from Experimental Free-Decay Data
J.B. Roberts, R. Holmes, P.J. Mason
Univ. of Sussex, Brighton, Sussex, UK
IMechE, Proc., Part C: Mech. Engrg. Sci., 200 (C2), pp 123-133 (1986) 8 figs, 1 table, 16 refs

KEY WORDS: Squeeze film bearings, Damping coefficients, Inertia forces

The results obtained from experimental program concerned with a parametric identification of the damping and inertial coefficients of a cylindrical squeeze-film bearing is described through an analysis of transient response data. The results enable the operating range for which a linear model of the squeeze-film is appropriate to be determined. Comparisons are made between the estimated coefficients and theoretical predictions.

86-1947
Externally-Pressurized Gas-Lubricated Floating-Ring Porous Journal Bearings Part 2: Dynamical State Analysis
M. Malik, Y. Hori
Univ. of Tokyo, Japan
IMechE, Proc. Part C: Mech. Engrg. Sci., 200 (C2), pp 101-109 (1986) 5 figs, 3 tables, 9 refs

KEY WORDS: Floating ring journal bearings, Porous materials, Dynamic stability

Theoretical stability characteristics of a new type of floating-ring bearing, proposed in an earlier paper, are presented. The results bring out the essential features of dynamical behavior of the proposed bearing against the externally-pressurized plain porous journal bearing. The numerical scheme for the computation of the stability margin adopted in this work is different, yet simple and very efficient.

86-1948
Aerodynamic Journal Tilting-Pad Bearings for High Speed Applications
J Simek
Natl. Res. Inst. for Machine Design, Bechovise, Czechoslovakia
Strojnicky Casopis, 37 (2), pp 237-244 (1986) 7 figs, 5 refs (in Czech)

KEY WORDS: Tilting pad bearings, Inertial forces

Dynamic properties of aerodynamic journal tilting-pad bearings are analyzed from the point of

view of inertia forces effects. The influence of some design parameters; e.g. bearing preload, pad mass, radial clearance, etc. on dynamic characteristics of these bearings is evaluated. Validity of theoretical conclusions is demonstrated by bearing support properties of expansion turbine rotor for speeds up to 3.10^5 rpm.

86-1949
A Thermohydrodynamic Solution of Pivoted Thrust Pads: Part III — Linearized Force Coefficients
M.C. Jeng, A.Z. Szeri
Univ. of Pittsburgh, Pittsburgh, PA 15261
J. Trib., Trans ASME, 108 (2), pp 214-218 (Apr 1986) 2 figs, 2 tables, 10 refs

KEY WORDS: Pivoted pad bearings, Damping coefficients, Stiffness coefficients

The linearized spring and damping coefficients of pivoted pads are calculated. Both the stiffness and the damping are shown to be strongly influenced by the degree of crowning. Spherical crowning is employed to simulate pad deformation under the combined action of pressure and heat.

BELTS

86-1950
Audio Signal Modulation Caused By Self-Excited Vibrations of Magnetic Tape
T. Majewski
Warsaw Technical Univ., Chodkiewicza, Poland
J. Sound Vib., 105 (1), pp 17-25 (Feb 22, 1986) 5 figs, 7 refs

KEY WORDS: Magnetic tapes, Longitudinal vibrations, Fundamental frequencies

The longitudinal vibrations of a magnetic tape can cause distortion of a reproduced signal. The dependence of the distortion on the various system parameters is investigated. The self-excited vibrations of a tape, caused by friction against the heads and guides, is analyzed. It can be determined on the basis of the relationships obtained when the self-excited vibrations can be generated and on what parameters the amplitude of these vibrations depends. The tape path can be optimized on this basis. The amplitude of vibration is inversely proportional to the natural frequency.

GEARS

86-1951
Computer-Aided Design and Analysis of Spur Gear Dynamics
H.H. Lin
Ph.D. Thesis, Univ. of Cincinnati, 184 pp (1985) DA 8526564

KEY WORDS: Spur gears, Computer aided techniques, Design techniques

An analytical approach, developed specifically for application of computer in the design and analysis of spur gear systems, is presented. This method and associated computer program are capable of determining the dynamic response of spur gear systems with involute tooth profile and normal contact ratio. Various parameters affecting the system dynamic behavior are examined. Results generated from the computer program are compared with semi-empirical formula, AGMA formula, and experimental data. Two design approaches are proposed to reduce dynamic response within system operating speed-range -- one uses geometric modification of gear tooth profile; the other uses modification of system mass and stiffness distributions.

86-1952
The Root of Gear Noise — Transmission Error
D.R. Houser
Ohio State Univ., Columbus, OH
Power Transm. Des., 28 (5), pp 27-30 (May 1986) 9 figs

KEY WORDS: Gears, Noise reduction, Design techniques

Controlling gear noise is a critical design objective for many modern PT applications. Basic research at the academic level uncovers causes of gear noise and defines new methods of control.

86-1953
Detecting Fatigue Cracks in Gears by Amplitude and Phase Demodulation of the Meshing Vibration
P.D. McFadden
Aeronautical Res. Labs., Melbourne, Australia
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME 108 (2), pp 165-170 (April 1986) 5 figs, 6 refs

KEY WORDS: Gears, Crack detection, Digital techniques, Signal processing techniques

A digital signal processing technique is proposed for calculating the amplitude and phase modulation of the tooth meshing vibration of a gear from the signal average of the vibration, with application to the early detection of local defects such as fatigue cracks. The importance of phase modulation in the detection of defects is confirmed.

86-1954

Vibration of Three Axes Gear System

K. Umezawa, T. Ajima, H. Houjoh
Tokyo Inst. of Technology, Yokohama, Japan
Bull. JSME, 29 (249), pp 950-957 (Mar 1986) 20 figs, 1 table 10 refs

KEY WORDS: Gearboxes, Automobiles

To reveal basic dynamic features of a gearbox for a four-wheel-drive automobile, a test gearing unit having a countershaft was manufactured. Gears can be placed at arbitrary positions on the shafts, and fixed with any phase shift between two meshing pairs. Through the vibration measurement of gears, it is evident that the effect of countershaft on vibration depends upon both spacing and phase difference between the two points.

FASTENERS

86-1955

Fatigue Rated Fastener Systems

H.H. van der Linden
Advisory Group for Aerospace Res. and Dev., Neuilly-sur-Seine, France
Rept. No. AGARD-R-721, 96 pp (Nov 1985) AD-A164 689/2/GAR

KEY WORDS: Fasteners, Fatigue life

In recent years the aerospace industry has developed many ways of joining parts together; despite all innovations, however, the most common means of doing this remains the mechanical fastener. The designer needs to know which fastener systems are the most efficient from his point of view; this report is the outcome of a collaborative program which aimed to evaluate some of the available fatigue-rated fastener systems. The program studied a number of systems; tests covered not only the fasteners themselves but also the preparation of the holes and the quality of fit.

86-1956

Fatigue Analysis of Stripper Bolt Under Combined Loading for Improvement of Stamping Die Design

S.H. Lee
MacNeal-Schwendler Corp., Los Angeles, CA
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 222-229 (Apr 1986) 6 figs, 4 tables, 6 refs

KEY WORDS: Bolts, Fatigue life

A common problem of fatigue failure of stamping dies was experienced during the stamping operation with socket-head screws. In order to establish a design standard for the stripper bolt, a methodology for determination of the loads and the fatigue strength of the stripper bolt was developed. Stresses due to an impulsive load and a rectangular pulse were calculated based on a simplified spring mass system and the appropriate corrections were made to elaborate the solution. This approximate solution was validated by a finite element analysis.

86-1957

The Tightening of Bolts to Yield and Their Performance Under Load

I. Chapman, J. Newnham, P. Wallace
SPS Assembly Systems, Coventry, UK
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 213-221 (Apr 1986) 13 figs, 3 tables, 8 refs

KEY WORDS: Bolts, Fatigue life

The mechanism of tightening bolted joints and the stress distribution in the bolt are analyzed. Measurements were made of static and dynamic strength of joints. It is shown that all bolts behave elastically when external loads are applied to the joint even when the fastener was tightened to its torque-tension yield point. It is shown that joints generally fail when the external loads are sufficient to overcome the bolt preload. Fatigue results show that joint fatigue strength increases with preload, and that high fatigue bolts gave an improvement over standard fasteners at all preloads.

86-1958

Planned Mathematical Experiment in Applied Problems of Mechanics

V.I. Sergeev, I.N. Statnikov
USSR Academy of Sciences, Moscow, USSR
Strojnicky Casopis, 36 (4/5), pp 618-630 (1985) 4 figs, 3 tables, 14 refs (in Russian)

KEY WORDS: Joints, Textile looms

An approach and method of research of dynamic systems using computers is described. The method developed is called planned LP-searching. A solution to the problem of synthesis of the hinge-joint mechanism of a textile machine is presented.

86-1959
Vibration of the Torsional Mechanical Systems with Solid Tridional Joints
J. Murin
Slovak Academy of Sciences, Bratislava, Czechoslovakia
Strojnicky Casopis, 36 (4/5), pp 586-598 (1985), 3 figs, 4 refs (In Slovak)

KEY WORDS: Joints, Coulomb damping

The dynamic properties of a four-mass torsional mechanical system with ideal gearing and solid joints, in which microshifts with dry (Coulomb) friction occur under torsional stress is examined. The damping joints are made as pressed-on or hot-assembled junctions.

LINKAGES

86-1960
Dynamic Instabilities in Flexible Planar Linkages
C.J. Younis
Ph.D. Thesis, Univ. of Iowa, 166 pp (1985) DA 8528010

KEY WORDS: Linkages, Bars, Flexural vibrations, Rotatory inertia effects

The exact partial differential equation (PDE) of the transverse motion of a flexible bar of an elastic linkage is derived. Large deflections are considered and rotating inertia effects are included. The Newton's equations of motion of the bars of the mechanism are employed to determine the dynamic connection forces (reactions) at the ends of each bar. Exact expressions for the kinematics of the linage and for the inertia forces are used in the Newton's equations, where large deflections are considered. The terms of the PDE of a specific bar are expanded in Taylor series with respect to the lateral deflection.

SEALS

86-1961
An Iwatsubo-Based Solution for Labyrinth Seals: Comparison to Experimental Results
D.W. Childs, J.K. Scharrer
Texas A&M Univ., College Station, TX
J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 325-331 (Apr 1986) 9 figs, 2 tables, 16 refs

KEY WORDS: Seals, Turbulence, Perturbation theory

The basic equations are derived for compressible flow in a labyrinth seal. The flow is assumed to be completely turbulent in the circumferential direction where the friction factor is determined by the Blasius relation. Linearized zeroth and first-order perturbation equations are developed for small motion about a centered position by an expansion in the eccentricity ration. The zeroth-order pressure distribution is found by satisfying the leakage equation while the circumferential velocity distribution is determined by satisfying the momentum equation. The first-order equations are solved by a separation of variable solution. Integration of the resultant pressure distribution along and around the seal defines the reaction force developed by the seal and the corresponding dynamic coefficients. The results of this analysis are compared to published test results.

86-1962
Mechanical Face Seal Dynamics
I. Etsion, I. Green
Technion Res. and Dev. Foundation, Ltd., Haifa, Israel
Rept. No. EEC-159, AFWAL-TR-85-2082, 68 pp (Dec 1985), AD-A164 978/9/GAR

KEY WORDS: Seals, Elastomers

This report summarizes a three year study of noncontacting coned-face mechanical seal dynamics. Both small perturbation and full nonlinear analyses are presented. An experimental technique to measure relevant dynamic properties of elastomeric secondary seals is described. The critical speed, for the dynamic stability threshold, and the critical rotor runout are presented. It is shown that the more simple to use small perturbation analysis gives very good results for most practical cases.

STRUCTURAL COMPONENTS

STRINGS AND ROPES

86-1963
Nonlinear Forced Oscillations of a String — Various Types of Responses Near Primary Resonance Points
K. Yasuda, T. Torii

Nagoya Univ., Furocho, Chikusaku, Nagoya, Japan
Bull. JSME, 29 (250), pp 1253-1260 (Apr 1986) 9 figs, 3 refs

KEY WORDS: Strings, Periodic excitation

Nonlinear dynamic response of a string to periodic excitation will differ qualitatively from the usual harmonic response because the natural frequencies of a string are in the ratios of integers. The dynamic responses near the first, third and fourth primary resonance points are studied. It is shown theoretically that near each of these primary resonance points various types of multimode responses, accompanied by super-harmonic or subharmonic oscillations, can occur in addition to the usual harmonic response. Numerical examples are given and the characters of the responses are examined. Experimental analysis is also performed with use of a thin steel strip, and the validity of the theoretical analysis is confirmed.

BARS AND RODS

86-1964
Nonlinear Dynamical Theory of the Elastica
R.E. Caflisch, J.H. Maddocks
Stanford Univ., Stanford, CA
Rept. No. ARO-17902.44-MA (Pub. in Proc. of Royal Society of Edinburgh, v. 99A, pp 1-23 (1984), AD A164 664/5/GAR

KEY WORDS: Rods, Elastic properties, Euler equation

The dynamical behavior of a slender rod is analyzed in terms of a generalization of Euler's elastica theory. The model includes a linear stress-strain relation but nonlinear geometric terms. Properties of the rod may vary along its length and various boundary conditions are considered. A rotational inertia term that is neglected in many theories is retained, and is essential to the analysis. By use of the equivalence of an energy and a Sobolev norm, and by reformulation of the equations as a semilinear system, global existence of solutions is proved for any smooth initial data. Equilibrium solutions that are stable in the static sense of minimizing the potential energy are then proved to be stable in the dynamic sense due to Liapounov.

86-1965
Transient Waves in a Rod Subjected to Impulsive End Loading
D.P. Thambiratnam
National Univ. of Singapore, Kent Ridge, Singapore
Earthquake Engrg. Struc. Dynam., 14 (3), pp 475-485 (May-June 1986) 4 figs, 12 refs

KEY WORDS: Rods, Impact excitation, Wave propagation, Poisson's ratio, Mindlin theory

The propagation of transient waves in a rod due to impulsive end loading is investigated using the method of wavefront expansion. The Mindlin-Herrmann equations which include the Poisson effect are used to model the rod. The impulsive end loading on the rod can be prescribed in the form of stress, strain, velocity or acceleration boundary conditions. The analysis is based on the concept of a wave as a carrier of discontinuities in the field variables and their derivatives. These discontinuities are determined from a set of recurrence relations which are in turn generated by the use of time harmonic asymptotic series solutions to the equations of motion. Transients due to both velocity and strain (or stress) boundary conditions are treated. Numerical examples are presented to illustrate the method of solution.

86-1966
Response of a Bar Constrained by a Non-Linear Spring to a Harmonic Excitation
A.H. Nayfeh, K.R. Asfar
Virginia Polytechnic Inst. and State Univ., Blacksburg, VA
J. Sound Vib., 105 (1), pp 1-15 (Feb 22, 1986) 5 figs, 9 refs

KEY WORDS: Bars, Springs, Harmonic excitation, Longitudinal response, Multiple scale method

An analysis is presented of the longitudinal response of a bar constrained by a nonlinear spring to a harmonic excitation. The method of multiple scales is used to determine equations describing the evolution of the amplitudes and phases with damping, nonlinearity and the cases of primary, subharmonic, superharmonic, combination and ultrasubharmonic resonances. These equations are used to determine the steady state responses and their stability.

BEAMS

86-1967
Impact Deflection Analysis of Concrete Beams
Yew-Chaye Loo, A.P. Santos
Univ. of Wollongong, NSW, Australia, 2500
ASCE J. Struc. Engrg., 112 (6), pp 1297-1312 (June 1986) 7 figs, 7 tables, 15 refs

KEY WORDS: Beams, Concrete, Impact response

An analytical solution is presented for the instantaneous deflection of pin-ended beams under mid-span impact of below-yield intensity. Hertz's contact law and vibration theory are incorporated, leading to an integral equation for the force history. The beam displacement and velocity at the end of impact are used as initial conditions for the free vibration that ensues. The maximum deflection that may occur during the forced or free vibration stage is obtained automatically on a computer.

86-1968
Nonlinear Response of Clamped Beam to Impact of a Mass
H. Sato
Kanazawa Univ., Kanazawa, Japan
Bull. JSME, 29 (250), pp 1246-1252 (Apr 1986) 7 figs, 2 tables, 3 refs

KEY WORDS: Beams, Impact response, Galerkin method, Harmonic balance method

The nonlinear response of a clamped beam to a mass which strikes it has been studied theoretically and experimentally. In the theoretical analysis the nonlinearity due to large deflection of the beam with immovable edges is taken into consideration. The governing equation is solved approximately by using both Galerkin's method and the harmonic balance method. Numerical results are compared with those of the experiment in which a steel sphere is used. For large mass and large impact velocity, a close agreement between both results is obtained.

86-1969
Dynamics of Beams Moving Over Supports
K.W. Buffinton
Ph.D. Thesis, Stanford Univ., 205 pp (1985) DA 8602460

KEY WORDS: Beams, Supports, Robots

As control techniques improve, increased elasticity of the components of complex mechanical systems is becoming ever more desirable due to concomitant reductions in mass and power requirements. To aid the development of new control schemes, as well as to verify the performance of schemes proposed, equations of motion for elastic systems, governing small deformations in combination with overall movements, are needed. In this study, equations of motion are developed for two elastic systems -- a beam moving longitudinally over fixed supports and a beam and block moving longitudinally over moving supports. The results provide insight into some of the issues and problems involved in the dynamics and control of robot manipulators with highly elastic prismatic members.

86-1970
Effect of Rotary Inertia on Vibration of Tapered Beams
A.K. Gupta
Quadrex Corp., Campbell, CA
Intl. J. Numer. Methods Engrg., 23 (5), pp 871-882 (May 1986), 5 figs, 5 tables, 4 refs

KEY WORDS: Beams, Variable cross section, Rotatory inertia effects, Vibration response

Rotary inertia and dynamic-correction rotary inertia matrices for a linearly tapered beam element of any cross-sectional shape are derived in explicit form. Exact expressions for the required displacement functions are used in the derivation of these matrices. Variation of area and moment of inertia of the cross-section along the axis of the element are exactly represented by simple functions involving shape factors. Vibration analysis results of a tapered cantilever beam of I-section, obtained with and without the rotary inertia matrices are compared and effect of rotary inertia on vibration of tapered beams discussed.

86-1971
Experiments on the Impact Bending of Continuous and Notched Steel Beams
R.L. Woodward, B.J. Baxter
Australian Dept. of Defense, Victoria, Australia
Intl. J. Impact Engrg., 4 (1), pp 57-68 (1986), 7 figs, 23 refs

KEY WORDS: Beams, Steel, Notched structures, Impact response, Bending

The results of quasi-static four-point bend tests and of dynamic bend tests on free-free beams, both continuous and notched, are reported. Angles of bend and rotation are measured as a function of time after impact, where the angle of bend is defined as the angle of deflection of one part of the beam relative to a neighboring segment of the beam, and the angle of rotation is the angle of deflection relative to a datum line through the initial axis of the beam. The effect of notches is to change the strain profile in the beams, localize plastic deformation and provide sites for fracture initiation. Comparisons of angles of bend and rotation as functions of time are made with a rigid-plastic solution and with two-dimensional finite-element computations, both of which slightly underestimate the angle of bend at any time after impact.

86-1972
Earthquake Load on R/C Beams: Building Versus Single Beam
V. Sattary-Javid, J.K. Wight
Univ. of Michigan, Ann Arbor, MI
ASCE J. Struc. Engrg., 112 (7), pp 1493-1508 (July 1986), 9 figs, 2 tables, 18 refs

KEY WORDS: Beams, Reinforced concrete, Seismic response, Buildings

The results of a series of tests on a full-scale reinforced concrete structure subjected to simulated earthquake loading are used to study the behavior of beam hinging regions. The measured beam rotations from an open frame and a shear wall frame are compared to the results from an analytical study to estimate the rotational ductility demand of beams at different stages of building displacement. The results indicate that there is a pronounced difference between the ductility demand of beams in an open frame and those connected to a shear wall. A relationship between the beam hinge rotation of the actual structure and displacements of individual beam elements is presented to establish a guideline for choosing displacement histories for experimental programs of beam elements.

86-1973
Theoretical Studies on Flexural Wave Propagation in Beams: A Comprehensive Review — Part II: Transient Response of Timoshenko Beams
M.M. Al-Mousawi
Univ. of Aberdeen, Aberdeen, Scotland
Shock Vib. Dig., 18 (5), pp 9-21 (May 1986), 107 refs

KEY WORDS: Beams, Timoshenko theory, Flexural vibrations, Transverse shear deformation effects, Rotatory inertia effects

A comprehensive review related to the problems of flexural wave propagation in beams is presented in three parts. Part I is a historical background. Part II describes the use of Timoshenko beam theory, including the effect of shear distortion and rotatory inertia, for vibrational and transient analysis of beams. Part III covers elastic stress wave propagation in beams with discontinuities of cross section.

86-1974
Finite Element Analysis of Vibration of Tapered Beams
A.K. Gupta
Gupta Engineers, Fremont, CA
Shock Vib. Dig., 18 (5), pp 3-6 (May 1986), 26 refs

KEY WORDS: Beams, Frames, Variable cross section, Finite element technique, Reviews

Various approaches for finite element analysis of vibration of tapered beams and frames composed of tapered beams are discussed. Applicability, accuracy, and computational efficiency of the stiffness and consistent mass matrices for tapered beam elements, derived by various authors, are reviewed.

86-1975
Vibration of a Cantilever Beam on a Composite Support with Base Excitation
A.K. Ghosh
Bhabha Atomic Res. Ctr., Bombay, India
J. Sound Vib., 105 (1), pp 91-99 (Feb 22, 1986), 5 figs, 3 tables, 7 refs

KEY WORDS: Cantilever beams, Supports, Base excitation

An analysis of natural frequency and dynamic response of a cantilever beam subjected to base motion is presented. The analysis is extended to a case in which the cantilever is mounted on a composite support. Typical numerical results for the natural frequency and the deflection of the beam are given for both cases to illustrate the attenuation of motion by the composite mount.

86-1976
An Equivalent Inertia Matrix for a Segment of a Uniform Timoshenko Beam of any Geometry and Material
B. Downs
Loughborough Univ. of Technology, Loughborough, UK
J. Sound Vib., 105 (1), pp 109-120 (Feb 22, 1986), 8 figs, 9 refs

KEY WORDS: Beams, Timoshenko theory, Variable cross section, Flexural vibration

Iteration equations are theoretically established by which Stodola iteration permits the progressive evaluation of the coefficients of the equivalent mass matrix for the transverse vibration of a uniform Timoshenko beam segment. The mass coefficients are universally applicable irrespective of material properties or section geometry. Coefficients calculated in this way and which provide two frequency corrections to the consistent mass matrix coefficients are presented as an Appendix. The vibration analysis of Timoshenko beams thus facilitated is applied to tapered cantilever beams of a wide variety of geometries and for an extensive range of slenderness ratios.

Results are presented graphically which permit the error involved in calculating natural frequencies by Euler theory to be discerned at a glance.

86-1977

On the Approximate Determination of the Fundamental Frequency of a Restrained Camilever Beam Carrying a Tip Heavy Body

M. Gurgoze

Tech. Univ. of Istanbul, Turkey

J. Sound Vib., 105 (3), pp 443-449 (Mar 22, 1986), 3 figs, 2 tables, 7 refs

KEY WORDS: Cantilever beams, Fundamental frequency

This paper deals with the approximate determination of the fundamental bending eigenfrequency of a restrained cantilevered beam carrying a tip heavy body by the combined use of the Dunkerley's and Southwell's methods. A simple algebraic expression is introduced to calculate the fundamental frequency with satisfactory accuracy for preliminary design purposes.

86-1978

A Note on Vibration of Beam-Columns

P. Pedersen

The Tech. Univ. of Denmark, Lyngby, Denmark

J. Sound Vib., 105 (1), pp 143-150 (Feb 22, 1986), 6 figs, 19 refs

KEY WORDS: Beam-columns, Elastic supports, Natural frequencies

Eigenfrequencies for beam-columns with flexible supports are determined by a unified equation which includes all classical, idealized boundary conditions as special cases. For the approximation of linear dependence between squared eigenfrequency and column load, good agreement is found when the supports are translationally fixed, but slight translational flexibility destroys this important approximation.

CYLINDERS

86-1979

Acoustic Characteristic of Two Circular Cylinders Forming a Cross in Uniform Flow — 1st Report, Effect on Noise Reduction

Y. Tomita, S. Inagaki, S. Suzuki, T. Yokoyama

Science Univ. of Tokyo, Chiba, Japan

Bull. JSME, 29 (250), pp 1163-1170 (Apr 1986), 12 figs, 4 refs

KEY WORDS: Cylinders, Fluid-induced excitation, Noise generation

In the turbulent wake of the upstream cylinder in a uniform flow, the downstream cylinder is set in the form of a cross with the upstream cylinder and the point of mutual contact comes at the center of the test section. It is found that the acoustic radiation from the two circular cylinders forming a cross is far smaller than that from one cylinder. In the contents of the noise reduced by adding the downstream cylinder, the broadband noise as well as the dominant frequency tone, is reduced. The variation of the acoustic radiation is measured as affected by the diametral ratio of the two cylinders, distance between them, and velocity of the air.

COLUMNS

86-1980

Stability and Vibrations of Rectangular Columns Made of a Compressible Hyperelastic Material

A. Ertepinar, N. Akkas

Karadeniz Universitesi, Trabazon, Turkey

Intl. J. Engrg. Sci., 24 (6), pp 953-962 (1986), 6 figs, 15 refs

KEY WORDS: Columns, Vibration response, Axial force

The stability and the small vibrations about the finitely deformed state of rectangular columns subjected to axial compressive forces are investigated. The material is assumed to a polynominal compressible material which is homogeneous, isotropic and hyperelastic. The theory of small deformations superposed on large deformations is used in the formulation of the problem. Numerical results are provided.

FRAMES AND ARCHES

86-1981

The Effect of Axial Inertia on the Bending Eigenfrequencies of a Tiomoshenko Two-Bar Frame

A.N. Kounadis, D. Sophianopoulos

National Tech. Univ. of Athens, Greece

Earthquake Engrg. Struc. Dynam., 14 (3), pp 429-437 (May-June 1986) 5 figs, 2 tables, 13 refs

KEY WORDS: Framed structures, Bars, Timoshenko theory, Lateral vibrations, Natural frequencies

The equations of free lateral vibrations of a uniform Timoshenko two-bar frame including the effects of axial motion and joint mass with its rotational inertia are presented. The influence on the flexural eigenfrequencies of the axial motion alone or in combination with other parameters is fully assessed and thoroughly discussed. These parameters are: the translational and rotational inertia of the joint mass, the transverse shear deformation and rotatory inertia, the length, stiffness and slenderness ratios of the two bars of the frame. The variety of numerical results presented leads to the important finding that for framed structures the effect of axial inertia on the flexural eigenfrequencies alone or in combination with the foregoing parameters may be considerable.

86-1982
Nonzero Mean Random Vibration of Hysteretic Frames
T.T. Baber
Univ. of Virginia, Charlottesville, VA
Computers Struc., 23 (2), pp 265-277 (1986), 11 figs, 1 table, 27 refs

KEY WORDS: Framed structures, Random vibration, Monte Carlo method, Stochastic processes, Equivalent linearization method

The response of hysteretic plane framed structures to random excitation, accompanied by a nonzero mean gravity load, is considered. The structure is idealized as an assemblage of elastic beam subelements, joined through discrete hysteretic flexural subelements, with lumped masses at the nodes. The excitation, intended to represent a seismic base disturbance, is modeled as a Gaussian white noise stochastic process. Filtered excitation models are also possible and add no complication. The model is analyzed by Monte Carlo simulation and by stochastic equivalent linearization. It is shown that the response interaction between steady-state mean and random excitations is dependent upon the model of the system.

86-1983
Buckling and Vibration of Arches and Tied Arches
R.S. Nair
625 N. Michigan Ave., Chicago, IL
ASCE J. Struc. Engrg., 112 (6), pp 1429-1440 (June 1986), 5 figs, 1 table, 4 refs

KEY WORDS: Arches, Natural frequencies, Mode shapes

A simple method of computing the planar elastic buckling loads, natural frequencies, and corresponding mode shapes for arches and tied arches has been developed. The proposed method is applicable to arches and tied arches of general shape. Stiffnesses of arch rib and tie may vary in any manner along the span. The procedure involves linear elastic analysis with multiple loading to obtain a simplified flexibility matrix, manual development of a stability matrix (for buckling) or mass matrix (for vibration), and solution of an eigenvalue equation.

PANELS

86-1984
Weight Minimization of Orthotropic Flat Panels Subjected to a Flutter Speed Constraint
L. Librescu, L. Beiner
Tel-Aviv Univ., Ramat-Aviv, Israel
AIAA J., 24 (6), pp 991-997 (June 1986) 14 figs, 14 refs

KEY WORDS: Panels, Flutter, Minimum weight design

This paper deals with the minimum weight design of orthotropic panels subjected to a supersonic flutter speed constraint and to a system of uniform in-plane loadings. In approaching the problem, use is made of the methods of optimal control theory of distributed parameter systems. This leads to a set of necessary optimality conditions that, together with a supplementary condition ensuring that the flutter speed of the optimal panels coincides with the constrained one, constitute the governing optimality equations of the problem. An alternative form of the optimality equations is derived and a symmetry property of the optimal thickness distribution is placed in evidence. Numerical solutions are obtained via Galerkin's procedure, providing rough estimates of the optimal panel design.

86-1985
Random Vibration Analysis of Stiffened Honeycomb Panels with Beveled Edges
J. Soovere
Lockheed-California Co., Burbank, CA
J. Aircraft, 23 (6), pp 537-544 (June 1986), 13 figs, 12 refs

KEY WORDS: Panels, Honeycomb structures, Acoustic response, Random response

A semi-empirical theory is presented for predicting the dynamic strains in the face sheets of honeycomb panels subjected to random acoustic loading. The honeycomb panels are constructed with beveled edges that terminate in a solid panel edge strip around the panel periphery for ease of attachment to the substructure with countersunk fasteners. It is shown that the rotation of the beveled edges introduces a linear dynamic membrane strain into the inner face sheet superimposed on the bending strain. Furthermore, the extensional stiffness of the beveled edge closeout plan is shown to provide the dominant contribution to the honeycomb core shear stiffness exceeding that of the core alone by almost an order of magnitude. Good agreement is obtained between the predicted and measured strains, the latter taken from existing test data representing a wide range of honeycomb panel dimensions.

86-1986

Exact Solution for the Vibrations of Circular Cylindrical Shell Panels with Freely Supported Curved Edges

L. Dongping
Huazhong Univ. of Science and Technology
Acta Mech., (4), pp 478-487 (1985), 6 figs, 8 refs (in Chinese)

KEY WORDS: Panels, Cylindrical shells, Flugge's shell theory

A general analytical method is presented for evaluating the free vibration characteristics of circular cylindrical shell panels with freely supported curved edges and arbitrarily supported longitudinal edges. The exact solution is obtained through a direct solution procedure in which Flugge's shell equations are used.

86-1987

Natural Frequencies and Mode Shapes of Curved Rectangular Composite Panels with Interior Cutouts

R. A. Walley
Air Forc' Inst. of Tech., Wright-Patterson AFB, OH
Rept. No. AFIT/GAE/AA/85D-16, 101 pp (Dec 1985), AD-A165 269/2/GAR

KEY WORDS: Rectangular panels, Hole-containing media, Natural frequencies, Mode shapes, Computer programs

A finite element computer code STAGSC-1 and holographic interferometry were used to determine the effects of interior cutouts on the first five natural frequencies and mode shapes of curved graphite epoxy panels. The panels are a quasi-isotropic layup with a 12-inch chord and height. Both the finite element and holographic analysis were conducted using clamped-clamped boundary conditions. The vibration branch of STAGSC-1 is an energy technique based on small displacements and linear elastic stress-strain relationships. When compared with the time averaged holograms of the experimentally determined natural frequencies and mode shapes, the two techniques show a close correlation of both frequency and shape.

PLATES

86-1988

Free Vibrations of a Specially Orthotropic Plate Having Two Opposite Sides Fixed and Two Sides Free

G.A. Rossi
Ph.D. Thesis, Univ. of Rhode Island, 134 pp (1985), DA 860097

KEY WORDS: Plates, Boundary condition effects, Natural frequencies, Mode shapes

After numerous unfruitful attempts to effect an exact solution to the problem of free vibrations of a specially orthotropic, thin, laminated plate having two opposite sides clamped and the other two sides free, the problem was solved approximately by the finite difference method and by the Rayleigh method using characteristic beam functions. In addition, experimental results were obtained using modal analysis of free vibrations of a specially orthotropic plate that was 12 inches square by 3/16-inch thick and made of graphite-epoxy. Good correlation was obtained with both approximate methods. However, greater accuracy was obtained with the finite difference approach because of the closer approximation to the true boundary conditions on the free edges. Natural frequencies and mode shapes were found using the finite difference approach; natural frequencies were obtained with the Rayleigh method; and natural frequencies and mode shapes were found using modal analysis. Results of the approximate numerical and experimental methods were compared, and possible sources of anomalies were noted and discussed.

86-1989

Finite Amplitude Waves on an Elastic Plate Horizontally Separating Two Different Fluid Streams

E. Hasegawa, S. Yamashita
Keio Univ., Yokohama, Japan
Bull. JSME, 29 (249), pp 787-794 (Mar 1986), 3 figs, 11 refs

KEY WORDS: Plates, Fluid-induced excitation

Nonlinear waves on a thin elastic plate horizontally separating upper and lower fluid streams are analyzed theoretically. The lower stream is denser. The elastic plate is governed by the equation for large deflections including the inplane forces due to the longitudinal deformations of the plate. Two fluid streams are assumed to be imcompressible and inviscid, but on the elastic plate the balance of the normal component of force is expressed by taking the viscous stress into account. Some progressive waves of finite amplitude are found on the elastic thin plate. The nonlinear elevation of the elastic plate is obtained up to the third order approximation in the wave amplitude. The unsteady amplitude of waves tend to a finite limit after a long time under effect of the viscosity of the fluid.

86-1990

Bending, Vibration and Buckling of Simply Supported Thick Multilayered Orthotropic Plates: An Evaluation of a New Displacement Model

M. Di Sciuva
Polytechnic of Turin, Turin, Italy
J. Sound Vib., 105 (3), pp 425-442 (Mar 22, 1986), 10 figs, 2 tables, 17 refs

KEY WORDS: Plates, Layered materials

Based upon a piecewise linear displacement field which allows the contact conditions for the displacements and the transverse shearing stresses at the interfaces to be satisfied simultaneously, the nonlinear (in the von Karman sense) equations of motion for thick multilayered orthotropic plates are developed. Successively, the equations are specified to the linear boundary value problem of the bending and to the linear eigenvalue problems of the undamped vibration and buckling of rectangular plates. In order to assess the accuracy of the proposed theory, the sample problem of the bending, free undamped vibration and buckling of a three-layered, symmetric cross-ply, square plate simply supported on all edges is investigated.

86-1991

Wave Propagation in Thick Damped Laminated Plates

D.J. Mead, R. Joannides
Southampton Univ., Southampton, UK
Rept. No. AASU-344, 88 pp (Jan 1985), N86-17787/0/GAR

KEY WORDS: Plates, Layered materials, Damped structures, Wave propagation

An approximate theory is presented for the plane wave motion in thick multilayered isotropic plates. The wave-speeds, wave-modes and the corresponding wave loss factors when some of the layers are damped were studied. Each layer is assumed to have longitudinal and transverse displacements which vary linearly through the layer thickness. Hamilton's Principle is used to set up corresponding equations of motion in terms of the four displacement coordinates which characterize the displacement of each layer. The whole set of equations so formed for a multiple-layered plate is reduced and simplified by making use of symmetry of the plate, and symmetry or antisymmetry of the wave motion. The single, triple and five-layered configurations are emphasized, and computed results are presented to show how the wave speeds and loss factors vary with wave number of motion. Approximate results are compared with results obtained from the exact theory of a single-layered plate, and with results from previously derived approximate theories.

86-1992

Mechanical Power Flow Between Stiffened Plates and Viscoelastic Discrete Systems

E. Goldfracht, G. Rosenhouse
Technion -- Israel Inst. of Technology, Haifa, Israel
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2)(, pp 155-164 (Apr 1986), 5 figs, 10 refs

KEY WORDS: Stiffened plates, Random excitation, Vibration transfer

A theory of power transmission and vibration energy distribution of dynamically loaded structures is discussed. The loads are random and the system comprises linked elements, which consist of machine-supported stiffened plates. Fundamentally, the theory is deterministic, but in addition it uses some features of the SEA. In fact, the analysis is intended to verify fundamental theorems of the Statistical Energy Analysis in the lower frequency range.

86-1993

An Approximate Solution for the Bending Vibrations of a Combination of Rectangular Thin Plates

Y. Shen, B.M. Gibbs
Univ. of Liverpool, Liverpool, UK
J. Sound Vib., 105 (1), pp 73-90 (Feb 22, 1986), 4 figs, 2 tables, 14 refs

KEY WORDS: Rectangular plates, Flexural vibrations, Harmonic excitation, Approximation methods

The appropriate method often used for calculating the bending vibration of a single rectangular plate is extended to calculate the bending vibrations of a global system of combinations of rectangular plates. These plates are elastically supported and have damped non-coupled edges. Two examples, a series of T-combinations and an L-combination of rectangular thin isotropic plates, are considered and the input and transfer mobilities due to point excitation derived. Numerical results are presented for the case of combinations of concrete plates and the effects of varying the material damping of the plates and edge damping are investigated.

86-1994
Study of Plate Impedances
P. Hagedorn, K. Kelkel
Technische Hochschule Darmstadt, Fed. Rep. Germany
Rept. No. ESA-CR(P)-2086, 210 pp (Apr 1985), N86-17802/7/GAR

KEY WORDS: Rectangular plates, Circular plates, Mechanical impedance

Expressions for impedances of rectangular and circular plates are derived by analytical and semianalytical methods. Physical interpretations of the mathematical formalism used and of the results are given. The impedances obtained are to be used in a distributed element program. It is shown that concentrated moments lead to infinite angular displacements in elastic plates. The concept of reduced multipoint impedance matrix is introduced. The circular plate with free boundary supported at a rigid, circular, central hub is solved in terms of Bessel functions. Results for the circular plate supported eccentrically at a single point and the reduced multipoint impedances are given in terms of Bessel functions.

86-1995
Analytical and Experimental Investigation on Vibrating Rectangular Plates with Two Opposite Free Edges and Internal Supports While the Remaining are Elastically Restrained Against Rotation
P.A.A. Laura, L. Ercoli
Inst. of Applied Mechanics, Puerto Belgrano Naval Base, Argentina
Ocean Engrg., 13 (3), pp 219-226 (1986), 2 figs, 3 tables, 4 refs

KEY WORDS: Rectangular plates, Fundamental frequencies, Boundary condition effects

This paper deals with the determination of an approximate fundamental frequency equation for a rectangular plate with two edges elastically restrained against rotation, while the edges are free but internal supports parallel to the free edges are present in the structural system. The algorithmic procedure can be easily implemented on a micro computer or even a hand, programmable calculator. Good engineering agreement with experimental results is shown to exist in the case of a plate with edges rigidly clamped.

86-1996
Study of Unconstrained Layer Damping Treatments Applied to Rectangular Plates Having Central Cutouts
G. Parthasarthy, N. Ganesan, C.V.R. Reddy
ISRO Satellite Centre, Bangalore, India
Computers Struc., 23 (3), pp 433-443 (1986), 11 figs, 4 tables, 15 refs

KEY WORDS: Rectangular plates, Hole-containing media, Layer damping, Natural frequencies, Loss factors

Theoretical and experimental investigations are made to study the damping effectiveness of partially applied unconstrained layer damping treatments on rectangular plates having central rectangular cutouts. The effect of such partial applications on the modal frequencies, loss factors, and mode shapes are estimated analytically by the finite element method. Different partially applied damping configurations have been studied with a view to realize maximum system damping for the minimum mass of the applied damping. The theoretical results are validated by suitable experiments.

86-1997
Static and Dynamic Response of Plates and Shells
B.V. Alavandi
Ph.D. Thesis, Univ. of Melbourne, Australia, 355 pp (1985) DA 8524253

KEY WORDS: Rectangular plates, Cylindrical shells, Composite materials

Plates and cylindrical shells, made up of composite materials, form basic structural components in aerospace, transportation, and building industries. Due to highly anisotropic nature of the composite materials the analysis of composite plates and shells requires the use of higher order theories. This thesis deals with the higher order theories proposed to analyze static, free and forced vibration response of rectangular plates

and cylindrical shells. The proposed theories have been formulated by abandoning the Kirchhoff-Love hypothesis of the classical theories and thus allowing the cross-sections to rotate relative to the midplane and to warp into non-planar sections.

86-1998

Three-Dimensional Vibration and Buckling Analysis of Twisted Parallelepipeds

K.I. Jacob

Ph.D. Thesis, Ohio State Univ., 196 pp (1985) DA 8603015

KEY WORDS: Plates, Parallelepiped bodies, Ritz method, Vibration response

Little work has been done by researchers in the stability of three-dimensional parallelepipeds. In the present investigation, the critical load problem is treated as an instability of a body with initial stresses and displacements. As a criterion of instability the existence of a critical original configuration and an adjacent equilibrium configuration is employed. A linearized formulation that determines the adjacent equilibrium configuration yields the governing equations and the integral functional for this instability problem. The Ritz method is employed, with all three displacement components taken in the form of algebraic polynomials satisfying the fixed-face boundary conditions exactly. This method is three-dimensional and requires no internal kinematical constraints.

SHELLS

86-1999

Vibration of Thin Shells of Revolution Based on a Mixed Finite Element Formulation

W. Altman, E.L. Neto

Instituto Tecnologico de Aeronautica, Brazil

Computers Struc., 23 (3), pp 291-303 (1986) 9 figs, 3 tables, 8 refs

KEY WORDS: Shells of revolution, Finite element technique, Vibration response

A modified Hellinger-Reissner functional for thin shells of revolution is presented. A mixed finite element formulation is developed from this functional which is free from line integrals and relaxed continuity terms. This formulation is applied to the problem of free vibration of spherical and conical shells. Bilinear trial functions are used for all field variables.

86-2000

Large Amplitude Free Vibrations of Shells of Variable Thickness — A New Approach

G.C. Sinharay, B. Banerjee

Hooghly Mohsin College, West Bengal, India

AIAA J., 24 (6), pp 998-1004 (June 1986) 1 fig, 6 tables, 9 refs

KEY WORDS: Shells, Variable cross section, Natural frequencies, Mode shapes

Large amplitude free vibrations of thin elastic shallow spherical and cylindrical shells of non-uniform thickness have been investigated following a new approach. Numerical results for movable as well as for immovable edge conditions are given in tabular forms and compared with other results.

86-2001

Fortran Program for Vibration and Sound Radiation of Spherical Shell

J.H. James

Admiralty Research Establishment, Portland, England

Rept. No. ARE/TM-(N1)-86501, DRIC-BR-98230, 20 pp (Jan 1986) AD-A163 752/9/GAR

KEY WORDS: Spherical shells, Harmonic excitation, Sound waves, Wave propagation, Computer programs

Mathematical formulae and a Fortran program listing are given for calculating the response and sound radiation due to prescribed time-harmonic excitation. The program is useful for bench-mark studies. Numerical results illustrate the applicability of the various DAA forms of the exterior fluid loading term.

86-2002

Elastic Impact of Spheres on Thin Shallow Spherical Shells

M.G. Koller, M. Busenhart

Swiss Federal Institute of Technology, Zurich, Switzerland

Intl. J. Impact Engrg., 4 (1), pp 11-21 (1986) 9 figs, 1 table, 12 refs

KEY WORDS: Spherical shells, Impact excitation, Fluid-filled containers, Reissner method, Hertzian contact

This investigation was concerned with the elastic impact of spheres on thin shallow spherical shells. A nonlinear integro-differential equation of the impact process was developed on the basis of Reissner's approximate theory for transverse vibrations of shallow shells and the quasi-static Hertzian impact theory. This equation was numerically integrated and its main results were experimentally verified.

86-2003

Damped Vibrations of a Simply Supported Two-Layered Half-Cylindrical Shell

O. Simkova, S. Markus
Slovak Academy of Sciences, Bratislava, Czechoslovakia

Strojnicky Casopis, 36 (4/5), pp 631-640 (1985) 4 figs, 7 refs (in Slovak

KEY WORDS: Cylindrical shells, Layered materials, Hysteretic damping, Viscoelastic damping

The equations of motion of a two-layered half-cylindrical shell have been solved under the assumption of hysteretic-type damping in the outer viscoelastic layer. The resulting loss factors are discussed in dependence on different wave numbers in transversal and longitudinal direction for various lengths of the shell.

86-2004

Impulsive Response of a Finite Circular Cylindrical Shell Subjected to Waterhammer Waves

T. Adachi, S. Ujihashi, H. Matsumoto
Tokyo Institute of Technology, Tokyo, Japan

Bull. JSME, 29 (249), pp 737-742 (Mar 1986) 8 figs, 10 refs

KEY WORDS: Cylindrical shells, Fluid-filled containers, Impulse response, Water hammer

The impulsive response of a fluid-filled finite cylindrical shell with both ends clamped subjected to waterhammer waves is analyzed on the basis of three axisymmetric shell theories and the potential theory for perfect fluid. In the analysis Mirsky-Herrmann's theory considering the influence of the transverse shear deformation, Flugge's theory as an accurate classical theory and a simplified theory most frequently used are employed. It is assumed that the influence of the fluid-shell interaction is negligible. As a result, it is shown that if the accurate bending moments and the shear force are to be obtained, the use of Mirsk-Herrmann's theory is recommended. The numerical inverse Laplace transformation with use of the FFT algorithm contributes to the reduction of CPU time and the increased accuracy of results.

86-2005

Dynamics of Vertically Excited Liquid Storage Tanks

A.S. Veletsos, Y. Tang
Rice Univ., Houston, TX

ASCE J. Struc. Engrg., 112 (6), pp 1228-1246 (June 1986) 7 figs, 3 tables, 12 refs

KEY WORDS. Storage tanks, Fluid-filled containers, Ground vibration, Galerkin method, Soil-structure interaction

A simple practical procedure is presented for evaluating the dynamic response of an upright circular cylindrical liquid storage tank to a vertical component of ground shaking, considering the flexibility of the supporting medium. The tank is presumed to be supported through a rigid circular mat at the surface of a homogeneous elastic half-space, and it is analyzed approximately by application of Galerkin's method considering the tank-liquid system to respond as a single-degree-of-freedom system in its fixed-base condition. Comprehensive numerical data are included that elucidate the actions of both rigidly and flexibly supported tanks, and the effects of the numerous parameters that influence the response. It is shown that soil-structure interaction reduces hydrodynamic effects and that the consequences of such interaction may be approximated with good accuracy by a change in natural frequency of the tank-liquid system and by increasing damping. The maximum hydrodynamic effects are related simply to the corresponding hydrostatic effects.

86-2006

A Study on Load Combination Method Considering the Correlation among Dynamic Loads — Load Combination for Seismic Response Analysis of Liquid Storage Tank

A. Sone, K. Suzuki
Tokyo Metropolitan Univ., Tokyo, Japan

Bull. JSME, 29 (249), pp 888-893 (Mar 1986) 8 figs, 3 tables, 8 refs

KEY WORDS: Storage tanks, Fluid-filled containers, Seismic response, Sloshing

This report deals with a fundamental study concerning various kinds of dynamic load combination problems. Up to the present, the square root of the sum of squares (SRSS) law has been widely utilized for various load combination problems. However, considerable error is produced during the combination based upon the SRSS law, particularly when correlation among loads to be combined becomes significant. In this study, a load combination technique introducing an evaluation of the correlation is proposed. It is applied to a seismic response analysis problem of a large-scale liquid storage tank inducing sloshing effect in order to evaluate the

base shear coefficient and the overturning moment.

86-2007
Acoustical Finite Source Modeling of a Vibrating Toroidal Structure
W.P. Hnat
Ph.D. Thesis, Univ. of Akron, 137 pp (1985) DA 8603135

KEY WORDS: Toroidal shells, Sound waves, Wave radiation, Point source excitation

A vibrating toroidal structure is modeled using a finite source approach. Changes in sound radiation caused by structure modifications are investigated. The model is based on monopole and dipole point sources. The point source characteristics were developed from measured acceleration levels of an actual rotating structure. The model results are presented in two forms, one for objective evaluations and one for subjective evaluations. Validity of the model was shown by the excellent agreement between the model results and the measured results for the specific structural characteristics investigated.

PIPES AND TUBES

86-2008
DOE/ANL/HTRI Heat Exchanger Tube Vibration Data Bank. Addendum 6
H. Halle, J.M. Chenoweth, M.W. Wambsganss
Argonne National Lab., Argonne, IL
Rept. No. ANL-CT-80-3-Add.6, 33 pp (Jan 1986) DE86006811/GAR

KEY WORDS: Heat exchangers, Tube arrays, Fluid-induced excitation, Case histories, Experimental data

This sixth addendum to the DOE/ANL/HTRI heat exchanger tube vibration data bank presents six new case histories of field experiences. The data bank was established in 1980 to accumulate comprehensive case histories on heat exchangers that have experienced tube-vibration problems and on units that have been trouble-free and to render this information available for evaluation, improvement, and development of vibration-prediction methods and design guidelines.

86-2009
Tube Vibration in Industrial Size Test Heat Exchanger (22 Additional Configurations)
H. Halle, J.M. Chenoweth, M.W. Wambsganss
Argonne National Lab., Argonne, IL
Rept. No. ANL-85-66, 102 pp (Dec 1985) DE86007010/GAR

KEY WORDS: Heat exchangers, Tube arrays, Fluid-induced excitation, Experimental data

Typical industrial shell-and-tube heat exchanger configurations are investigated systematically for the occurrence of potentially damaging tube vibration as a function of flowrate. In continuation of an ongoing experimental program, results from shellside water flow tests of twenty-two additional test exchanger configurations are reported. The test cases include single- and double-segmentally baffled tube bundles having various combinations of triangular and square tube layout patterns, baffle arrangements, and baffle edge orientations. All layouts had a tube pitch-to-diameter ratio of 1.25. The testing focused on identification of the lowest critical flowrates to initiate fluidelastic instability and/or large amplitude tube motion and the location within the bundle of the tubes which first experience these responses.

86-2010
Turbulent Buffeting of a Multispan Tube Bundle
M.K. Au-Yang
Babcock & Wilcox, Lynchburg, VA
J. Vib., Acoust., Stress, Rel. Des., Trans. ASME, 108 (2), pp 150-154 (Apr 1986) 2 figs, 1 table, 7 refs

KEY WORDS: Tube arrays, Fluid-induced excitation, Turbulence, Random vibration, Buffeting

An expression to calculate the buffeting response of a multispan tube bundle with nonconstant linear mass density is derived by generalizing Powell's joint acceptance concept. Application of the equation to lock-in vortex-induced vibration analysis is also discussed.

86-2011
A Constrained-Mode Analysis of the Fluidelastic Instability of a Double Row of Flexible Circular Cylinders Subject to Cross-Flow: A Theoretical Investigation of System Parameters
S.J. Price, M.P. Paidoussis
McGill Univ., Montreal, Quebec, Canada
J. Sound Vib., 105 (1), pp 121-142 (Feb 22, 1986) 8 figs, 5 tables, 29 refs

KEY WORDS: Cylinders, Tube arrays, Fluid-induced excitation, Constraint modes method

A new method of solution is proposed for a previously developed stability analysis of a double row of flexible cylinders subject to a fluid cross-flow. The double row of flexible cylinders may either be by itself or positioned in an array of rigid cylinders, the latter case being more representative of heat exchanger tube arrays. This new method of solution enables a long double row of fluid-dynamically coupled flexible cylinders to be adequately represented, from a stability viewpoint, by a two-cylinder kernel. This is done by prescribing a specific inter-cylinder modal pattern, and this is the reason for calling this tie constrained-mode solution. A comparison of the critical flow velocities obtained via this solution and the more complete long-row solution shows that the agreement between them is excellent.

86-2012

Evaluation and Prediction of Critical Overhang Length Under Pipe Whip Accident

T. Yano, N. Miyazaki, S. Miyazono
Ishikawajima-Harima Heavy Industries Co., Ltd., Yokohama, Japan
J. Pressure Vessel Tech., Trans ASME, 108 (2), pp 182-187 (May 1986) 7 figs, 1 table, 22 refs

KEY WORDS: Pipe whip, Nuclear reactor components

When the pipe length between break exit and restraint is long in the pipe whip accident, the pipe will undergo a plastic collapse as the moment increases. The length at which plastic collapse may occur is called the critical overhang length. The experimental results of critical overhang length show good agreement with the prediction by a static simplified estimation method for critical overhang length although the pipe whipping is a dynamic phenomenon. Diagrams are also described for a range of sizes of stainless steel pipe under the loss of coolant accident conditions of light water reactors.

86-2013

Analytical Studies of Blowdown Thrust Force and Elastic-Plastic Behavior of Pipe at Pipe Rupture Accident

N. Miyazaki, S. Ueda
Kyushu Univ., Fukuoka-ken, Japan
J. Pressure Vessel Tech., Trans ASME, 108 (2), pp 175-181 (May 1986) 11 figs, 3 tables, 13 refs

KEY WORDS: Pipes, Blowdown response, Finite element technique, Computer programs

When high-temperature and high-pressure water is ejected from pipe, a blowdown thrust force will act on the pipe and it will cause pipe movement. The analytical methods of blowdown thrust force and pipe movement are presented. The equation of momentum conservation is used to calculate the blowdown thrust force, together with the results of the thermal-hydraulic analysis code RELAP4/MOD6. The finite element method is used to calculate the dynamic movement of pipe. The equations for calculating the maximum strain at the outer surface of pipe are derived by assuming the static equilibrium condition.

86-2014

Distorted Pressure Histories Due to the Step Responses in a Linear Tapered Pipe -- for Arbitrary Cross-Sections

Takahiko Tanahashi, Tatsuo Sawada, Kazuyuki Shizawa, Tsuneyo Ando
Keio Univ., Yokohama, Japan
Bull. JSME, 29 (249), pp 795-801 (Mar 1986) 11 figs, 1 table, 5 refs

KEY WORDS: Pipes, Variable cross section, Wave equation

Although much progress has already been made in solving problems in step responses of pressure in a linear tapered pipe, new developments are still needed before the two-dimensional wave equation can be solved routinely. This paper describes a new method of solving a one-dimensional wave equation in linear tapered compound pipes with arbitrary cross-sections. Results obtained by this theory are compared with experiments in pipes with square cross-sections.

86-2015

Seismic Design of Buried Pipeline for Fault Movement Effects

L.R. Wang, Y.-H. Yeh
Old Dominion Univ., Norfolk, VA
J. Pressure Vessel Tech., Trans ASME, 108 (2), pp 202-208 (May 1986) 8 figs, 2 tables, 13 refs

KEY WORDS: Underground structures, Pipelines, Seismic response, Parametric response

A design procedure for buried pipelines subjected to both strike-slip and reverse strike-slip faults after modifying some of the assumptions used previously is presented. Based on the analysis results, the design criteria for buried pipelines subjected to various fault movement effects is discussed. Parametric responses of buried pipeline for various fault movements, angles of crossing, buries depths and pipe diameters are presented.

86-2016
On Wave Propagation in Fluid-filled Circular Cylindrical Tubes
M. Moser, M. Heckl, K.-H. Ginters
Technische Universitat, Berlin
Acustica, 60 (1), pp 34-44 (Mar 1985) 15 figs, 7 refs (in German)

KEY WORDS: Pipes, Tubes, Fluid-filled containers, Fluid-induced excitation, Wave propagation

The phase velocities and group velocities of fluid-filled, long cylinders are calculated. The results are used to derive the input admittances when the pipe-wall is excited by a point force. It is shown that for the velocities, as well as the admittances, the ring frequencies play an important role. Fluid loading causes a decrease of the ring frequencies which can be estimated by a simple formula. Approximate formulas for the frequency average of the admittance are also given. Experiments show that even in the absence of reflections at the pipe-ends an impulse source generates a long signal which easily can be explained by the numerous waves screwing down in the axial direction. In frequency bands containing a ring frequency the signals are particularly long. In the middle frequency range a good formula for the overall trend between solid body wave velocity and water wave pressure is obtained.

86-2017
Studies on Stability of Pipes Conveying Fluid — The Effect of a Lumped Mass and Damping
Y. Sugiyama, Y. Kumagai, T. Kishi, H. Kawagoe
Tottori Univ., Japan
Bull. JSME, 29 (249), pp 929-934 (Mar 1986) 10 figs, 17 refs

KEY WORDS: Pipes, Cantilevers, Fluid-filled containers, Flutter, Damping coefficients

The effect of a lumped mass and damping on stability of tubular cantilevers conveying fluid is studied theoretically and experimentally. The cantilevers are nonconservative and become subject to flutter-type instability. Comparisons are made between the theoretical flutter velocities and the corresponding experimental results. The experimental values were close to the theoretical predictions made by taking a measured damping coefficient into account.

86-2018
The Normal Incidence Absorption Coefficient of a Matrix of Narrow Tubes with Constant Cross-Section
A Craggs, J.G. Hildebrandt
Univ. of Alberta, Edmonton, Alberta, Canada
J. Sound Vib., 105 (1), pp 101-107 (Feb 22, 1986) 4 figs, 2 tables, 5 refs

KEY WORDS: Tubes, Sound waves, Wave propagation, Acoustic absorption

The data from a previous paper in which effective density and resistivity were calculated for various tube cross sections are summarized and used to calculate the normal incidence absorption coefficient of a matrix of uniform tubes. The results of the theory are compared with those from experiments for two of the sections, the right equilateral triangle and the square, and good agreement, for engineering purposes, is shown, over a frequency range including the low frequency Poiseuille flow regime up to the Helmholtz regime. Heat conduction effects have been included only in a simplified way, with the assumption of isothermal conditions for the whole frequency range considered.

86-2019
Fatigue Behavior of Flexhoses and Bellows Due to Flow-Induced Vibrations
P.V. Desai, L. Thornhill
Georgia Inst. of Tech., Atlanta, GA
Rept. No. NASA-CR-176481, 84 pp (Jan 1986) N86-19662/3/GAR

KEY WORDS: Bellows, Fatigue life, Fluid-induced excitation

The analysis and results developed in a fresh approach to calculate flow induced vibration response of a flexible flow passage are summarized. The vibration results are further examined in the frequency domain to obtain dominant frequency information. A cumulative damage analysis due to cyclic strains is performed to obtain the number of cycles to failure for a metallic bellows of particular specifications under a variety of operational conditions. Sample plots of time and frequency domain responses are included. The complex listing of a computer program is provided.

86-2020
On the Estimation of Loss Factors in Lightly Damped Pipeline Systems: Some Measurement Techniques and Their Limitations
M.P. Norton, R. Greenhalgh
Univ. of Western Australia, Nedlands, Australia
J. Sound Vib., 105 (3), pp 397-423 (Mar 22, 1986) 11 figs, 5 tables, 12 refs

KEY WORDS: Pipelines, Damped structures, Loss factors

Two alternative digital techniques for measuring modal and band averaged internal loss factors in lightly damped pipeline systems are described. In the first the attenuation of the amplitude of each resonance in the frequency domain is monitored at specific time intervals after removal of the excitation source. This is achieved by amplitude tracking specific spectral components in the transformed signal. The second method involves the usage of constant bandwidth random noise burst excitation. The decaying response signal is subsequently digitally filtered and averaged. Both techniques produce reliable estimates and generally provide lower loss factors than would otherwise be obtained by existing techniques such as the steady state power flow technique.

86-2021

Acoustic Natural Frequency Analysis of Tree-Structure Pipeline Systems by Personal Computer

I. Gyori, G. Joo
Technical Univ. for Heavy Industry, Miskolc, Hungary

J. Sound Vib., 105 (1), pp 61-72 (Feb 22, 1986) 8 figs, 1 table, 20 refs

KEY WORDS: Pipelines, Reciprocating compressors, Natural frequencies, Sound waves, Personal computers

An extension of the Schmidt-Kuhlmann method for reciprocating compressor pipeline systems having a tree-structure, consisting of receivers and pipes with an optional number of branching is presented. A generalized algorithm is given which makes it possible to mechanize program construction for the purpose of determining acoustic natural frequencies of complex structures and the use of personal computers is illustrated -- as well as actual numerical calculations -- for automatic program-writing. The program developed is very useful in design practice for determining the effects caused by modifications of the geometric dimensions, and it permits one to shift and avoid harmful acoustic resonances in preliminary planning.

86-2022

Variational Analysis of a Slender Fluid-Structure System: The Elasto-Acoustic Beam — A New Symmetric Formulation

R. Ohayon
Office National d'Etudes et de Recherches Aerospatiales, Chatillon, France

Intl. J. Numer. Methods Engrg., 22 (3), pp 637-647 (Mar 1986) 3 figs, 28 refs

KEY WORDS: Fluid-filled containers, Finite element technique, Fluid-induced excitation

A new finite element analysis of the linear dynamic responses of a slender fluid-structure system, namely, the elasto-acoustic beam, neglecting flow and viscosity effects, is presented. Using one unknown field in the fluid, the mass-flow corresponding to a cross-section mean value of the longitudinal displacement field component, an original symmetric formulation is derived which does not exhibit the usual spurious modes associated with the irrotationality constraint occurring in displacements formulations of fluid-structure problems.

DUCTS

86-2023

Structural Analysis of an LMFBR Shield Assembly Duct Under Thermo-Mechanical and Seismic Loads

S.N. Malik, V.K. Sazawal
General Electric Co., Cincinnati, OH

J. Pressure Vessel Tech., Trans ASME, 108 (2), pp 151-157 (May 1986) 8 figs, 7 tables, 5 refs

KEY WORDS: Ducts, Nuclear reactor containment, Seismic excitation, Fatigue life, Finite element technique

The stress analysis performed to assess structural adequacy of the Clinch River Breeder Reactor core removable shield assemblies is described. Removable shield assemblies are located in the peripheral region of the core and are subjected to severe cross-sectional thermal gradients and seismic loads requiring a relatively complex duct load pad design. For cost-effectiveness, the analysis was conducted in two stages. First, an elasto-plastic seismic stress analysis was performed using a detailed nonlinear finite element model (with gaps) of the load pad configuration. Next, in order to determine the total strain accumulation and the creep-fatigue damage the maximum seismic stresses combined with the worst thermal stress from a single assembly model were used to perform a simplified inelastic analysis using two sets of material properties to bound the changing material conditions during reactor operation.

86-2024

Attenuation of Sound Due to Vortex Shedding from a Splitter Plate in a Mean Flow Duct

M.S. Howe

Univ. of Southampton, Southampton, England
J. Sound Vib., 105 (3), pp 385-396 (Mar 22, 1986) 5 figs, 13 refs

KEY WORDS: Ducts, Plates, Hole-containing media, Sound attenuation, Vortex shedding

A theoretical analysis is given of an experiment being performed as part of a program to quantify the effectiveness of perforated screens in dissipating sound in the presence of tangential mean flow. In the experiment vorticity is generated at the trailing edge of a splitter plate in a mean flow duct by a plane sound wave incident from upstream, acoustic energy being ceded to the kinetic energy of the vortex field. An expression is derived for the dissipated sound power at arbitrary subsonic mean flow Mach number and frequency. The calculation is performed both by a consideration of the net flux of acoustic energy into the trailing edge region of the splitter plate, and by evaluating the rate of working of the vortex lift forces in the field of the acoustic particle velocity. It is shown that the absorption is independent of frequency, provided the frequency does not exceed the minimum cut-on frequency of transverse acoustic modes within the duct.

BUILDING COMPONENTS

86-2025
Dynamic Testing of Wood-Framed Building Partitions
S.S. Rihal, G. Granneman
California Polytechnic State Univ., San Luis Obispo, CA
Rept. No. ARCER85-1, NSF/ENG-85054, 184 pp (Aug 1985) (Spon. by Natl. Science Foundation, Washington, DC, Directorate for Engrg.) PB86-163037/GAR

KEY WORDS: Walls, Wood, Dynamic tests, Seismic tests

The results of a testing program to investigate the seismic behavior and thresholds of damage of full-height building partitions are presented. Cyclic in-plane racking tests of four full-height wood-stud framed building partitions were carried out at different frequencies of imposed block cyclic displacements. Test results provide quantitative data on the earthquake resistance of typical full-height partition assemblies, as well as the relationship between input motion parameters (e.g., amplitude and frequencies of imposed cyclic displacements) and resulting damage.

86-2026
Openings in Earthquake-Resistant Structural Walls
J.I. Daniel, K.N. Shiu, W.G. Corley
Construction Tech. Labs., Skokie, IL
ASCE J. Struc. Engrg., 112 (7), pp 1660-1676 (July 1986) 15 figs, 2 tables, 15 refs

KEY WORDS: Walls, Reinforced concrete, Opening-containing media, Earthquake resistant structures

To determine effects of centrally located openings on earthquake-resistant structural walls, two 1/3 scale structural wall specimens were tested. Reinforcement details around openings were selected to represent current design practice. Similar load histories representing severe earthquakes were applied to both specimens, whose behavior was then compared. Effects of openings on strength and deformation were determined.

ELECTRIC COMPONENTS

CONTROLS
(SWITCHES, CIRCUIT BREAKERS)

86-2027
Controller Design of an Unregulated Alternator via Output Feedback
D.P. Papadopoulos
Democritus Univ. of Thrace, Xanthi, Greece
J. Franklin Inst., 321 (3), pp 127-133 (Mar 1986) 2 figs, 1 table, 14 refs

KEY WORDS: Feedback control, Control systems

Well known constant output feedback techniques are applied to a 2-input, 2-output time invariant linear model of an unregulated turbo-alternator to design a suitable excitation controller in order to improve the dynamic response of the unit, by controlling the eigenvalues of the resulting closed-loop system in a predescribed manner. The results of the simulated cases indicate a significant improvement of the dynamic response of the designed closed-loop system.

DYNAMIC ENVIRONMENT

ACOUSTIC EXCITATION

86-2028
Active Sound Attenuation Using Adaptive Digital Signal Processing Techniques
L.J. Eriksson

Ph.D. Thesis, Univ. of Wisconsin, Madison, WI, 212 pp (1985) DA 8522508

KEY WORDS: Active attenuation, Active noise control, Digital techniques, Signal processing techniques

Active attenuation systems for the reduction of acoustic noise using adaptive digital signal processing techniques are analyzed. Problems associated with acoustic feedback, error path and auxiliary path transfer functions, transducer responses, and model order are discussed in detail. System identification concepts are used to discuss the problem. Observability considerations are used to analyze the potential of several adaptive filter configurations for use in active attenuation systems. Several new approaches are presented to overcome the problems of acoustic feedback as well as correct for error path and auxiliary path transfer functions. Compensation techniques for transducer modeling are described.

86-2029
AE Source Wave Analysis
J. Takatsubo, K. Yoshida
Government Industrial Research Institute, Hiroshima-ken, Japan
Bull. JSME, 29 (250), pp 1261-1268 (Apr 1986) 14 figs, 1 table, 7 refs

KEY WORDS: Acoustic excitation, Sound generation

A computational method to determine the original waveforms at source points where acoustic emission (AE) is generated is presented. Using a fast electrical pulse as a standard input signal the reproducible transfer function of the AE measuring system is obtained from generation of AE to the detection of received signals. By introducing numerical operations to minimize noise and distortion, which are often contained in analyzed waveforms, Fourier synthesis is made applicable to an inverse problem. A few experiments to determine source waves are carried out and results show the validity of the method.

86-2030
Modeling Wind Tunnel Effects on the Radiation Characteristics of Acoustic Sources
W. Eversman, K.J. Baumeister
Univ. of Missouri-Rolla, Rolla, MO
J. Aircraft, 23 (6), pp 455-463 (June 1986) 13 figs, 13 refs

KEY WORDS: Propeller noise, Wind tunnels, Finite element technique, Sound waves, Wave radiation

The important features of the acoustic field of a propeller operating within a wind tunnel are modeled. The wind tunnel is taken to be of circular cross section, with the flowfield assumed to be uniform. A finite element formulation based on a Gutin type of propeller theory is used to represent the acoustic source both in the wind tunnel and in a free field for comparison purposes. The information sought is the accuracy with which propeller acoustic directivity on the wind tunnel wall matches directivity measured on a reflecting plane placed near the propeller in the free field. An important analytical result shows that it is not possible to obtain an accurate directivity in the tunnel environment unless the modal cutoff ratio for the source exceeds unity for at least the lowest-order mode generated. This result is verified numerically. Acoustic fields and their corresponding directivities in the wind tunnel and free field are compared for situations in which the cutoff conditions is satisfied.

86-2031
A Novel Method for Solving the Inverse Scattering Problem for Time-Harmonic Acoustic Waves in the Resonance Region II
D. Colton, P. Monk
Univ. of Delaware, Newark, DE
SIAM J. Appl. Math., 46 (3), pp 506-523 (June 1986) 5 figs, 1 table, 16 refs

KEY WORDS: Sound waves, Wave scattering, Harmonic waves

An extension of a new method for determining the shape of an acoustically soft obstacle from a knowledge of the time-harmonic incident wave and the far field pattern of the scattered wave is presented. The analysis includes the case of the impedance boundary value problem. Numerical examples are given showing the practicality of the method.

86-2032
The Transmission of Ultrasound through a Stratified Lossy Medium having Triple Layers (La transmission ultrasonore par un milieu stratifie a triple epaisseur avec pertes)
J.L. Dion, J.C. Morissette
Universite du Quebec a Trois-Rivieres, Quebec, Canada
Acustica, 60 (2), pp 144-151 (Apr 1986) 13 figs, 17 refs (in French)

KEY WORDS: Sound waves, Wave transmission, Layered materials

Using the electrical line theory the normal incidence acoustical transmission through a triple-layer medium (glass-plastic-glass) is analyzed, including the effect of attenuation in the 0.5 to 4 MHz interval. The experimental results agree with the computed values. The total thickness of the triple layer at maximum transmission frequency is less than one fourth of a wave length in glass. It is also observed that at a given frequency, transmission is nearly 100% for widely varying angles of incidence.

86-2033
Underwater Acoustics for Remote Measurement of Oceanographic Parameters
K. Kloser, T. Kvinge
Christian Michelsens Inst. for Videnskap og Aandsfrihet, Bergen, Norway
Rept. No. CMI-84-371105-1, 18 pp (Feb 1984) PB86-170362/GAR

KEY WORDS: Underwater sound, Sound measurement

Acoustic projects and acoustic signal properties in ocean waters are presented. Doppler sonar, correlation sonar and tomography methods for current measurements are discussed.

86-2034
Acoustically Compact Transient Sources for Underwater Measurement and Calibration
J. Nedwell
Southampton Univ., Southampton, England
Rept. No. ISVR-TR-129, 44 pp (Apr 1985) PB86-177938/GAR

KEY WORDS: Underwater sound, Sound measurement

The document reports the results of an investigation into several types of sound sources with the aim of developing a repeatable, compact, transient source. It is hoped that such a source will be useful for other investigations, and therefore full constructional and electronic information is given where appropriate.

86-2035
Status and Capabilities of Sonic Boom Simulators
K.P. Shepherd, C.A. Powell
NASA Langley Res. Ctr., Hampton, VA
Rept. No. NASA-TM-87664, 8 pp (Jan 1986) N86-20088/8/GAR

KEY WORDS: Sonic boom, Simulation

The current status and capabilities of sonic boom simulators which might be used in future studies of the effects of sonic boom on people, animals, or structures is summarized. The list of candidate simulators is based on a literature search which was confined to the United States and Canada. Some of the simulators are fully operational; others could be made operational with a modest investment, and still others would require a major investment.

86-2036
Reflection from a One-Dimensional, Totally Refracting Random Multilayer
W.E. Kohler
Virginia Polytechnic Institute and State Univ., Blacksburg, VA
SIAM J. Appl. Math., 46 (3), pp 464-482 (June 1986) 5 figs, 1 table, 18 refs

KEY WORDS: Sound waves, Wave scattering, Underwater sound, Asymptotic approximations

The interplay of random scattering and total internal reflection is studied in the context of an idealized one-dimensional problem arising in acoustic scattering from ocean sediments. Appropriate scalings are introduced; the asymptotic analysis of the Fokker-Planck equation for the reflection coefficient is performed and subsequently compared with the results of numerical simulations.

SHOCK EXCITATION

86-2037
Attenuation of Shocks by Viscoelastic Support
M. Elzanowski, M. Epstein
Univ. of Calgary, Calgary, Alberta, Canada
ASCE J. Engrg., Mech., 112 (6), pp 587-592 (June 1986) 1 fig, 3 refs

KEY WORDS: Shock waves attenuation, Elastic media, Viscous friction, Elastic supports, Soil-foundation interaction

The method of singular surfaces was used in a recent paper to develop a numerical procedure for calculating the growth and decay of the amplitude of shock waves propagating into a one-dimensional nonlinearly elastic body. This approach is extended to estimate the influence of such external effects as elastic support and viscous friction on the propagation of shocks. It is concluded that even in the case of a homogeneous linearly elastic material these external effects account for some attenuation of the amplitude of the shock and/or the secondary waves. Further analysis of a nonlinear elastic material readily shows that an increase in the viscosity produces, among other things, a slower growth of the shock amplitude and that for some critical value it will even start with a decay. Numerical examples illustrate the applicability of the technique in the case of a homogeneous nonlinear elastic body subjected to external viscous friction.

86-2038
A Simple Rigid Bo', Algorithm for Structural Dynamics Programs
D.J. Benson, J.O. Hallquist
Univ. of California, Livermore, CA
Intl. J. Numer. Methods Engrg., 22 (3), pp 723-749 (Mar 1986) 8 figs, 27 refs

KEY WORDS: Impact response, Lagrange equations, Computer programs

The equations of motion for finite elements, rigid bodies and modal representations of deformable bodies were derived from the weak form of Lagrange's equation. By deriving the three sets of equations from a single equation, the common structure of the equations is demonstrated. The common structure simplifies the implementation of all three representations of a body into a single program. It is shown how to transform the finite element equations of motion into the equations for rigid bodies and modal representations, which allows expansion of the capabilities of a nonlinear structural dynamics program with relatively minor changes. The implementation of rigid bodies in DYNA3D is described in detail.

86-2039
Structural Response to Uncertain Seismic Excitations
M. Grigoriu
Cornell Univ., Ithaca, NY
ASCE J. Struc. Engrg., 112 (6), pp 1355-1365 (June 1986) 4 figs, 21 refs

KEY WORDS: Seismic excitation, Statistical analysis, Probability theory

Probabilistic and statistical descriptors are developed for the response of nonhysteretic oscillators subject to modulated Gaussian ground acceleration with uncertain scale. The probabilistic descriptors correspond to postulated values of the scale of the ground acceleration process while the statistical descriptors account for the uncertainty in this parameter. The analysis focuses on the mean (failure) rate at which the response exceeds the structural strength. It shows that unconservative designs can result when the uncertainty in the scale of the ground acceleration is disregarded.

86-2040
Bl' Measurements and Equivalency for Spherical .arges at Small Scaled Distances
E.D. Esparza
Southwest Research Institute, San Antonio, TX
Intl. J. Impact Engrg., 4 (1), pp 23-40 (1986) 10 figs, 4 tables, 32 refs

KEY WORDS: Explosion effects, Blast effects, Force measurement, Experimental data

An experimental program was conducted to obtain direct measurements of side-on overpressures at small scaled distances from spherical charges of six different high explosives The pressure-time recordings made on the experiments were processed to obtain peak over pressures, shock wave arrival times, side-on impulses, and positive durations of the incident or side-on pressure pulse. In addition to comparisons of the data with TNT reference curves for these four parameters, TNT equivalency for each explosive was obtained base on side-on peak overpressures and impulses.

86-2041
Structural Element Tests in Support of the Keyworker Blast Shelter Program
T.R. Slawson, H.M. Taylor, Jr., F.D. Dallriva, S.A. Kiger
Army Engr. Waterways Experiment Station, Vicksburg, MS
Rept. No. WES/TR/SL-85-8, 330 pp (Oct 1985) AD-A165 136/3/GAR

KEY WORDS: Blast resistant structures, Nuclear explosion effects, Underground structures, Soil-structure interaction

Six static tests and twelve dynamic tests were conducted on approximately 1/4-scale models of blast shelters. Specific objectives of these tests were to evaluate the preliminary structural design, to investigate structural response in various backfills, to investigate and recommend minimum concrete strength requirements, to evaluate structural response calculations, and to develop a data base on repeated hits so that structural response computational procedures can be developed to include the effects of repeated hits. Test results indicate that the keyworker blast shelter design will resist a peak overpressure of 150 psi from a 1-MT nuclear weapon.

86-2042
Some Aspects of Shock-Wave Research
I.I. Glass
Univ. of Toronto, Downsview, Ontario, Canada
Rept. No. UTIAS-REVIEW-48, AIAA-86-0306, 114 pp (Jan 1986) (24th AIAA Aerospace Sciences Mtg., Reno, NV, Jan 7, 1986) N86-19553/4/GAR

KEY WORDS: Shock waves

Examples are given of shock-wave phenomena on earth and in space. A specific shock-wave research problem; namely pseudostationary oblique shock-wave reflections in perfect and imperfect gases, is presented. Consideration is given to what has been achieved to date by using two- and three-shock theory to predict what type of reflection results when a planar shock wave in a shock tube collides with a sharp compressive wedge of angle. Experimental data are presented.

VIBRATION EXCITATION

86-2043
Structural Response to Low Frequency Environments (Reponse des Structures a un Environement Basse Frequence)
A. Girard
Centre National d'Etudes Spatiales, Toulouse, France
Rept. No. CNES-NT-116, 56 pp (June 1985) N86-19676/3/GAR (in French)

KEY WORDS: Harmonic response, Transient response, Random response

The computation of the response of a structure to a low frequency sine, transient, or random environment is discussed. The structure is characterized by the eigenmodes which are assimilated to single degree-of-freedom systems. The structural response is computed by superposition of the model response of single degree-of-freedom systems. The analysis of the sine response introduces the concept of transfer functions between excitation and responses. The same transfer functions are used to compute random and transient response. The shock spectrum associated with the mode to single degree-cf-freedom system equivalence gives quick information about structural response.

86-2044
Parametric Excitation with an Asymmetric Characteristic in a Self-Exciting System — Behaviors of Region of Resonance of Order 1/2
S. Yano, T. Kotera, T. Hiramatsu
Fukui Univ., Fukui, Japan
Bull. JSME, 29 (249), pp 902-907 (Mar 1986) 7 figs, 5 refs

KEY WORDS: Self-excited vibrations, Van der Pol method, Parametric excitation

Behavior of a self-exciting system of van der Pol type subjected to a parametric excitation are investigated. The parametric excitation is expressed by the product of a nonlinear function of deflection with an asymmetric characteristic and a periodic function of time. A resonance of order 1/2 and the solution of the neighborhood of the resonance are obtained by the averaging method and the effects of nonlinearity are investigated. Since a squared nonlinearity merely makes the resonance have a constant component, it is found that a cubic nonlinearity plays a more important part in the occurence of the resonance.

86-2045
Generation of Subharmonic and Superharmonic Oscillations in the Systems with the Non-Linear Electromagnetic Exiter
M.V. Khvingia, I.A. Pitimashvili
Georgian Academy of Sciences, Tbilisi, SSSR
Strojnicky Casopis, 36 (4/5), pp 506-518 (1985) 5 figs, 1 table, 6 refs (in Russian)

KEY WORDS: Subharmonic oscillations, Superharmonic vibrations, Electromagnetic exciters

A method of definition of periodic solution in systems with harmonic outer influence based on application of the methods of harmonic balance and accidental search is presented. Search of parameters of the system is carried out in which the given law of motion is realized. The diagram of solution of the problem is shown in case of piece-interrupted source, based on application of the method of small parameter and alignment. Criterion of generation of stability of subharmonic oscillations is defined depending on initial conditions and parameters of the system.

86-2046
Dynamic and Design Sensitivity Analysis of Rigid and Elastic Mechanical Systems with Intermittent Motion
E.J. Haug
Univ. of Iowa, Iowa City, IA
Rept. No. ARO-18576.15-MA, 9 pp (Dec 12, 1985) AD-A163 982/2/GAR

KEY WORDS: Elastic systems, Intermittent motion

Methods developed for analysis of intermittent motion, flexible system dynamics, design sensitivity, and differential-algebraic equations are summarized. New techniques for dynamics of multibody flexible systems include mixed vibration and static correction modes. Dynamic design sensitivity analysis methods are developed, using singular value decomposition. Numerical integration methods for mixed differential-algebraic equations developed are based on singular value decomposition and hybrid generalized coordinate partitioning-constraint stabilization.

86-2047
Infinite Elements for Two-Dimensional Fluid-Structure Interaction Problems
E.A. Schroeder
David W. Taylor Naval Ship Res. and Development Ctr., Bethesda, MD
Rept. No. DTNSRDC-86/001, 22 pp (Feb 1986)
AD-A164 749/4/GAR

KEY WORDS: Fluid-structure interaction, Infinite element technique

This report describes an effective method for using two-dimensional infinite elements to compute acoustic or magnetic fields in the unbounded fluid region surrounding a submerged vehicle. In this method, finite elements represent the bounded region containing the vehicle and may also be used to represent a layer of fluid surrounding the vehicle. Infinite elements are used to represent the unbounded exterior region. Since infinite elements are not bounded, their shape functions are chosen to contain decay factors to produce convergent integrals. If, from physical or other considerations, the order of decay of the solution as the radius increases is known, infinite elements should be chosen with the same order of decay. The results obtained in this study were found to be within 2% when the decay factor of infinite elements matched that of the solution.

86-2048
The Stability of the Periodic Motions of the Shock-Vibration Systems
L. Brindeu
Polytechnic Institute "Traian Vuia", Timisoara, Romania
Rev. Roumaine Sci. Tech., Mecanique Appl., 30 (5), pp 497-501 (Sept-Oct 1985) 11 refs

KEY WORDS: Periodic response, Multidegree of freedom systems

The direct method used in determining the stability conditions of the periodic motions for shock vibration systems, a method stated and applied for systems with one or two degrees-of-freedom, may also be extended to the case of systems with several degrees-of-freedom, whose motion is analyzed by Lagrange equations. The equations in variations determined from the differential equations are considered, which by applying the limit conditions obtained for the moments of collisions, lead by integration to the linearized equations in perturbations necessary to write the stability conditions.

86-2049
Structural Responses in a Random Environment (Reponse des structures en environmente aleatoire)
A. Girard
Centre National d'Etudes Spatiales, Toulouse, France
Rept. No. CNES-NT-115, 73 pp (Mar 1985)
N86-17800/1/GAR (in French)

KEY WORDS: Random vibration, Frequency domain method, Time domain method, Modal analysis

Random vibrations are statistically described and analyzed in the time domain and in the frequency domain. The principles of the determination of the structural response are given. The modal solution is presented, and applied to shaker and reverberating field excitation. To overcome the high frequency limitations of the method a statistical energy analysis is proposed. The use of simplifying assumptions facilitates calculation of the response of relatively complex structures, provided that the appropriate parameters are properly determined.

86-2050
Stochastic Averaging: An Approximate Method of Solving Random Vibration Problems
J.B. Roberts, P.D. Spanos
Univ. of Sussex, Sussex, UK
Intl. J. Nonlin. Mech., 21 (2), pp 111-134 (1986) 129 refs

KEY WORDS: Random vibration, Stochastic processes, Parametric excitation

Results obtained by applying the method of stochastic averaging to random vibration problems are discussed. This method is applicable to a variety of problems involving the response of lightly damped systems to broad-band random excitations. Solutions pertaining to both linear and nonlinear vibrations are reviewed, and it is shown that the technique enables, in the case of

parametric excitation, stability criteria to be established. Some results which have been obtained relating to the first-passage reliability problems are also surveyed. Various applications of the theory to engineering problems are outlined.

86-2051

Dynamic Response of Random Parametered Structures with Random Excitation

L.J. Branstetter, T.L. Paez

Sandia National Labs., Albuquerque, NM

Rept. No. SAND-85-1175, 161 pp (Feb 1986) DE86007246/GAR

KEY WORDS: Multidegree of freedom systems, Random parameters, Random excitation, Taylor series, Computer programs

A Taylor series expansion technique is used for numerical evaluation of the statistical response moments of a linear multidegree of freedom system having random stiffness characteristics, when excited by either stationary or nonstationary random load components. Equations are developed for the cases of white noise loading and single step memory loading, and a method is presented to extend the solution to multistep memory loading. The equations are greatly simplified by the assumption that all random quantities are normally distributed. A computer program is developed to calculate the response moments of example systems.

MECHANICAL PROPERTIES

DAMPING

86-2052

Cavitation Effects on Squeeze-Film Damper Performance

N.S. Feng, E.J. Hahn

Univ. of New South Wales, Kensington, Australia

ASLE, Trans., 29 (3), pp 353-360 (July 1986) 11 figs, 15 refs

KEY WORDS: Squeeze film dampers, Cavitation

Experimental observations on unpressurized dynamically loaded hydrodynamic bearings and squeeze-film dampers indicate that cavitation bubbles, once formed, do not completely redissolve upon the reappearance of positive pressures. Instead, one is left with a spongy compressible fluid. Assuming this to be a homogeneous gas-liquid mixture, with density and viscosity dependent on pressure, the load capacity of squeeze-film dampers is compared with that obtained using hitherto adopted cavitation models which assume an incompressible lubricant with the fluid-film pressures being set to the saturated vapor pressure (SVP) of the lubricant whenever the pressure falls below the SVP. To save computation effort, a short bearing approximation is derived for the compressible Reynolds equation.

86-2053

Effects of Fluid Inertia and Turbulence on the Force Coefficients for Squeeze Film Dampers

L. San Andres, J.M. Vance

Texas A&M Univ., College Station, TX

J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 332-339 (Apr 1986) 9 figs, 2 tables, 13 refs

KEY WORDS: Squeeze film dampers, Inertial forces, Turbulence

The effects of fluid inertia and turbulence on the force coefficients of squeeze film dampers are investigated analytically. Both the convective and the temporal terms are included in the analysis of inertia effects. The analysis of turbulence is based on friction coefficients currently found in the literature for Poiseuille flow. The effect of fluid inertia on the magnitude of the radial direct inertia coefficient is found to be completely reversed at large eccentricity ratios. The reversal is due entirely to the inclusion of the convective inertia terms in the analysis. Turbulence is found to produce a large effect on the direct damping coefficient at high eccentricity ratios. For the long or sealed squeeze film damper at high eccentricity ratios, the damping prediction with turbulence included is an order of magnitude higher than the laminar solution.

86-2054

Modelling of Radiation Damping in Fluids by Finite Elements

S.K. Sharan

Laurentian Univ., Sudbury, Canada

Intl. J. Numer. Methods Engrg., 23 (5), pp 945-957 (May 1986) 12 figs, 4 tables, 15 refs

KEY WORDS: Submerged structures, Fluid-structure interaction, Damping

A very efficient technique is presented to model the effects of radiation damping in the computation of added mass for the dynamic analysis of submerged structures. The structure is assumed to be surrounded by an infinite, incompressible and inviscid fluid field and the effect of the free surface is neglected. The technique is implemented in the finite element analysis of two-dimensional problems, assuming pressure to be the nodal unknown. The implementation procedure is quite simple and the symmetrical and banded form of the matrix of coefficients remains unchanged. With the use of the proposed radiation condition, the fluid field may be truncated at a relatively very short distance from the solid-fluid interface. This results in great computational advantages. A guideline is suggested for the selection of the geometry and the location of the truncation boundary to enhance the computational efficiency. The effectiveness and efficiency of the technique is demonstrated by analyzing several cases for different geometries of the solid-fluid interface and the truncation boundary.

86-2055

The Effect of a Viscously Damped Dynamic Absorber on a Linear Multi-Degree-of-Freedom System

A.F. Vakakis, S.A. Paipetis
Univ. of Patras, Patras, Greece

J. Sound Vib., 105 (1), pp 49-60 (Feb 22, 1986) 12 figs, 1 table, 18 refs

KEY WORDS: Dynamic vibration absorption (equipment), Viscous damping, Multidegree of freedom systems, Vibration isolators

The effect of a viscously damped dynamic absorber on the dynamic behavior of a linear vibration system with many degrees of freedom is investigated. The dynamic absorber is connected to the roof of the primary system. In the sequence, optimal values for the parameters describing the behavior of the dynamic absorber are determined, in order that the transmissibility of the composite system be minimized over the whole frequency range. As an application, respective types of anti-vibration mountings are proposed.

86-2056

An Asymptotic Method for Second-Order Critically Damped Nonlinear Equations

M.A. Sattar
Simon Fraser Univ., Burnaby, BC, Canada

J. Franklin Inst., 321 (2), pp 109-113 (Feb 1986) 9 refs

KEY WORDS: Critical damping, Perturbation theory, Asymptotic approximation

A second-order nonlinear differential system modeling nonoscillatory processes and characterized by critical damping is considered. A new perturbation technique, based on the work of Krylov, Bogoliubov, and Mitropolskii, is developed to find the solution of the system. The method is illustrated by an example.

86-2057

Experimental Study of Active Vibration Control

W.L.Hallauer, Jr., A.P. Nayak
Virginia Polytechnic Inst. and State Univ., Blacksburg, VA

Rept. No. AFOSR-TR-85-1234, 66 pp (Feb 13, 1985) AD-164 162/0/GAR

KEY WORDS: Vibration damping, Active vibration control, Pendulums, Experimental data

Three different types of active vibration damping were implemented on a pendulous, two-dimensional laboratory structure having high modal density at low frequencies (0-10 Hz) and very light inherent damping. The most effective control system included an array processor (the controller) and five pairs of dual (colocated) velocity sensors and force actuators. This control system was used for implementation of two different active damping techniques, uncoupled and coupled rate feedback. Very good agreement was achieved between experimentally measured and theoretically calculated structure-control system dynamic response. The most significant result is that the technique of coupled rate feedback with dual sensors and actuators effectively damped many more modes than the number of control actuators while producing no spillover instability.

86-2058

Studies on Ball Screw Type Damper with Flyball Governor — Case in which Ball Nut is Attached to Main Mass

K. Ohmata, H. Shimoda
Meiji Univ., Kanagawa, Japan

Bull. JSME, 29 (249) pp 908-915 (Mar 1986) 11 figs, 2 tables, 4 refs

KEY WORDS: Dampers, Ball screw type dampers

The forced nonlinear vibration and its stability of a single-degree-of-freedom system with a ball screw type damper which is composed of a ball screw, a flywheel and a flyball governor are discussed theoretically. The results are compared with a linear solution and the experimental results. The effect of vibration isolation of the damper is also discussed. Numerical examples

are given for several ratios of the natural frequencies in the primary system to the governor.

86-2059

On Hysteretic Damping of Non-Sinusoidal Motions

R.E.D. Bishop, W.G. Price

Brunel Univ., Middlesex, England

Strojnicky Casopis, 36 (4/5), pp 413-426 (1985) 5 figs, 4 refs

KEY WORDS: Hysteretic damping

Instead of defining hysteretic damping in terms of sinusoidal motion, a description in terms of a simple convolution integral is devised. This shows that the concept of hysteretic damping is logically inconsistent if used for any but sinusoidal motions. It can, however, be modified so as to make it mathematically acceptable without destroying its practical usefulness. By contrast, viscous damping raises no such problems.

86-2060

The Influence of a Variable Normal Load on the Forced Vibration of a Frictionally Damped Structure

C.-H. Menq, J.H. Griffin, J. Bielak

Carnegie-Mellon Univ., Pittsburg, PA

J. Engrg. Gas Turbines Power, Trans. ASME, 108 (2), pp 300-305 (apr 1986) 11 figs, 15 refs

KEY WORDS: Coulomb friction, Blades

An approximate procedure is developed for calculating the steady-state response of frictionally damped structures for which the normal load across the friction interface consists of a constant force and a force that varies linearly with the vibratory displacement. Such situations occur quite frequently in practice, as, for example, in the case of shrouded fan blades or in certain types of turbine-blade friction dampers. Depending on the magnitudes of the constant and the variable normal loads, the friction element will either stick, slip, or lift off at various intervals during a cycle of oscillation. The various possibilities are considered in the present study. Results from the approximate method are compared with long-time solutions obtained from a conventional transient analysis of the problem in order to assess the accuracy of the proposed procedure.

86-2061

Polymers in Vibration Damping and Soundproofing. 1970-February 1986 (Citations from the U.S. Patent Database)

National Technical Information Service, Springfield, VA

Rept. for 1970-Feb 86, 88 pp (Mar 1986) PB86-858966/GAR

KEY WORDS: Vibration damping, Polymers, Bibliographies

This bibliography contains selected patents concerning synthetic resin compositions which demonstrate vibration damping and soundproofing properties. Thermoplastic and thermosetting plastics and elastomers are discussed relative to filters, modifiers, reinforcing agents, molding processes, laminating structures, and coating compositions. Aeronautics, sporting goods, manufacturing, and electrical engineering are among the applications discussed.

FATIGUE

86-2062

Determination of the Dynamic Characteristics of Rubber-Metal-Elements (Ermittlung dynamischer Kennwerte an Gummi-Metall-Elementen)

A. Wick

Automobiltech. Z., 88 (4), pp 247-254 (Apr 1986) 24 figs, 3 refs (in German)

KEY WORDS: Fatigue tests, Fatigue life, Automobiles, Elastomers

During the constant amplitude fatigue test of ready for use rubber-metal-elements for the car, a defined test frequency and a defined test force is applied until failure. Test frequency and test force depend on the dynamic-mechanical conditions prevailing in the car. Each cycle gives information about test parts' change of characteristical properties during loading. This document presents the dynamic characteristics, describes test conditions, explains their taking up and their evaluation and discusses their application.

86-2063

Fatigue-Life Evaluation Under the Random Behavior of the Loading Process

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Slovak Academy of Sciences, Bratislava, Czechoslovakia

Strojnicky Casopis, 36 (4/5), pp 519-531 (1985) 4 figs, 9 refs (in Slovak)

KEY WORDS: Fatigue life, Random excitation

The problem of estimating fatigue life under the random behavior of the loading process is examined. The calculating procedure is presented, based on the energetic criterion of fatigue strength that respects the characteristics of the material representing its behavior under repeated load, as well as the characteristics of the loading process describing its stochastic character. The calculation procedure consists in transforming the random process into a fictive equivalent harmonic process. Various modifications of relations for calculating useful life are presented in dependence on the length of the stage of fatigue hardening or softening.

86-2064
Mechanics of Fatigue Damage and Degradation in Random Short-Fiber Composites, Part II —Analysis of Anisotropic Property Degradation
S.S. Wang, E.S.-M. Chim, H. Suemasu
J. Appl. Mech. Trans. ASME, 53 (2), pp 347-353 (June 1986) 11 figs, 1 table, 18 refs

KEY WORDS: Fatigue life, Fiber composites

Based on microcrack density and cumulative distribution functions, cyclic fatigue degradation and associated damage-induced anisotropy of elastic properties of random short-fiber composites are studied. Constitutive equations of the fatigue-damaged composite are derived on the basis of the well-known self-consistent mechanics scheme in conjunction with a three-dimensional elliptic crack theory and the probabilistic functions of microcrack density and cumulative distribution. The anisotropic stiffness degradation is determined as a function of microcrack evolution and accumulation in the damaged composite. Theoretical predictions and experimental data of effective modulus decay during fatigue are in excellent agreement.

ELASTICITY AND PLASTICITY

86-2065
The Asymptotic Solution to the Dynamic Crack-Tip Field in a Strain-Damage Material
Y.C. Gao
Harbin Shipbuilding Engineering Institute, Harbin, China
Intl. J. Engrg. Sci., 24 (6), pp 1045-1055 (1986) 14 refs

KEY WORDS: Elastic plastic properties, Fracture properties, Asymptotic approximation

The dynamic elastic-plastic field near a crack tip running in a strain-damage material is investigated.

86-2066
Wave Fronts in Nonhomogeneous Elastic Layer
S.J. Matysiak
Univ. of Warsaw, Warsaw, Poland
Rev. Roumaine Sci. Tech., Mecanique Appl., 30 (5), pp 523-526 (Sept-Oct 1985) 1 fig, 7 refs

KEY WORDS: Elastic media, Wave propagation

This paper deals with the propagation of wave fronts (shock or acceleration) in nonhomogeneous isotropic elastic layer. Neglecting boundary effects (reflections and refractions), the problem is exactly solved for the special case of nonhomogeneity.

EXPERIMENTATION

MEASUREMENT AND ANALYSIS

86-2067
Numerical Study of Mode Selection in Response Spectrum Analysis
D.S. Ng
Lawrence Livermore National Lab., CA
Rept. No. UCRL-53699, 154 pp (Jan 1986) DE86006841/GAR

KEY WORDS: Spectrum analysis, Response spectra

This dissertation presents a numerical study of structural responses with three mode selection methods used in response spectrum analysis; namely, the modal effective mass, elastic force, and strain energy methods. These methods can be applied to the analysis for the whole structure or for defined substructures. A simple frame-type structure is generated as a baseline frame. Groups of oscillators representing substructures are added onto the frame to study substructure behavior. A base case is established for each frame by including the specific number of modes used. The tests are conducted by incrementing the number of modes in the response spectrum analyses starting with one mode. The structural response of each modal increment is compared with the base case to identify the efficiency of mode selection method. All three methods are then applied to the MFTF-B Axicell Vacuum Vessel. The responses in critical components of the vessel, such as hangers and foundations, will be analyzed to confirm the accuracy of the selected method.

86-2068
Natural Modes Formulation and Modal Identities for Structures with Linear Viscous Damping
F.R. Vigneron
Communications Research Center, Ottawa, Ontario, Canada
Rept. No. CRC-1382, 29 pp (Jan 1985) PB86-171972/GAR

KEY WORDS: Modal models, Viscous damping, Experimental modal analysis

A modal model is developed for an elastic structure with linear viscous damping. The transfer functions and normalizations that are of use in experimental modal parameter estimation are given special attention. Procedures for extraction of damped natural modes from experiment-derived residues are outlined. Mass-properties-related modal identities are obtained for the damped modes.

86-2069
Component Mode Synthesis Methods for Test-Based, Rigidly Connected Flexible Components
M. Baker
Structural Dynamics Research Corporation, San Diego, CA
J. Spacecraft Rockets, 23 (3), pp 316-322 (May-June 1986) 2 figs, 7 tables, 33 refs

KEY WORDS: Component mode synthesis, Testing techniques

With the objective of enhancing test-based modal synthesis and planning the development of test methods, simple examples were run using finite element-based components to compare accuracy and define test requirements for the following approaches to component mode synthesis: restrained modal component, residual flexibility, mass-loaded connect degrees-of-freedom, and rotational connect degrees-of-freedom.

86-2070
Multiphase-Step-Sine Method for Experimental Modal Analysis
R. Williams, H. Vold
Structural Dynamics Research Corp , Hertfordshire, England
Intl. J. Analyt. Exptl. Modal Analysis, 1 (2), pp 25-34 (Apr 1986) 9 figs, 12 refs

KEY WORDS: Experimental modal analysis, Multiphase-step-sine method

An approach to large-scale modal tests that combine the multishaker methodologies of sinusoidal and random excitation is presented. The first phase of this method consists of verifying a single exciter location with either stepped sine or random excitation. Then, using closed-loop force control, a series of multishaker stepped-sine surveys are performed, alternating polarity patterns between the surveys (multiphase step sine). The responses in each such survey may be considered frequency-response functions with respect to a generalized force, since force amplitudes and polarities are controlled to be constant within each survey. Mode-indicator functions may hence be calculated and modal parameters can be extracted from these individual surveys, just as for standard single-point excitation methods.

86-2071
A System for the Measurement of Sound Intensity by Means of a Fourier Analyzer (System zur Schallintensitatsmessung mittels Fourieranalysator)
U. Jansen
Industrie Anz., 29 (11), pp 54-55 (Mar 1986) 4 figs (in German)

KEY WORDS: Acoustic intensity method, Fourier transformation

Acoustic intensity measurement technology provides better results than acoustic pressure measurement. However, the price of the instrumentation and complicated handling has precluded a wider application of this technology. A simple and cheap system is described which is based on an indirect method of acoustic intensity measurement. While the direct method requires special instrumentation, with the indirect method the available instrumentation can often be used. The noise pressure, measured during two micropores, is transformed into angular spectrum by means of Fourier transform and the acoustic intensity is calculated from its imaginary component.

86-2072
Generalized Coordinates Affected by External Term in Structural Dynamic Analysis — Basic Concept and Calculation Scheme of Presented Generalized Coordinates
S. Hatake
Hitachi, Ltd., Ibaraki, Japan
Bull. JSME, 29 (250), pp 1225-1232 (Apr 1986) 7 figs, 2 tables, 9 refs

KEY WORDS: Modal analysis, Modal superposition method, Component mode synthesis

The effectiveness of a correction method using static response as an approximate solution for response value of higher modes has been shown. A method is presented in the form of generalized coordinates, for the purpose of extension to component mode synthesis or a free-free (incompletely supported) system. The basic concept of the generalized coordinates and calculation algorithms are shown. External term error estimation is then considered, when generalized coordinates are employed. Two models are used to verify that the error norm of external load vectors is close to zero.

86-2073
On the Dynamic Analysis of the Complex Structures by Vibration Testing of the Substructures
G. Silas, T. Cioara
The Polytechnic Institute "Tr. Vuia", Timisoara, Romania
Rev. Roumaine Sci. Tech., Mecanique Appl., 30 (5), pp 467-476 (Sept-Oct 1985) 2 figs, 7 refs

KEY WORDS: Vibration tests, Substructuring methods

Problems arising in the experimental dynamic analysis of a complex structure are presented. The structure is analyzed by vibration testing of the isolated substructures in free-free mode. A method for separation of rigid body motions from the deformation motions in the substructure measured response is provided as well as the matrix of inertia moments.

86-2074
Vibration Analysis by Component Mode Synthesis Method — Comparison of Three Methods (1)
M. Ookuma, A. Nagamatsu
Tokyo Institute of Technology, Tokyo, Japan
Bull. JSME, 29 (249), pp 882-887 (Mar 1986) 7 figs, 4 tables, 9 refs

KEY WORDS: Component mode synthesis, Residual compliance matrix

Three kinds of component mode synthesis methods are compared. The first method is CMS; the second a method with the residual compliance matrix; the third, without the residual compliance matrix. Comparing accuracy and calculational speeds, the characteristics of these methods are studied. As an example of the application to actual mechanical structures, a crank-shaft is analyzed by CMS and the method with the residual compliance matrix.

86-2075
Evaluation of an Experimental Modal Analysis Technique
M. Rades
Polytechnic Institute of Bucharest, Romania
Rev. Roumaine Sci. Tech. Mecanique Appl., 30 (6), pp 623-633 (Nov-Dec 1985) 2 figs, 3 tables, 8 refs

KEY WORDS: Experimental modal analysis, Frequency domain method

The purpose of this paper is to attempt to evaluate the ability of a frequency domain modal vibration testing technique to accurately estimate the parameters of simple structural models for different degrees of damping, and spacing of natural frequencies. Numerically simulated frequency response function data for a two-degree-of-freedom model is used to illustrate and test the procedure.

86-2076
Investigation of Multiple Input Frequency Response Function Estimation Techniques for Experimental Modal Analysis
R.W. Rost
Ph.D. Thesis, Univ. of Cincinnati, 237 pp (1985) DA 8526568

KEY WORDS: Frequency response function, Experimental modal analysis

The accurate measurement of the frequency response function is vital to the estimation of the modal parameters (damped natural frequency, damping, and mode shape) of a system. The use of single input/output theory to formulate the equations for the frequency response function can be replaced by an equivalent theory involving multiple inputs. The results of this approach provide frequency response functions comparable to the single input/output case but with an increase in the consistency of modal frequency and damping values estimated from different frequency response functions. When the advantages of the multiple input estimates of frequency response functions are weighed versus equivalent single input estimates, time considerations are secondary. As opposed to the forced normal mode testing, the technique presented requires the simultaneous application of multiple, uncorrelated random inputs. In this way, frequency response functions are estimated over a frequency range. The parameters extracted from these frequency response functions can be used in system evaluation algorithms. The number of inputs and the input locations depend on the structure being tested. Since the inputs must be uncorrelated, systematic methods designed to evaluate the inputs have been investigated. Also, methods aimed at identifying, reducing, or eliminating random, bias, nonlinear and numerical (computer dynamic range) errors have been investigated.

86-2077

Evaluation of the Coefficient of Nonlinear Resonance for SC-Cut Quartz Resonators

H.F. Tiersten, D.S. Stevens
Rensselaer Polytechnic Inst., Troy, NY
Rept. No. ARO-18977.10-EL, 10 pp (1985) (Proc. of the Annual Symposium on Frequency Control (39th) pp 325-332, 1985) AD-A164 027/5/GAR

KEY WORDS: Quartz crystals, Resonators

In the recent treatment of nonlinear resonance in contoured quartz resonators the influence of the quadratic nonlinearities was included in addition to the cubic nonlinearity. In that work the solutions resulting from the quadratic nonlinearities were taken in the form of infinite series, from each of which one dominant term was selected and the others were assumed to be negligible. However, since some of the other terms that were ignored are not actually negligible, the procedure is deemed to be not quite adequate. Consequently, in this work forms of solutions resulting from the quadratic nonlinearities are found, each of which consists of a sum of only two terms. Since these new forms contain only a relatively small number of terms, the entire effect of the quadratic nonlinearities may readily be included in the nonlinear resonance analysis. Hence, the solution for nonlinear resonance in contoured SC-cut quartz resonators containing the complete influence of the quadratic nonlinearities is obtained.

86-2078

Fiber Optic Laser Vibration Sensor

J.P. Waters, F.M. Mottier
United Technologies Res. Ctr.
ISA, Trans, 25 (1), pp 63-70 (1986) 14 figs, 7 refs

KEY WORDS: Vibration detectors, Lasers

With the advent of solid-state lasers and fiber optic technology, it is now possible to remotely sense localized vibrations with a compact portable instrumentation package. The package, known as the fiber optic laser vibration sensor (FOLVS), is the result of extensive research and development. The laser vibration sensor, as presently configured, is composed of an electro-optic processing unit with an attached fiber optic wand. The wand has been designed so that it can be used in a variety of applications and can be easily positioned where noncontact vibration measurements are required. The data provided by the FOLVS are an absolute measure of the surface movement over an extremely wide dynamic range of frequencies. These data are also suitable for subsequent processing by microcomputers to extract vital diagnostic information.

86-2079

Rotation Effects on Measurements of Lateral Motion

J.H. Rainer
National Research Council Canada, Ottawa, Ontario, Canada
Earthquake Engrg. Struc. Dynam., 14 (3), pp 369-377 (May-June 1986) 5 figs, 1 table, 12 refs

KEY WORDS: Amplitude measurement, Mode shapes, Error analysis

Inertial transducers that measure horizontal movement are affected by rotation of the measurement location. The effect of rotation is expressed quantitatively as a fraction of the translational signal amplitude and is shown to depend inversely on the effective radius of rotation of the measurement location and the square of the frequency component of the signal. Correction procedures are presented for various cases that arise in the determination of modal amplitudes and mode shapes for tower structures, suspension bridges and frame building structures.

86-2080

Modal Analysis as a Means of Explaining the Oscillatory Behavior of Transformers

P. Glaninger
Brown Boveri Rev., 73 (1), pp 41-49 (Jan 1986) 12 figs, 6 refs

KEY WORDS: Modal analysis, Transformers

Modal analysis has proved to be an outstanding aid in the calculation and measurement of natural oscillations of transformers. With modal parameters it is possible to determine by direct means how resonance and impulse voltages affect any point in a winding. It is explained, with reference to the switching of an open-circuited 850/1100 MVA transformer, how a modal analysis is carried out and how it differs from application of the traveling wave theory. The article also reports on the possibility of selectively influencing the oscillatory characteristics for reliable dimensioning of the insulation. The modal parameters are used to derive a circuit diagram with which a transformer's effect on the power system can be accounted for and the voltages transmitted calculated.

86-2081
Instruments Used and Points to be Aware of when Measuring Low Frequency Sound
H. Fukuhara
Rion Co., Ltd., Tokyo, Japan
J. Low Freq. Noise Vib., 4 (3), pp 120-132 (1985) 16 figs, 1 table, 14 refs

KEY WORDS: Noise measurement, Measuring instruments

Though solutions have been sought concerning noise pollution and vibration, low frequency noise pollution still exists in the environment and this phenomenon is now receiving special attention. The points that require attention concerning low frequency measuring instruments and measurement times for the frequency band of 1 Hz to 100 Hz are determined.

DYNAMIC TESTS

86-2082
Verifying Strain Gage Installations for Dynamic Tests
R.T. Reese, R.A. May
Sandia National Labs., Albuquerque, NM
Rept. No. SAND-86-0349C, 10 pp (May 1986) DE86006469/GAR

KEY WORDS: Strain gages, Dynamic tests

Strain gages have been used to determine the dynamic response of test structures subjected to high speed water entry. The strain gage installations were verified to be functional prior to and after the conclusion of a series of water entry tests. The procedures used to verify the gage installations are described.

86-2083
Gearbox Testing in Top Gear
L.J. Boarer
Cambridge Electronic Design Ltd., Cambridge, UK
Chart. Mech. Engrg., 32 (12), pp 23-26 (Dec 1985) 4 figs

KEY WORDS: Gear boxes, Testing techniques

Until recently, automating the analysis of gearbox test results has implied a prohibitive investment in expensive minicomputer hardware and a knowledge of the latest research methods. Specifically in the automotive industry there has always been an enormous incentive for automation of gearbox testing, yet it is only recently that significant advances have been made towards full automation. The key features of the necessary hardware and computer software required for the measurement and analysis of gearbox test results are examined. Although described in the context of the automotive industry, they are equally applicable to related fields of rotating machinery testing, machine health monitoring and machine balancing.

86-2084
Activities Report of the Institute of Sound and Vibration Research
Southampton Univ., England
Annual Rept., 46 pp (1985) N86-17685/6/GAR

KEY WORDS: Test facilities

Research in fluid dynamics and acoustics (noise and vibration control), audiology and human effects (auditory communication and hearing conservation), structures and machinery (automotive design), and shock analysis is summarized. Underwater acoustics, active noise control, aircraft noise, wind turbine noise, laminar flow fans, helmet design, and the acoustics of flow ducts were studied.

SCALING AND MODELING

86-2085
Scale Modeling of Reinforced Concrete Category I Structures Subjected to Seismic Loading
R.C. Dove, J.G. Bennett
Los Alamos National Lab., NM
Rept. No. LA-10624-MS, 27 pp (Jan 1986) NUREG/CR-4474/GAR

KEY WORDS: Scaling, Seismic response, Reinforced concrete

The laws that govern the scale-model requirements for reinforced concrete Category I structures over a full range of seismic loading extending from the elastic through the inelastic ranges of response are developed. Three types of scaling are then examined. The third type, called Q scaling, is the most useful for tailoring structural models to existing seismic test facilities. The way in which the three types of commonly used damping (viscous, structural, and Coulomb) scale in these models is derived.

DIAGNOSTICS

86-2086

An Impulse Evaluation Method for the Diagnosis of Machine Elements (Ein Impulsbewertungsverfahren zur Diagnose an Maschinenelementen)

A. Sturm, D. Rosch, S. Uhlemann
Ingenieurhochschule Zittau, German Dem. Rep.
Maschinenbautechnik, 35 (3), pp 125-127 (Mar 1986) 8 figs, 8 refs (in German)

KEY WORDS: Diagnostic techniques

A new method for the evaluation of damage caused by impulse is presented. During periodic excitations any present damage leads to the emission of periodic pulse groups which cause periodic fluctuations of impulse density, independent of the intensity and character of the superimposed pulse train. From the frequency and amplitude of periodic fluctuation components the type, location, and degree of damage is determined. If the impulse train emitted by the damage process is stochastic the stochastic fluctuations of impulse intensity are increased which shows up as an increased fluctuation of the entire spectrum.

86-2087

Vibration Detection. 1970-April 1986 (Citations from the U.S. Patent Database).

National Technical Information Service, Springfield, VA
139 pp (May 1986) PB86-865409/GAR

KEY WORDS: Vibration detectors, Bibliographies

This bibliography contains 159 citations of selected patents concerning the design and utilization of vibration sensing and detection devices. Electronic, optical, and magnetic detectors are among the types discussed. Uses in turbine blade vibration detection, and knock detection and control in internal combustion engines are included.

86-2088

Incipient Failure Detection from Random-Decrement Time Functions

S.R. Ibrahim
Old Dominion Univ., Norfolk, VA
Intl. J. Analyt. Exptl. Modal Analysis, 1 (2), pp 1-8 (Apr 1986) 2 figs, 3 tables, 25 refs

KEY WORDS: Diagnostic techniques, Incipient failure detection, Random decrement technique, Time domain method, Mode shapes

This paper deals with a class of structures whose operating responses are due to some stationary random input(s) plus some possible harmonic excitation. These inputs need not be known or measurable. A time-domain modal identification technique developed for a limited number of measurements, possibly one, with high identification accuracy and repeatability is suggested as the modal-identification method for this purpose. Converting the operational responses to a form usable for identification will be performed using the multi-measurement-multimode random-decrement technique. The theoretical basis and possible limitations of the random-decrement technique are summarized. The computational requirements for the two combined techniques are simple and stable and could possibly be implemented on minicomputers.

BALANCING

86-2089

Automatic Balancer (Pendulum Balancer)

S. Kubo, Y. Jinnouchi, Y. Araki, J. Inoue
Kurume Institute of Technology, Kurume, Japan
Bull. JSME, 29 (249), pp 924-928 (Mar 1986) 7 figs, 4 refs

KEY WORDS: Balancing techniques, Centrifugal forces, Pendulums, Shafts

Theoretical and experimental investigations on the dynamic behavior and stability of an automatic balancer using centrifugal pendulums are presented. It is found that the unbalance of the rotor can be completely corrected only when the pivots of the pendulums are at the center of the shaft. A violent self-excited vibration can occur when the speed of the shaft is nearly equal to the sum of the critical speed of the rotor and the natural frequency of the pendulum. To verify the theoretical results experiments are carried out.

86-2090

Notes on the Development of Balancing Techniques

N.F. Rieger
Stress Technology Inc., Rochester, NY
Vibrations, 2 (1), pp 3-8 (June 1986) 7 figs, 28 refs

KEY WORDS: Balancing techniques, Rotors

This article outlines some significant events in the development of rotor-balancing techniques. Included are early work on critical speeds and the evolution of balancing machines.

MONITORING

86-2091
Condition Monitoring Using Data Collectors
C. Nicholls
IRD Mechanalysis Ltd., UK
Chart. Mech. Engr., 33 (5), pp 50-51 (May 1986) 2 figs

KEY WORDS: Monitoring techniques

Many engineers believe that the most significant improvement in machinery reliability has resulted from the use of a condition monitoring program utilizing measurement and analysis of machinery vibration. This article describes a system using data collectors.

86-2092
Cavitation Vibration and Noise Around a Butterfly Valve
T. Kimura, K. Ogawa
Kobe Univ., Kobe, Japan
ISA, Trans., 25 (1), pp 53-61 (1986) 11 figs, 4 refs

KEY WORDS: Valves, Cavitation, Prediction techniques, Frequency analysis

The intensity of cavitation vibration and the sound pressure level of cavitation noise in butterfly valves were measured with an accelerometer mounted on the wall of a pipe and with an external microphone. A frequency analysis of vibration and noise was then conducted. It was found that the characteristic frequency of vibration was about 6.3 kHz and that the characteristic frequency of noise was about 2.5 kHz. The inception of cavitation can be predicted from an abrupt rise of the vibration acceleration at the characteristic frequency (6.3 kHz). Is was found that an abrupt rise of the sound pressure level indicated that cavitation occurred from the entire circumference of the butterfly valve. The cavitation characteristics of butterfly valves can be predicted objectively and accurately by measuring the vibration and the noise caused only by cavitation and performing a frequency analysis.

ANALYSIS AND DESIGN

ANALYTICAL METHODS

86-2093
Higher Approximate Solutions of the Duffing Equation (Odd Order Superharmonic Resonances in the Hard Spring System)
H. Tamura, T. Kondou, A. Sueoka
Kyushu Univ., Fukuoka-shi, Japan
Bull. JSME, 29 (249), pp 894-901 (Mar 1986) 6 figs, 6 refs

KEY WORDS: Duffing differential equation, Springs, Frequency response, Nonlinear systems, Multidegree of freedom systems

In a previous paper an algorithm was presented to obtain the periodic solutions and stability of nonlinear multi-degree-of-freedom systems with high speed and high accuracy, based on the harmonic balance method and the infinitesimal stability criterion. A revised algorithm is presented to give only odd order solutions which are composed of odd order harmonics only and so reduce the dimensions of the amplitude vector and Jacobian matrix to about one-half of the previous ones. The Duffing system with hard spring is analyzed by this algorithm and the detailed frequency responses are computed for odd order superharmonic resonances (order 3,5,7,9) which are odd order solutions.

86-2094
Eigenvalue Reanalysis of Locally Modified Structures Using a Generalized Rayleigh's Method
B.P. Wang, W.D. Pilkey
Univ. of Texas, Arlington, TX
AIAA J., 24 (6), pp 983-990 (June 1986) 4 figs, 7 tables, 32 refs

KEY WORDS: Eigenvalue problems, Structural modification techniques, Rayleigh method

Approximate eigenvalue reanalysis methods for locally modified structures are developed based on the generalized Rayleigh's quotients. For simple modifications such as adding springs and masses or changing the truss member's cross-sectional area, closed-form formulas are included. Several applications are presented.

86-2095
Response of Linear Systems to Quadratic Gaussian Excitations
M. Grigoriu
Cornell Univ., Ithaca, NY
ASCE J. Engrg. Mech., 112 (6), pp 523-535 (June 1986) 4 tables, 18 refs

KEY WORDS: Probability density function, Linear systems, Wind-induced excitation, Structural response

Probability density functions, mean crossing rates, and other descriptors are developed for the response of linear systems to squares of Gaussian excitations. The analysis is based on discrete approximations of the spectrum of the Gaussian excitation. Accordingly, the response can be expressed as a finite quadratic form in Gaussian variables, whose characteristic function has a closed form. The characteristic function can be inverted by Fast Fourier Transform algorithms to find the first order probability and the response. Several approximations are applied to determine crossing and peak characteristics of the response. The proposed methodology is applied to estimate structural response to wind loads and the mean failure rate of systems subjected to bivariate Gaussian stress processes.

86-2096
The First Passage Problem in Random Vibration for a Simple Hysteretic Oscillator
B.F. Spencer
Ph.D. Thesis, Univ. of Illinois, Champaign-Urbana, IL, 152 pp (1985) DA 8600321

KEY WORDS: Random vibration, Oscillators

A method to determine the ordinary statistical moments of time to first passage and to determine the probability of first passage failure for a simple oscillator, incorporating the modified Bouc hysteresis model, has been developed. Two boundary value problems are formulated from Markov process theory and solved by a Petrov-Galerkin finite element method. A comparison of the finite element results with those obtained by Monte Carlo simulation is given to demonstrate the accuracy of the finite element method. A method to estimate the reliability of the hysteretic oscillator having prescribed the first few moments of first passage time is considered.

86-2097
Some Closure Problems in Stochastic Dynamics of Solids
W.F. Wu
Ph.D. Thesis, Univ. of Illinois, Champaign-Urbana, IL, 171 pp (1985) DA 8600351

KEY WORDS: Stochastic processes, Random excitation

In the studying of a nonlinear system under random excitation, it is usually difficult to determine the probability density of the system response. On the other hand, the equations for the statistical moments can be formulated rather easily, except that these equations form an infinite hierarchy rendering an exact solution impossible. A closure procedure is then needed to truncate the infinite hierarchy and to solve for some of the moments approximately. Several closure schemes are discussed in the context, particularly the cumulant-neglect closure. Emphasis is put on the applications of these closure schemes to several stochastic dynamics problems rather than theoretical development of these schemes.

86-2098
Dynamic Stress Intensity Factors Studied by Boundary Integro-Differential Equations
J. Sladek, V. Sladek
Slovak Academy of Sciences, Bratislava, Czechoslovakia
Intl. J. Numer. Methods Engrg., 23 (5), pp 919-928 (May 1986) 4 figs, 14 refs

KEY WORDS: Stress intensity factors, Cracked media, Harmonic excitation, Impact excitation, Laplace transformation

The boundary integro-differential equation method is illustrated by two numerical examples concerning the study of the dynamic stress intensity factor around a penny-shaped crack in an infinite elastic body. Harmonic and impact load on the crack surface has been considered. Applying the Laplace transform with respect to time to the governing equations of motion the problem is solved in the transformed domain by the boundary integro-differential equations. The Laplace transformed general transient problem can be used to solve the steady-state problem as a special case where no numerical inversion is involved.

86-2099
On the Multi-Scale Analysis of Strongly Non-Linear Forced Oscillators
T.D. Burton, Z. Rahman
Washington State Univ., Pullman, WA
Intl. J. Nonlin. Mech., 21 (2), pp 135-146 (1986) 5 figs, 1 table, 29 refs

KEY WORDS: Resonant response, Nonlinear systems

The resonant response of strongly nonlinear oscillators are considered. Approximate solutions are obtained using a multiple-scale approach with two procedural steps which differ from the usual ones.

86-2100
Periodic Solutions of Second-Order Nonlinear Difference Equations Containing a Small Parameter — III. Perturbation Theory
R.E. Mickens

Atlanta Univ., Atlanta, GA
J. Franklin Inst., 321 (1), pp 39-47 (Jan 1986) 10 refs

KEY WORDS: Purturbation theory

A technique to construct a uniformly valid perturbation series solution to a particular class of nonlinear difference equations is shown. The method allows the determination of approximations to the periodic solutions to these equations. An example illustrating the technique is presented.

86-2101

Asymptotic Analysis of the Lyapunov Exponent and Rotation Number of the Random Oscillator and Applications

L. Arnold, G. Papanicolaou, V. Wihstutz
Universitat Bremen, Fed. Rep. Germany
SIAM J. Appl. Math., 46 (3), pp 427-450 (June 1986) 5 figs, 31 refs

KEY WORDS: Asymptotic approximation, Random response, Wave propagation

Asymptotic expansions are constructed for the exponential growth rate (Lyapunov exponent) and rotation number of the random oscillator when the noise is large, small, rapidly varying or slowly varying. Results are applied to problems in the stability of the random oscillator, the spectrum of the one-dimensional random Schrodinger operator and wave propagation in a one-dimensional random medium.

86-2102

Instability of the Harmonic Oscillator with Small Noise

M.A. Pinsky
Northwestern Univ., Evanston, IL
SIAM J. Appl. Math., 46 (3), pp 451-463 (June 1986) 13 refs

KEY WORDS: Asymptotic series, Harmonic response

Asymptotic expansions are constructed for the exponential growth rate (Lyapunov exponent) and rotation number of the random oscillator when the noise is small and defined by a temporally homogeneous Markov process with a finite number of states. In the case of two states (the telegraph process) additional terms are obtained in the expansions, affording comparison between the exact values and the asymptotic formulas.

86-2103

Dynamics of Flexible Mechanical Systems Using Finite Element Lumped Mass Approximation and Static Correction Modes

W.S. Yoo
Ph.D. Thesis, Univ. of Iowa, 166 pp (1985) DA 8528010

KEY WORDS: Finite element technique, Computer programs

A finite element based method is developed for geometrically nonlinear dynamic analysis of spatial mechanical systems that contain complex-shaped, elastic bodies. Vibration and static correction modes are used to account for linear elastic deformation of components. Kinematic constraints between components of a system are used to define boundary conditions for vibration analysis and loads for static correction mode analysis. Constraint equations between flexible bodies are derived in a systematic way. A Lagrange multiplier technique is used to generate the coupled large displacement-small deformation equations of motion. A standard, finite element structural analysis code is used to generate deformation modes. An intermediate-processor is used to calculate time-independent terms in the equations of motion and to generate input data for a large scale dynamic analysis code that includes coupled effects of geometric nonlinearity and elastic deformation.

86-2104

A Variational-Vector Calculus Approach to Machine Dynamics

E.J. Haug, M.K. McCullough
Univ. of Iowa, Iowa City, IA
J. Mech., Transm., Autom. in Des., Trans ASME, 108 (1), pp 25-30 (Mar 1986) 4 figs, 7 refs

KEY WORDS: Mechanical components, Variational methods

A variational-vector calculus approach is presented to define virtual displacements and rotations and position, velocity, and acceleration of individual components of a multibody mechanical system. A two-body subsystem with both Cartesian and relative coordinates is used to illustrate a systematic method of exploiting the linear structure of both vector and differential calculus, in conjunction with a variational formulation of the equations of motion of rigid bodies, to derive the matrix structure of governing multibody system equations of motion. A pattern for construction of the system mass matrix and generalized force terms is developed and applied to derivation of the equations of motion of a vehicle system. The development demonstrates an approach to multibody machine dynamics that closely parallels methods used in finite-element structural analysis.

86-2105
Fuzzy Set Approach to Linguistic Seismic Load and Damage Assessments
C. Souflis, D.A. Grivas
Rensselaer Polytechnic Inst., Troy, NY
ASCE J. Engrg. Mech., 112 (6), pp 605-618 (June 1986) 4 figs, 7 tables, 35 refs

KEY WORDS: Earthquake damage, Seismic excitation

A framework is developed within which linguistic assessments of seismic loads and structural damage can be assigned fuzzy set representations. This involves a set of rules in the form of a language organized in an algorithmic manner. Factors that affect the function of language elements are discussed and the use of the language is shown in an example.

NUMERICAL METHODS

86-2106
Comparison of the Finite Element Method and the Boundary Element Method for the Numerical Calculation of Sound Fields (Vergleich der Methoden der Finiten Elemente und der Boundary-Elemente bei der numerischen Berechnung von Schallfeldern)
P. Becker, H. Waller
Bundesanstalt fur Arbeitsschutz, Dortmund, Fed. Rep. Germany
Acustica, 60 (1), pp 21-33 (Mar 1986) 22 figs, 12 refs (in German)

KEY WORDS: Numerical methods, Finite element technique, Boundary element technique, Sound waves, Helmholtz integral method

The finite element method is the method most often used for the numerical solution of Helmholtz's equation. The application of such numerical methods is, however, limited for high frequencies and large sound fields. For the calculation of the acoustic properties of passenger compartments of cars and of silencers, good results have already been obtained. The recently developed boundary element method is also appropriate. It is the aim of this contribution to introduce both methods and to compare their advantages and disadvantages.

86-2107
A Unified Set of Single Step Algorithms. Part 4: Backward Error Analysis Applied to the Solutions of the Dynamic Vibration Equation
W.L. Wood
Univ. of Reading, Reading, UK
Intl. J. Numer. Methods Engrg., 23 (5), pp 929-944 (May 1986) 11 figs, 2 tables, 10 refs

KEY WORDS: Numerical methods, Error analysis, Vibration response

The method of backward error analysis is applied to the numerical solution of the dynamic vibration equation by single step algorithms. Some general rules to help with the choice of parameters are presented.

86-2108
Multiple Scales Analysis of Poynting Effect for Torsional Oscillator with Neo-Hookean Spring
R.J. Tait, J.B. Haddow
Univ. of Alberta, Edmonton, Alberta, Canada
Intl. J. Nonlin. Mech., 21 (2), pp 157-164 (1986) 4 figs, 2 refs

KEY WORDS: Multiple scale method, Coupled response, Torsional vibrations, Axial vibrations

The method of multiple scales is applied to the analysis of the coupled torsional-axial oscillations of a torsional spring mass oscillator consisting of a neo-Hookean bar fixed at one end and with a heavy disc attached to the other end. This coupling is due to the Poynting effect. Numerical results obtained from the method of multiple scales are compared with those obtained from numerical integration of the system of two second order nonlinear governing equations of the system. Two different cases are considered.

DESIGN TECHNIQUES

86-2109
Seismic Inelastic Design Spectra
N. Mostaghel, A.G. Hernried
Univ. of Utah, Salt Lake City, UT
Earthquake Engrg. Struc. Dynam., 14 (3), pp 379-389 (May-June 1986) 8 figs, 16 refs

KEY WORDS: Seismic response spectra, Seismic design

To alleviate some of the shortcomings associated with the statistically based inelastic spectral shapes, a rigorous method for the construction of inelastic design spectra is proposed. The method is based on several bounds which are derived from the differential equations of motion for a single degree of freedom system. Comparisons of the proposed spectral bounds with the actual elastoplastic response spectra and with the 84 per cent Newmark elastoplastic design spectra reveal that the proposed method yields a more economical, reliable and simple design aid.

86-2110
Methodology for Computer-Aided Design of Earthquake-Resistant Steel Structures
M.A. Austin, K.S. Pister, S.A. Mahin
Univ. of California, Richmond, CA
Rept. No. UCB/EERC-85/13, NSF/ENG-85028, 218 pp (Dec 1985) (Spons. National Science Foundation, Washington, DC) PB86-159480/GAR

KEY WORDS: Seismic design, Computer-aided techniques, Steel

The report focuses on the development and preliminary testing of a methodology for the probabilistic limit states design of seismic-resistant steel structures. Emphasis is placed on the formulation of a mechanism which allows a designer to include the effects of uncertainties and multiple design objectives in an optimization-based design process. Sources of uncertainty in the seismic design environment are identified and described.

COMPUTER PROGRAMS

86-2111
ROBDIS — A Finite Element Computer Program for a Small Computer (ROBDIS — Ein Finite-Elemente-Programmsystem fur den Kleinrechner)
U. Fischer, W. Weese, J. Grochla
Technische Hochschule, Magdeburg, German Dem. Rep.
Maschinenbautechnik, 35 (3), pp 142-144 (Mar 1986) 5 figs, 3 refs (in German)

KEY WORDS: Computer programs, Finite element technique

A finite element computer program is described which runs on a computer with at least 64K memory and which has the capability to superimpose portions of programs. The program will be published as a book in 198[illegible]

86-2112
DYNA2D; Explicit 2-D Hydrodynamic FEM Program
J.O. Hallquist
Lawrence Livermore National Lab, CA
Magtape ANL/NESC-9910, DE86057910/GAR

KEY WORDS: Computer programs, Hydrodynamic response, Finite element technique

DYNA2D is a vectorized, explicit, two-dimensional, axisymmetric and plane strain finite element program for analyzing the large deformation dynamic and hydrodynamic response of inelastic solids. A contact-impact algorithm permits gaps and sliding with friction along material interfaces. By a specialization of this algorithm, such interfaces can be rigidly tied to admit variable zoning with no need for transition regions. Spatial discretization is achieved by the use of 4-node solid elements, and the equations-of-motion are integrated by the central difference method. An interactive rezoning capability eliminates the need to terminate the calculation when the mesh becomes too distorted. Rather, the mesh can be rezoned and the calculation continued.

86-2113
NIKE2D; Static & Dynamic Response of 2D Solids Software
J.O. Hallquist
Lawrence Livermore National Lab., CA
Magtape ANL/NESC-9923 (1985) DE86057923/GAR

KEY WORDS: Computer programs, Finite element technique

NIKE2D is a vectorized, implicit, finite-deformation, large strain, finite-element code for analyzing the response of two-dimensional axisymmetric and plane strain solids. A variety of loading conditions can be handled including traction boundary conditions, displacement boundary conditions, concentrate nodal load points, body force loads due to base accelerations, and body force loads due to spinning. Slide-lines with interface friction are available. Elastic, orthotropic, elastic-plastic, soil and crushable foam, thermo-elastic-plastic, and linear viscoelastic material models are implemented. Nearly incompressible behavior that arises in plasticity problems and elasticity problems with Poisson's ratio approaching 0.5 is accounted for in the element formulation to preclude mesh lock-ups and the associated anomalous stress states. Four-node isoparametric elements are used for the spatial discretization, and profile (bandwidth) minimization is optional.

GENERAL TOPICS

USEFUL APPLICATIONS

86-2114
Measurement of Dynamic Young's Modulus of Paperboard
T. Nakao, M. Kimura
Univ. of Tokyo, Tokyo, Japan
Tappi J., 69 (5), pp 129-133 (May 1986) 1 fig, 5 tables, 20 refs

KEY WORDS: Paper products, Young modulus, Shear modulus, Measurement techniques, Vibratory techniques

The dynamic Young's modulus of paperboards measured by a free-free beam method is compared to that obtained using a vibrating-reed method to check if the vibrating-reed method yields a reliable value. The free-free beam vibrating mode yields one of the most reliable values because it satisfies the boundary conditions of the differential equation for vibration. The two sets of values are found to be close. In the process of correcting for the shear effect on Young's modulus resulting from higher vibrating modes in the free-free vibrating beam method with a concentrated mass attached to one end of the specimen, the transverse shear modulus can be calculated.

AUTHOR INDEX

CALENDAR

NOVEMBER

3-6 14th Space Simulation Conference [IES, AIAA, ASTM, NASA] Baltimore, MD (Institute of Environmental Sciences, 940 E. Northwest Highway, Mt. Prospect, IL 60056 - (312) 255-1561)

7-14 Turbomachinery Symposium, Corpus Christi, TX (Turbomachinery Laboratories, Dept. of Mech. Engrg., Texas A & M Univ., College Station, TX 77843)

30-5 American Society of Mechanical Engineers, Winter Annual Meeting [ASME] San Francisco, CA (ASME)

DECEMBER

7-12 ASME Winter Annual Meeting, Anaheim, CA (ASME, United Engrg Center, 345 East 45th Street, New York, NY 10017)

8-12 ASA, Anaheim, CA (Joie P. Jones, Dept. Radiology Sciences, Univ. of California, Irvine, CA 92717)

9-11 ASA Fall Acoustical Show, Anaheim, CA (katherine Cane, ASA Show Manager, Amer. Inst. of Physics, 335 E 45th St., New York, NY 10017)

1987

JANUARY

12-15 AIAA 25th Aerospace Sciences Meeting, Reno, NV

FEBRUARY

24-28 SAE International Congress "Excellence in Engineering," Cobo Hall, Detroit, MI (SAE Engrg. Activities Div., 400 Commonwealth Drive, Warrendale, PA 15096)

MARCH

10-12 Power Plant Pumps Symposium [Electric Power Research Institute], New Orleans, LA (Electric Power Research Institute, 3412 Hillview Avenue, Palo, Alto, CA 94304)

6-9 56th International Modal Analysis Conference [Union College and Imperial College of Science], London, England (IMAC, Union College, Graduate and Continuing Studies, Wells House -- 1 Union Ave., Schenectady, NY 12308)

6-8 AIAA 28th Structures, Structural Dynamics and Materials Conference, Monterey, CA

9-10 AIAA Dynamics Specialist Conference, Monterey, CA

APRIL

13-16 IEEE Intl. Conf. on Acoustics, Speech, and Signal Processing, Dallas, TX

13-16 IUTAM Symp. on Advanced Boundary Element Methods, San Antonio, TX

28-30 1987 SAE Noise and Vibration Conference, Traverse City, Michigan (SAE, 400 Commonwealth Drive, Warrendale, PA 15086 (412) 776-4841)

MAY

3-8 33rd International Instrumentation Symposium [Aerospace Industries and Test Measurement Divisions, Instrument Society of America], Las Vegas, NV (33rd International Instrumentation Symposium, 738 W. Larigo Ave., Littleton, CO 80120)

11-15 ASA Spring Meeting, Indianapolis, IN

12-13 International Appliance Technical Conference, Columbus, OH

JUNE

8-10 AIAA 19th Fluid Dynamics, Plasma Dynamics and Laser Conference

8-10 Noise-Con 87, Pennsylvania State University (Conference Secretariat, NOISE-CON 87, The Graduate Program in Acoustics, Applied Science Building, University Park, PA 16802)

16-18 11th Annual Meeting [Vibration Institute], St. Louis, MO (Dr. Ronald L. Eshleman, Director, Vibration Institute, 55th and Holmes, Clarendon Hills, IL 60514 - (312) 654-2254)

29-2 AIAA/SAE/ASME/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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END 2-87