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SVIC NOTES

The 2nd International Modal Analysis Conference, which was held in Orlando, Florida, this past February, was highly successful in all respects. A review of the content of selected sessions in this conference appears elsewhere in this issue.

One of the highlights of this conference was the announcement of the formation of a new technical society dedicated to advancing the modal analysis technology, the International Society for Modal Testing and Analysis. This new society is unique in two respects. First, it is dedicated to a specific branch of a specialized technical field. Second, it is a branch of the shock and vibration technology that has advanced substantially during the past ten years.

The formation of this new technical society is just one indication of the maturing of the modal analysis technology. Up to ten years ago, modal analysis was largely aerospace-vehicle or aircraft oriented; modal tests were run to confirm a vehicle's mathematical model, and the test excitation was predominantly limited to the multi-shaker-sine-dwell approach. This made these tests tedious and time consuming. The recent literature, and the many papers presented at this conference, have shown that the modal analysis technology has made significant progress over the past ten years. More advanced excitation techniques are now available, but more important, modal analysis has become an important part of the design and analysis process for the many different types of systems that must survive dynamic loads. It is being increasingly used in the design and analysis of machine tools, nuclear reactor power plant components and structures, automobiles and electronic cabinets.

The recent literature and the conference papers reflect another indication of the maturity of the modal analysis technology. It has become a valuable tool for diagnosing the causes of fatigue failures or excessive noise due to excessive structural vibration. In addition, some research has been undertaken into use of modal analysis to detect incipient structural damage, and potential applications include offshore oil drilling platforms, pressure vessels, aerospace vehicles, and the like. One of the papers in this conference discussed the use of modal analysis to detect hidden delaminations in composite material structures.

Even though the modal analysis technology has greatly matured, questions still arise over some of the less understood concepts. The lively panel discussion which was held on Wednesday afternoon, February 8, provided a forum for airing some of these concerns and interchanging ideas. Many technical questions arose, and these will be dealt with elsewhere. But, one area of concern to all was the need for more education or training in modal analysis, particularly in experimental techniques. Beyond that there was no agreement on how to provide the needed training or who should do it. This issue certainly has to be discussed further.

In conclusion, the organizers of this conference should be commended for providing an interesting and informative meeting.

R.H.V.

EDITORS RATTLE SPACE

ENGINEERING EDUCATION AND TRAINING

The Short Courses section of the DIGEST attests to the level of activity in engineering education and training in that each month a variety of courses is described. Managements in government and industry have found that such education and training of engineers and technicians have benefited programs of all kinds -- design and development, maintenance, and manufacturing. The courses have served as a mechanism for interchange and transfer of ideas, techniques, and data. The end result has been to raise the level of efficiency of operating personnel.

The short course provides a more formal atmosphere than the technical meetings listed in the Calendar section of the DIGEST. The notes on which a course is based are usually closely followed by the attendees and the lecturers during the course. In many instances professional engineers from government and industry who are active in some aspect of engineering work present the lectures. The short course is thus a technology transfer process, in which information from lecturers who have developed and formalized techniques in thier work is presented to individuals not yet familiar with such techniques. The course reflects the experience of the lecturers in solving a wide range of technical problems. The courses have a beneficial side effect that most people do not recognize. The interchanges among the class participants -- usually a mixture of engineers and technicians -- provide new insights into methods and practices.

Such training is not inexpensive, but the cost is usually paid back to a company or institution many times in improved operating efficiency and machine reliability. The increased skills and knowledge about specific techniques increase the interest, pride, and confidence of the engineering and technical participants. Most organizations who conduct regular training programs have found that the costs can be justified. In fact these programs have become a normal part of company operation in many cases.

R.L.E.

CRITICAL SPEED OF CENTRIFUGAL PUMPS

S. Gopalakrishnan* and Y. Usui**

Abstract. Until recently critical speed calculations of pumps were made without considering the rotor dynamic effects of close clearance running fits. Publications in the last few years have made it clear that these effects must be considered in order to make the computations relevant to pump operation. This paper is a review of methods available for calculating critical speeds of pumps including rotor dynamic effects.

It is known operation of a centrifugal pump at or near a critical speed can lead to unacceptable vibration levels. As a consequence many pump user specifications explicitly require that operating speeds differ from critical speeds by safe margins. For example, in API Standard 610 [1] the critical speed is required to be at least 20% greater or 15% less than any operating speed. Compliance with such specifications requires that critical speeds be calculated as part of design and pump selection procedures.

For rotating machinery that handles gaseous mediums -- e.g., gas turbines and gas compressors -- calculation of critical speeds is a well established procedure. A 1969 monograph [2] cites 554 references in the field of dynamics of rotating shafts. However, specific calculation procedures are few for machines that handle liquids. The primary reason for this lack of adequate and acceptable procedures seems to be close clearance running fits around the rotating element. Most of these fits control leakage flows on either side of the impellers. In some pump designs, additional running fits are used for other functions such as hydraulic balancing. The liquid flowing through these tight clearances is subject to a significant pressure drop that exerts a lateral force on the shaft. These additional forces greatly change the critical speed. Naturally, when a pump runs dry (i.e., no liquid in the running fits), lateral forces do not exist; as a result the dry running critical speed is different from the wet critical speed. This difference plays an extremely important role in the vibration characteristics of centrigugal pumps.

This paper first surveys the status of techniques for calculating the dry critical speed because these techniques are now well established. The paper then surveys procedures for calculating wet critical speeds. Even though these methods are not yet thoroughly established, they are receiving wide attention in the pump industry.

DRY CRITICAL SPEED

A complete dynamic analysis of a rotating machine would involve such calculations as undamped natural frequencies, linear stability, damped natural frequencies, and response of the system to exciting forces. A good survey of procedures is available [3]. This review deals only with critical speed calculations.

For the calculation of undamped natural frequencies the system is treated as having mass and flexibility. Damping is completely ignored, as are mechanisms that can lead to dynamic instability. Rotary inertia and gyroscopic effects are included. The system is represented as a linear model [4-8]. The purpose of an undamped analysis is to provide a close, initial estimate of the critical speed of the system. Because damping in systems driven by inertial exciting forces increases the critical speed only slightly [9], an undamped critical speed can immediately indicate if additional analysis is necessary. Further, such an analysis can be completed relatively quickly for shafting systems with modern computer programs.

When damping is included in the analysis, results are sought in terms of the response of the rotor to a

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known input exciting force as a function of operating speed. The usual exciting force for pump shafts is mass imbalance, which is synchronous with shaft rotation. The existence of nonsynchronous forces has been recognized for some time, but they have not been quantified. Various aspects of force response analysis have been described [8, 10-13].

In order for the above-mentioned damped or undamped analysis to be done, all of the important mechanical components must be represented with regard to their rotor-dynamic characteristics. The following key components are usually considered.

Shaft. A typical pump shaft consists of several sections of different diameters. The most commonly used shaft modeling is the transfer matrix method [4-6, 14-16]. With this method displacements and forces are calculated at a predetermined point from values at a previous location. Shaft masses as well as impeller and other masses attached to the shaft are considered to be concentrated at their respective centers of gravity. The locations for deflection calculations are chosen conveniently -- at points where the shaft changes diameter and at the locations of impellers and bearings. This method, often referred to as Myklestad-Prohl technique, deals with relatively few equations and is readily adaptable to computer implementation.

Another method for shaft modeling is the finite element technique [17-19], in which the geometry is represented by a number of discrete, specifically shaped, computational elements. Even though this method is widely used in structural analysis, it has not been commonly employed for rotor dynamic analysis because the simple geometry of the pump rotating element does not warrant the complexity of finite element representation.

The shaft element between locations in the Myklestad-Prohl method is specified by means of outside and inside diameters and length between locations. The shaft sleeves are represented as additional masses, as in the case of impeller(s), or distributed over several segments.

Impeller hub and sleeves provide an additional stiffening effect to the shaft. This effect is usually handled by adding a fraction of the moment of inertia of the sleeve or hub to that of the corresponding shaft section. The fraction can vary from 0 to 1; the latter number is used when the sleeve is shrunk to the shaft, substantially eliminating relative motion [20]. A value between 0.5 and 0.65 has been recommended irrespective of fit [21].

Couplings. When a pump rotor is connected to a motor shaft by a flexible coupling, transverse vibrations of the pump shaft are generally assumed to be completely independent of the motor shaft. In this case the pump shaft is treated as terminating at the coupling; the pump half of the coupling acts as a cantilevered mass. When the coupling is rigid, the complete rotating element must be treated as one dynamic system.

Bearings. Pump shafts are supported on a variety of bearing types, including antifriction, hydrodynamic, and hydrostatic. Bearings are represented in rotor-dynamic analysis by force coefficients, which depend upon displacement and velocity. Such coefficients are usually determined by separate analysis appropriate for the bearing type. Typical inputs for these analyses include static load, rotor speed, bearing geometry, lubricating fluid, and supply pressure. A large body of data exists for calculating these coefficients. The reader is referred to a literature survey for details of bearing calculations [3]. In general, use is made either of computer programs or published data. For sleeve type bearings, the coefficients depend upon the Sommerfeld number and the Reynolds number. Design data for hydrodynamic bearings is available [22-26].

Other factors. Some additional effects that must be considered in critical speed computation are gyroscopic effects, hydraulic axial thrust, and shaft bow. When an impeller does not vibrate in its own plane, as can occur on overhung designs or those off-centered with respect to end bearings, the critical speed is altered. The reason is that the centrifugal force of the various particles constituting the impeller produces a couple and affects the apparent stiffness of the shaft. For overhung designs the couple tends to straighten the shaft and increase the critical speed [27].

Because of the difference in area and pressure from front to back of single suction impellers, an axial thrust is generated on the rotating element. In a vertical pump, the axial thrust generally acts downward. The addition of axial thrust to the dead weight of a rotating element puts the shaft in tension. The critical speed of the shaft increases as a result of the shaft tension [28, 29]. This phenomenon is similar to the increase in natural frequency of strings under tension.

When a residual shaft bow exists in a shaft system, amplitude, phase angle, and frequency at the point of maximum response are altered [30, 31]. Residual shaft bow occurs as a result of thermal distortion, gravity sag, and prior imbalance.

At present, critical speeds for pumps are calculated using computer programs. These programs are not generally found in the public domain. Among the many sources from which good computer programs can be purchased are University of Virginia, Swansen Analysis Systems, Inc., NASA, Mechanical Technology Inc., and University of California at Berkeley.

WET CRITICAL SPEED

The calculation of dry critical speeds assumes that fluid dynamic phenomena in close clearance running fits do not affect the rotor-dynamic behavior of the pump. Recent research has proved that this assumption is untenable.

Close clearance running fits in centrifugal pumps include wear rings -- sometimes called neck rings or simply seals and not to be confused with packings or end face mechanical seals -- throttle bushings, and center stage pieces. A sectional drawing showing these components has been published [32]. As these fits are used to break down pressure, leakage flow in the direction of pressure drop occurs. It has been shown [33] that, when a shaft is displayed laterally in such a ring, a strong restoring force is set up in the clearance space. This force increases with the pressure drop and the extent of shaft lateral motion. In effect the clearance ring acts as a spring, and the phenomenon is often referred to as the Lomakin effect. Because this force tends to push the shaft back to equilibrium position, it tends to suppress shaft whirling and hence to raise the critical speed.

Until work by Black and others was published [34, 35], it was not realized that this force, the Lomakin effect, can indeed be substantial in magnitude for common pump geometries. Black [34] in particular showed that the restoring force increases with the square of the speed and hence can be thought of as being generated by a fictitious mass, now called the Lomakin mass. If the Lomakin mass exceeds the geometric mass of the rotating element, the critical speed becomes imaginary! In other words, the rotating element does not possess a critical speed. This idea has been explained in detail [36].

It is now clear that computation of the critical speed of a pump without including the Lomakin effect is irrelevant to pump operation except when the pump is required to operate dry. However, such a specification to protect against total loss of liquid to a pump are uncommon.

In order to compute the wet critical speed the magnitude of the fluid dynamic effects in the rings must be established. Considerable research has gone into the study of these effects.

In general, the ring effects are in the form of stiffness, damping, and hydrodynamic mass. Each of the three quantities has four components. In turn, these four components are due to two direct and two cross-coupled terms. For motion in the X-Y plane, the general notations for the components are:

Stiffness	K_{xx}, K_{yy}	direct
	K_{xy}, K_{yx}	cross-coupled
Damping	C_{xx}, C_{yy}	direct
	C_{xy}, C_{yx}	cross-coupled
Hydrodynamic Mass	M_{xx}, M_{yy}	direct
	M_{xy}, M_{yx}	cross-coupled

The earliest calculation method for the hydrostatic restoring force was that developed by Lomakin [33]. He neglected shaft rotation and lateral motion, so that only the stiffness coefficient could be calculated. Black published a series of papers [37-44] dealing with the calculation of dynamic properties of annular clearance components. He used a bulk-flow approach in which the radial variation of fluid properties across the film is neglected. The governing equations were written in a radially averaged form; then perturbation in the eccentricity ratio was analyzed. The pressure drop used in the axial momentum equation was deduced from an empirical correlation established by Yamada [45]. Yamada's equation employs an entry loss coefficient and a friction coefficient, which is dependent on the circumferential and axial Reynolds numbers. In one case [37] circumferential flow was considered small with respect to shear-induced flow; the result was what is called a short seal solution. This solution was expanded for a finite length seal by a numerical procedure [39]. A simple correction factor based on the length to diameter ratio was developed to account for the finite length of the seal. When clearance varied around the circumference, Black [42] allowed for the variation of friction factor as a function of local Reynolds number.

Black's analyses have been extended to large eccentricity ratios using numerical techniques by Allaire [46]. For high-speed machines, in which circumferential Reynolds numbers can be large, Lin has used Hirs theory for turbulent lubricant films [47] to predict seal dynamic coefficients [48].

Childs [49-51] applied a small eccentricity perturbation solution to Hirs equation and incorporated the effects of inlet swirl velocity. He demonstrated that swirl reduces the cross-coupled dynamic stiffness coefficients, while slightly increasing direct stiffness and damping.

Simple, closed form solutions for the direct stiffness and damping coefficients have been derived [36]. For a double-bearing pump geometry, these coefficients are shown to be adequate for predicting the wet critical speed.

Formulas for hydrodynamic masses of solids immersed in liquids have been tabulated [52]. For close clearance rings, hydrodynamic mass effects have been shown to be strong.

Additional references on the theoretical calculations of dynamic coefficients and brief reviews of significant papers are available [3, 53].

Experimental verification of seal ring coefficients have been attempted in test rigs using either stiff or flexible shafts. In the latter type of testing [36] critical speed is measured and compared to calculations using predicted seal ring coefficient values. Such verification is indeed indirect and could be in considerable error because critical speeds in damped systems cannot be pinpointed accurately in tests. The measurement of seal ring coefficients using stiff shaft testing is much more straightforward.

In early testing the shaft was simply offset by a small amount and the resulting forces were measured. Because the shaft does not whirl in this case, only the four stiffness coefficients could be measured [39, 42, 43]. In some tests the shaft is offset and whirled so as to execute a centered circular orbit [54]. Forces were obtained by integrating the pressures along the axis and around the circumference. The 12 dynamic coefficients were reduced to five by assuming

$$K_{xx} = K_{yy}; \qquad K_{xy} = -K_{yx}$$

$$C_{xx} = C_{yy}; \qquad C_{xy} = -C_{yx}$$

$$M_{xx} = M_{yy}; \qquad M_{xy} = M_{yx} = 0$$

Thus test data were developed for five coefficients. In order to develop all 12 coefficients by test, the offset shaft is vibrated translationally and rotated about its own center [55]. In an alternate form of testing to develop the 12 coefficients, the offset shaft is processed about the seal center at speeds that are not necessarily synchronous [56, 57].

The correspondence between test data and predictions in all of the references cited varies from poor to excellent. Based on experience the following recommendation has been made by Childs [58].

$$K_{xx} = K_{yy} \qquad K_{xy} = -K_{yx}$$

$$C_{xx} = C_{yy} \qquad C_{xy} = C_{yx} = 0$$

$$M_{xx} = M_{yy} = M_{xy} = M_{yx} = 0$$

Thus, only three coefficients need to be used for modeling seals in rotordynamic analysis of pumps. For small pressure drops across wear rings, good correspondence with test data has been obtained for critical speeds by using only one coefficient, namely, the direct stiffness K_{xx} [36].

It must be noted that some uncertainty exists as to the manner in which the dynamic effects of the rings are to be included in critical speed computation. In a boiler feed pump example the Lamakin effect was treated as a virtual mass [36]. As the virtual mass was found to be greater than the geometric mass, the critical speed was concluded to have been suppressed. Such an approach would be correct for systems in which the masses (Lomakin and geometric) occur at the same locations. For systems in which this does not occur, the Lomakin effect should be treated as a stiffness and hence as a function of speed. Even though this method of treatment appears to be known in the pump industry, there are at present no documents in the public domain describing this procedure adequately.

CONCLUSIONS

Until recently pump critical speed calculations were performed without explicitly recognizing the importance of close clearance running fits. Publications in the last few years on this subject have made it abundantly clear that, for centrifugal pumps, the computation of dry critical speed is irrelevant. Even though difficulties remain in the accurate determination of the dynamic coefficients of sealing rings and in the incorporation of these coefficients in critical speed computation, pump manufacturers and users have begun to realize that these effects must be included in order to make meaningful predictions of the rotor-dynamic behavior of pumps.

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

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles 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.

This issue of the DIGEST contains an article about the response of nonlinear structures to random excitation.

Dr. C.W.S. To of The University of Calgary, Calgary, Alberta, Canada has written a paper that provides an update of the state of the art of techniques used for the analysis of general nonlinear mechanical systems to random excitation. Special attention is paid to methods applied to multi-degree-of-freedom nonlinear systems subjected to nonstationary random excitation.

THE RESPONSE OF NONLINEAR STRUCTURES TO RANDOM EXCITATION

C.W.S. To*

Abstract. This paper provides an update of the state of the art of techniques used for the analysis of general nonlinear mechanical systems to random excitation. Special attention is paid to methods applied to multi-degree-of-freedom nonlinear systems subjected to nonstationary random excitation. Their suitability and adaptability to finite element analysis of complicated nonlinear structures with large deformation and finite strain are also assessed. Conclusions are drawn and a recommendation for future studies is given.

For safety reasons, the designers of such modern structures as tall buildings, buildings that house nuclear reactors, and naval and aerospace structures must consider the effects of various intensive random excitations. These include earthquake excitation, pressure waves of explosions, and continuous atmospheric turbulence. For economic reasons the substantial reserve of strength inherent in most structures due to plastic effects is required. Consequently, for both safety and economic considerations the nonstationarity of response and excitation and the nonlinearity of structures must be taken into account in design procedures. This, in turn, requires the prediction of the nonstationary random response of nonlinear structures to nonstationary random excitation.

The problem of predicting the response of multi-degree-of-freedom (MDF) nonlinear systems to random excitation has received considerable attention in the last two decades in comprehensive and excellent reviews [1-5]. Structural nonlinearities and the nature of excitation have been considered in some detail [2], and trends in research and the range of problems that have been solved have been described [4, 5].

The main objective of this paper is to update the state of the art of techniques used for the random analysis of the response of general nonlinear mechanical systems to random excitation. Special attention is paid to methods applied to MDF nonlinear systems subjected to nonstationary random excitation. Their suitability and adaptability to finite element analysis of complicated nonlinear structures with large deformation and finite strain are assessed.

This paper contains four main sections. The first section has to do with structural models; the nature of excitation, damping, and nonlinearities are dealt with. Section two reviews various methods used in the analysis of response of single-degree-of-freedom (SDF) systems to random excitation. The methods considered in this section include statistical linearization or equivalent linearization techniques, Fokker-Planck-Kolmogorov equation approaches, perturbation approaches, bilinear or two-state model methods, functional series representation approaches, and analog and digital simulation.

The third section examines methods applied in the analysis of response of MDF systems to random excitation. The methods reviewed include statistical linearization techniques, Fokker-Planck-Kolmogorov equation approaches, normal mode approaches, perturbation methods, and simulation techniques. The final section presents an appraisal of existing methods for application to discretized nonlinear structures. Conclusions and a recommendation for further studies conclude the article.

STRUCTURAL MODELS

A suitable model must be chosen before an accurate analysis can be performed for a mechanical or structural system. The following considerations are important in selecting a suitable model: nature of the

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excitation, damping, and nonlinearities of the system.

Nature of excitation. Random excitations can be classified according to the ways in which they interact with a system. Two categories of random excitations exist in mechanical and structural systems. One, so-called parametric excitations, can affect the stability of systems. Mathematically, they are time-dependent coefficients of the governing equations of motion of systems. The other category, non-parametric excitations, are nonhomogeneous parts of the second order differential equations of motion. In this article only non-parametric random excitations are considered; systems with parametric excitations have been thoroughly reviewed [6].

Non-parametric random excitations can be divided into stationary and nonstationary types. When the duration of an excitation such as an earthquake, a gust wind loading, or an explosion is relatively much longer than the period of the system, the excitation can be regarded as a stationary process. On the other hand, when the duration of the excitation is not much longer than the period of the system, the excitation can be regarded as a nonstationary process. It should be noted that stationary and nonstationary random excitations can be Gaussian and non-Gaussian. Nonstationary random excitations are frequently modeled as the product of a deterministic function in the time domain and a stationary process. The deterministic function is exponential, sinusoidal, or an exponential envelope.

Damping. Three types of damping generally affect the dynamic response of an actual structure. The first type, ambient damping, is due to the surrounding fluid. The second type, material damping, is due to the internal friction of the structural material. Interface damping, the third type, arises as a result of the relative slippage of different parts of a structure that are fastened together with rivets and bolts. The last two types are collectively referred to as structural damping. Only structural damping is considered in this article.

The characteristics of structural damping are complicated, and no single adequate theory accurately describes its behavior. Most of the information about structural damping has been obtained from experimental studies. For material damping an empirical formula has been given [7] as

$$D = \left(\frac{s}{s_e}\right)^{2.3} + 6\left(\frac{s}{s_e}\right)^{8} \tag{1}$$

D is the specific damping, which is the energy loss per unit volume of the material per unit cycle; s is the stress-amplitude for the cycle; and s_e is the fatigue strength at 2×10^7 cycles for the material.

If material damping were linear, the specific damping D would be proportional to

$$\left(\frac{s}{s_e}\right)^{2}$$

Equation (1) indicates that material damping is not linear. Indeed, when stress amplitude is close to or greater than s_e material damping becomes highly nonlinear.

Another empirical formula [8] is

$$D = 0.7\left[\left(\frac{s}{s_e}\right)^{2} + 6\left(\frac{s}{s_e}\right)^{8}\right] \tag{2}$$

This formula closely represents the geometric mean of test data for a number of materials.

Interface damping depends heavily on existing pressure at the interface. Theoretically, energy dissipation due to this type of damping is zero for either zero or a large interface pressure and reaches a maximum value when the pressure is between the two extremes. This type of damping is essentially proportional to the third power of the applied force amplitude [9].

For most structural problems material damping accounts entirely for structural damping when the stress range is low. The reason is that, at low stress ranges, slippage at the joints does not occur. In such cases linear damping can be assumed. When the stress range is high, interface damping can be relatively significant. In finite element analysis the representation of damping in a structure can be a problem because it involves MDF systems. Knowledge in this area is very limited. A common practice is to assume the damping matrix as a linear combination of the inertia matrix and the stiffness matrix such that

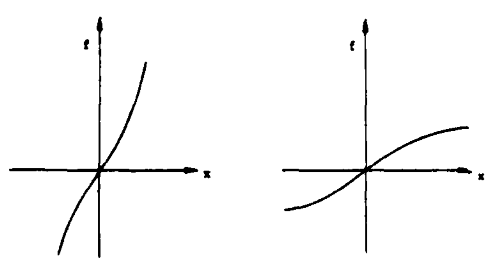
$$\underline{C} = \lambda_m \underline{M} + \lambda_k \underline{K} \tag{3}$$

where λ_m and λ_k are real constants.

Equation (3) is known as proportional damping, or Rayleigh damping. This form of representation cannot be applied to structures with widely varying material properties. For instance, in the analysis of foundation-structure interactions damping is non-proportional.

Nonlinearities. The most simple form of nonlinearity that can be dealt with analytically describes the nonlinear elastic behavior of a structure. Nonlinear elastic behavior can be hardening elastic or softening elastic as indicated by the force-displacement relationship in Figure 1(a) and 1(b) respectively. Hardening arises as a result of geometric nonlinearities and therefore associates with large elastic deflection. A softening elastic model can be used as a first approximation to the behavior of prestressed concrete [10], to characterize the behavior of an axially loaded column [11], or to describe the destabilizing effect of gravity on a simple structure [12].

Hardening and softening elastic systems can be modeled by means of a power series expansion of displacement or a piecewise linear representation [3]. The lowest order symmetric nonlinear power



(a) Hardening ning

Figure 1. Hardening Elastic and Softening Elastic Systems

series representation of an elastic system is the so-called Duffing oscillator; it has the following equation of motion

$$\ddot{x} + c\dot{x} + kx + \epsilon x^3 = f(t) \tag{4}$$

where c, k, and ϵ are respectively damping constant, stiffness, and small parameter; f(t), or simply f, is the stochastic excitation; x, $\dot{x}$, and $\ddot{x}$ are respectively the displacement, velocity, and acceleration.

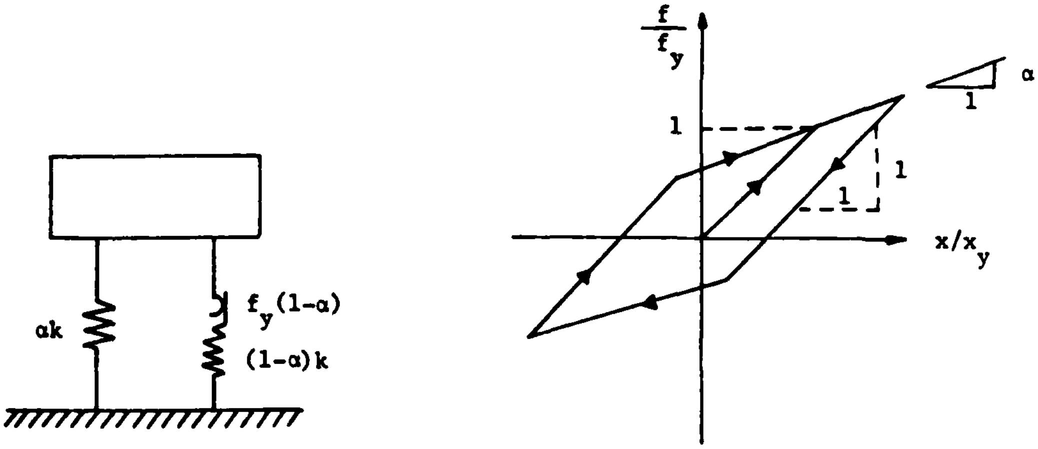
For a hardening elastic oscillator ϵ is positive. When ϵ is negative, equation (4) belongs to a softening elastic oscillator.

The most common form of nonlinearity involved in large amplitude oscillation of structures is associated with inelastic hysteretic behavior. Such nonlinearities are referred to as geometrical and material nonlinearities in the field of finite element analysis [13]. Inelastic hysteretic behavior can result from interface slip between adjacent elements or from yielding of various elements. The behavior is hysteretic in the sense that the generalized force depends upon the entire history of the generalized displacement and not just upon its instantaneous value [3]. In the field of earthquake engineering the simplest and most popular model is the bilinear hysteretic model, indicated in Figure 2.

Other models such as the limited slip hysteretic model associated with slip in riveted and bolted connections and some reinforced concrete structures; the double bilinear hysteretic model, which describes some features observed in wooden structures for which the hysteretic energy dissipation is less than that associated with bilinear hysteretic model; and the piecewise linear hysteretic model that was used in the study of structures with cross bracing [14] have been described [3].

METHODS FOR SINGLE-DEGREE-OF-FREEDOM SYSTEMS

In many cases a simple structure can be approximated as a single-degree-of-freedom system. Such a model frequently provides insight into the dynamic behavior of an actual simple structure. In this section methods used to analyze the response of SDF systems to random excitation are reviewed. The methods



(a) Physical idealization

(b) Generalized force-displacement behavior

Figure 2. The Bilinear Hysteretic Model

considered include statistical or equivalent linearization (SL) techniques, Fokker-Planck-Kolmogorov equation (FPKE) approaches, perturbation approaches, bilinear or two-state model methods, functional series representation approaches, and analog and digital simulation.

Statistical or equivalent linearization techniques. One general approximate method for the analysis of nonlinear dynamic systems to random excitation is the statistical or equivalent linearization (SL) technique; it was independently developed by Booton [15, 16] and Kazakov [17] in the field of control engineering and by Caughey [18] for mechanical and structural systems. In essence the techniques are generalizations of the deterministic linearization methods of Krylov and Bogoliubov [19] to the random case.

In the context of mechanical and structural systems the equation of motion for a SDF nonlinear oscillator is

$$\ddot{x} + g(x,\dot{x}) = f(t) \tag{5}$$

where $g(x,\dot{x})$ is an arbitrary nonlinear function of x and $\dot{x}$.

The underlying idea of the SL techniques is to replace the nonlinear oscillator by a linear one such that the behavior of the equivalent linear system approximates that of the original nonlinear oscillator. Equation (5) is thus replaced with the equivalent form

$$\ddot{x} + \beta\dot{x} + kx = f(t) \tag{6}$$

where β and k are the damping constant and stiffness of the equivalent linear oscillator respectively.

The problem is to find β and k. After they have been determined, the solution process x can be obtained using equation (6) by means of linear theory.

To illustrate the technique consider equation (5). Add $(\dot{x} + kx)$ to both sides of equation (5) and rearrange to obtain

$$\ddot{x} + \beta\dot{x} + kx = f + \xi \tag{7}$$

where $\xi = \beta\dot{x} + kx - g(x, \dot{x})$ can be considered as the error in the approximation procedure.

In order to best approximate the original nonlinear oscillator the error term ξ in equation (7) must be minimized. As ξ is a stochastic process, a common criterion is to minimize the mean square value of the error process. Hence,

$$\frac{\partial}{\partial \beta} \{E<\xi^2>\} = \frac{\partial}{\partial k} \{E<\xi^2>\} = 0 \qquad (8)$$

$E(\cdot)$ denotes the mathematical expectation operator. The quantities β and k are the solutions of the pair of algebraic equations

$$\beta\ E<\dot{x}^2> + k\ \ E<x\dot{x}> \ - E<\dot{x}g> = 0 \qquad (9a)$$

and

$$k\ E<x^2> + \beta E<x\dot{x}> \ - E<xg> = 0 \qquad (9b)$$

The solution for β and k in this form requires knowledge of the indicated expectations; but they are not easy to find because they generally require the unknown joint density function p(x,t; $\dot{x}$,t). At this point two approximations are possible [16, 18]. One replaces p(x,t; $\dot{x}$,t) by the stationary density function p(x; $\dot{x}$) computed from the original nonlinear equation (5). The other is to determine p(x; $\dot{x}$) approximately by using the linearized equation (6). Under this approximation equation (9) becomes nonlinear in β and k. If f(t) is stationary Gaussian with zero mean, the second alternative leads to the result that x and $\dot{x}$ are stationary independent Gaussian processes with the joint density function.

$$p(x;\dot{x}) = \frac{1}{2\pi\sigma_x\sigma_{\dot{x}}} \quad \exp\left[-\frac{1}{2}\left(\frac{x^2}{\sigma_x^2} + \frac{\dot{x}^2}{\sigma_{\dot{x}}^2}\right)\right] \qquad (10)$$

The variances σ_x^2 and $\sigma_{\dot{x}}^2$ are functions of β and k in general.

The SL technique has been used to examine the response of a Duffing oscillator to narrowband random excitation [20-22]. Richard [22] showed that jumping depends critically on the bandwidth of the excitation process. Iwan and Mason [23] applied the technique to a Duffing oscillator excited by modulated white noise. About the same time Ahmadi [24] applied the technique; he replaced the impulse response function of the original Duffing oscillator subjected to modulated white noise by the impulse response function of the equivalent linear system.

For systems with hysteresis the responses in equation (5) depend not only on the instantaneous value of x, $\dot{x}$, and $\ddot{x}$ but also on the history of the responses. Caughey [18, 25] applied a modified version of the SL technique to a nonlinear hysteretic oscillator. The method is based on the averaging principle of Krylov and Bogoliubov [19]. Central to this method is the assumption that the response motion resembles a sinusoid with slowly varying amplitude and phase; that is, the response is assumed to be narrowband in nature. This is true so long as the energy dissipation per cycle is relatively small. This averaging method with modifications was subsequently applied to oscillators having various kinds of hysteresis [26-29]. The method is related to some extent to Karnopp's power balance technique [30, 31]. It has been shown, however, [32] that the energy dissipation in hysteretic structures can sometimes be relatively large. The response process then has a wide-band character rather than the narrow-band behavior assumed in the Krylov and Bogoliubov averaging method. That is, the response process has a tendency to drift and does not undergo as many displacement reversals as in the sinusoid oscillator implied by the Krylov and Bogoliubov averaging technique. Consequently, the latter can seriously overestimate the energy dissipation capacity of a system. To overcome this difficulty Wen [33] proposed a method of SL for hysteretic systems having smooth restoring forces. In this method the nonlinear equation of motion is linearized directly in closed form without recourse to the Krylov and Bogoliubov technique. Wen described the hysteretic force g(x,$\dot{x}$) as

$$g(x,\dot{x}) = h(x,\dot{x}) + z(x) \qquad (11)$$

where h is the non-hysteretic component, which is a function of the instantaneous x and $\dot{x}$; z is the hysteretic component, which is a function of the time history of x; z is related to x through the following equation

$$\dot{z} = -\gamma|\dot{x}|\ z\ |z|^{n-1} - \beta\dot{x}\ |z|^n + A\dot{x} \qquad (12)$$

where γ, β, A, and n are constants.

Bonc [34] pointed out that equation (12) gives a hysteretic relationship between z and x when n = 1. Wen [35] pointed out that the constants can be adjusted to provide a wide range of hysteretic force characteristics such as softening or hardening or narrow- or wide-band systems. As has been indicated [33] γ and β control the shape of the hysteresis loop; A the restoring force amplitude, and n the smoothness of the transition from elastic to plastic response; for instance, a large value of n corresponds to an almost elasto-plastic system. Baker [36] has recently extended equation (12) to include nonzero mean random response of a yielding system.

Fokker-Planck-Kolmogorov equation approaches. These methods make use of the concept of the Markov process and are capable of providing exact solutions for the transition probability density function. The response process is assumed to be Markovian or one whose projection is Markovian; that is, the stochastic process itself is not Markovian but is a component of a vector Markov process such that the transition probability density function of the response $p(x,t;\ x_o,\ t_o)$ satisfies the diffusion equation

$$\frac{\partial p}{\partial t} = Lp \tag{13}$$

where

$$L = -\frac{\partial}{\partial x}\,[a(x,t)] + \frac{1}{2}\frac{\partial^2}{\partial x^2}\,[b(x,t)]$$

Equation (13) is sometimes called the second or forward Kolmogorov equation. It is also known as the Fokker-Planck, or Fokker-Planck-Kolmogorov, equation [37] as it appeared in the work of these physicists [38, 39].

Another equation satisfied by $p(x,t;\ x_o,\ t_o)$, which is the adjoint of equation (13), is

$$\frac{\partial p}{\partial t_o} = L^* p \tag{14}$$

where

$$L^* = -\frac{\partial}{\partial x_o}\,[a(x_o,t_o)] - \frac{1}{2}\frac{\partial^2}{\partial x_o^2}\,[b(x_o,t_o)]$$

Equation (14) is known as the backward Kolmogorov equation. In equations (13) and (14) the terms a and b are the derivate moments. The initial condition of equation (13) is

$$\lim_{t\to o} p(x,t;\ x_o,\ t_o) = \delta(x - x_o) \tag{15}$$

where δ is the Dirac delta function.

If the steady-state density $p(x;\ x_o) = \lim_{t\to\infty} p(x,t;\ x_o,t_o)$ exists, the solution of equation (13) is

$$Lp = 0 \tag{16}$$

Exact solutions have been given for systems whose excitations are stationary random [40-43] and the arbitrary nonlinear function $g(x,\dot{x})$ of equation (5) can be expressed as

$$g(x,\dot{x}) = \beta\dot{x} + h(x) \tag{17}$$

Exact solutions for systems including nonlinear damping such that

$$g(x,\dot{x}) = \beta\dot{x}\ w(E) + h(x) \tag{18}$$

where

$$E = \frac{\dot{x}^2}{2} + \int_o^x h\ (u)\ du,$$

have been obtained [44, 45].

An exact solution for a class of nonlinear second order systems subjected to white noise has recently been obtained by Caughey and Ma [46]. They pointed out that the approximate nonstationary response could be obtained by a perturbation analysis of Caughey and Payne [47].

The exact solution of equations (13) and (14) for general nonlinear oscillators subjected to stationary random excitation has not yet been found. Moreover, the exact solution of equations (13) and (14) when the oscillator is excited by a nonstationary random disturbance has also not yet been found. However, approximate solutions are available. The most powerful approximate technique in the context of FPKE methods for some practical nonlinear oscillators is the stochastic averaging method of Stratonovich [48]. It is a generalization of a deterministic averaging procedure [49]. Central to this technique is the assumption that the system is lightly damped so that the response processes are narrowband. The method is useful in dealing with systems that have nonlinear damping. Roberts [50] applied this method to the problem of the stationary response of oscillators with nonlinear damping to stationary random excitation. Spanos [51] and Kolomietz [52] also considered this problem and obtained results relating to the amplitude process. The problem was extended to include the case in which the excitation is a modulated white noise process [53]. The Van der Pol oscillator [54] has also been considered [53].

Another application of the stochastic averaging technique was to the response of a bilinear hysteresis oscillator to random excitation [55, 56]. The technique has been extended to an oscillator with both nonlinear damping and stiffness by Iwan and Spanos [57]. The resulting equation was solved by a perturbation technique [58]. The Duffing oscillator [58] and hysteresis oscillator [59] were considered. They [57] allowed for nonlinear stiffness effects through an amplitude dependent frequency [57]. A similar attempt was also made by Naprstek [60]. Ariaratnam [61] raised the question of consistency of the approximations of Iwan and Spanos [57]. The work of Naprstek [60] is thus open to similar question.

A different approach for oscillators with combined nonlinear damping and stiffness to stationary random excitation has also been developed [62-64]. In this approach the energy envelope of the system is approximated as a one-dimensional Markov process. Further application of the approach has also been made [65] for the transient response of oscillators with arbitrary nonlinear restoring forces to suddenly applied wide-band random excitation.

Other procedures for approximate solutions to the FPK equations have also been proposed. They include series expansion methods, the random walk analogy, and moment closure methods. Atkinson [66] used a series expansion method to estimate the correlation function and spectrum of the response of several oscillators. However, damping in the system was assumed to be non-zero. For zero damping the FPK equation became singular. A different eigenfunction expansion technique has been put forward [48]. A somewhat different eigenfunction-expansion method has been used for the steady-state solutions of a first order system [67] and a Duffing oscillator [68]. Another series expansion method has been suggested by Bhandari and Sherrer [69]. They dealt with a stationary solution $z(x,\dot{x})$ for an oscillator

$$z(x,\dot{x}) = \sum_{i}^{n} \sum_{j}^{n} a_{ij}\, H_i(x)\, H_j(\dot{x}) \quad (19)$$

H_i and H_j are related to the Hermite polynomials. They used the Galerkin method to determine the coefficients a_{ij}.

Wen [70] extended this Galerkin method and obtained nonstationary response statistics by allowing the terms in the series expansion to be time dependent. He further extended the method for hysteresis oscillators [35] by increasing the dimension of the FPK equation from two to three.

The random walk analogy [71-73] has been used [65] to solve for the transient response of nonlinear oscillators to suddenly applied wide-band excitations.

Finally, various closure methods have been proposed [74-81]. They assumed some relationship between the higher order moments and the lower order moments in the infinite set, or hierarchy, of coupled moment equations.

Perturbation approaches. In these approaches the stochastically excited nonlinear oscillator is treated in a similar manner as a deterministically excited oscillator. The nonlinearity must be sufficiently small that the solution can be represented as an expansion in powers of some small parameter that describes the size of the nonlinearity.

Consider the governing equation of motion for the oscillator

$$\ddot{x} + \beta\dot{x} + \omega_o^2\,[x + \varepsilon h(x)] = f(t) \quad (20)$$

The nonlinear function $h(x)$ is assumed to be differentiable with respect to x up to a suitable order; $f(t)$ is a random excitation.

The solution process x can be written as

$$x = x_o + \varepsilon x_1 + \varepsilon^2 x_2 + \ldots \quad (21)$$

where ϵ is the small parameter.

Substitute equation (21) into (20) and equate terms of the same power of ϵ.

$$\begin{aligned}
\ddot{x}_o + \beta\dot{x}_o + \omega_o^2 x_o &= f(t) \\
\ddot{x}_1 + \beta\dot{x}_1 + \omega_o^2 x_1 &= -\omega_o^2 h(x_o) \\
\ddot{x}_2 + \beta\dot{x}_2 + \omega_o^2 x_2 &= -\omega_o^2 x_1 h'(x_o) \\
\vdots \qquad & \qquad \vdots
\end{aligned} \quad (22)$$

where $h'(x_o)$ is the derivative of $h(x)$ evaluated at $x = x_o$. Equation (22) indicates that every term in the expansion of x satisfies a linear differential equation with a random input. Therefore, the nonlinear problem is reduced to solution of a set of linear random differential equations. This approach was first proposed by Crandall [82] for the steady-state solution of nonlinear systems to stationary random excitation. This technique [8] was used to obtain moments of response of oscillators with nonlinear damping. This technique has also been used to study the spectrum of the response of a nonlinear oscillator to stationary excitation [83-87].

Two observations should be made at this point. First, it is practically impossible to extend this procedure beyond the first approximation except in trivial cases because the probability density of the first-order correction term is non-Gaussian. Second, no proof is available to show that the random process x in equation (21) is convergent in the mean square or in any other sense. Thus, the perturbation technique hinges on the assumption that every sample function of the solution process x can be represented by a convergent series in power of ϵ.

Bilinear model approaches. The bilinear model approach is also called the two-state approach. It is possible with this technique to compute such response quantities as the yielding increment, the permanent set, dissipated energy, and crossing rates of an elastic-plastic oscillator. The idea of this approach is to separate the elastic and plastic parts of the response so that they can be analyzed as two linear oscillators. It should be pointed out that this technique can be applied only to structures involved with small strain deformation. For finite strain deformation the response cannot be simply separated into the elastic and plastic parts [88, 89]. The original approach was proposed by Karnopp and Scharton [30]. Vanmarcke [90] later presented a technique for calculating the response of elastic-plastic systems by using an estimate for the yield increment -- that is, the amount of yielding during one yield event -- that was first introduced by Karnopp and Scharton [30]. Vanmarcke [90], Iyengar and Iyengar [91], and Grossmayer [92] disregarded the drift -- that is, the instantaneous permanent displacement of the system associated with one located at a frequency much below the nominal frequency -- of the two peaks of the response power spectral density function observed in analog computer studies [32]. An improved version [93, 94] included the drift phenomenon and changes in effective structural stiffness and damping properties due to yielding. Gaussian white noise and filtered noise inputs were also considered.

Functional series approaches. For a linear oscillator excited by a random load f(t) the response x(t) is given by the convolution integral

$$x(t) = \int_{-\infty}^{\infty} h(\tau) f(t-\tau) d\tau \qquad (23)$$

where h is the impulse response function of the oscillator.

A generalization of equation (23) has been given [95-98] for nonlinear oscillators the response of which is

$$x = \sum_{i=1}^{\infty} \frac{1}{i!} \int_{-\infty}^{\infty} dt_1 \ldots \int_{-\infty}^{\infty} dt_i \, h_i(t_1,\ldots,t_i) \prod_{r=1}^{i} f(t-t_r) \qquad (24)$$

The kernel h_i can be regarded as the i'th degree impulse response function.

For a time-invariant oscillator the kernels h_i depend only on time differences and are completely symmetrical in their arguments [96, 97]. Equation (24) is usually called a Voltera series expansion for systems with memory; that is, the output of a nonlinear system is expressed as powers of the input.

The series has been truncated at i = 3 and the results compared with simulated ones [98]. This suggests that the approach using series truncated at i = 3 was useful for small degrees of nonlinearity [98]. For moderate and strong nonlinearities higher terms in equation (24) must be considered.

Analog and digital simulation approaches. Analog and digital simulation procedures have generally been used for two reasons. They are used in situations for which analytical methods is not available. Second, they are used to verify analytical results.

A large number of samples is needed to reduce statistical uncertainty of simulated results to acceptable limits. This makes simulation procedures unattractive for nonstationary nonlinear problems because an ensemble averaging is necessary. One analog simulation approach is to use a random signal generator and filters to generate the excitation and an analog computer system to produce the output [32, 99-101].

Digital simulation procedures are now popular mainly due to their capability for increased mathematical sophistication and availability. Roberts [62-64] and Spanos [54] applied digital simulation techniques to nonlinear oscillators excited by white noise. Iwan and Mason [23] used digital simulation to verify the results of a SDF oscillator to modulated white noise excitation.

METHODS FOR MULTI-DEGREE-OF-FREEDOM SYSTEMS

Many practical engineering structures require a MDF approximation to describe their dynamic behavior, especially when the finite element method is used to discretize the structure in the spatial domain. In this section methods used to analyze the response of MDF systems to random excitation are reviewed. The methods include SL tehniques, FPKE approaches, normal mode approaches, perturbation techniques, and simulation procedures. *Apart from normal mode* approaches, the methods considered in this section are generalization of their counterparts for SDF systems.

Statistical linearization techniques. The SL techniques described for SDF systems can easily be extended to handle MDF nonlinear systems. A number of generalized formulations for the steady-state solution of discrete MDF systems to stationary random excitation have been proposed [2, 33, 102-113]. The work of Beaman and Hedrick [110-112] improved the accuracy of the Gaussian SL technique by making use of the Gram-Charlier expansion. The so-called second-order SL technique for MDF nonlinear systems [113] can handle a wider range of nonlinearities than first-order SL techniques.

Formulations for response of MDF nonlinear systems to nonstationary excitation have been presented [23, 114-120]. Certain formulations [115, 120] apply to asymmetric MDF nonlinear systems.

Consider the stochastic matrix equation of motion for the MDF nonlinear system

$$\underline{M}\,\ddot{\underset{\sim}{x}} + \underline{C}\,\dot{\underset{\sim}{x}} + \underline{K}\,\underset{\sim}{x} + g(\underset{\sim}{x},\dot{\underset{\sim}{x}}) = \underset{\sim}{e}(t)\; w(t) \tag{25}$$

where

$\underline{M}$, $\underline{C}$ and $\underline{K}$ are the assembled linear mass and damping and stiffness matrices respectively

$\ddot{\underset{\sim}{x}}$, $\dot{\underset{\sim}{x}}$, and $\underset{\sim}{x}$ are the acceleration, velocity, and displacement response vectors of the MDF nonlinear system

$g(\underset{\sim}{x},\dot{\underset{\sim}{x}})$ is the nonlinear term

$\underset{\sim}{e}(t)$ is the time-dependent deterministic vector

$w(t)$ is the Gaussian white noise process

For asymmetric MDF nonlinear systems such as those involving sloshing in liquid-filled tanks during earthquakes and the vibration of trolley wires under wind loads

$$g(\underset{\sim}{x},\dot{\underset{\sim}{x}}) \neq -g(-\underset{\sim}{x},-\dot{\underset{\sim}{x}}) \tag{26}$$

Because of the asymmetry the solution of equation (25) might not have a zero mean value.

Fokker-Planck-Kolmogorov equation approaches. For n-degree-of-freedom nonlinear systems equation (13) can be generalized as follows

$$\frac{\partial p}{\partial t} = \underset{\sim}{L} p \tag{27}$$

The transition probability density function is

$$p(\underset{\sim}{x},t;\ \underset{\sim}{x}_o,t_o);$$

$$\underset{\sim}{L} = -\sum_{i=1}^{n} \frac{\partial}{\partial x_i}[a_i(\underset{\sim}{x},t)] + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{\partial^2}{\partial x_i \partial x_j}[b_{ij}(\underset{\sim}{x},t)];$$

$\underset{\sim}{x}$ and $\underset{\sim}{x}_o$ are vectors of displacement response at time t and t_o respectively.

The initial conditions of equation (27) are

$$\lim_{t \to o} p(\underset{\sim}{x},t;\ \underset{\sim}{x}_o,t_o) = \delta(\underset{\sim}{x} - \underset{\sim}{x}_o) \tag{28}$$

If the steady-state density $p(\underset{\sim}{x},t;\ \underset{\sim}{x}_o,t_o) = \lim_{t\to\infty} p(\underset{\sim}{x},t;\ \underset{\sim}{x}_o,t_o)$ exists, the solution of equation (27) is

$$\underset{\sim}{L}\, p = 0 \tag{29}$$

The adjoint of equation (27) is

$$\frac{\partial p}{\partial t_o} = \underset{\sim}{L}^{*} \, p \tag{30}$$

where

$$\underset{\sim}{L}^{*} = - \sum_{i=1}^{n} \frac{\partial}{\partial y_i} [a_i(\underset{\sim}{y}, t_o)] - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial^2}{\partial y_i \partial y_j} [b_{ij}(\underset{\sim}{y}, t_o)]$$

$$\underset{\sim}{y} = \underset{\sim}{x}_o$$

Exact steady-state solutions of MDF nonlinear systems to stationary excitation have been given [44, 121-125].

Caughey and Ma [126] recently obtained exact steady-state responses for a wide class of MDF nonlinear systems to white noise excitation. They indicated that the approximate nonstationary response can be obtained by a perturbation analysis [47].

Normal mode approaches. The purpose of the normal mode approaches is to reduce a given set of generally coupled nonlinear second order stochastic differential equations to one that contains coupling only in the nonlinear terms.

Consider the equation of motion for the MDF nonlinear system

$$\underline{M}\,\ddot{\underset{\sim}{x}} + \underline{C}\,\dot{\underset{\sim}{x}} + \underline{K}\,\underset{\sim}{x} + \varepsilon\, g(\underset{\sim}{x}, \dot{\underset{\sim}{x}}) = \underset{\sim}{F}(t) \tag{31}$$

where $\underline{M}$, $\underline{C}$, $\underline{K}$, $g(\underset{\sim}{x},\dot{\underset{\sim}{x}})$, $\underset{\sim}{x}$, $\dot{\underset{\sim}{x}}$, and $\ddot{\underset{\sim}{x}}$ are defined in equation (25); $\underset{\sim}{F}(t)$ is the applied random excitation vector; ϵ is a small parameter.

Apply the transformation

$$\underset{\sim}{x} = \underline{R}\,\underset{\sim}{q} \tag{32}$$

Perform the usual uncoupling procedure to obtain

$$\ddot{\underset{\sim}{q}} + \underline{\beta}\dot{\underset{\sim}{q}} + \underline{\Omega}\underset{\sim}{q} + \varepsilon \underline{R}^T g(\underset{\sim}{x}, \dot{\underset{\sim}{x}}) = \underset{\sim}{P}(t) \tag{33}$$

where

$$\underline{\Omega} = \underline{R}^T \underline{K}\, \underline{R},$$

$$\underline{\beta} = \underline{R}^T \underline{C}\, \underline{R},$$

$$\underset{\sim}{P}(t) = \underline{R}^T \underset{\sim}{F}(t)$$

The superscript T designates "the transpose of." The reduced equation (33) can be solved by using some approximate techniques. Grossmayer's two-state approach [92] belongs to this category.

Perturbation techniques. The extension of the perturbation techniques for discrete MDF nonlinear systems has been proposed by various investigators [82, 127-129]. The transient response of MDF nonlinear system to stationary random excitation has also been studied [129].

The major difficulty in using these techniques is solving the equation for the first-order correction term. The reason is that this equation generally has a non-Gaussian excitation. This difficulty can be identified by considering the equations of motion, equation (31). When ϵ is sufficiently small, the solution to equation (31) can be approximated by

$$\underset{\sim}{x} = \underset{\sim}{x}_o + \varepsilon\, \underset{\sim}{x}_1 + \dots \tag{34}$$

Substitute equation (34) into (31), rearrange, and disregard terms associated with ϵ^2 and higher powers of ϵ to obtain

$$\underline{M}\,\ddot{\underset{\sim}{x}}_o + \underline{C}\,\dot{\underset{\sim}{x}}_o + \underline{K}\,\underset{\sim}{x}_o = \underset{\sim}{F} \tag{35}$$

and

$$\underline{M}\,\ddot{\underset{\sim}{x}}_1 + \underline{C}\,\dot{\underset{\sim}{x}}_1 + \underline{K}\,\underset{\sim}{x}_1 = - g(\underset{\sim}{x}_o, \dot{\underset{\sim}{x}}_o) \tag{36}$$

According to the response in equation (34), the auto-correlation of $\underset{\sim}{x}$ is

$$E\langle \underset{\sim}{x}\, \underset{\sim}{x}^T \rangle = E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_o^T \rangle + \varepsilon E\langle \underset{\sim}{x}_1\, \underset{\sim}{x}_o^T \rangle + \varepsilon E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_1^T \rangle .$$

But, $E\langle \underset{\sim}{x}_1\, \underset{\sim}{x}_o^T \rangle = [E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_1^T \rangle]^T$. Therefore, (37)

$$E\langle \underset{\sim}{x}\, \underset{\sim}{x}^T \rangle = E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_o^T \rangle + \varepsilon \{ [E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_1^T \rangle]^T + E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_1^T \rangle \}$$

$E\langle \underset{\sim}{x}_o\, \underset{\sim}{x}_o^T \rangle$ can readily be determined as equation (35) is linear.

Assume the impulse response function matrix $\underline{h}(t)$

$$\underset{\sim}{x}_o = \int_{-\infty}^{\infty} \underline{h}\,(t-\tau)\, \underset{\sim}{F}\,(\tau)\, d\tau \tag{38}$$

Therefore,

$$E\langle \underset{\sim}{x}_o \underset{\sim}{x}_o^T \rangle = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \underline{h}(t-\tau_1)\, \underline{h}^T(t-\tau_2) \tag{39}$$

$$E\langle \underset{\sim}{f}(\tau_1)\, \underset{\sim}{f}^T(\tau_2) \rangle \, d\tau_1 \, d\tau_2 .$$

Because $\underline{M}$, $\underline{C}$, and $\underline{K}$ are common in equations (35) and (36), the impulse response function matrix of equation (36) is identical to $\underline{h}(t)$ for equation (35). Thus,

$$E\langle \underset{\sim}{x}_o \underset{\sim}{x}_1^T \rangle = -\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \underline{h}(t-\tau_1)\, \underline{h}^T(t-\tau_2) \tag{40}$$

$$E\langle \underset{\sim}{f}(\tau_1)\, g[\underset{\sim}{x}_o(\tau_2),\ \dot{\underset{\sim}{x}}_o(\tau_2)] \rangle d\tau_1 \, d\tau_2$$

Substitute equations (40) and (39) into equation (37); the auto-correlation of $\underset{\sim}{x}$ can be obtained. Because of the term

$$E\langle \underset{\sim}{f}(\tau_1)\ g[\underset{\sim}{x}_o(\tau_2),\ \dot{\underset{\sim}{x}}_o(\tau_2)] \rangle$$

equation (40) is difficult to operate in general. Tung [127] attacked this difficulty by using Foss method [130].

Simulation procedures. Digital simulation of multidimensional and multivariate processes of nonlinear structures has been presented [131-134] as has a nonlinear panel response to nonstationary wind forces [135]. These techniques can readily be applied to discrete MDF systems. Algorithms for generating sample functions of the response directly can be developed if the nonlinear system is excited by white noise [134]. One example problem [134] indicated that, to provide an accurate value such as the variance of the displacement response, 5000 samples are required. This implies that, for large number-of-degree-of-freedom systems – such as are frequently encountered in finite element analyses – computational costs can be formidable. When the number of degree of freedom of a nonlinear system is large and the excitation is nonstationary, simulation is not economically feasible.

AN APPRAISAL OF EXISTING METHODS FOR APPLICATION TO DISCRETIZED NONLINEAR STRUCTURES

Over the last 20 years a great deal of effort has been devoted to solutions for problems of nonlinear mechanical and structural systems excited by random disturbances. Five categories of techniques can be applied to the random analysis of the response of MDF nonlinear systems. Assuming the structural model adequately resembles the actual system, an immediate concern in the analysis is the question of accuracy. Because this paper emphasizes methods applied to MDF nonlinear systems subjected to nonstationary random excitation, only the accuracy of SL techniques, FPKE approaches, normal mode approaches, perturbation approaches, and simulation methods are discussed below.

Accuracy of statistical linearization techniques. Iwan and Yang [105] assessed the accuracy of the SL technique using cubic hardening and softening MDF systems subjected to white noise. The assessment applied only to SDF nonlinear oscillators. For the cubic hardening oscillator Atalik and Utku [136] proved that the error in using the direct SL technique to calculate the mean square displacement was 14.6% with respect to the exact solution. The error was independent of the nonlinear parameter. This finding agrees with that presented by Iwan and Yang [105]. Atalik and Utku [136] have also shown that the mean square equation error $E\langle \xi^2 \rangle$ was also unbounded as the nonlinearity parameter reached infinity. They showed that, for an oscillator with a particular nonlinear damping, the error for the mean square velocity was 11.4% with respect to the exact solution. For this case the mean square equation error $E\langle \xi^2 \rangle$ was also unbounded as the nonlinearity parameter reached infinity.

For systems with a very small nonlinearity, perturbation solutions are available for comparison. Crandall [83] considered the spectrum of the response of an oscillator with a small degree of nonlinear stiffness. He found that the results of SL and perturbation methods were identical to the first order in the nonlinearity parameter. Similar findings have been obtained for oscillators with nonlinear damping [45, 50]. Payne [137] showed that the SL method was not correct to the second order in the nonlinearity parameter.

Beaman [138] showed that the variances predicted by SL techniques were lower bounds for the actual variances in a class of Hamiltonian-like systems. Included in this class of systems is the general nonlinear mass-spring-damper oscillator.

Many authors [32, 33, 50, 114, 115, 120] have compared results obtained by the SL techniques with analog and digital simulated values. These comparisons indicated that SL techniques were sufficiently accurate for the cases considered and could be satisfactory for general engineering purposes. The existence and uniqueness of solutions has been considered [109].

The formulations by Iwan and Mason [23] and Spanos [120] can be considered the most general with regard to their adoption in the finite element analysis of nonlinear structures excited by nonstationary random disturbances. However, questions remain with regard to their applicability to the finite element analysis of nonlinear structures involving large deformation and finite strain.

Accuracy of FPKE approaches. One major attraction of these approaches is their ability to provide exact solutions. Only steady-state exact solutions of a rather wide class of MDF nonlinear systems to white noise excitation are available [126]. However, the nonstationary solution of MDF nonlinear systems to nonstationary stochastic excitation has yet to be found.

In general the FPKE approaches are difficult and computationally not feasible to apply to structures discretized by the finite element method. The reason is that the nonlinear terms associated with the set of second order differential equations of motion must be explicitly expressed in terms of displacement and velocity responses. Much work remains to be done in this area.

Accuracy of normal mode approaches. These methods can incorporate arbitrarily large nonlinearity terms in MDF systems. The set of coupled nonlinear equations of motion for an MDF nonlinear system is reduced to one containing coupling only in the nonlinear terms. The major assumption in these approaches is the question of existence of normal modes of vibration. In the deterministic case Rosenberg [139, 140] addressed this question. Rigorous stochastic equivalence on this question has yet to be found.

These methods have the potential to be applied to nonlinear structures with large deformation and finite strain in the context of finite element analysis. There are, however, two penalties. The first is associated with structures discretized into a very large number of degrees of freedom such as one with tens of thousands of degrees. The task of finding accurate normal modes for a nonlinear structure with a very large number of degrees of freedom can be difficult and expensive. The frontal, or wave, method [141-143] can be used to assemble and reduce the equations at the same time and thus improve the problem. The other penalty is associated with large deformation and finite strain because the eigenvalue solution for the governing matrix equation of motion must be obtained at every discrete time step.

Accuracy of perturbation methods. Perturbation methods can be applied to MDF nonlinear systems with a small nonlinearity parameter. For SDF systems with a very small nonlinearity parameter Crandall [83] showed that results for the spectrum of the response were identical to the first order of the nonlinearity parameter to those obtained by using the direct SL method. For MDF nonlinear systems the amount of algebraic effort required to obtain the solution is enormous [127].

Simulation methods. Results obtained by analog and digital approaches are frequently compared to those using analytical means. Harris [134] showed that 5000 samples were required to provide accurate results. His graphs [134] indicated that considerable discrepancy can occur between theoretical and simulated results with 2500 samples in the simulation.

CONCLUSIONS AND RECOMMENDATIONS

The main objective of the investigation reported here was to provide an updated review of the state of the art of techniques used for the random analysis of the response of general nonlinear mechanical systems to random excitation. Special attention has been paid to methods applied to multi-degree-of-freedom nonlinear systems subjected to nonstationary random excitation. Their suitability and adaptability to finite element analysis of complicated nonlinear structures with large deformation and finite strain have been assessed. The following points are noteworthy.

The statistical linearization techniques presented by Iwan and Mason [23] and Spanos [120] can be considered the most promising with regard to their suitability and adaptability to finite element analysis of nonlinear structures excited by nonstationary random disturbances. However, the question remains with regard to their applicability to structures involving large deformation and finite strain. The Fokker-Planck-Kolmogorov equation approaches in their present forms are difficult and not computationally feasible for application to discretized nonlinear structures excited by nonstationary random excitations.

The normal mode approaches have the potential to be applied to the random analysis of discretized nonlinear structures with large deformation and finite strain. However, when the number of degrees of freedom is large, these methods can be expensive. The perturbation methods can be applied only to discretized structures with small nonlinearities.

In order to provide reliable results simulation methods can be just as expensive as normal mode approaches for nonlinear systems with a large number of degrees of freedom to nonstationary random excitations.

With these points in mind it is recommended that immediate future studies be directed at applying combinations of existing methods -- such as the normal mode and Fokker-Planck-Kolmogorov equation approach -- in conjunction with the stochastic averaging technique of Stratonovich for discretized nonlinear structures involving large deformation and finite strain to nonstationary random excitation.

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NOTATION

In addition to the notation defined in what follows, symbols have been defined throughout the paper whenever necessary for clarity.

A	constant
a	parameter
$a(x,t)$	the derivate moment
b	parameter
$b(x,t)$	derivate moment
$\underline{C}$	assembled damping matrix of the discretized structure
c	damping constant or the coefficient of viscous damping
D	specific damping
$E\langle\cdot\rangle$	statistical average or mathematical expectation of the appropriate variable
$\underset{\sim}{e}(t)$	time-dependent deterministic vector or envelope vector or modulating function vector
$\underset{\sim}{F}$ or $\underset{\sim}{F}(t)$	applied random excitation vector
f or $f(t)$	applied random excitation per unit mass
f_y	applied force that causes the system to yield
$g(\underset{\sim}{x},\underset{\sim}{\dot{x}})$	nonlinear function of $\underset{\sim}{x}$ and $\underset{\sim}{\dot{x}}$
$g(x,x)$	nonlinear function of x and $\dot{x}$
$H_i(x), H_j(x)$	function related to the Hermite polynomials
$h(x,\dot{x})$	non-hysteretic component of the hysteretic force
$h(x)$	nonlinear function of x
$h(t)$	impulse response function
i	integer
j	integer

$\underline{K}$	assembled stiffness matrix
k	stiffness or spring constant per unit mass
$\underset{\sim}{L}$	operator vector
L	operator
$\underline{M}$	assembled mass matrix
m	mass of the oscillator
$\underset{\sim}{P}(t)$	random excitation vector
$p(\underset{\sim}{x},t;\underset{\sim}{x}_0,t_0)$ or $\underset{\sim}{p}$	transition probability density function
$\underset{\sim}{q}$	vector of the generalized coordinates
$\underline{R}$	transformation matrix
s	stress amplitude for the cycle
t	time variable
w(E)	function of E
w(t)	Gaussian white noise process
$\underset{\sim}{x}$	response vector of the structure
x_y	response at yielding
x	response of the oscillator
z(x)	hysteretic component of the hysteretic force
α	constant parameter
β	constant parameter; coefficient of viscous damping per unit mass
γ	constant parameter
δ	Dirac delta function
ϵ	size of nonlinearities or constant parameter
ξ	error in the approximation or the equation error
ω_0	natural frequency in radians per second
ω	applied angular frequency.

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BOOK REVIEWS

DYNAMICS OF VEHICLE COLLISIONS

R.H. Macmillan
Inderscience Enterprises, Ltd., Channel Islands, UK
1983, 141 pages, $50.00

This publication, one of a series in Technological Advances in VEHICLE DESIGN, presents a detailed, analytical treatment of many aspects of vehicle motions; emphasis is on the dynamics of vehicle impact. The author develops the necessary equations based on simplifying but reasonable assumptions; he presents numerical examples to illustrate application of the equations. Tables and graphs show the effect of selected parameter changes on response variables.

The presentation is broken down into nine chapters; a helpful list of notations and symbols is given at the end. A selective listing of 16 references related to the subject of automotive collisions is also included.

The first chapter addresses the basic equations for central and oblique impact between two vehicles and introduces the concepts of coefficient of restitution (e) and tangential impulse factor (λ). Special cases considered for frontal impact include inelastic ($e = 0$) vs elastic ($e = 1$), struck vehicle stationary ($V_1 = 0$), and impact into a fixed block ($M = \infty$). Special cases considered for oblique impact include frontal angular impact into a fixed barrier, symmetrical collision of two vehicles at an angle, and a partial frontal head-on collision. The general equations and reduced equations for each case are derived; numerical examples illustrate the procedures.

Chapter Two covers energy conversion and transfer in single vehicle rigid barrier impact and in two car head-on and oblique impacts. Sixteen energy expressions are derived and numerically illustrated for a typical oblique impact; data are presented in metric units. The effects of varying the coefficient of restitution (e) and the tangential impulse factor (λ) are presented in tables that show the energy parameters as monotonically varying functions of e and λ.

In Chapter Three the crushing process (in the time domain) is discussed in detail; in contrast, the previous chapters were primarily concerned with the initial and final states of the collision. The author establishes a mathematical model for representative vehicle acceleration-time histories; this model is easily differentiated (with respect to time) and has two variables that can be assigned values to vary the acceleration-time curves. Various crash-related parameters are introduced, such as the structural index (β_0), crush modulus (C_m), impact resistance factor (K_r), mean force ($\bar{P}$), and impact number (N_i). These parameters are combined into nondimensional groups; graphs and tables show the variation of one group against another for various values of e and λ. The inverse problem of predicting the crush and other crash parameters when a vehicle of known impact characteristics hits a fixed barrier is also addressed.

Chapter Four continues the analytical treatment of the crushing process and presents test data to support the validation of the acceleration-time model for frontal barrier impact. A non-dimensional force-crush curve is derived from the acceleration-time curve model with the specified assumption that it is independent of the rate of strain; i.e., it is the same in a 30 MPH impact as in a static test. Derivations of upper and lower limits for the various impact constraints are based on a range of vehicles in the assumed road environment.

Chapter Five applies to central and oblique impacts between two vehicles. Pertinent combined parameters are defined, equations are developed, and solutions for cases of known crush or known speed are given in detail; numerical examples are given. Limiting cases of elasticity/plasticity, rigid vehicle, and rigid barrier are addressed; the equivalent rigid moving barrier or fixed flexible structure characteristics to simulate a vehicle-to-vehicle collision are derived. An elliptical function for the crush constant is assumed for use in oblique frontal impact. Finally vehicle aggressivity is defined (in terms of vehicle damage) and an index of aggressivity (I_a) is proposed.

Belt restraint systems performance is analyzed in Chapter Six in terms of four phases (I - belt slack, II - to vehicle rebound, III - to belt slackening, IV - occupant rebound). A single mass model for the occupant is assumed, with an acceleration-time function similar in mathematical form to that used for the vehicle in Chapter Two. A numerical example illustrates the use of the derived equations.

Chapter Seven on restraint system operation considers the effects of belt stiffness and initial slackness on the prevention of occupant contact with the vehicle interior while limiting occupant deceleration to an acceptable value. Equations are derived and pertinent response parameters are plotted. An interesting section addresses cargo load restraint in a commercial vehicle. An index of protectivity (I_p) is defined that, when appropriately combined with the vehicle aggressivity index (I_a), yields a proposed vehicle safety index (I_s). Recommendations to vehicle designers to maximize the vehicle safety index are presented.

Chapters Eight and Nine cover non-collision factors relating to movement on the road and vehicle rotation. These analyses are concerned with single vehicle dynamics pertinent to accident investigation and reconstruction. Analyses include speed estimation from skid marks, collision avoidance factors, braking on a slope, the effects of locked or free wheels, banked curves, and impact with curbs.

This publication is recommended for senior or graduate students in automotive engineering, theoretic mechanics, or physics as a supplement to the more usual treatment of the dynamics of moving bodies. Graduate students who critically review the assumptions made, particularly as they relate to the broader range of current American cars, may find fertile areas for thesis research. The practicing engineer involved in automotive safety design will find the collection of formulas invaluable as a ready reference source.

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ELASTOMERE FEDERUNG, ELASTISCHE LAGERUNGEN

W. Battermann and R. Köhler
Verlag W. Ernst & Sohn, Berlin München
1982, 132 pages, 49.00 DM (in German)

The purpose of this book is to provide the user of rubber and rubber elements with data useful in the design of such elements and in their optimal use in mechanical systems and civil engineering structures. Natural and synthetic material rubbers are available in a wide range of properties and geometric shapes for use as springs, bearings, and shock and vibration absorbers. Information about the mechanical behavior of rubber and rubber elements and the fundamentals of the vibration theory of mechanical systems are being applied to new solutions to design and noise reduction problems.

Chapter 1 contains a general description of the mechanical behavior of elastomeric materials based on their chemical structure; mechanical testing methods according to DIN norms; data on such mechanical properties as moduli, creep, relaxation, strength, longtime behavior, abrasion, and temperature dependence; and data on resistance to such environmental influences as chemicals, vapors, illumination, and micro-organisms. Chapter 2 shows qualitatively the influence of edge effects on stress distribution in compression and tension at large deformations. Data on strength in compression, tension, and shear for different shape factors are presented.

Chapter 3 treats the general characteristics of elastomeric tension and shear and compression springs; i.e., tension vs strain, modulus vs hardness, sample modulus vs shape factor. Material damping and various damping measures are also mentioned.

Chapter 4 gives the force-displacement characteristics of commonly used industrial rubber elements that are especially useful in vibration applications. In most applications of elastomeric materials the deformations are orders of magnitude larger than for classical engineering materials; therefore, nonlinear behavior is very important. Basic concepts from the theory of finite elasticity would be useful in understanding the complex characteristics of rubber elements.

The first section of Chapter 5 contains some elements of vibration theory related to the use of rubber elements as bearings for vibration isolation. Emphasis is on coupled modes in multiple-element suspension systems. In the next section the shock isolation problem is treated in some detail; formulas and monograms for the design and choice of a rubber spring for use as a shock isolation element are given. Possibilities for reducing transmitted high frequency vibrations (Körperschall) in structures using rubber pads are briefly discussed and some empirical formula are given. The next section contains data on pneumatic rubber elements. The last section describes applications of elastomer bearings in civil engineering.

The reviewer has the following critical remarks. Treatment of the problem of time-dependent material behavior is superficial. Many elastomers have considerable material damping; i.e., behave as visco-elastic bodies. The reviewer finds, however, that the authors' intention to present essential information on the design and use of elastomeric materials and elements in a condensed and well-presented form has largely been met.

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DYNAMIC ANALYSIS OF OFFSHORE STRUCTURES -- RECENT DEVELOPMENTS

C.L. Kirk, Editor
Gulf Publishing Co., Houston, TX
1982, 122 pages, $29.95

Dynamic behavior of offshore structures in deep-water ocean environments is important in design procedures. Motions arising as a result of interaction between waves, currents, and wave forces require comprehensive theoretical analysis and model tests. This volume consists of 12 interesting papers on dynamics associated with offshore structures.

The initial paper introduces the interaction of fluid and structure in offshore structures. Fluid viscosity effects are negligible; the structure is denoted by the dry modes. Free surface and three-dimensional fluid flow effects are kept in the analysis. The boundary integral method is used to compute the frequency-dependent matrices. Results of wave-excited dynamic response of offshore structures using dry modes and conventional strip theory compared well with those of wet modes.

The second paper discusses sensitivity analysis for steel jacket offshore platforms. The analysis focuses on responses to variation in wave height, uncertainties in wave period to associated wave height, choice of hydrodynamic force coefficients C_M and C_D, and changes in deck mass and hysteretic structural damping. Numerical solutions are accompanied by detailed accounts of the uncertainties.

The third paper treats the sloshing of liquids in storage tanks of offshore structures. The sloshing affects both natural frequencies and damping. Analytical methods are used to predict the new frequencies and damping. Supporting studies of a U.S. Coast Guard Diamond Shoals Light Station were used to compare analysis and test.

The next paper presents exact and hybrid-element solutions for the vibration of thin elastic structures seated on the sea floor. Exact solutions using linear acoustic and beam theories are utilized in several cases; approximate solutions were previously applied. A hybrid element method founded on a localized variational principle is numerically applied to a beam dam. This is then extended to an arbitrary two-dimensional elastic structure.

The fifth paper describes a computer simulation study of offshore collisions and analysis of ship-platform impacts. The objective of this study was to acquire information about probabilities of and results of collisions to allow development of rational design criteria that consider realistic-impact forces, energy distribution, and protective means for offshore structures fixed in the deep sea.

The next paper treats drift oscillations of a ship in irregular waves. The horizontal slow drift excitation forces on an infinitely long horizontal beam in irregular sea waves are first calculated. The hydrodynamic boundary value problem is resolved for a second order wave amplitude. Newman's approximate method is a good procedure for calculating the slow drift excitation forces on a ship at sea. It can be used to calculate slow drift excitation forces for the more general case.

The seventh paper reports on three-dimensional Fourier analysis of drag force-compliant offshore structures. A good representation of the drag is necessary if the quasi-linear spectral approach is to be used in the evaluation of the response of a three-dimensional compliant structure to ocean waves.

The next paper considers hydrodynamic coefficients for a vertical tube in an array. The tubes are arranged transverse to the wave direction. The effect of tube spacing on the forces determines the mass and drag coefficients. These forces are based upon the mean values of the hydrodynamic coefficients. The correlation between calculated and measured forces was good.

The next two papers treat the random dynamic response of a tethered buoyant platform production riser and the dynamic and static analysis of a marine riser. The former employs the normal mode spectrum analysis for calculating the rms riser deflection, bending stresses, and lower ball joint angle. A static analysis is also included for determining the bending stresses due to wave and current-induced forces. The latter paper employs a frequency domain normal mode to ascertain the dynamic response of an unbuoyed marine riser subjected to periodic excitation due to a surface vessel. A solution is obtained by an iteration procedure of the frequency response function. Favorable comparison exists between results obtained by this method and those obtained by other methods.

The eleventh has to do with two-dimensional problems of wave transformation due to motion of moored floating objects. The authors use Green's identity formula for a potential function and show good correspondence between theory and experiment, provided the damping due to flow separation is small.

The last paper focuses on a numerical technique applicable to investigating the problem of wave attenuation by moored floating breakwater. Experimental determination of the transmitted wave, sway, heave, and roll motions of the breakwater as well as mooring forces compare favorably with theory. Close to the values for modal frequencies flow separation damped the body motion, and agreement was not so close.

This volume should be of interest to those involved in offshore analysis and design.

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THE ANALYSIS OF TIME SERIES: AN INTRODUCTION

C. Chatfield
Methuen, Inc., New York, NY
2nd edition, reprinted
1982, 268 pages, $16.95 (paperback)

Spectral analysis, which is one of the more sophisticated techniques now being used, is based on the theory of stationary time series. A statistical process can be described as "a statistical phenomenon that evolves in time according to the probabilistic laws." The book, although slanted toward mathematical statistics, will be useful to the engineer.

Chapter 1 introduces time series by stating the various terminologies employed (sampled series, order of observation) and describing time series that can be predicted exactly. Chapter 2 treats simple techniques, including types of variation, trends, curve fitting, and filtering of data. The chapter concludes with a lengthy discussion of autocorrelation, the correlogram and its interpretation, and tests for randomness.

Chapter 3 has to do with probability models for time series, including a definition of stationarity. The autocorrelation function, moving average (MA), and autoregressive processes (AR) are described. A mixture of MA and AR is ARMA; its importance has to do with the fact that regression systems are static whereas ARMA is dynamic. This has recently been applied to earthquake analysis, vibration data, and modeling of machine tool chatter.

Chapter 4 discusses the problem of fitting a suitable model to an observed time series. First, autocovariance and autocorrelation functions must be estimated. This involves interpretation of the correlogram, ergodic theorems, and fitting and estimating the autoregressive process. Fitting an MA process to a given time series is described, as are determination of the order of an MA process and estimation of the parameters of the ARMA model in an integrated model (AR/MA). The chapter concludes with general remarks on finding a suitable model for a given time series.

Chapter 5 is concerned with various aspects of forecasting, which involves extrapolating trend curves and applying exponential, smoothing, and forecast procedures to univariate procedures. Multivariate procedures employ multiple regression and econometric models. This chapter is aimed at production and stock control.

Frequency domain is the next topic. The complimentary function to autocorrelation in the frequency domain is power spectral density (PSD). PSD, which is widely used in electrical and mechanical engineering as well as geophysics, is the Fourier transform of the autocorrelation function. Mathematical relations are derived for AR and PSD.

Chapter 7 has to do with the estimation of spectral density function or spectrum of a given time series. A simple sinusoidal model, Nyquist frequency, and periodogram analysis and its relationship to the autocovariance function are described, as are lag windows -- Tukey, Parzen, Hanning, and Hamming -- and the Fast Fourier transform (FFT). Lag windows are a prerequisite for proper data processing. The Goodman-Enochson-Otnes window and illustrative examples applied to data processing of random vibration records should have been included.

Chapter 8 continues with bivariate processes; i.e., cross covariance, cross spectrum and cross correlation. Interpretive and mathematical representations are furnished. Chapter 9 contains a general discussion of linear systems in the time domain, including impulse and step response function. The relationship between transfer functions and their constituents -- i.e., gain and phase diagrams -- general relationship between input and output, and design of filters for estimating or removing a trend in the time series are described. The chapter concludes with a short discussion of systems involving feedback used in control and vibratory systems.

The concluding chapter briefly points out a number of other areas in which time series are employed; i.e., nonlinear stationary series, model identification tools of ARMA, autoregressive spectrum estimation, cepstrum, and observation at unequal time intervals.

This good book fulfills the author's intent. However, the reviewer feels that sections on data processing of structural elements and computer programs should have been included, as should partial coherence.

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SHORT COURSES

MAY

VIBRATION AND SHOCK SURVIVABILITY, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION

Dates: May 7-11, 1984
Place: Boston, Massachusetts
Dates: June 4-8, 1984
Place: Santa Barbara, California
Dates: August 27-31, 1984
Place: Santa Barbara, California
Dates: September 17-21, 1984
Place: Ottawa, Ontario
Dates: October 15-19, 1984
Place: New York, New York
Dates: November 5-9, 1984
Place: San Francisco, California

Objective: Topics to be covered are resonance and fragility phenomena, and environmental vibration and shock measurement and analysis; also vibration and shock environmental testing to prove survivability. This course will concentrate upon equipments and techniques, rather than upon mathematics and theory.

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

ELECTROEXPLOSIVES DEVICES

Dates: May 15-17, 1984
October 16-19, 1984
Place: Philadelphia, Pennsylvania

Objective: Topics will include but not be limited to the following: history of explosives and definitions; types of pyrotechnics, explosives and propellants; types of EEDs, explosive trains and systems, fuzes, safe-arm devices; sensitivity and functioning mechanisms; output and applications; safety versus reliability; hazard sources; lightning, static electricity, electromagnetic energy (RF, EMP, light, etc.), heat, flame, impact, vibration, friction, shock, blast, ionizing radiation, hostile environments, human error; precautions, safe practices, standard operating procedures; grounding, shorting, shielding; inspection techniques, system check-out trouble shooting and problem solving; safety devices, packaging and transportation; specifications, documentation, information sources, record keeping; tagging, detection and identification of clandestine explosives; reaction mechanisms, solid state reactions; chemical deactivation, disposal methods and problem, toxic effects; laboratory analytical techniques and instrumentation; surface chemistry.

Contact: E&P Affairs, The Franklin Research Center, 20th and Race Streets, Philadelphia, PA 19103 - (215) 448-1000.

MACHINERY VIBRATION ANALYSIS

Dates: May 15-18, 1984
Place: Nashville, Tennessee
Dates: August 14-17, 1984
Place: New Orleans, Louisiana
Dates: October 9-12, 1984
Place: Houston, Texas
Dates: November 27-30, 1984
Place: Lisle, Illinois

Objective: In this four-day course on practical machinery vibration analysis, savings in production losses and equipment costs through vibration analysis and correction will be stressed. Techniques will be reviewed along with examples and case histories to illustrate their use. Demonstrations of measurement and analysis equipment will be conducted during the course. The course will include lectures on test equipment selection and use, vibration measurement and analysis including the latest information on spectral analysis, balancing, alignment, isolation and damping. Plant predictive maintenance programs, monitoring equipment and programs, and equipment evaluation are topics included. Specific components and equipment covered in the lectures include gears, bearings (fluid film and antifriction), shafts, couplings, motors, turbines, engines, pumps, compressors, fluid drives, gearboxes, and slow-speed paper rolls.

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

MACHINERY VIBRATION ENGINEERING

Dates: May 15-18, 1984
Place: Nashville, Tennessee
Dates: August 14-17, 1984
Place: New Orleans, Louisiana
Dates: October 9-12, 1984
Place: Houston, Texas
Dates: November 27-30, 1984
Place: Lisle, Illinois

Objective: Techniques for the solution of machinery vibration problems will be discussed. These techniques are based on the knowledge of the dynamics of machinery; vibration measurement, computation, and analysis; and machinery characteristics. The techniques will be illustrated with case histories involving field and design problems. Familiarity with the methods will be gained by participants in the workshops. The course will include lectures on natural frequency, resonance, and critical speed determination for rotating and reciprocating equipment using test and computational techniques; equipment evaluation techniques including test equipment; vibration analysis of general equipment including bearings and gears using the time and frequency domains; vibratory forces in rotating and reciprocating equipment; torsional vibration measurement, analysis, and computation on systems involving engines, compressors, pumps, and motors; basic rotor dynamics including fluid film bearing characteristics, critical speeds, instabilities, and mass imbalance response; and vibration control including isolation and damping of equipment installation.

Contact: The Vibration Institute, 101 West 55th Street, Clarendon Hills, IL 60514 - (312) 654-2254.

DYNAMIC BALANCING SEMINAR/WORKSHOP

Dates: May 23-24, 1984
Place: Columbus, Ohio

Objective: Balancing experts will contribute a series of lectures on field balancing and balancing machines. Subjects include: field balancing methods; single, two and multi-plane balancing techniques; balancing tolerances and correction methods. The latest in-place balancing techniques will be demonstrated and used in the workshops. Balancing machines equipped with microprocessor instrumentation will also be demonstrated in the workshop sessions, where each student will be involved in hands-on problem-solving using actual armatures, pump impellers, turbine wheels, etc., with emphasis on reducing costs and improving quality in balancing operations.

Contact: R.E. Ellis, IRD Mechanalysis, Inc., 6150 Huntley Rd., Columbus, OH 43229 - (614) 885-5376.

ROTORDYNAMIC INSTABILITY PROBLEMS IN HIGH-PERFORMANCE TURBOMACHINERY

Dates: May 28-30, 1984
Place: College Station, Texas

Objective: The third workshop continues the following basic objectives of the first two (held in 1980 and 1982): development of an increased understanding of rotordynamic instability mechanisms in high-performance turbomachinery; a sharing of experiences in diagnosing causes of unstable vibrations in operating turbomachinery, and in remedying them; documentation of the current state-of-the-art for analysis and design of stable turbomachinery; and suggestion of new directions for research aimed at resolving unstable turbomachinery problems.

Contact: Dr. John Vance or Dr. Dara Childs, Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843 - (409) 845-1257/1268.

JUNE

VIBRATION DAMPING

Dates: June 17-21, 1984
Place: Dayton, Ohio

Objective: The utilization of the vibration damping properties of viscoelastic materials to reduce structural vibration and noise has become well developed and successfully demonstrated in recent years. The course is intended to give the participant an understanding of the principles of vibration damping necessary for the successful application of this technology. Topics included are: damping fundamentals, damping behavior of materials, response measurements of damped systems, layered damping treatments, tuned dampers, finite element techniques, case histories, problem solving sessions.

Contact: Michael L. Drake, Jessee Philips Center 36, 300 College Park Avenue, Dayton, OH 45469 - (513) 229-2644.

MECHANICS OF HEAVY-DUTY TRUCKS AND TRUCK COMBINATIONS

Dates: June 25-29, 1984

Place: Ann Arbor, Michigan

Objective: This course describes the physics of heavy-truck components in terms of how these components determine the braking, steering, and riding performance of the total vehicle. Covers analytical methods, parameter measurement procedures, and test procedures, useful for performance analysis, prediction and design.

Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, University of Michigan, Ann Arbor, MI 48109 - (313) 764-8490.

JULY

FINITE ELEMENTS IN MECHANICAL AND STRUCTURAL DESIGN B: DYNAMIC AND NON-LINEAR ANALYSIS

Dates: July 23-27, 1984

Place: Ann Arbor, Michigan

Objective: Covers vibration, material nonlinearities and geometric nonlinearities. Includes normal modes, transient response, Euler buckling and heat conduction. Attendees use personal computers to develop models of several problems and use MSC/NASTRAN in laboratory sessions.

Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, University of Michigan, Ann Arbor, MI 48109 - (313) 764-8490.

DESIGN AND ANALYSIS OF ENGINEERING EXPERIMENTS

Dates: July 30 - August 10, 1984

Place: Ann Arbor, Michigan

Objective: Recent developments in the field of testing, methods for designing experiments, interpretation of test data, and procedures for better utilization of existing data. Design of experiments with small numbers of test pieces and runs with high dispersion are emphasized. Obtaining maximum information from limited data is stressed.

Contact: Engineering Summer Conferences, 200 Chrysler Center, North Campus, University of Michigan, Ann Arbor, MI 48109 - (313) 764-8490.

AUGUST

MODAL TESTING

Dates: August 14-17, 1984

Place: New Orleans, Louisiana

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: The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

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

39TH ANNUAL MEETING OF AMERICAN SOCIETY OF LUBRICATION ENGINEERS
May 7-10, 1984
Chicago, Illinois

The American Society of Lubrication Engineers is holding its 39th Annual Meeting and Technical Conference in Chicago, May 7-10, 1984, at the Hotel Continental. The conference is the largest of its kind focusing on lubrication science and engineering. Over 140 technical presentations will be made by engineers and scientists from industry, universities and government covering new advances and applications in: aerospace; engine lubrication; food, drugs and cosmetics; lubrication equipment/practice; lubrication fundamentals; metalworking fluids; mining; non-ferrous metals; petroleum and chemicals; power generation; railroads; rolling bearings; seals; sliding bearings; solid lubricants; steel, and wear.

In addition educational courses will be offered in basic lubrication, basic hydraulics, bearing damage analysis, metalworking, and technical communications.

Registration fees for ASLE members are: $175 for full conference and $100 for one day; non-member registration fee is $225 for full conference and $125 for one day.

For further information contact: American Society of Lubrication Engineers, 838 Busse Hwy., Park Ridge, IL 60068 - (312) 825-5536.

VDI VIBRATIONS CONFERENCE 1984
October 11-12, 1984
Bad-Soden

VDI - Society for Design and Development (VDI-GKE) is holding its next Vibrations Conference on October 11-12, 1984 in Bad-Soden. The following topics will be covered:

- vehicle vibrations
- build vibrations
- rotordynamics, including vibration of drives and gears as well as measurement and monitoring technology

Four to six papers on each topic are expected. The topic of vehicle vibration will not be restricted to the rail-vehicle interaction.

For further information contact: VDI-GKE, Postfach 1139, 4000 Dusseldorf 1, Germany.

REVIEWS OF MEETINGS

THE SECOND INTERNATIONAL MODAL ANALYSIS CONFERENCE

This conference was sponsored by Union College, Schenectady, New York, and it was held in Orlando, Florida, February 6-9, 1984.

Over 150 papers were programmed into the 36 technical sessions which were held during the four days of the conference. A keynote session and a general session were held in addition to the technical sessions.

Multiple sessions were organized to consider the following topics:

1. Acoustic Topics (2 Sessions)
2. Analytical Methods (8 Sessions)
3. Experimental Case Histories (6 Sessions)
4. Linking Analysis and Test (4 Sessions)
5. Modal Test Methods (5 Sessions)
6. Processing Modal Data (4 Sessions)
7. Structural Dynamics Modification (2 Sessions)

The following topics were treated in single sessions:

1. Seismic Analysis and Qualification
2. Damping
3. Rotating Equipment
4. Strain Gauges in Modal Testing
5. Modal Testing of the GALILEO Spacecraft

An interesting session on the use of strain gauges in modal testing was organized by Dr. Michael Pakstys. The first paper in this session, "Verification of Modal Testing and Analysis Techniques for Predictions of Dynamic Strain in Impact-Loaded Structures," was written by J.M. Komrower and M.P. Pakstys. The authors discussed the feasibility of using strain measurements in modal testing to directly determine strain eigenfunctions for a simulated lightweight equipment-foundation structure. The strain eigenfunctions could then be used to predict the maximum strain response of the test structure when it is subjected to a shock motion input. The authors of the second paper in this session, B. Hillary and D.J. Ewins, discussed a similar problem, the feasibility of recovering harmonic excitation force signature using strain response measurements and measured or predicted frequency response functions. The experimental study included the ability to recover force input signatures from response measurements on a cantilever beam. The authors extended the study to recover force signature inputs to a gas turbine compressor blade. A numerical study was also undertaken to assess the effects of errors in the measured strain response, and the frequency responses on the recovered input force signatures. Other papers in this session concerned an integrated modal test and finite element analysis to estimate the random fatigue life of a damaged structural component and the use of a modal test for correcting a finite element model.

Experimental Case Histories, Session IV, contained papers related to the modal testing of various sizes of structures, ranging from the small to the large. N. Okubo et al, described modal tests on a computer disc unit to acquire input data for structural modification to improve the disc unit's overall dynamic performance. Modal tests were carried out on many of its components; one of the components, a gimbal structure, was so light that conventional transducers could not be used to measure its frequency response function. They used an optical fiber displacement transducer to make non-contact measurements of the response of the gimbal structure. E. Unver described the application of modal analysis to determine the cause of chatter of the rollers in mill stands for cold rolling steel strip. Two chatter phenomena were identified, third-octave mode chatter and fifth-octave mode chatter. The third-octave mode chatter causes vertical bouncing of the top roller in the roller stack, while the fifth-octave mode chatter causes the higher frequency vertical oscillation of the two rollers which actually roll the steel strip -- the work rollers. A paper by J.J. Tracy, D.J. Dimas, and G.C. Pardoen described the feasibility of using modal testing to detect hidden delamination damage in graphite-epoxy plates. A finite element analysis was conducted first to predict the mode shapes and natural frequencies of the plates before damage and after damage. Modal tests were then run to verify the dynamic characteristics of the plates before damage, and to detect changes in the dynamic characteristics of the plates after damage. The authors concluded modal testing can indicate the presence of hidden delamination damage in composite material plates, but further work is necessary before modal analysis can be used to determine the extent of the damage and its location. The last paper in the session, by N.W. Smith, described the design and development of a large fixture for modal tests on Space Shuttle payloads. The fixture was designed to closely simulate the effects of the Orbiter's Payload Bay boundary conditions on the test payloads.

One of the highlights of this conference was the special session on the Modal Test Program for the GALILEO spacecraft. This program was significant because it provided an unusual opportunity to compare the results of modal tests on real hardware using the classical multi-shaker-sine-dwell technique and advanced modal test techniques. Following an overview of the entire program by the session chairman, Dr. Ben Wada, the first paper by J.C. Chen and M. Trubert described the GALILEO spacecraft loads analysis model, the pre-test analysis efforts, and the test analysis model. The test analysis model is a condensed model which allows the measured dynamic properties of the test article to be related to the predicted dynamic properties of the loads model. The second paper in this session, by H.P. Bausch and R.C. Stroud described the instrumentation and the software that were used to tune the modes, acquire the data, process the data and perform the orthogonality checks. The results of the GALILEO modal test using multiple sine dwell excitation were presented by Dr. Marc Trubert. Two configurations of the spacecraft were tested, the "near cruise" condition and the launch condition. The GALILEO spacecraft modal test diffused from modal tests on some of JPL's other spacecraft in that the GALILEO spacecraft has appendages with significant mass; it is not surprising, that some of the lowest natural frequencies of this spacecraft were in the appendages. Further, the GALILEO spacecraft has a high modal density, 1 mode/Hz, and the natural frequencies of some of the major modes of vibration only differed by 1%. The modal test was also conducted at higher levels to induce the modes of vibration that would be representaive of actual flight levels. In addition to the 162 channels of fixed accelerometers, 100 additional measurements were made with a roving accelerometer; these measurements were made to better define the mode shapes of those modes where discrepancies between test and analysis showed up during the course of the test. The fourth paper in this session was written by R.N. Coppolino, S.R. Ibrahim, D.L. Hunt, and R.C. Stroud; and it described the use of some of the advanced excitation functions that were used in the modal tests on the GALILEO spacecraft; it also described some of the advanced methods for processing the data and extracting the modal parameters. J.C. Chen presented a comparison of the results of the modal tests using the multi-shaker sine dwell method and the recently developed multi-shaker random vibration method.

A general session was held on Wednesday afternoon, February 8. Following the announcement of the formation of the International Society for Modal Testing and Analysis, Dr. David Brown moderated a lively panel discussion whose topic was supposed to be "Future Directions in Modal Analysis." In my estimation the theme of the panel discussion seemed to be the future needs in modal analysis. This panel discussion nevertheless was highly successful because exposing the future needs in modal analysis will influence its future direction. Many different issues were discussed, and most of these were raised by the audience. Some of these issues included modal analysis and testing at very high frequencies (e.g., 100 kHz), the need for education and more training in experimental modal analysis, modal tests on nonlinear structures and how to support structures for modal tests to reproduce the appropriate boundary conditions.

Specific questions raised were:

- How many people have tried structural modification and failed? No answer.
- Is it possible to increase dynamic range of instrumentation needed for multiple input testing? it is possible but very expensive. In the near future 90 dB may be reached; however, the requirements of the rest of the market need to be taken into consideration. The market for spectrum analyzers is very broad.
- How do you do high frequency (100,000 Hz) modal analysis? It is beyond the state-of-the-

art. Laser holography has possibilities; however, it provides only mode shapes and not phases. Thus, the analysis is qualitative but not quantitative.

- Heated discussions were raised about the gap between the developer of technology and the user. Is the weak spot in modal analysis the hardware, software, or the qualification of the users? Depending on the affiliation of the speaker, the blame shifted from vendors for not supplying suitable instrumentation, to the users for their lack of qualifications, and to the universities for their shortcomings in providing suitable instructions.

A fifth session on experimental case histories contained three papers. The first paper by B. Seth and N. Field, described the use of impact tests to verify the dynamic characteristics of production balancing machines for automobile engines. The authors used the impact tests to determine the influence coefficients between the unbalance planes and the sensors to calibrate the balancing machine; they used the results of the impact tests to determine the natural frequencies, the bending modes of vibration and the torsional modes of vibration of the balancing machine. R.C. Varga and E.J. Tanner described how they used modal testing to improve the line-of-sight stability for a light weight electro-optical gimbal system. The authors showed how modal testing was used to provide the additional detail needed to examine the effects of weight reduction on the ability of the gimbal to meet line-of-sight stabilization requirements. The last paper in this session, by Z. Revesz and F. Ferroni described a combined test and analysis approach for correcting vibrations in nuclear power plant piping systems.

In the Modal Test Methods V session, papers were presented on topics related to testing techniques. L. Mitchell and K. Elliott presented a systematic method for designing stingers for vibration exciters to minimize the effects of the exciter's rotary inertia on mobility or modal test measurements. C. Yasuda, P. Riehle, D. Brown, and R. Allemang described a method for estimating rotational degrees of freedom of structures by adding mass to the structure at certain points of interest, and measuring the rigid body motions of the added mass. H.J. Weaver and R.B. Burdick compared the modal parameters of thin plates and thick plates which were obtained by using acoustic excitation and mechanical excitation. The advantages and disadvantages of using acoustic excitation for modal testing were also disclosed. A number of excitation functions can be used to make frequency response function measurements to characterize a structure's modal properties. N. Olsen first classified the excitation into their different types, e.g., steady state, periodic, random, transient or operating, and then he discussed advantages and disadvantages of each of the different excitation signals. He compared the advantages and the disadvantages of the different excitation signals according to several common parameters for selecting the excitation function to be used; some of these parameters are the test measurement time, the ability to characterize test article nonlinearity and the ability to remove distortion. To conclude this session, P. Ibanez and K. Blakely briefly reviewed currently available techniques for distributing forces among multiple exciters in modal tests using the combination of some type of system matrix and multi-point sine excitation. The authors then proposed an algorithm to automate the force distribution process among multiple exciters for multi-point sine excitation modal tests where the number of response measurement points exceed the number of exciter inputs.

Four papers were programmed for the Experimental Case Histories Session III, but only one paper was presented. The authors of this paper, J.G. Gimenez and L.I. Carrascosa, discussed the use of modal testing to help solve several dynamics problems associated with the high speed operation of railway vehicles. Their first study was undertaken to determine the dynamic characteristics of pantographs, or overhead current collectors, to understand their in-service dynamic behavior. The second study was undertaken to determine the cause of failure of a support for truck-mounted safety equipment. The third study concerned a modal test on a railroad coach to verify its predicted modal parameters. Both rigid body modes and elastic modes were identified in this study. The other three papers that were assigned to this session were on the influence of the suspension method on the results of modal tests of an aircraft, the effect of steam condensation oscillation loads on nuclear reactor structures and the use of structural modification software.

The outstanding success of the modal Conferences has shown the need to provide a continuing outlet for communication in the modal analysis field. Accordingly, the IMAC staff announced the Third International Modal Analysis Conference to be sponsored by The International Society for Modal Testing and Analysis and Union College on January 28-31, 1985 at Orlando Marriott Inn, Orlando, Florida.

Papers are sought on the following topics: mechanical impedance, processing modal data, finite element analysis, substructuring, case histories, linking analysis and test, design methods, analytical modal analysis, machinery diagnostics, modal testing software, experimental techniques, computer graphics, modeling, structural dynamics modification and transducers and instrumentation.

The purpose of the Conference is to provide a forum for all those concerned with the rapidly changing technology of modal analysis. Anyone interested in the dynamic behavior of mechanical structures will not want to miss this opportunity for technical interchange.

Short abstracts of the papers (not more than 200 words) should be submitted by May 1, 1984 to: Peter B. Juhl, Union College, Graduate and Continuing Studies, Wells House - 1 Union Avenue, Schenectady, New York 12308.

If the abstract is selected, the author will be asked to submit his finished paper, suitable for publication in the Conference Proceedings, by September 1, 1984.

R.H.V.

ABSTRACTS FROM THE CURRENT LITERATURE

ABSTRACT CONTENTS

AVAILABILITY OF PUBLICATIONS ABSTRACTED

Government Reports:	NTIS Springfield, VA 22151 (unless otherwise indicated)
Ph.D. Dissertations:	University Microfilms International 300 N. Zeeb Rd. Ann Arbor, MI 48106
U.S. Patents:	Commissioner of Patents Washington, DC 20231
Chinese Publications (CSTA):	International Information Service, Ltd. P.O. Box 24683 ABD Post Office Hong Kong (In Chinese or in English translation)

In all cases appropriate order numbers should be used (last line of citation).

When not available in local libraries, copies of the majority of papers or articles may be obtained at Engineering Societies Center, 345 E. 47th St., New York, NY 10017, or Library of Congress, Washington, DC.

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

A list of periodicals scanned in published in issues 1, 6, and 12.

MECHANICAL SYSTEMS

ROTATING MACHINES

(Also see Nos. 756, 762, 779)

84-579

Dynamic Characteristics of a Jeffcott Rotor Including Foundation Effects

R.W. Armentrout, E.J. Gunter, and R.R. Humphris
Univ. of Virginia, Charlottesville, VA, ASME Paper No. 83-DET-98

Key Words: Rotors, Interaction: rotor-foundation, Vibration measurement, Resonant frequencies

The dynamic characteristics of a vertical single-mass rotor are examined using noncontacting displacement probes to measure the rotor center motion and accelerometers to measure the bearing housing motion. Resonant frequencies of the rotor and foundation predicted by impact testing correlated well with those observed during actual rotor runs.

84-580

Making Quick Estimates of Critical Shaft Speeds

V. Ganapathy
Struthers Thermoflood Corp., Winfield, KS, Plant Engrg., 37 (18), pp 50-52 (Sept 1, 1983) 7 figs

Key Words: Shafts, Critical speeds, Nomographs

A nomograph for a quick calculation of critical speeds for four configurations of steel shafts is presented. These configurations are: a shaft with restrained ends carrying a single point load, a simply supported shaft with single point load, a simply supported shaft with load distributed along the shaft, and a shaft with restrained ends and load distributed along the shaft. A modulus of elasticity of 29,000,000 is assumed.

84-581

Dynamic Behavior of a Simple Rotor with Dissimilar Hydrodynamic Bearings by Modal Analysis

R.B. Bhat, R. Subbiah, and T.S. Sankar
Concordia Univ., Montreal, Canada, ASME Paper No. 83-DET-75

Key Words: Rotors, Unbalanced mass response, Modal analysis

The unbalance response of a simple rotor, supported on dissimilar hydrodynamic bearings at the two ends, is studied employing modal analysis. Equations of motion for the rotor-bearing system are developed using Lagrangian approach.

84-582

Impact Response of Rotor-Bearing System to an Arbitrary Excitation of Pedestals (1st Report: Comparison of Linear Analysis with Experiment)

H. Koike and K. Ishihara
Technical Inst., Kawasaki Heavy Industries Ltd., Kawasaki-cho 1-1, Akashi, Japan, Bull. JSME, 26 (220), pp 1783-1790 (Oct 1983) 14 figs, 1 table, 3 refs

Key Words: Rotors, Bearings, Impact response, Ground motion, Linear theories

Assuming linearized coefficients of oil film, impact response analyses of a rotor-bearing system subjected to an arbitrary excitation of pedestals were made and an experiment was executed. The analyzed characteristics were in good agreement with experimental ones, in reference to two eigenvalues with different whirl directions and impact response by the forces generated.

84-583

The Dynamic Stability of a Rotor System Supported on Tilting-Pad Bearings with Consideration of Pivot Stiffness and Damping

Zhang Zhi Ming
Chinese J. of Mech. Engrg., 19 (2), pp 9-21 (1983) CSTA No. 621.8-83.14

Key Words: Rotors, Tilting pad bearings, Bearings, Stiffness coefficients, Damping coefficients

The influences of pad moment of inertia, pad mass, mass eccentricity, stiffness and damping of pivot in downward direction and tilting direction on the damping factor of the rotor system are studied. A numerical method used to develop the eigendeterminant into eigenpolynomials is described.

84-584

Rotor Dynamics Modification of an Eight Stage Compressor for Safety/Reliability Improvement

F.H. Kludt and D.J. Salamone

Celanese Chemical Co., Pampa, TX, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 81-96, 44 figs, 7 tables, 7 refs

Key Words: Rotors, Compressors, Structural modification techniques

The catastrophic failure of a high pressure centrifugal air compressor utilizing air-pressurized bearing housings dictated the redesign of its sister compressor, which is described in this paper. The modification of this early 1950's compressor involved elements of both practical and analytical design. The project included the design of new bearings and seals and the alteration of various support systems to permit operation with non-pressurized bearing housings.

84-585

Practical Aspects of Centrifugal Compressor Surge and Surge Control

M.P. Boyce, W.R. Bohannan, R.N. Brown, J.R. Gaston, C. Meher-Homji, R.H. Meier, and N.E. Pobanz

Boyce Engineering International, Houston, TX, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 147-173, 51 figs, 2 tables, 13 refs

Key Words: Compressors, Centrifugal compressors, Surges

This paper addresses the area of compressor stability, surge and surge control and relates to the practical aspects involved. An emphasis is placed on the physical understanding of surge phenomena and on the practical limitations of surge control systems. Topics discussed are physical interpretation of instability, causative factors, types of stall, machine and process design factors, surge effects and characteristics, control system types and practical application aspects. Some case studies also are presented.

84-586

The Effect of the Transient Process on the Steady State of a Compressor (Vliv přechodového deje na ustálený stav kompresoru)

A. Tondl

Natl. Res. Inst. for Machine Des., Praha-Bechovice, Czechoslovakia, Strojnícky Časopis, 34 (5), pp 521-532 (1983) 18 figs, 4 refs

(In Czech)

Key Words: Compressors, Surges

To find which of two locally stable steady states exist when a compressor reaches running speed and nominal load is the aim of the analysis. The effect of the rate of speed and load change is investigated.

84-587

Low Frequency Buckets for Industrial Steam Turbines

F.L. Weaver

Engrg. Consultant, Sun City Ctr., FL, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 15-20, 5 figs, 2 tables, 3 refs

Key Words: Steam turbines, Fatigue life

Bucket failures have been known to occur on the later stages of industrial type steam turbines after prolonged operational life of as much as five or six years. All of these failures are characteristically fatigue in nature. It is the purpose of this paper to discuss the reasons for these failures as related to the operating load and speed of the turbine and to the design of the buckets. Bucket banding can be used to minimize the possibility of failure.

84-588

Structural Integrity of Large Steam Turbine Rotors

G.W. Rogers, C.H. Wells, and D.P. Johnson

Failure Analysis Associates, 2234 S. McClintock Dr., Tempe, AZ, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 31-44, 28 figs, 2 tables, 20 refs

Key Words: Rotors, Steam turbines, Fatigue life

Nondestructive inspection methods and lifetime prediction computer programs have been developed for turbine rotors. The prediction of lifetime requires detailed analysis of potential flaw linkup in regions of high ultrasonic indication density. Transient stress and temperature analysis for the specific turbine duty cycle and rotor geometry, and the calculation of crack growth rates for several possible fracture mechanisms are discussed.

84-589
Pressure Oscillations During Re-Expansion of Gases in Rotary Vane Compressors by a Modified Helmholtz Resonator Approach
V. Yee and W. Soedel
Ray W. Herrick Labs., School of Mech. Engrg., Purdue Univ., West Lafayette, IN 47907, J. Sound Vib., 91 (1), pp 27-36 (Nov 8, 1983) 9 figs, 11 refs

Key Words: Compressors, Helmholtz resonators

This paper describes a mathematical model in wihch some assumptions of the Helmholtz resonator theory are used, but extended to large pressure amplitudes. The model is verified by simple experiments and applied to the study of re-expansion oscillations that occur in rotary vane compressors.

84-590
Influence of Wear-Rings on Stability and Critical Speeds of Boiler Feed Pumps
I. Anwar, R. Colsher, and V. Obeid
Franklin Inst. Res. Lab., Philadelphia, PA, ASME Paper No. 83-DET-99

Key Words: Pumps, Critical speeds

In estimating the dynamic characteristics of wear-rings, the effects of fluid inertia and turbulence are retained. In addition to wear-rings, the influence of hydraulic forces due to impeller and diffuser interaction at low flow condition is considered.

RECIPROCATING MACHINES
(See No. 646)

METAL WORKING AND FORMING
(See Nos. 643, 644, 781)

MATERIALS HANDLING EQUIPMENT
(Also see No. 647)

84-591
On the Problems of Biharmonically Oscillating Conveyers (Příspěvek k problematice biharmonických vibračních dopravníků)
A. Loprais
Faculty of Mech. Engrg., Technical Univ. Brno, Czechoslovakia, Strojnicky Casopis, 34 (4), pp 437-444 (1983) 4 figs, 2 refs
(In Czech)

Key Words: Conveyors

The paper deals with the phase optimization of biharmonic motion of an unloaded horizontal oscillating conveyer from the point of view of maximal transporting velocity. The motion of the platform is derived as a function of the value of a transported load.

STRUCTURAL SYSTEMS

BRIDGES

84-592
Earthquake Response of Long-Span Suspension Bridges
L.I. Rubin
Ph.D. Thesis, Princeton Univ., 583 pp (1983)
DA8322584

Key Words: Bridges, Suspension bridges, Earthquake response, Seismic response

The present study investigates (analytically and numerically) the earthquake response of long-span suspension bridges when subjected to multiple-support seismic excitations for vertical, torsional, and lateral vibrations of the cable-suspended structure as well as longitudinal vibration of the tower-pier system. Calculations are performed in both the time and frequency domains and these two methods are compared in order to determine appropriate peak factors for the suspension bridge vibration problem.

BUILDINGS
(Also see No. 717)

84-593
Analytical Models for the Dynamics of Buildings
S.K. Jain

Ph.D. Thesis, California Inst. of Tech., 198 pp (1983)
DA8322671

Key Words: Buildings, Mathematical models

The significance of in-plane floor flexibility on the dynamics of buildings is investigated and analytical models for structures that have flexible floor diaphragms are developed. Experience with past earthquakes demonstrates that this feature is *particularly important for long, narrow buildings and* buildings with stiff end walls. In the method developed in this study, the equations of motion and appropriate boundary conditions for various elements of the structure are written in a single coordinate system and then are solved exactly.

84-594

Stochastic Seismic Performance Evaluation of Buildings

R.H. Sues

Ph.D. Thesis, Univ. of Illinois at Urbana-Champaign, 147 pp (1983)
DA8324651

Key Words: Buildings, Seismic response, Stochastic processes

A method is presented for determining the probabilities that a structure will sustain various levels of damage or become unsafe due to earthquake loading during its lifetime. Uncertainties in the dynamic analysis associated with both the loading and the prediction of the structural response are considered. The method is based on a nonlinear random vibration analysis and an analytical technique for evaluating the sensitivity of the response to various structural and load parameters.

84-595

Optimal Open-Loop Control of Building Structures under Earthquake Excitation

Ming-Chien J. Lin

Ph.D. Thesis, George Washington Univ., 179 pp (1982)
DA8321584

Key Words: Buildings, Seismic response, Earthquakes, Active vibration control, Active damping

A study is made of the optimal open-loop control theory and its application to tall buildings under earthquake excitations. An active tendon control system and an active mass damper system are investigated. The earthquake ground acceleration is modeled as a stationary random process as well as a nonstationary random process. Random vibration analyses in conjunction with the optimal control theory are carried out to determine the building response and the required active control force.

84-596

Measurements and Interpretation of Full Scale Building Responses

S. Chi-Sun Huang

Ph.D. Thesis, Univ. of California, Los Angeles, 177 pp (1983)
DA8321933

Key Words: Buildings, Earthquake response, Seismic response

Full scaled building responses of two similar building systems were measured at different excitation levels: ambient vibration, forced vibration and actual strong motion earthquake. Results show that the common assumption that a floor slab will behave rigidly and the ground floor is a fixed base for the building system may be incorrect. Influence of these assumptions on the behavior of the building system were examined using static and dynamic analysis.

84-597

Experimental Study on Basic Mechanical Properties of Brick Buildings

Xia Jing Qian, et al

EEEV, 3 (1), pp 43-56 (1983)
CSTA No. 624-83.31

Key Words: Buildings, Masonry, Dynamic tests, Seismic *response*

Tests of mechanical behavior of brick masonry under static and dynamic axial compression are described. Test results including ultimate strength, elastic modulus, Poisson ratio, internal damping of brick masonry and the comparison between the static and dynamic conditions are given.

TOWERS

84-598

Guyed Tower with Dynamic Mooring Properties

D.G. Morrison

Geustyn, Forsyth and Joubert, Inc., 63 Dorp St., Stellenbosch 7600, Rep. of South Africa, ASCE J. Struc. Engrg., 109 (11), pp 2578-2590 (Nov 1983) 12 figs, 4 refs

Key Words: Towers, Guyed structures, Moorings, Off-shore structures

The guyed tower concept is designed for use in relatively deep waters [more than 1,000 ft (300 m)]. A model is described that mimics the response by a single degree of freedom (SDOF). The properties of this simple model are derived from stiffness, mass, and hydrodynamic properties of more detailed models. The ability of the simple model to represent the tower response is evaluated by comparing calculated SDOF response with that of multi-degree of freedom finite element models.

84-599

Response to Wind Action of 265-M Mount ISA Stack

W.H. Melbourne, J.C.K. Cheung, and C.R. Goddard

Monash Univ., Victoria, Australia, ASCE J. Struc. Engrg., 109 (11), pp 2561-2577 (Nov 1983) 12 figs, 15 refs

Key Words: Chimneys, Reinforced concrete, Wind-induced excitation

Measurements were made of the response to wind action of a 265-m high, reinforced concrete stack. Data were reduced from accelerometer, strain gage and pressure transducer records from four wind storms. Particular attention was paid to determining reference freestream wind speeds at stack height and wind structure. Full scale data are reduced and presented so that they can readily be used to compare with results from physical and mathematical model studies of stack response to wind action.

UNDERGROUND STRUCTURES

84-600

Modeling of Silo Response to Ground Motion

L. Thigpen and J.C. Peterson

Lawrence Livermore Natl. Lab., Lawrence, CA, Rept. No. UCRL-53396. 90 pp (Mar 1, 1983) DE83013534

Key Words: Missile silos, Nuclear explosion effects, Explosion effects, Underground explosions

The response of a silo-type structure to the ground motion resulting from a near-surface nuclear burst is modeled. This complex problem is modeled using the soil island approach, which combines finite-difference and finite-element methods. The free-field ground motion is determined using a two-dimensional finite-difference code in the absence of a structure.

POWER PLANTS

(Also see Nos. 678, 679, 680, 776)

84-601

Fluid-Structure Interaction via Boundary Operator Method

M.M. Cepkauskas and J.A. Stevens

Combustion Engineering, Inc., C-E Power Systems, 1000 Prospect Hill Road, Windsor, CT 06095, J. Sound Vib., 90 (2), pp 229-236 (Sept 22, 1983) 7 figs, 8 refs

Key Words: Interaction: structure-fluid, Nuclear reactor components, Boundary condition effects

This paper is an examination of a simple fluid-structure interaction problem in which a technique for solving time dependent boundary condition problems, the Boundary Operator Method, is used to gain further insight into fluid-structure response characteristics.

84-602

Dynamic Analysis of Large Suspended LMFBR Reactor Vessels

D.C. Ma, J. Gvildys, and Y.W. Chang

Argonne Natl. Lab., Argonne, IL, Rept. No. CONF-830805-14, 19 pp (1983) (Intl. Conf. on Struc. Mechanics in Reactor Tech., Chicago, IL, Aug 22, 1983)

DE83008898

Key Words: Nuclear reactors, Interaction: structure-fluid, Sloshing, Seismic response, Earthquake response

This paper presents a dynamic analysis of a large suspended breeder reactor vessel subjected to horizontal earthquake excitation with emphasis on the effect of bottom head vibration on fluid pressure and sloshing response. Unlike the conventional lumped mass method, the present analysis treats the liquid sodium as a continuum medium. As a result, the important effects ignored in the lumped mass method such as fluid coupling, f'u.' structure interaction, interaction between sloshing and v-s.e' vibration, etc. can be accounted into the analysis.

84-603

Nonlinear Seismic Response of Small Reinforced-Concrete Shear Wall Structures

E.G. Endebrock and R.C. Dove

Los Alamos Natl. Lab., Los Alamos, NM, Rept. No. LA-UR-83-318, CONF-830805-3, 11 pp (1983) (Intl. Conf. on Struc. Mechanics in Reactor Tech., Chicago, IL, Aug 22, 1983)

DE83007542

Key Words: Seismic response, Earthquake response, Nuclear power plants, Reinforced concrete, Nonlinear response

Dynamic tests on small shear wall structures are described. The purpose of the tests is to obtain information on the behavior of reinforced concrete structures loaded into their nonlinear range. The small shear wall structures were subjected to classical sinesweep vibration tests and to generated earthquake records.

84-604

Seismic and Dynamic Qualification of Safety-Related Electrical and Mechanical Equipment in Operating Nuclear Power Plants: Development of a Method to Generate Generic Floor Response Spectra

J. Curreri, C. Costantino, M. Subudhi, and M. Reich

Brookhaven Natl. Lab., Upton, NY, Rept. No. BNL-NUREG-51667, 106 pp (Sept 1983)

NUREG/CR-3266

Key Words: Nuclear power plants, Seismic response, Qualification tests

A generic floor response spectra has been developed for use in the qualification of electrical and mechanical equipment in operating nuclear power plants. The characteristics of 1000 floor response spectra were studied to determine the generic spectra. A procedure for its application to any operating plant has been established.

84-605

Estimation of Structural Reliability under Combined Loads (PWR; BWR)

M. Shinozuka, T. Kako, H. Hwang, P. Brown, and M. Reich

Columbia Univ., Columbia, NY, Rept. No. BNL-NUREG-32624, CONF-830805-22, 12 pp (1983) (Intl. Conf. on Struc. Mechanics in Reactor Tech., Chicago, IL, Aug 22, 1983)

DE83010460

Key Words: Nuclear power plants, Nuclear reactors, Seismic response, Nuclear reactor containment, Reinforced concrete, Qualification tests

For the overall safety evaluation of seismic category I structures subjected to various load combinations, a quantitative measure of the structural reliability in terms of a limit state probability can be conveniently used. For this purpose, the reliability analysis method for dynamic loads was combined with the existing standard reliability analysis procedure for static and quasi-static loads. The structure considered in the present paper is a reinforced concrete containment structure subjected to various static and dynamic loads such as dead loads, accidental pressure, earthquake acceleration, etc.

84-606

FEM-Based Random-Vibration Analysis of Nuclear Structures under Seismic Loading (PWR; BWR)

T. Kako, M. Shinozuka, H. Hwang, and M. Reich

Toshiba, Tokyo, Japan, Rept. No. BNL-NUREG-32626, CONF-830805-21, 12 pp (1983) (Intl. Conf. on Struc. Mechanics in Reactor Tech., Chicago, IL, Aug 22, 1983)

DE83010459

Key Words: Nuclear power plants, Nuclear reactor containment, Shells, Seismic analysis, Finite element technique, Random vibration, Computer programs

This paper outlines an analytical and numerical procedure developed for the frequency domain finite element analysis of category I nuclear structures; in particular, of reinforced concrete containment shell structures, subjected to earthquake ground acceleration. Emphasized in this presentation is the analytical procedure associated with the random vibration analysis.

84-607

Nuclear Power Plant Piping Damping Parametric Effects

A.G. Ware

EG and G Idaho, Inc., Idaho Falls, ID, Rept. No. EGG-M-26182, CONF-830607-17, 9 pp (1983) DE83014965

Key Words: Nuclear power plants, Piping systems, Damping effects

This paper presents current state-of-the-art knowledge in the United States on parameters which influence piping-system damping. Examples of inconsistencies in the data and areas of uncertainty are explained. A discussion of programs to evaluate various effects are included, and both short- and long-range goals of the program are outlined.

84-608

Review of Leakage-Flow-Induced Vibrations of Reactor Components (LMFBR)

T.M. Mulcahy

Argonne Natl. Lab., IL, Rept. No. ANL-83-43, 31 pp (May 1983)

DE83015753

Key Words: Nuclear reactors, Fluid-induced excitation

The primary-coolant flow paths of a reactor system are usually subject to close scrutiny in a design review to identify potential flow-induced vibration sources. However, secondary-flow paths through narrow gaps in component supports, which parallel the primary-flow path, occasionally are the excitation source for significant vibrations even though the secondary-flow rates are orders of magnitude smaller than the primary-flow rate. These so-called leakage flow problems are reviewed here to identify design features and excitation sources that should be avoided.

84-609

R/C Containment Safety under Hydrogen Detonation

M.N. Fardis, A. Nacar, and M.A. Delichatsios

Massachusetts Inst. of Tech., Cambridge, MA 02139, ASCE J. Struc. Engrg., 109 (11), pp 2511-2527 (Nov 1983) 8 figs, 1 table, 14 refs

Key Words: Nuclear reactor containment, Reinforced concrete, Internal explosions

The response of a typical steel-lined reinforced concrete nuclear reactor containment to postulated internal hydrogen detonations is investigated by axisymmetric nonlinear dynamic finite element analyses. Internal wall pressure histories used as input to the analysis are first generated by numerical solution of the hydrogen detonation problem with a technique that reproduces the sharp discontinuity at the shock front. In place variability of the mechanical properties of reinforcing bars and of the strengths of mechanical splices is included in the containment model through effective stress-strain laws of the elements modeling the reinforcement.

VEHICLE SYSTEMS

GROUND VEHICLES

84-610

A Study of the Frequency Response Function of the Wheeled Tractor Steering System

Zhao Rong Bao and Cheng Yue Sun

Trans. of Chinese Soc. of Agri. Mach., (1), pp 1-14 (1983)

CSTA No. 631.3-83.01

Key Words: Steering gear, Tractors, Frequency response function, Vibration control

A dynamic model of a tractor steering system is presented and the frequency response function of the system is determined. A simulated calculation of the frequency response function is applied in order to analyze the effects of variations of steering system parameters on vibrations. Theoretical analysis and calculations are compared with road experiment results. Some methods to reduce vibrations of the steering system are suggested.

84-611

Solution of Nonlinear Vibration of a Wheel Tractor with a Trunk by Statistical Linearization (Riešenie nelineárneho kmitania kolesového t'ahača s kmeňom metódou štatistickej linearizácie)

L. Starek and Do Tien Vu

Dept. of Technical Mechanics of Faculty of Mech. Engrg., Slovak Tech. Univ., 812 31 Bratislava, Czech-

oslovakia, Strojnicky Casopis, 34 (4), pp 459-472 (1983) 8 figs, 7 refs
(In Slovak)

Key Words: Tractors, Nonlinear vibration

A model of vertical nonlinear vibration of a wheel tractor with a trunk has been solved by statistical linearization. This model will serve for determination of the dynamic load of the wheel tractor under given conditions. The model presents a mathematical description of a discrete dynamic system with 5 degrees of freedom. The model verification was realized through the comparison of power spectral densities calculated on the basis of linear and linearization models and measured in the exploitation experiment.

84-612

Mathematical Modelling of Dynamic Handling of Road Articulated Vehicles (Matematické simulováni dynamické řiditelnosti silničních jízdních souprav)

F. Vlk
Dept. of Combustion Engines and Motor Vehicles, Faculty of Mech. Engrg. of High Technical Univ., Brno, Czechoslovakia, Strojnicky Casopis, 34 (5), pp 533-550 (1983) 11 figs, 1 table, 9 refs
(In Czech)

Key Words: Articulated vehicles, Trucks, Tractors, Ride dynamics

The paper is concerned with handling of truck-trailers and tractor-semitrailers. Derivation of equations of motion are presented for a linear dynamic model, describing side movements of an articulated vehicle dependent on steer angle of vehicle front wheels. The results of calculations are presented graphically.

84-613

Reduction of Noise and Vibration on Fork Lift Trucks

P. Bartels, H. Dupuis, P. Jenik, and G. Tronich
Steinbock GmbH, Moosburg, Fed. Rep. Germany, Rept. No. BMFT-FB-HA-83-010, ISSN-0171-7618, 136 pp (Mar 1983)
N83-31334
(In German)

Key Words: Ground vehicles, Trucks, Noise reduction

A prototype 2.5 ton diesel fork lift truck is described. A reduction of the medium noise level as per DIN 45635, T.36 at the driver's ear of 10.0 dB(A) to 77.5 dB(A), and reduction of vibration of 50% to 65% measured at the driver's seat are achieved.

84-614

Estimation of Transit Rail Vehicle Parameters from Roller Rig Tests

R.H. Fries
Ph.D. Thesis, Arizona State Univ., 186 pp (1983)
DA8322530

Key Words: Railroad trains, Dynamic tests, Parameter identification technique

Testing a rail vehicle on a roller rig rather than on track facilitates the accurate control and measurement of test conditions and offers the advantages attendant to testing in a laboratory rather than testing in the field. In this work tests of a transit rail vehicle conducted on a roller rig provided the data for estimating the parameters of a linear 17-degree-of-freedom rail vehicle model and for validating the model. An output error parameter estimation method that used Bayesian a priori parameter estimates was selected for use in this work. The estimation process was conducted in the frequency domain and used frequency response functions to compare experimental and theoretical dynamic characteristics.

AIRCRAFT

(Also see No. 622)

84-615

CAT for Ground Vibration Testing

J. Long and T. Davis
Lear Fan, Wichita, KS, Mech. Engrg., 105 (11), pp 40-42 (Nov 1983) 1 fig

Key Words: Aircraft, Testing techniques, Qualification tests

A ground vibration testing technique for airframes is described which comprises a simultaneous, multipoint random excitation coupled with a sophisticated multi-degree-of-freedom poly reference curve fitting routine. This technique allows the engineer to excite the entire structure at one time, exciting all modes of vibration simultaneously and collects frequency response functions from all points and all areas of the structure under test.

84-616

A Simple Method for the Derivation of Isolated and Installed Store Loads

S.H. Goudie

Aeronaut. J., 87 (869), pp 343-347 (Nov 1983) 11 figs, 1 table, 6 refs

Key Words: Aircraft, Wing stores

As military aircraft become more multi-role in design, the use of externally carried ordnance has increased both in frequency and variety resulting in increased use of wind tunnels for store load measurement. This report may be useful in predicting loads on a variety of isolated stores at transonic speeds and in providing loading data on a new store carried on an aircraft by converting wind-tunnel measurements made on an existing store.

84-617

Unsteady Aerodynamic Forces and Flutter Analysis for a Wing-Aileron-Tab Configuration

Yang Yong Nian and Cheng Jing Yun

Acta Aeron. et Astron. Sinica, 4 (1), pp 1-7 (1983) CSTA No. 629.1-83.13

Key Words: Aircraft wings, Flutter, Aerodynamic loads

An analysis of unsteady aerodynamic forces and flutter for a wing-aileron-tab configuration by doublet-lattice method is presented. Six cases are calculated; maximum variance of flutter velocity and flutter frequency is 6.92% and 2.24%, respectively. The difference between calculated and experimental flutter velocities is 18.8% and 24.4%.

84-618

Noise Monitoring in the Vicinity of General Aviation Airports

P.D. Schomer

Dept. of Electrical Engrg., Univ. of Illinois, Urbana, IL 61801, J. Acoust. Soc. Amer., 74 (6), pp 1764-1772 (Dec 1983) 5 figs, 7 tables, 7 refs

Key Words: Noise measurement, Aircraft noise, Airports

In order to examine issues related to noise monitoring in the vicinity of moderate-sized airports, monitoring was performed for 5 months at three sites in the vicinity of a municipal airport. Study issues included comparison of predicted and measured day/night average sound levels (DNL), comparison of individual aircraft levels with prediction, temporal sampling requirements for monitoring, and validation that the measured noise is aircraft noise and not other community noise.

84-619

Development and Flight Test of an Active Flutter Suppression System for the F-4F with Stores. Part 3. Flight Demonstration of the Active Flutter Suppression System

H. Hoenlinger, D. Mussman, R. Manser, and L.J. Huttsell

Air Force Wright Aeronautical Labs., Wright-Patterson AFB, OH, Rept. No. AFWAL-TR-82-3040-PT-3, 66 pp (June 1983)
AD-A131 972

Key Words: Aircraft, Flutter, Active flutter control

A flutter suppression system was developed and flight tested on an F-4F aircraft. The control law was designed using optimal control theory to minimize control surface motion and to provide the required stability margins.

84-620

Review of Aircraft Crash Structural Response Research

E.A. Witmer and D.J. Steigmann

Aeroelastic and Structures Res. Lab., Massachusetts Inst. of Tech., Cambridge, MA, Rept. No. ASRL-TR-198-1, DOT/FAA/CT-82-152, 136 pp (Aug 1982)
AD-A131 696

Key Words: Aircraft, Crash research (aircraft), Composite materials, Reviews

A review of aircraft crash structural response research has been carried out by studying the literature, discussions with researchers working in that area, and visits to facilities/personnel involved in conducting and/or monitoring aircraft crash structural response investigations. Aircraft structures consisting of conventional built-up metallic construction and those consisting of advanced composite materials were of interest.

84-621

A Study of Helicopter Rotor Aerodynamics in Ground-Effect at Low Speeds

M. Sun
Ph.D. Thesis, Princeton Univ., 265 pp (1983)
DA8323886

Key Words: Helicopters, Rotors, Aerodynamic loads

An experimental and analytical study of helicopter rotor aerodynamics in ground effect at low speeds has been conducted. The experimental studies included flow visualization experiments and measurements of the mean induced velocity distribution near the rotor plane using the hot wire technique using a model rotor.

BIOLOGICAL SYSTEMS

HUMAN

84-622

A Survey of Community Attitudes Towards Noise Near a General Aviation Airport

P.D. Schomer

Dept. of Electrical Engrg., Univ. of Illinois, Urbana, IL 61801, J. Acoust. Soc. Amer., 74 (6), pp 1773-1781 (Dec 1983) 3 figs, 6 tables, 14 refs

Key Words: Human response, Aircraft noise, Airports

This paper describes a community attitudinal noise survey performed in the vicinity of a municipal airport. The day/night average sound levels (DNL) ranged from 44-66 dB. The primary analysis arrayed the percent of respondents highly annoyed versus DNL. Good agreement was found between the results of this survey and the general relation developed from surveys worldwide.

84-623

Long Term Sleep Disturbance Due to Traffic Noise

M. Vallet, J.-M. Gagneux, V. Blanchet, B. Favre, and G. Labiale

Institut de Recherche de Transports - CERNE, 109 Avenue Salvador Allende, 69500 Bron, France, J. Sound Vib., 90 (2), pp 173-191 (Sept 22, 1983) 5 figs, 8 tables, 26 refs

Key Words: Traffic noise, Human response

This contribution to the evaluation of the effects of traffic noise on sleep disturbance is focused on the responses of people living near a main road. Experiments were carried out in the homes of subjects who had habitually been exposed to noise for periods of more than four years. The chronic changes in overall sleep patterns and the temporary sleep responses to particular noise events caused by traffic are demonstrated.

84-624

Experimental Investigation on the Effect of Some Temporal Factors of Nonsteady Noise on Annoyance

K. Hiramatsu, K. Takagi, and T. Yamamoto

Dept. of Sanitary Engrg., Faculty of Engrg., Kyoto Univ., 606 Kyoto, Japan, J. Acoust. Soc. Amer., 74 (6), pp 1782-1793 (Dec 1983) 22 figs, 7 tables, 6 refs

Key Words: Human response, Noise tolerance

The effects of some temporal factors of nonsteady noise on annoyance was investigated by means of six experiments. The factors are rising speed, fluctuation speed, fluctuation frequency, and fluctuation deviation. Results show that the ratio of annoyance and the rising speed are in linear relation in log-log coordinates and the annoyance increase with the increase of rising speed from 25 to 1000 dB/s corresponds to the increase of sound pressure level of 2.6 dB.

MECHANICAL COMPONENTS

ABSORBERS AND ISOLATORS

(Also see Nos. 638, 698)

84-625

Study on Physical Model of Small Size Gasoline Engine Silencers and Its Optimum Design Parameters

Ren Wen Tang, et al

Trans. of Chinese Soc. of Agri. Mach., (1), pp 15-22 (1983)

CSTA No. 631.3-83.02

Key Words: Silencers, Engine noise, Optimization

It is verified that components of exhaust noise in small gasoline engines are composed of the resonance of the cylinder. Based on this theory, a physical model of a silencer is developed and design of the silencer is simplified using the data of insert loss connected with macroscopic parameters of silencers.

84-626

The Reduction of Blast Noise with Aqueous Foam

R. Raspet and S. K. Griffiths

U.S. Army Construction Engrg. Res. Lab., P.O. Box 4005, Champaign, IL 61820, J. Acoust. Soc. Amer., 74 (6), pp 1757-1763 (Dec 1983) 6 figs, 11 refs

Key Words: Foams, Noise reduction, Blast loads

Experiments were performed to investigate the potential of water-based foams to reduce the farfield noise levels produced by demolitions activity. Measurements of the noise reductions in flat-weighted sound exposure level, C-weighted sound exposure level, and peak level were made for a variety of charge masses, foam depths, and foam densities. Scaling laws were developed to relate the foam depth, foam density, and charge mass to noise reductions.

84-627

Active Protection of Domains of a Vibrating Structure by Using Optimal Control Theory: A Model Determination

E. Luzzato

Département d'Acoustique, Electricité de France, 7 Avenue de Gaulle, 92141 Clamart Cedex, France, J. Sound Vib., 91 (2), pp 161-180 (Nov 22, 1983) 11 figs, 2 tables, 36 refs

Key Words: Active vibration control, Optimization

The problem of active protection of continuous structure domains is developed by using the well known results of optimal control theory. A mathematical model of the mechanical system is defined and a spatial approximation process is presented according to the basis theory of functional analysis applied to the discretization problem. In finite dimension spaces, the state analysis is developed, including the models of the structure and the perturbation sources, and the corresponding state equations are presented.

84-628

Comparison of Three Methods for Measuring Acoustic Properties of Bulk Materials

C.D Smith and T.L Parrott

Kentron Technical Ctr., Hampton, VA 23666, J. Acoust. Soc. Amer., 74 (5), pp 1577-1582 (Nov 1983) 4 figs, 1 table, 8 refs

Key Words: Acoustic absorption, Absorbers (materials), Measurement techniques

Three methods for measuring the acoustic properties of bulk materials are evaluated. The methods differ from one another in their practical implementation and reliability. The two more convenient methods exploit changes in surface impedance of test samples resulting from a change in the test sample geometry or boundary conditions.

SPRINGS

84-629

The Emerging Science of Spring Dynamics

R.T. Dann, editor

Mach. Des., 55 (24), pp 77-79 (Oct 20, 1983) 5 figs

Key Words: Springs, Automobile engines, Surges

The valve springs in some newly designed high efficiency and high-rpm auto engines have failed prematurely and surge was suspected as the prime cause. To pinpoint surge waves, engine tests of the springs on intake valves were conducted. Three approaches to refine spring design are suggested.

84-630

Analysis of Properties of the Railway Vehicle Springing Equipped with Non-Linear Element with Negative Stiffness under Random Excitation (Rozbor vlastností náhodne budenej sústavy vypruženia kolajového vozidla s nelineárnym prvkom vypruženia so zápornou tuhosťou)

D. Kalincak

Technical Univ. of Transport and Communications, Faculty of Mech. and Elect. Engrg., Dept. of Rolling Stock, Engines and Lifting Machines, Žilina, Czechoslovakia, Strojnícky Časopis, 34 (5), pp 591-606 (1983) 8 figs, 17 refs

(In Slovak)

Key Words: Suspension systems (vehicles), Railroad trains, Random excitation

The paper deals with the nonlinear springing element, negel, which, when used in car suspension, improves overall accel-

eration levels in the car body. The author deals with the solving of the nonlinear suspension of a car which is excited by stochastic track irregularities. Methods of statistical linearization and optimization of the parameters of the springing are given.

84-631

Softening of Vehicle Suspension by Means of a New Element with Negative Stiffness (Zmekceni vypruzeni vozidel pomoci prvku se zapornou tuhosti)

L. Freibauer

150 00 Praha 5, Vrchlickeho 80, CSSR, Strojnicky Casopis, 34 (5), pp 581-589 (1983) 7 figs, 2 refs (In Czech)

Key Words: Suspension systems (vehicles)

Advantages of soft vehicle suspension, realized by means of a new element, negel, are investigated.

TIRES AND WHEELS

84-632

Automobile Wheel with Pneumatic Damping

B.I. Bachrach and E. Rivin

Ford Motor Co., Dearborn, MI, ASME Paper No. 83-DET-17

Key Words: Wheels, Tires, Pneumatic dampers

A tire/wheel system with two air chambers connected by an orifice or capillary was studied to determine the potential for increasing tire damping without affecting rolling resistance. A 6-DOF computer simulation showed that ride quality can be improved by increasing tire damping.

84-633

The Effect of Inflation Stiffening and Surface Contact Geometry on Truck Tire Vibrational Response

A.C. Eberhardt and D.E. Southworth

North Carolina State Univ., Raleigh, NC, ASME Paper No. 83-DET-18

Key Words: Tires, Truck tires, Shells, Beams, Elastic foundations, Timoshenko theory, Modal analysis

The tire structure is treated as an inflated shell with the tread-band modeled as a Timoshenko beam in tension on an elastic foundation. The effects of stress stiffening due to inflation pretension are evaluated experimentally using a multiple-point modal analysis and frequency response deflection survey to determine structural wave phase velocities.

84-634

Ring Model of Railroad Wheel Vibrations

S. Haran and R.D. Finch

Dept. of Mech. Engrg., Univ. of Houston, Houston, TX 77004, J. Acoust. Soc. Amer., 74 (5), pp 1433-1440 (Nov 1983) 9 figs, 4 tables, 17 refs

Key Words: Wheels, Railway wheels, Rings

A model for prediction of the vibration characteristics of railroad wheels is presented. The wheel is modeled by taking the flange, rim, and plate as a series of elastically connected rings. The differential equations governing the normal mode flexural vibrations are developed for such a system. The free vibration of the system with displacement out of the plane of the wheel was studied.

BLADES

84-635

Fan Blade Vibration Analysis via Dynamic Data System Technique

S.G. Kappor and G.L. Fish

Univ. of Illinois at Urbana-Champaign, IL, ASME Paper No. 83-DET-71

Key Words: Blades, Fan blades, Vibration analysis

A recently developed dynamic data system approach is proposed to analyze the axial fan blade vibrations. This technique develops mathematical models from the time history of strain gage signals.

84-636

Analysis and Correlation of the Test Data from an Advanced Technology Rotor System

D. Jepson, R. Moffitt, K. Hilzinger, and J. Bissell

Sikorsky Aircraft Div., United Technologies Corp., Stratford, CT, Rept. No. SER-510034, NASA-CR-3714, 169 pp (Aug 1983)
N83-32777

Key Words: Blades, Propeller blades, Aircraft

Comparisons were made of the performance and blade vibratory loads characteristics for an advanced rotor system as predicted by analysis and as measured in a 1/5 scale model wind tunnel test, a full scale model wind tunnel test and flight test. The accuracy with which the various tools available at the various stages in the design/development process (analysis, model test etc.) could predict final characteristics as measured on the aircraft was determined. The accuracy of the analyses in predicting the effects of systematic tip planform variations investigated in the full scale wind tunnel test was evaluated.

84-637
Propeller Noise at Subsonic Blade Tip Speeds, Torque and Thrust Force
R. Stuff
Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt e.V., Goettingen, Fed. Rep. Germany, Rept. No. DFVLR-MITT-82-17, ESA-TT-821, 95 pp (Oct 1982)
N83-31425
(In German)

Key Words: Blades, Propeller blades, Sound generation

Sound generation due to propeller blade forces is described by an acceleration source. Closed form solutions are presented for the sound field of a propeller in yaw with asymmetric disk loading. The sound generation is assessed as a function of propeller blade forces (in dipole and quadrupole terms), of torque and thrust force by symmetrical and asymmetrical admission, as well as of forward speed. The three dimensional directional characteristics of an angular flux propeller are shown in an analytical formula.

BEARINGS

(Also see No. 583)

84-638
Elastomeric Bearings: State-of-the Art
C.W. Roeder and J.F. Stanton
Univ. of Washington, Seattle, WA 98195, ASCE J. Struc. Engrg., 109 (12), pp 2853-2871 (Dec 1983) 11 figs, 1 table, 60 refs

Key Words: Bearings, Elastomeric bearings, Reviews

A brief description of the state of knowledge throughout the world with respect to elastomeric bearings is provided. Material behavior of elastomers is summarized along with theoretical and experimental research on bearings. Various modes of failure are noted and major design methods are described and compared.

GEARS

84-639
Design and Calculation Methods for High-Speed Gears of Advanced Technology
M. Hirt
Renk Gear Co., Augsburg, W. Germany, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 1-7, 15 figs, 7 refs

Key Words: Gears, Design techniques

High-speed gears of very high powers and/or very high speeds must be exactly analyzed and optimized in gearing, bearing and housing in order to achieve low noise, low vibration running with maximum safety in operation. The gearing must be checked by detailed calculations in load capacity, including an exact analysis of the scoring safety. Special design means must be applied in order to cover thermal problems at the gearing. Practical examples of some of the highest-powered high-speed gears of the world prove the methods used in design, calculations and manufacturing.

FASTENERS

84-640
Lateral-Load Tests of R/C Slab-Column Connections
D.G. Morrison, I. Hirasawa, and M.A. Sozen
Geustyn, Forsyth, and Joubert, Inc., 63 Dorp St., Stellenbosch 7600, Rep. of South Africa, ASCE J. Struc. Engrg., 109 (11), pp 2698-2714 (Nov 1983) 15 figs, 2 tables, 8 refs

Key Words: Joints (junctions), Columns, Slabs, Reinforced concrete, Seismic excitation, Dynamic tests

The response of interior reinforced concrete plate column connections in a laterally loaded structure is investigated. Nine specimens were tested, five statically and four dynamically to simulate earthquake loading. This paper describes results from statically tested specimens.

84-641

Modeling of R/C Joints under Cyclic Excitations

F.C. Filippou, E.P. Popov, and V.V. Bertero

Dept. of Civil Engrg., Univ. of California, Berkeley, CA, ASCE J. Struc. Engrg., 109 (11), pp 2666-2684 (Nov 1983) 12 figs, 26 refs

Key Words: Joints (junctions), Beam-columns, Reinforced concrete, Cyclic loading, Seismic excitation

An accurate and efficient analytical model describing the hysteretic behavior of R/C beam-column joints subjected to random cyclic excitations is presented. The model takes into account the cyclic bond deterioration along anchored bars as well as the hysteretic behavior of cracked R/C sections at beam-column interfaces, thus allowing consideration of the interaction between the two end sections of the joint.

84-642

Damping of Torsional Vibrations by Friction in Pressing Joints (Tlmenie torzných kmitov trením v nalisovaných spojoch)

J. Murin

Institut of Materials and Machine Mechanics of Slovak Academy of Sciences, Februaroveho vit, 836 06 Bratislava, Czechoslovakia, Strojnícky Časopis, 34 (4), pp 421-436 (1983) 9 figs, 3 refs

(In Slovak)

Key Words: Joints (junctions), Torsional vibration, Coulomb friction

Dynamical and damping properties of a torsionally loaded mechanical system with immovable joints are investigated.

84-643

Static and Dynamic Characteristics of Normally Loaded Joints (Statische und dynamische Kennwerte normalbelasteter Fügestellen)

M. Weck and G. Petuelli

Aachen, W. Germany, Indus. Anzeiger, 105 (6), pp 18-22 (1983) 12 figs, 6 refs

(In German)

Key Words: Joints (junctions), Machine tools

Test results for the determination of stiffness and damping coefficients of clamped machine tools are presented. They can be used in a finite element determination of static and dynamic behavior of joints during the dynamic relative motion normal to the contact surface.

84-644

Static and Dynamic Behavior of Welded Components (Statisches und dynamisches Verhalten geschweisster Gestellbauteile)

E. Schibanow

Kalinin, USSR, Indus. Anzeiger, 105 (6), pp 24-27 (1983) 9 figs

(In German)

Key Words: Machine tools, Welded joints

Welded components of machine tools exert a considerable effect on the dynamic and static properties of machine tools. In the article the effect of design parameters, body shape, and the length of weld seams of model posts on these properties are investigated. The results showed that welded structures, compared with cast components, can achieve the same static and dynamic stiffness with half the material. In addition, the welded components enable easy modifications of design.

LINKAGES

84-645

Variation of the Range of Jump Phenomenon with the Harmonic Cam Follower Stiffness

J.A. Mendez-Adriani

Central Univ. of Venezuela, Caracas, Venezuela, ASME Paper No. 83-DET-5

Key Words: Cam followers, Jump phenomena

The purpose of this research is to report the existence of a range of jump phenomena for a harmonic cam-follower torsional mechanical system, and to investigate the variation of the range of jump phenomena with the harmonic cam follower stiffness.

84-646

An Accurate Method for Calculating the Kinematics and Dynamics of Connecting Rods of Diesel Engines

Wong De Xing

CSICE, 1 (1), pp 29-50 (1983)

CSTA No. 621.43-83.31

Key Words: Diesel engines, Rods, Linkages

An investigation into the calculation of the kinematics and dynamics of main and articulated connecting rods of diesel engines is described. The method introduced in this paper gives more reliable boundary conditions for the calculation of strength, balance and vibration of any diesel engine.

STRUCTURAL COMPONENTS

CABLES

84-647

A Study of Nonlinear Vibrations Occurring in Mine Hoisting Cables

R.R. Mankowski

Ph.D. Thesis, Univ. of the Witwatersrand, South Africa (1983)

Key Words: Cables, Mines (excavations), Hoists, Nonlinear response, Vibration analysis

A digital computer model is developed to simulate the dynamic behavior of a hoist for a vertical mine shaft. The system consists of the conveyance, headsheave and winding drum. Various types of input can be simulated and, in particular, the mechanical pulses generated by the coil cross-overs at the winding drum are approximated. The model is based on an extension of Bergeron's graphical method of mechanical impedance.

BARS AND RODS

84-648

Dynamic Analysis of a System of Bars Encased in Elastic Medium

S.M. Aljaweini

Ph.D. Thesis, Arizona State Univ., 140 pp (1983)

DA8322529

Key Words: Bars, Framed structures, Elastic media, Time-dependent excitation

A general stiffness method is presented for the analysis of space frames encased fully or partially in an elastic medium and subjected to time-dependent loads of harmonic variation. The analysis is based on the assumptions of linear elasticity, small deformations, linear vibration, with damping neglected, and restricted to systems of straight bars with constant and doubly symmetrical cross-sections.

BEAMS

(Also see Nos. 633, 690)

84-649

The Normal Modes of Beams by a Lanczos-Stodola Method

L.T. Niblett

Materials and Structures Dept., Royal Aircraft Establishment, Farnborough GU14 6TD, UK, J. Sound Vib., 91 (2), pp 247-253 (Nov 22, 1983) 6 refs

Key Words: Beams, Flexural vibration, Torsional vibration, Natural frequencies, Mode shapes

A method of finding the flexural and torsional normal modes of beams which have straight stiffness axes is given. The Lanzcos method of minimized iterations, based on the integral equation of beam vibrations, is used to obtain intermediate modes with the distributions along the beam of its mass and rigidity as data.

84-650

Visco-Plastic and Large Deformation Analysis by FEM (Investigation of Numerical Analysis and Collapse of a Beam by Transverse Impact Load)

K. Murase, H. Katori, and T. Nishimura

Meijo Univ., Faculty of Science and Engrg., Yagoto-Urayama Tenpaku Nagoya, Japan, Bull. JSME, 26 (220), pp 1696-1702 (Oct 1983) 15 figs, 12 refs

Key Words: Beams, Impact response, Viscoplastic properties, Finite element technique

This paper is the third part of a visco-plastic and large deformation analysis by the finite element method. The dynamic characteristics of a collapsing beam were investigated. The experimental values were shown to be in good agreement with the theoretical results.

84-651

The Dynamic Response Characteristics of a Viscoelastic Beam on Periodically-Spaced, Viscoelastic Supports

F.R. Bourne
Ph.D. Thesis, Clemson Univ., 143 pp (1983)
DA8320261

Key Words: Beams, Viscoelastic foundations, Computer programs

Many physical systems can be modeled as a continuous beam on periodically-spaced, flexible supports. In order to properly design such a system, an understanding of its characteristic dynamic behavior is helpful. The objective of this work is to establish the dynamic response characteristics of a continuous beam on discrete, periodically-spaced, flexible supports as a function of several system parameters.

84-652

On Dynamics and Stability of Continuous Systems Subjected to a Distributed Moving Load

R. Bogacz
Polish Academy of Sciences, Inst. Fundamental Tech. Res., Warsaw, Poland, Ing. Arch., 53 (4), pp 243-255 (1983) 7 figs, 14 refs

Key Words: Beams, Viscoelastic foundations, Moving loads, Transverse shear deformation effect, Rotatory inertia effects, Continuous systems

An analysis of different models of continuous systems subjected to a load distributed over a given length and moving at a constant velocity is presented. A beam resting on a viscoelastic semi-space is studied.

84-653

Effects of Rotary Inertia and Shear Deformation on Extensional Vibrations of Continuous Circular Curved Beams

M.E.-S. Said Issa
Ph.D. Thesis, Univ. of New Hampshire, 110 pp (1983)
DA8322739

Key Words: Beams, Curved beams, Transverse shear deformation effects, Rotatory inertia effects, Longitudinal vibration

Dynamic analysis of continuous circular curved beams is investigated. Two continuous circular curved beams subjected to free and forced vibrations are given to illustrate the application of the proposed method and to show the effects of rotary inertia, shear deformation, axial deformation, frequency of the applied load and the central angle of the arc on the beams.

84-654

Elasto-Plastic Dynamic Response of Frames to Multi-dimensional Ground Motion

Zhang Huan Hua
EEEN, 3 (1), pp 25-42 (1983)
CSTA No. 624-83.30

Key Words: Beam-columns, Frames, Elastic plastic properties, Ground motion

A set of general force-displacement constitutive equations is derived for a beam-column element regarded as a single-component model. The calculation of modulus-hardening H is explored, an approximate formula is given, and the applied conditions of the single curve hardening law are discussed. A simple numerical example is presented to illustrate how the method developed can be applied.

84-655

Forced Response of a Cantilever Beam with a Dry Friction Damper Attached. Part 1: Theory; Part 2: Experiment

E.H. Dowell and H.B. Schwartz
Dept. of Mech. and Aerospace Engrg., Princeton Univ., Princeton, NJ 08544, J. Sound Vib., 91 (2) (Nov 22, 1983). Part 1 - pp 255-267, 7 figs, 11 refs; Part 2 - pp 269-291, 11 figs, 13 refs

Key Words: Beams, Cantilever beams, Coulomb friction

A theoretical-experimental study of the forced vibration response of a cantilevered beam with Coulomb damping nonlinearity is described. Particular emphasis is placed upon the types of nonlinear behavior and system response spectral characteristics observed theoretically and experimentally, upon the design of the experimental apparatus and the utilization of associated instrumentation, and upon the methodology developed for system calibration.

COLUMNS

84-656

Vibration Characteristics of Self-Expanding Stayed Columns for Use in Space

J.R. Banerjee and F.W. Williams
Dept. of Civil Engrg. and Bldg. Tech., Univ. of Wales Inst. of Science and Tech., King Edward VII Avenue, Cardiff CF1 3NU, UK, J. Sound Vib., 90 (2), pp 245-261 (Sept 22, 1983) 9 figs, 7 tables, 8 refs

Key Words: Columns, Cable-stayed structures, Natural frequencies, Mode shapes

The type of stayed column considered was designed to be deployed in space after forming a light, compact package in the Space Shuttle. It consists of a core with three identical stay frames equally spaced around it. NASA performed vibration tests on a model of such a column and compared their results with approximate theoretical predictions. Exact theoretical results are given, including natural frequencies and mode types.

84-657

Influence of a Viscoelastic Foundation on the Stability of Beck's Column: An Exact Analysis

M.R. Morgan and S.C. Sinha
Dept. of Mech. Engrg., Kansas State Univ., Manhattan, KS 66506, J. Sound Vib., 91 (1), pp 85-101 (Nov 8, 1983) 9 figs, 22 refs

Key Words: Columns, Viscoelastic foundations

The stability of Beck's column supported by three different viscoelastic foundations, viz., the standard linear solid, the Maxwell and the Kelvin-Voigt, is investigated. Closed form stability criteria are obtained for the entire range of system parameters through an exact dynamic analysis for each foundation model.

84-658

Forced Flexural Vibrations of a Timoshenko Column Suported by an Elastic Half-Space

H. Wada
Dept. of Mech. Engrg., Tohoku Univ., Sendai 980, Japan, Intl. J. Engrg. Sci., 22 (1), pp 1-12 (1984) 5 figs, 1 table, 13 refs

Key Words: Columns, Elastic half-space, Timoshenko theory, Forced vibration, Resonant frequencies

The plane stress problem of forced flexural vibrations of an elastic column suported by an elastic half-space and subjected to a sinusoidally varying force at the free end is investigated analytically by applying the Timoshenko theory to the column. Numerical results obtained from the Timoshenko theory are compared with those from the Bernoulli-Euler theory, and the effects of column slenderness and foundation stiffness on the column response curves and the resonant frequencies of the system are clarified.

FRAMES AND ARCHES

(See No. 654)

PANELS

84-659

Unified Aeroelastic Flutter Theory for Very Low Aspect Ratio Panels

G.A. Oyibo
Fairchild Republic Company, Farmingdale, NY, AIAA J., 21 (11), pp 1581-1587 (Nov 1983) 14 figs, 20 refs

Key Words: Panels, Elastic foundations, Flutter

A theory unifying the flutter analyses of orthotropic and isotropic panels having very low aspect ratios and exposed to an inviscid potential flow on the upper surfaces is developed. The analysis considers an infinitely long panel of finite width, simply supported on the side edges, and resting on a spring foundation.

PLATES

84-660

An Approximation for the Point Mobility at the Intersection of Two Perpendicular Plates

B. Petersson

Dept. of Bldg. Acoustics, Chalmers Univ. of Tech., S-412 96, Gothenberg, Sweden, J. Sound Vib., 91 (2), pp 219-238 (Nov 22, 1983) 18 figs, 1 table, 11 refs

Key Words: Plates, Sound transmission, Structure-borne noise

The problem of point excitation at a T-intersection of two perpendicular plates is studied in order to establish expressions for the point mobility. It is found that the theory for point excitation of the free surface of a semi-infinite elastic solid is applicable in the frequency range associated with structure-borne sound transmission. From this theory the mobility for an infinite system is derived. Based on this model and on an experimental investigation an estimation procedure for the point mobility in the finite dimension case is developed.

84-661

Cluster Frequencies of Continuous Uniform Plates

B. Qin and C.C. Feng

Research Inst. of Construction Machinery, Changsha, The People's Republic of China; currently, visiting scholar, Univ. of Colorado, Boulder, CO 80309, ASCE J. Struc. Engrg., 109 (12), pp 2893-2904 (Dec 1983) 4 figs, 2 tables, 10 refs

Key Words: Plates, Natural frequencies

Numerical formulas are presented for quick determination of natural frequencies of orthotropic and isotropic continuous uniform plates.

84-662

Frequencies of Continuous Plates by Moment-Ratio Method

B. Qin and C.C. Feng

Univ. of Colorado, Boulder, CO 80309, ASCE J. Struc. Engrg., 109 (12), pp 2905-2921 (Dec 1983) 7 figs, 4 tables, 28 refs

Key Words: Plates, Natural frequencies

The moment-ratio method developed is a numerical procedure to determine the natural frequencies of continuous orthotropic and isotropic plates. The basic concept employs dynamic flexibility functions at the panel joints. Four types of boundary conditions of continuous plates -- partial constraint, simple-simple, simple-clamp, and clamp-clamp -- are developed. An equivalent analysis of continuous orthotropic and isotropic plate systems is presented and their numerical frequencies are compared.

84-663

Modal Density of Honeycomb Plates

B.L. Clarkson and M.F. Ranky

Inst. of Sound and Vib. Res., Univ. of Southampton, Southampton S09 5NH, UK, J. Sound Vib., 91 (1), pp 103-118 (Nov 8, 1983) 19 figs, 7 refs

Key Words: Plates, Honeycomb structures, Modal densities

Honeycomb plates are much stiffer than uniform plates of similar mass and consequently their modal density is relatively low. This report describes an experimental study of the modal density of uniform honeycomb plates undertaken to verify the theoretical results available in the literature. The effect of a large cut-out in the center of the honeycomb panel typical of a spacecraft platform was determined.

84-664

Shock Response of Undamped Three-Layer Sandwich Plates

A.S. Grover and A.D. Kapur

Dept. of Mech. Engrg., Punjab Engrg. College, Chandigarh, India, Strojnícky Časopis, 34 (5), pp 551-565 (1983) 9 figs, 14 refs

Key Words: Plates, Sandwich structures, Undamped structures, Shock response

The transverse displacement response of a simply supported three-layer undamped sandwich plate subjected to a rectangular pulse of a finite duration is analyzed. The solution for the shock response is obtained using Laplace transformation.

84-665

Natural Vibrations of Laminated Anisotropic Plates Using 3-D Elasticity Theory

J.N. Reddy and T. Kuppusamy

Virginia Polytechnic Inst. and State Univ., Blacksburg, VA, ASME Paper No. 83-DET-95

Key Words: Plates, Rectangular plates, Natural frequencies, Anisotropy, Layered materials

A number of cross-ply and angle-ply rectangular plates are analyzed for natural frequencies. For relatively thick plates, the shear deformable-plate theory element predicts frequencies higher than those predicted by the 3-D elasticity theory element.

84-666

Large Amplitude Axisymmetric Vibrations of Geometrically Imperfect Circular Plates

D. Hui
Dept. of Engrg. Mechanics, Ohio State Univ., Columbus, OH 43210, J. Sound Vib., 91 (2), pp 239-246 (Nov 22, 1983) 2 figs, 20 refs

Key Words: Plates, Circular plates, Geometric imperfection effects, Large amplitudes, Axisymmetric vibrations

This paper deals with the effects of geometric imperfections on the large amplitude vibrations of circular plates. It is found that geometric imperfections of the order of a fraction of the plate thickness may significantly raise the linear vibration frequencies. Such imperfections may even change the inherent nonlinear hard-spring character of the circular plates and cause them to exhibit soft-spring behavior.

84-667

Vibrations of a Circular Plate with Non-Linear Elastic Constraints

K. Mori
Mech. Engrg. Lab., Namiki, Sakura-mura, Niiharai-gun, Ibaraki, Japan, J. Sound Vib., 91 (2), pp 211-218 (Nov 22, 1983) 7 figs, 5 refs

Key Words: Plates, Circular plates, Elastic foundations, Flexural vibration

The axisymmetric transverse vibrations of a circular plate with nonlinear elastic support constraints, carrying a concentrated mass and subjected to a transverse periodic force at the center, are studied. The steady state solution involving the third order superharmonic and the one-third order subharmonic as well as the fundamental harmonic is obtained.

84-668

Optimization of Cylindrically Orthotropic Circular Plates Including Geometric Non-Linearity with a Constraint on the Fundamental Frequency

G. Venkateswara Rao and K. Kanaka Raju
Aerospace Structures Div., Vikram Sarabhai Space Ctr., Trivandrum - 695 022, India, Computers Struc., 18 (2), pp 301-305 (1984) 5 tables, 12 refs

Key Words: Plates, Circular plates, Orthotropism, Optimization, Fundamental frequency

Optimization of cylindrically orthotropic circular plates is studied with a constraint on the fundamental frequency when the effect of geometric nonlinearity is included. Details of finite element formulation for inclusion of geometric nonlinearity, derivation of optimality criterion and recurrence relations are presented. Results for various values of orthotropy parameter are given.

SHELLS

(Also see No. 633)

84-669

Dynamic Response of a Pre-Stressed Cylindrical Shell to a Moving Load

K. Shirakawa
Dept. of Mech. Engrg., Univ. of Osaka Prefecture, Mozu-Umemachi, Sakai, Osaka 591, Japan, J. Sound Vib., 90 (2), pp 263-273 (Sept 22, 1983) 7 figs, 14 refs

Key Words: Shells, Circular shells, Cylindrical shells, Moving loads

The response of a pre-stressed, finite, thin circular cylindrical shell under a moving local load with a constant velocity is studied. An analysis is carried out by a dynamic method and the solutions which are bounded even at the critical velocity are obtained. The effects of the initial stresses on the dynamic responses of the displacement and the stresses are examined in connection with the velocity of the load.

84-670

Large-Amplitude Vibrations of Geometrically Imperfect Shallow Spherical Shells with Structural Damping

D. Hui

Ohio State Univ., Columbus, OH, AIAA J., 21 (12), pp 1736-1741 (Dec 1983) 5 figs, 19 refs

Key Words: Shells, Spherical shells, Geometric imperfection effects, Damping effects, Large amplitudes

The effects of geometric imperfections on the large-amplitude vibrations of shallow spherical shells are investigated. The initial geometric imperfection, the vibration mode, and the forcing function are of the same spatial shape. It is found that the presence of geometric imperfections of the order of a fraction of the shell thickness may significantly raise the free line vibration frequencies.

84-671

Vibration and Stability of a Circular Cylindrical Shell Subjected to a Torque

T. Irie, G. Yamada, and T. Kanada
Dept. of Mech. Engrg., Hokkaido Univ., Sapporo, 060 Japan, J. Sound Vib., 91 (1), pp 37-44 (Nov 8, 1983) 5 figs, 2 tables, 16 refs

Key Words: Shells, Cylindrical shells, Torque, Vibration analysis, Stability

An analysis is presented for the vibration and stability of a circular cylindrical shell subjected to a torque. The displacements of a circular shell are written in a series of beam eigenfunctions satisfying the boundary conditions. The kinetic and strain energies of the shell are evaluated analytically, and the frequency equation of the shell is derived by the Ritz method.

84-672

Vibrations of a Cylindrical Shell with Variable Thckness Capped by a Circular Plate

K. Suzuki, S. Takahashi, E. Anzai, and T. Kosawada
Faculty of Engrg., Yamagata Univ., Yonezawa, Japan, Bull. JSME, 26 (220), pp 1775-1782 (Oct 1983) 8 figs, 1 table, 10 refs

Key Words: Shells, Cylindrical shells, Plates, Variable cross section, Natural frequencies, Mode shapes

Vibrations of a combined system of a circular cylindrical shell with variable thickness with one end clamped and the other connected to a circular plate with variable thickness are analyzed by means of the improved thick plate and shell theories.

84-673

On Some Treatment of the Equations of Motion for Cylindrical Shells Based on an Improved Theory

K. Shirakawa and W. Schnell
Univ. of Osaka Prefecture, Mozu-Umemachi, Sakai Osaka 591, Japan, Ing. Arch., 53 (4), pp 257-263 (1983) 2 tables, 9 refs

Key Words: Shells, Cylindrical shells, Transverse shear deformation effects, Rotatory inertia effects, Equations of motion

The present paper is concerned with a treatment of the equations for the vibration problem of a cylindrical shell including the effects of shear deformation and rotatory inertia. A method is proposed that reduces the equation system for the improved theory to one containing only three unknowns. The frequencies calculated from the proposed equations are compared with the results from the classical theory.

84-674

A Contribution to the Dynamical Analysis of Two-Layered Half-Cylindrical Shell (Príspevok k dynamickej analýze dvojvrstvovej polvalcovej škrupiny)

O. Šimkova and Š. Markuš
Inst. of Machine Materials and Mechanics, Slovak Academy of Sciences, Bratislava, Czechoslovakia, Strojnícky Časopis, 34 (4), pp 445-458 (1983) 1 fig, 2 tables, 4 refs
(In Slovak)

Key Words: Shells, Cylindrical shells, Natural frequencies, Mode shapes

A dynamic analysis (determination of eigenfrequencies and eigenmodes) is carried out for a two-layered half-cylindrical shell having curved edges supported by shear diaphragms and longitudinal clamped edges. Numerical results are presented.

84-675

Geometrical Aspects of Acoustic Radiation from a Shallow Spherical Cap

S. Krenk
Riso Natl. Lab., Roskilde, Denmark, J. Acoust. Soc. Amer., 74 (5), pp 1617-1622 (Nov 1983) 9 figs, 16 refs

Key Words: Shells, Spherical shells, Caps (supports), Harmonic excitation, Pulse excitation

Geometrical properties are used to obtain the acoustic field from harmonic and pulse excitation of a shallow spherical cap in a baffle. The axial field from harmonic oscillation is obtained by observing the equivalence with the field from oscillation of a suitably chosen full sphere. This defines a convenient Legendre polynomial expansion of the velocity on the cap and leads to an axial field in the form of a series of products of spherical Bessel and Hankel functions.

84-676

Non-Linear Parametric Liquid Sloshing under Wide Band Random Excitation

R.A. Ibrahim and A. Soundararajan
Dept. of Mech. Engrg., Texas Tech Univ., Lubbock, TX 79409, J. Sound Vib., 91 (1), pp 119-134 (Nov 8, 1983) 6 figs, 34 refs

Key Words: Containers, Sloshing, Random excitation

The stationary response of a liquid free surface, in a partially filled cylindrical container, to a wide band random parametric excitation is investigated. Two analytical approaches are employed. These are the Gaussian closure scheme to truncate the infinite hierarchy moment equations, and the Stratonovich stochastic averaging method. The validity of the two solutions is examined by comparing the two predicted probability densities with the one measured experimentally.

RINGS

(Also see No. 634)

84-677

Vibration of a Thick Polygonal Ring in Its Plane

K. Nagaya
Dept. of Mech. Engrg., Faculty of Engrg., Gunma Univ., Kiryu, Gunma 376, Japan, J. Acoust. Soc. Amer., 74 (5), pp 1441-1447 (Nov 1983) 6 figs, 5 tables, 13 refs

Key Words: Rings, Vibration analysis

A method for solving vibration problems of polygonal rings is presented. In the analysis, the equation of motion based on the two-dimensional theory of elasticity is applied under the plane strain assumption. The exact solution for the equation of motion is obtained. The boundary conditions along both the outer and the inner surfaces of the polygonal ring are satisfied directly by means of the Fourier expansion collocation method.

PIPES AND TUBES

84-678

Combination of the Primary and Secondary Stress Components for Piping Systems (PWR; BWR)

M. Subudhi, Y.K. Wang, and P. Bezler
Brookhaven Natl. Lab., Upton, NY, Rept. No. BNL-NUREG-32618, CONF-830805-17, 12 pp (1983) (Intl. Conf. on Struc. Mech. in Reactor Tech., Chicago, IL, Aug 22, 1983)
DE83010455

Key Words: Piping systems, Vibrating foundations, Nuclear power plants, Seismic response, Earthquake response

Several typical piping models subjected to distinct support motions are considered. The independent time history analysis yields both primary stresses due to inertia and secondary stresses due to relative support motions. In addition, this analysis predicts the total response due to both effects. These results presumably are the best estimate of the actual response of a piping system subjected to a real earthquake.

84-679

Pipe Damping Studies and Nonlinear Pipe Benchmarks from Snapback Tests at the Heissdampfreaktor

K.D. Blakely, G.E. Howard, W.B. Walton, B.A. Johnson, and D.E. Chitty
ANCO Engineers, Inc., Culver City, CA, 481 pp (July 1983)
NUREG/CR-3180

Key Words: Piping systems, Nuclear reactors, Seismic analysis

Response of a nonlinear finite element model of the Heissdampfreaktor recirculating piping loop (URL) was compared to measured data, representing the physical benchmarking of a nonlinear model. Analysis-test comparisons of piping response are presented for snapback tests that induced extreme nonlinear behavior at the URL system. In addition, seismic analyses are reported for a nonlinear and a linear piping model.

84-680

Experimental Damping Data for Dynamic Analysis of Nuclear Power Plant Piping Systems (PWR; BWR)

A.G. Ware

EG and G Idaho, Inc., Idaho Falls, ID, Rept. No. EGG-M-14682, CONF-830607-18, 19 pp (1983) (ASME Pressure Vessel and Piping Conf., Portland, OR, June 19, 1983)

DE83014920

Key Words: Piping systems, Nuclear power plants, Damping coefficients, Experimental test data

A summary of damping values reported in some recent piping system damping experiments and best estimate values for those systems is presented. From the data surveyed, the most significant influence on damping was the type of supports used. Other influential parameters were excitation level and response frequency.

DUCTS

(Also see No. 703)

84-681

Approximate Asymptotic Solutions for Acoustic Transmission through the Walls of Rectangular Ducts

A. Cummings

Dept. of Mech. and Aerospace Engrg., Univ. of Missouri-Rolla, Rolla, MO 65401, J. Sound Vib., 90 (2), pp 211-227 (Sept 22, 1983) 4 figs, 12 refs

Key Words: Ducts, Rectangular ducts, Noise transmission

Approximate expressions -- valid at sufficiently high frequencies -- are obtained for the acoustic transmission loss of the walls of rectangular ducts. Single mode propagation inside the duct, both in the fundamental mode and in higher order modes, is considered and a multimode model is also proposed. These theories lead to very simple formulae for the transmission loss, which prove to be in tolerably good agreement with measurements.

84-682

Higher Order Mode Acoustic Transmission through the Walls of Rectangular Ducts

A. Cummings

Dept. of Mech. and Aerospace Engrg., Univ. of Missouri-Rolla, Rolla, MO 65401, J. Sound Vib., 90 (2), pp 193-209 (Sept 22, 1983) 10 figs, 16 refs

Key Words: Ducts, Rectangular ducts, Noise transmission

As an extension of previous work on low frequency fundamental mode acoustic transmission through the walls of rectangular ducts, results are presented on the transmission of internally propagated higher order acoustic modes through the duct walls. Subject to various assumptions, it is possible to obtain a closed form solution to the structural wave equation governing the motion of the duct's walls, and this is used to predict the response of the walls to the internal pressure field.

84-683

A Study of n-Source Active Attenuator Arrays for Noise in Ducts

Kh. Eghtesadi and H.G. Leventhall

Dept. of Electrical Engrg., Abadan Inst. of Tech., Abadan, Iran, J. Sound Vib., 91 (1), pp 11-19 (Nov 8, 1983) 6 figs, 1 table, 12 refs

Key Words: Ducts, Sound waves, Wave attenuation, Active attenuation

Active attenuators conventionally have one or two sources as the basic element, but it is shown that multiple source attenuator arrays have potential advantages which could outweigh their disadvantages. A general equation is derived for system response in terms of number of sources and spacing. The main advantages are in increase in useful bandwidth with a decrease of output fluctuations within this band, reduction of reflections within a duct and improved isolation of the sources from the attenuator microphone.

84-684

A Method to Determine the Acoustical Properties of Locally and Nonlocally Reacting Duct Liners in Grazing Flow

G. Succi

Bolt Beranek and Newman, Inc., Cambridge, MA, Rept. No. NASA-CR-165983, 30 pp (June 1982) N83-33681

Key Words: Ducts, Acoustic linings

The acoustical properties of locally and nonlocally reacting acoustical liners in grazing flow are described. The effect of mean flow and shear flow are considered as well as the application to rigid and limp bulk reacting materials.

ELECTRIC COMPONENTS

MOTORS

(Also see No. 757)

84-685

Piezoceramic Vibromotors (Piezokeramische Vibromotoren)

H.H. Anger

1H Mittweida, Sektion Technologie des Elektronischen Gerätebaus, E. Germany, Feingeratetechnik, 32 (10), pp 470-473 (1983) 5 figs, 18 refs
(In German)

Key Words: Vibromotors, Piezoceramics

In recent years piezoelectric translational elements and piezoelectric step motors have been developed. In the article several basic designs of piezoelectric drives are described and microimpact drives are discussed in detail.

84-686

Design, Testing and Commissioning of a Synchronous Motor-Gear-Axial Compressor

C. Jackson and M.E. Leader

Monsanto Fibers and Intermediates Co., Texas City, TX, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 97-111, 39 figs

Key Words: Motors, Compressors, Testing techniques

This paper presents the design features involved in providing two air compressor trains at high efficiency. Testing and commissioning data are also presented, including specific electrical requirements; foundation and assembly features; grade maintained air filter designs at 0.5 in. water drop; torsional features not using soft elastomeric couplings; bearing designs for motor, gear and compressors; and test and commissioning data.

84-687

A Generalized and Simplified Transient Torque Analysis for Synchronous Motor Drive Trains

H. Ming Chen and S.B. Malanc.ki

Mechanical Technology, Inc., Latham, NY, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 115-119, 8 figs, 1 table, 4 refs

Key Words: Motors, Synchronous motors, Torsional excitation, Fatigue life

The start-up of synchronous motor drive trains is usually associated with torsionally excited vibrations and low-cycle fatigue problems. Traditional calculation methods used for analysis of such a system involve computerized integrations with very small time steps and many degrees of freedom. A simple method is presented which uses the knowledge of system natural frequencies and mode shapes and a general dimensionless integration data plot. A sample problem is included to demonstrate the application of the method.

DYNAMIC ENVIRONMENT

ACOUSTIC EXCITATION

(Also see Nos. 589, 618, 622, 625, 628, 683, 743, 744, 751)

84-688

Response of a Laminar Boundary Layer to Sound and Wall Vibration

C.J. Gedney

Massachusetts Inst. of Tech., Cambridge, MA, Rept. No. A/V-83560-3, 189 pp (May 1983)
AD-A132 843

Key Words: Interaction: structure-fluid, Noise reduction

An experimental analysis of the interaction of sound and plate vibration with a laminar boundary layer is presented. The two excitations generate disturbances at the leading edge of the plate which develop into Tollmien-Schlichting (TS) waves in the quasi-parallel region of the boundary layer. It is demonstrated that the TS wave and the sound wave coexist independently in this region, as predicted by the linear theory.

84-689

Acoustic Emission in Concrete During Mechanical Tests

C. Birac, P. Jamet, and D. de Prunele

CEA Centre d'Etudes Nucleaires de Saclay, Gif-sur-Yvette, France, Rept. No. CEA-CONF-6256, CONF-8204102-1, 39 pp (Apr 1982)
DE83700983
(In French)

Key Words: Acoustic emission, Concretes

The first stage of this study on laboratory samples is devoted to the most representative individual cases of concrete behavior: single stage compression on cylindrical samples, four-point bending on reinforced and non-reinforced prisms. The second stage, composed of tests on beams with a 3.50 m span, forms the transition from laboratory samples to scale 1 test pieces.

84-690

Transient Acoustic Radiation from Impacted Beam-Like Structures

A. Akay, M.T. Bengisu, and M. Latcha
Dept. of Mech. Engrg., Wayne State Univ., Detroit, MI 48202, J. Sound Vib., 91 (1), pp 135-145 (Nov 8, 1983) 6 figs, 15 refs

Key Words: Beams, Sound waves, Wave radiation, Impact noise

Transient acoustic radiation from transverse vibrations of beams and beam-like structures is obtained by modeling the structure as a series of contiguous dipoles. A time-dependent expression is developed for sound radiation from a dipole source by Fourier synthesis.

84-691

Acoustic Propagation in Wall Shear Flows and the Formation of Caustics

G.A. Kriegsmann and E.L. Reiss
Dept. of Engrg. Sciences and Aplied Mathematics, The Technological Inst., Northwestern Univ., Evanston, IL 60201, J. Acoust. Soc. Amer., 74 (6), pp 1869-1879 (Dec 1983) 4 figs, 2 tables, 14 refs

Key Words: Sound waves, Wave propagation

The propagation of acoustic waves from a high-frequency line source in a two-dimensional parallel shear flow adjacent to a rigid wall is analyzed by a ray method. The leading term in the resulting expansion is equivalent to the geometrical acoustics theory of classical wave propagation.

84-692

Determination of the Acoustic Nonlinearity Parameter B/A from Phase Measurements

Z. Zhu, M.S. Roos, W.N. Cobb, and K. Jensen
Applied Mechanics, Yale Univ., New Haven, CT 06520, J. Acoust. Soc. Amer., 74 (5), pp 1518-1521 (Nov 1983) 2 figs, 1 table, 15 refs

Key Words: Sound waves, Wave propagation

A technique for measurement of the acoustic nonlinearity parameter B/A in liquids is presented, along with results for several liquids. The nonlinearity parameter is determined by measuring changes in the travel time of ultrasonic tone bursts which are caused by prescribed changes in the ambient pressure. The travel time differences are measured by comparing the phase of the tone burst with that of a reference signal.

84-693

Acoustic Wave Propagation in Randomly Distributed Spherical Particles

J.C. Machado, R.A. Sigelmann, and A. Ishimaru
Dept. of Electrical Engrg., Univ. of Washington, Seattle, WA 98195, J. Acoust. Soc. Amer., 74 (5), pp 1529-1534 (Nov 1983) 2 figs, 7 refs

Key Words: Sound waves, Wave propagation

An experimental study has been conducted on the propagation of ultrasound at 1 and 5 MHz in a random medium consisting of a suspension of polystyrene spheres (mean diameter 0.589 mm, standard deviation 0.666 mm) in a solution of water and sugar. A burst of sine waves with repetition frequency of 200 Hz and pulse width of 15-20 μs was transmitted to the random medium. The experimental results for the attenuation and pulse broadening for the transmission and backscattering plus attenuation as a function of the receiving angle for transmission at different frequencies and particle concentrations are presented.

84-694

Nonlinear Scattering of Acoustic Waves by Vibrating Obstacles

J.C. Piquette
Ph.D. Thesis, Stevens Inst. of Tech., 236 pp (1983)
DA8323098

Key Words: Sound waves, Wave scattering

The problem of the generation of sum- and difference-frequency waves produced via the scattering of an acoustic wave by an obstacle whose surface vibrates harmonically was studied both theoretically and experimentally. The theoretical approach involved solving the nonlinear wave equation, subject to appropriate boundary conditions, by use of a perturbation expansion of the fields and a Green's function method.

84-695

Direct and Inverse Scattering in the Time Domain via Invariant Imbedding Equations

J.P. Corones, M.E. Davison, and R.J. Krueger
Iowa State Univ., Ames, IA 50011, J. Acoust. Soc. Amer., 74 (5), pp 1535-1541 (Nov 1983) 3 figs, 17 refs

Key Words: Sound waves, Wave scattering, Time domain method

This paper examines the implementation of a new approach to direct and inverse scattering problems in the time domain, which is applied here to the case of a one-dimensional lossless medium. The method is based on an integro-differential equation which is satisfied by the reflection kernel and has been derived elsewhere using invariant imbedding techniques. An example of an exact solution to this equation is given.

84-696

Thermoviscous Effects on Acoustic Scattering by Thermoelastic Solid Cylinders and Spheres

W.H. Lin and A.C. Raptis
Argonne Natl. Lab., Argonne, IL 60439, J. Acoust. Soc. Amer., 74 (5), pp 1542-1554 (Nov 1983) 10 figs, 1 table, 21 refs

Key Words: Sound waves, Wave scattering, Temperature effects

Analytic solutions and numerical results of the scattering of plane sound waves from a thermoelastic circular cylinder and from a thermoelastic sphere in an infinite, thermoviscous fluid medium are presented. The thermoelastic properties of the cylinder and the sphere and the viscosity and thermal conductivity of the surrounding fluid are taken into consideration in the solutions of the acoustic-scattering problems.

84-697

The Extreme Nearfield of an Acoustic Diffraction Grating

R.L. Ochs, Jr., J.D. Maynard, E.G. Williams, and W.J. Hughes
The Pennsylvania State Univ., P.O. Box 30, State College, PA 16801, J. Acoust. Soc. Amer., 74 (5), pp 1572-1576 (Nov 1983) 8 figs, 8 refs

Key Words: Sound waves, Wave diffraction

An expression for the transmitted sound field near (within a fraction of a wavelength) an array of slits is derived under the assumption that the normal component of the particle velocity is the same, in the slits, as if no grating were present and zero everywhere else in the plane of the grating. The expression is in the form of an inverse Fourier transform and can be evaluated quickly using a standard fast-Fourier-transform algorithm.

84-698

Some Practical Aspects of Absorption Measurements in Reverberation Rooms

A.C.C. Warnock
Div. of Bldg. Res., Natl. Res. Council, Montreal Road, Bldg. M-27, Ottawa, Ontario, K1A OR6, Canada, J. Acoust. Soc. Amer., 74 (5), pp 1422-1432 (Nov 1983) 15 figs, 4 tables, 19 refs

Key Words: Acoustic absorption, Measurement techniques, Reverberation chambers

Results of a series of computer controlled measurements of sound absorption coefficients in a single reverberation room are discussed including the effects of factors such as diffuser area, microphone position, and rotating diffusers on the measurements. Spatial variations of decay rate, curvature, and measured absorption coefficients determine the precision of the measurements.

84-699

Acoustic Propagation in Resonant Axisymmetric Cavities Enclosing an Inhomogeneous Medium. Part I: Hollow Cavity

M. El-Raheb and P. Wagner
Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA 91109, J. Acoust. Soc. Amer., 74 (5), pp 1583-1596 (Nov 1983) 24 figs, 8 refs

Key Words: Sound waves, Wave propagation

Longitudinal and transverse standing waves in rigid cylindrical and conical cavities enclosing an inhomogeneous

medium are studied. The inhomogeneity in speed of sound c is analyzed in terms of c gradient location, intensity, and shape. The inhomogeneity in both density and speed of sound is then considered and differences between the two types of inhomogeneity are explained.

84-700

Acoustic Propagation in Resonant Axisymmetric Cavities Enclosing an Inhomogeneous Medium. Part II: Cavity with Center Body

M. El-Raheb and P. Wagner

California Inst. of Tech., Pasadena, CA 91109, J. Acoust. Soc. Amer., 74 (5), pp 1597-1604 (Nov 1983) 10 figs, 3 refs

Key Words: Sound waves, Wave propagation

Analysis of acoustic propagation of standing waves in rigid axisymmetric cavities enclosing an inhomogeneous medium is extended to cavities with concentric center bodies. An approximation is adopted to study the problem parametrically. Results from this analysis are checked against a more accurate numerical model which relies on surface elements and a Green's function modified to account for medium inhomogeneity.

84-701

Propagation of Acoustic Waves in a Fluid-Filled Borehole Surrounded by a Concentrically Layered Transversely Isotropic Formation

A.K. Chan and L. Tsang

Texas A&M Univ., College Station, TX 77843, J. Acoust. Soc. Amer., 74 (5), pp 1605-1616 (Nov 1983) 13 figs, 6 tables, 13 refs

Key Words: Sound waves, Wave propagation

The method of real axis integration is applied to compute the acoustic waveform due to a point source in a fluid-filled borehole surrounded by a concentrically layered transversely isotropic formation. The problem is of interest in acoustic logging because the earth, due to its intrinsic horizontally layering structure, is essentially a transversely isotropic medium. The effects of the anisotropy and concentric layering on the acoustic waveforms are studied.

84-702

Transient Noise Source Identification by Multi-Channel Digital Signal Processing and Finite-Element Modeling

M. Caliskan

Ph.D. Thesis, North Carolina State Univ. at Raleigh, 199 pp (1983)

DA8318932

Key Words: Noise source identification, Signal processing techniques, Finite element technique

A procedure to identify transient noise sources on industrial machinery is presented. The methodology incorporates an iterative multi-channel digital signal processing algorithm implemented on a minicomputer along with finite-element analysis. Multi-channel data acquisition techniques are reviewed with emphasis on transducer locations, multiple-input single-output model constructions, and time delay estimations prior to digital signal processing techniques.

84-703

The Effects of Non-Ideal Elements and Geometry on the Performance of the Chelsea Dipole Active Attenuator

Kh. Eghtesadi and H.G. Leventhall

Dept. of Electrical Engrg., Abadan Inst. of Tech., Abadan, Iran, J. Sound Vib., 91 (1), pp 1-10 (Nov 8, 1983) 8 figs, 1 table, 13 refs

Key Words: Sound waves, Wave attenuation, Active attenuation, Ducts

In the development of dipole active attenuators it has been shown that the Chelsea dipole can give attenuation over a wide band. In this paper the effects on system performance of the departure of loudspeaker and microphone characteristics from the ideal case are considered. Fluctuations in air-flow and temperature are also considered.

84-704

Reflection, Scattering, and Absorption of Acoustic Waves by Rough Surfaces

J.G. Watson and J.B. Keller

Dept. of Mathematics, Stanford Univ., Stanford, CA 94305, J. Acoust. Soc. Amer., 74 (6), pp 1887-1894 (Dec 1983) 4 tables, 6 refs

Key Words: Sound waves, Wave reflection, Wave scattering, Wave absorption

The first and second moments; i.e., the coherent field and the two-point, two-time correlation function, are calculated for the acoustic fields scattered from various rough surfaces. For each surface they yield the reflection, absorption, and differential scattering coefficients, as well as an equivalent boundary condition for the coherent field. Renormalized coefficients are constructed to eliminate divergences at grazing incidence.

84-705

Extended Sources Radiation and Laplace Type Integral Representation: Application to Wave Propagation Above and Within Layered Media

P.J.T. Filippi
Laboratoire de Mecanique et d'Acoustique, 31 Chemin Joseph Aiguier, 13277 Marseille Cedex 9, France, J. Sound Vib., 91 (1), pp 65-84 (Nov 8, 1983) 2 figs, 14 refs

Key Words: Sound waves, Wave propagation, Layered materials, Underwater sound

It has been shown that the sound field reflected by the plane boundary of a layered ground can always be described by a specularly reflected wave and layer potentials. Despite its generality, this representation is not quite suitable for numerical computation. A representation of the solution has been proposed in which the layer potential terms are replaced by the sum of a surface wave and a Laplace type integral. Such an integral is very convenient for numerical purposes. In this paper, it is shown that this kind of representation can be obtained for a very wide class of sound propagation problems above or within layered media.

84-706

Field of a Finite-Amplitude Focusing Source

B.G. Lucas and T.G. Muir
Applied Res. Labs., The Univ. of Texas at Austin, Austin, TX 78712, J. Acoust. Soc. Amer., 74 (5), pp 1522-1528 (Nov 1983) 9 figs, 1 table, 8 refs

Key Words: Underwater sound, Sound waves

An analytical description for the field of a harmonic focusing source is derived. It is valid for spherically concave sources with small aperture angle and high ka, under conditions of quasilinear distortion (strong shocks precluded). The solution furnishes access to the phase and amplitude of second harmonic sound. Underwater experiments conducted with an f/2 lens coupled to a low-density source array are discussed.

84-707

The Uniform WKB Modal Approach to Pulsed and Broadband Propagation

R.F. Henrick, J.R. Brannan, D.B. Warner, and G.P. Forney
Applied Physics Lab., The Johns Hopkins Univ., Johns Hopkins Rd., Laurel, MD 20707, J. Acoust. Soc. Amer., 74 (5), pp 1464-1473 (Nov 1983) 5 figs, 2 tables, 12 refs

Key Words: Underwater sound, Sound waves, Wave propagation

A uniform asymptotic approach is utilized to consider pulsed and broadband propagation. For a given frequency, the WKB approach with boundary layer corrections is used to approximate the normal modes of the sound channel. This approach is demonstrated to yield significant reductions in computer processing time and high accuracy when compared to a conventional code.

84-708

Measurements of Transmission Fluctuations at Three Ranges for Refracted Paths through the Deep Ocean

H.A. DeFerrari, R.I. Davis, H. Nguygen, R.F. Tusting, and N.J. Williams
Univ. of Miami, Rosenstiel School of Marine and Atmospheric Science, 4600 Rickenbacker Causeway, Miami, FL 33149, J. Acoust. Soc. Amer., 74 (5), pp 1448-1463 (Nov 1983) 22 figs, 6 tables, 23 refs

Key Words: Underwater sound, Sound waves, Wave transmission, Measurement techniques

Fluctuations of acoustic transmission were measured for resolved refracted-refracted ray paths at three long ranges in the deep ocean (258, 410, 560 km). A moored broadband source with center frequency of 460 Hz transmitted continuously for a period of several days from each range. Received signals were processed to give time histories of complex pulse response. Fluctuation statistics are computed for the carrier line, the combined multipath signal and for time gated arrivals associated with predicted paths. A second mooring was used to measure temperature fluctuations associated with internal waves and for estimating the magnitude and vertical coherence of sound-speed fluctuations during the acoustic experiments.

84-709

On the Use of Focused Horizontal Arrays as Mode Separation and Source Location Devices in Ocean Acoustics. Part I: Theory

J.F. Lynch

Woods Hole Oceanographic Instn., Woods Hole, MA 02543, J. Acoust. Soc. Amer., 74 (5), pp 1406-1417 (Nov 1983) 7 figs, 16 refs

Key Words: Underwater sound, Acoustic arrays

It is shown that mode separation and source location can be performed using a focused horizontal array by utilizing the fact that the system response is greatest to a source located at or near the focal point. This mode separation/source location scheme is discussed for four different physical situations: a motionless point cw source in a range invariant environment, a motionless point cw source in a range varying environment, a motionless point broadband source in a range invariant environment, and a moving cw source in a range invariant waveguide environment.

84-710

Augmented Adiabatic Mode Theory for Upslope Propagation from a Point Source in Variable-Depth Shallow Water Overlying a Fluid Bottom

A.D. Pierce

School of Mech. Engrg., Georgia Inst. of Tech., Atlanta, GA 30332, J. Acoust. Soc. Amer., 74 (6), pp 1837-1847 (Dec 1983) 14 figs, 12 refs

Key Words: Underwater sound, Sound waves, Wave propagation

A uniform asymptotic solution is presented for sound propagation from a constant frequency point source in shallow water whose depth H(r) decreases monotonically with cylindrical distance r. Numerical results are compared with four parabolic equation computations.

84-711

Normal Mode Filtering in Shallow Water

En-Cen Lo, Ji-Xun Zhou, and Er-Chang Shang

Inst. of Acoustics, Academia Sinica, Peking, Rep. of China, J. Acoust. Soc. Amer., 74 (6), pp 1833-1836 (Dec 1983) 15 figs, 3 tables, 11 refs

Key Words: Underwater sound, Sound waves

In the shallow water of the Yellow Sea, filtering of mode 1 and mode 2, by employing a vertical array of nine hydrophones, has been realized in the frequency range of 250-800 Hz with a near isovelocity condition. Eigenfunctions of the mode were calculated by two parameters (P, Q) to describe the characteristics of bottom reflection approximately at small grazing angles. The advantage of treating the bottom in terms of P and Q rather than using the familiar sound speed, density, and attenuation coefficient is that the bottom reflection loss due to the effect of bottom roughness can be incorporated.

SHOCK EXCITATION

(Also see Nos. 603, 782)

84-712

Non-Steady Gas Dynamic Effects in the Induction Domain Behind a Strong Shock Wave

J.F. Clarke and R.S. Cant

College of Aeronautics, Cranfield, UK, Rept. No. CA-8229, ISBN-0-902937-79-0, 27 pp (Dec 1982) (Pres. at 9th Intl. Colloq. on Dyn. and Explosions and Reactive Systems, Poitiers, France, July 3-8, 1982)

N83-29633

Key Words: Shock wave propagation

Processes in the region between a driving piston or contact surface and a strong shock wave is modeled theoretically as relatively small perturbation events. The combustion reaction is assumed to be of simple irreversible Arrhenius type; perturbations are then of the order of the dimensionless inverse activation energy. Events behind the shock are then described by either an integral equation, which is solved by straightforward numerical iterative methods, or by a differential equation.

84-713

Effect of Vibrational Relaxation on Rise Times of Shock Waves in the Atmosphere

H.E. Bass, J. Ezell, and R. Raspet

Physical Acoustics Res. Lab., The Univ. of Mississippi, University, MS 38677, J. Acoust. Soc. Amer., 74 (5), pp 1514-1517 (Nov 1983) 3 figs, 14 refs

Key Words: Shock wave propagation

The effect of atmospheric absorption including vibrational relaxation absorption of N_2 and O_2 on shock wave rise times was presented in a previous paper. In this paper velocity dispersion due to these same relaxation mechanisms is included. The added effect of dispersion is to lengthen predicted rise times except for large amplitude (peak pressure greater than 100 Pa) shocks. The rise times computed with both absorption and dispersion are in excellent agreement with experimental data.

84-714

Critical Time for Asymptotic Waves in Self-Similar Flows

N. Virgopia

Inst. of Mathematics 'G. Castelnuovo,' Univ. of Rome, Italy, Intl. J. Nonlin. Mech., 18 (5), pp 363-376 (1983) 6 figs, 10 refs

Key Words: Shock waves, Wave propagation

The problem of shock wave formation within a self-similar flow is studied through the asymptotic wave methodology. The conditions for the breakdown of the perturbations are discussed in terms of the adiabatic index.

84-715

Unsteadiness of the Separation Shock Wave Structure in a Supersonic Compression Ramp Flowfield

D.S. Dolling and M.T. Murphy

Princeton Univ., Princeton, NJ, AIAA J., 21 (12), pp 1628-1634 (Dec 1983) 9 figs, 23 refs

Key Words: Shock waves, Interaction: shock waves-boundary layer

Wall pressure fluctuations have been measured in a two-dimensional separated compression ramp-induced shock wave turbulent boundary-layer interaction. The tests were made at a nominal freestream Mach number of 3 and at Reynolds numbers based on boundary-layer thickness of 7.8×10^5 and 1.4×10^6. The wall temperature condition was approximately adiabatic. Large-amplitude pressure fluctuations exist throughout the interaction, particularly near separation and reattachment.

84-716

Virtual Work Principles for Two Elastoimpact Contact Bodies

N. Asano

Dept. of Mech. Engrg., Tamagawa Univ., Machida, Tokyo, Japan, Bull. JSME, 26 (220), pp 1687-1695 (Oct 1983) 4 figs, 1 table, 17 refs

Key Words: Impact pairs, Stick-slip response, Principle of virtual work

Some aspects of the virtual work principles and their subsidiary contact conditions in various contact and separate states of two elastoimpact bodies are summarized. A new principle is presented for two bodies in a slip state and the subsidiary conditions which introduce the relative movements between the two bodies required in a stick-slip behavior.

84-717

Combination of Seismic Force with Other Loads

Pei Wen Jin

EEEV, 3 (1), pp 15-24 (1983)
CSTA No. 624-83.29

Key Words: Earthquake response, Seismic response

A method is presented for determining the distribution of extrema of combinations of seismic loads with other loads. When structures are designed to resist earthquake action, consideration of the combination of seismic loads with those from other sources such as wind, mechanical vibrations, etc. must be taken. Such combinations or coincidence problems can sometimes be quite complex and difficult to solve numerically.

84-718

Study of Normal Shock-Wave Turbulent Boundary-Layer Interactions at Mach Numbers of 1.3, 1.4 and 1.5

W.G. Sawyer and C.J. Long

Royal Aircraft Establishment, Farnborough, UK, Rept. No. RAE-TR-82099, DRIC-BR-88360, 155 pp (Oct 1982)
AD-A123 033

Key Words: Interaction: shock waves-boundary layer

This report presents the results of a study of seven flows involving the interaction between a normal shock wave and a two-dimensional turbulent boundary layer. The measurements were made at free-stream Mach numbers of 1.3, 1.4 and 1.5 and at Reynolds numbers based on an effective

streamwise run of 10 to 30-million. The results were obtained from comprehensive traverses with both pilot and static probes. Standard boundary-layer integral parameters based on wall and measured static pressures are presented, together with velocity profiles and the Mach number distribution over the interaction region.

84-719

Failure Criteria for Blast Loads Structures. A Review

A. Longinow, S.A. Gurainick, and J. Mohammadi
Dept. of Civil Engrg., Illinois Inst. of Tech., Chicago, IL, 6 pp (1982) (Proc. of Asilomar Conf. on Fire and Blast Effects of Nuclear Weapons (17th), May 30 - June 3, 1983, Asilomar Conf. Ctr., Pacific Grove, CA, pp 29-34)
AD-P001 800

Key Words: Protective shelters, Blast resistant structures, Reinforced concrete, Reviews

This paper briefly reviews the state-of-the-art of predicting the incipient collapse of structures subjected to blast loads and presents a suggested experimental and analytic, probability based program capable of producing the required data and criteria by the use of full-scale tests and model studies. The emphasis of this review is on reinforced concrete structures.

84-720

DIRECT COURSE Blast Shelter Entranceway and Blast Door Experiments

S.A. Kiger and D.W. Hyde
Army Engineer Waterways Experiment Station, Vicksburg, MS, 6 pp (1981) (Proc. of Asilomar Conf. on Fire and Blast Effects of Nuclear Weapons, May 30 - June 3, 1983, Asilomar Conf. Ctr., Pacific Grove, CA, pp 14-19)
AD-P001 799

Key Words: Protective shelters, Blast resistant structures, Doors, Nuclear weapons effects

The DIRECT COURSE Event is a high-explosive simulation of a 1-kt height-of-burst nuclear weapon. Three entranceway experiments will be fielded, one full size complete with two blast doors to document structural response and loading in the simulated 1-kt blast environment. Two 1/10-scale models, one double and one single entrance configuration, will be used to obtain blast pressure data that can be scaled to a 1-Mt blast environment. Results from these experiments will be used to evaluate and improve structural response calculations for the 1-kt environment, and to obtain loading data for a 1-Mt environment.

VIBRATION EXCITATION

84-721

Vibration of Axially Moving Material Using the FEM

A. Pramila, J. Laukkanen, and M. Pautamo
Univ. of Oulu, Finland, ASME Paper No. 83-DET-96

Key Words: Vibration analysis, Finite element technique, Computer-aided techniques

The free vibration of axially moving material has been considered employing the FEM program system developed. For the visualization of the complex modes (i.e., there are phase differences between the displacements at different points) the results are conveyed to a CAD/CAM system, which allows various kinds of visualization including animation.

84-722

Sensitivity Functions as Predictions of the Influence of Design Parameters on Natural Response Properties

K. Tomita and D.A. Frohrib
Univ. of Minnesota, Minneapolis, MN, ASME Paper No. 83-DET-97

Key Words: Eigenvalue problems, Vibration control

Three eigenvalue sensitivities are discussed and their relevance to mechanical vibration control is examined.

84-723

Vibration Modes of a Disc of Wood Laminate

D.S. Dugdale
Dept. of Mech. Engrg., Univ. of Sheffield, UK, Intl. J. Engrg. Sci., 22 (1), pp 77-86 (1984) 5 figs, 1 table, 5 refs

Key Words: Disks, Orthotropism, Layered materials, Variable material properties, Anisotropy, Natural frequencies, Mode shapes

Orthotropic elastic constants were obtained from tensile specimens cut at various directions relative to the grain direction. A strain energy function was derived for the flexure of a centrally clamped disc with a free rim. Test functions specifying deflection were used, with parameters having values that gave stationary frequencies according to the Rayleigh principle. Calculated frequencies and mode shapes for the five lowest principal modes showed good agreement with experimental measurements and illustrated the distortion of the mode shapes caused by anisotropy.

84-724

Study of an Oscillator Parametrically Excited with a Variable Sine Wave (Étude de l'Oscillateur Excité Paramétriquement par l'Intermediaire d'Un Sinus de la Variable)

A. Meneimeneh

Departement de Mathematiques, Faculte des Sciences, Universite Libanaise, Beyrough, Liban, Intl. J. Nonlin. Mech., 18 (5), pp 377-383 (1983) 3 figs, 6 refs

(In French)

Key Words: Periodic excitation

The excitation of an oscillator by a variable sinusoidal force is studied. The existence of an infinity of possible synchronizations is shown and the stability is studied. The evolution of the system dating from the given initial condition (transitory behavior) is also taken into consideration.

84-725

Response of Non-Linear Non-Conservative Systems of Two Degrees of Freedom to Transient Excitations

M.A.V. Rangacharyulu

Mech. Engrg. Group, Birla Inst. of Tech. and Science, Pilani 333031, India, J. Sound Vib., 91 (1), pp 45-56 (Nov 8, 1983) 4 figs, 8 refs

Key Words: Two degree of freedom systems, Nonlinear systems, Transient response

This paper deals with the approximate analysis of nonlinear non-conservative systems of two degrees of freedom subjected to transient excitations. By using a transformation of the co-ordinates, the governing differential equations of the system are brought into a form to which the method of averaging of Krylov and Bogoliubov can be applied. The response of a representative spring-mass-damper system to typical pulses like a blast pulse and a half sinusoidal pulse is determined.

84-726

Assessing Stability of Elastic Systems by Considering Their Small Vibrations

H.H.E. Leipholz

Dept. of Civil Engrg., Univ. of Waterloo, Waterloo, Ontario, Canada N2L 3G1, Ing. Arch., 53 (5), pp 345-362 (1983) 1 ref

Key Words: Stability, Elastic systems, Vibration analysis

The question of how well the stability of small vibrations ensures the stability of general motions of an elastic system caused by time depending perturbations is investigated. This same question is studied for a certain class of nonconservative systems following closely the pattern established for conservative systems.

84-727

Non-Stationary Responses of a System with Bilinear Hysteresis Subjected to Non-White Random Excitation

K. Kimura, K. Yagasaki, and M. Sakata

Dept. of Physical Engrg., Tokyo Inst. of Tech., Meguro-ku, Tokyo 152, Japan, J. Sound Vib., 91 (2), pp 181-194 (Nov 22, 1983) 14 figs, 18 refs

Key Words: Random excitation, Hysteretic damping

A technique is developed for calculating the non-stationary responses of a system with bilinear hysteresis subjected to non-white random excitations. An approximate equation of motion describing the hysteretic behavior is constructed by introducing an additional state variable and nonlinear functions. The moment equations of an equivalent linear system are derived and solved numerically by utilizing a recurrence algorithm to determine the inhomogeneous terms, and thus the mean square responses are obtained. Results are compared with corresponding digital simulation results.

84-728

Generalized Solution of Time Dependent Traveling Load Problem via Moving Finite Element Scheme

J. Padovan and O. Paramodilok

Dept. of Mech. Engrg., Univ. of Akron, Akron, OH 44325, J. Sound Vib., 91 (2), pp 195-209 (Nov 22, 1983) 8 figs, 23 refs

Key Words: Transient response, Moving loads, Time-dependent excitation, Finite element technique

A finite element methodology is described which can handle the transient response of moving structures which are themselves subject to time dependent traveling load fields. The generality of the approach is such that it can handle the overall transient response due to moving loads whose magnitude, zone of application and trajectory are time dependent. In addition to developing the overall transient solution methodology, attention is also given to establishing the overall eigenvalue properties of the linear problem as well as developing a solution for the steady vibrating case.

84-729

Laminar Flow in the Plane Gap with the Influence of Transverse Harmonic Force (Laminární proudění v Rovinné mezeře s vlivem příčné harmonické síly)

E. Janotková and O. Ošlejšek
Faculty of Mech. Engrg., Technical Univ. Brno,
Strojnícky Časopis, 34 (5), pp 635-646 (1983) 6 figs, 6 refs
(In Czech)

Key Words: Flexural vibration, Harmonic excitation

This contribution deals with a theoretical solution of the laminar isothermal incompressible flow in the plane gap being disturbed by transverse harmonic force. The equation describing a secondary flow is derived here and its numerical solution is presented.

84-730

Two Studies in Nonlinear Dynamical Systems

B.H. Tongue
Ph.D. Thesis, Princeton Univ., 167 pp (1983)
DA8322585

Key Words: Component mode analysis, Periodic response, Nonlinear systems, Free vibration, Forced vibration

A study to improve a generic methodology for attacking nonlinear dynamical problems is presented. The method is shown to generate a number of equations of motion that are proportional to the number of nonlinear constraints on the system rather than being proportional to the number of linear modes of the system. The steady state vibrations of a generalized dynamical system are studied for both free and forced vibrations. Two methods of analyzing the transient motion of the system are presented.

84-731

Some Results on Phase-Locking of Forced Oscillators

M. St. Vincent
Ph.D. Thesis, Northeastern Univ., 68 pp (1982)
DA8323007

Key Words: Forced vibration, Phase effects

Sinusoidal forcing of a circularly symmetric two-dimensional nonlinear oscillator having a unique stable limit cycle is investigated. Properties of the period map are obtained by approximating the system by a phase equation.

84-732

A Periodically Forced Piecewise Linear Oscillator

S.W. Shaw
Ph.D. Thesis, Cornell Univ., 165 pp (1983)
DA8321904

Key Words: Linear systems, Periodic excitation

A single degree of freedom nonlinear oscillator with periodic forcing is considered. The nonlinearity is in the restoring force, which is piecewise linear with a single change in slope at displacement x_0. The oscillator serves as a model for more complex mechanical linkages and systems which contain one-sided amplitude constraints. In order to study the motions of this system a method of Poincare is employed. Experiments on a beam with a nonlinear boundary condition (an amplitude constraint) were also performed.

MECHANICAL PROPERTIES

DAMPING

84-733

Multibody Systems with Friction (Reibungsbehaftete Bindungen in Mehrkörpersystemen)

W. Schiehlen
Inst. B fur Mechanik, Universitat Stuttgart, Pfaffenwaldring 9, D-7000 Stuttgart 80, Fed. Rep. Ger-

many, Ing. Arch., 53 (4), pp 265-273 (1983) 4 figs, 14 refs
(In German)

Key Words: Coulomb friction

The dynamical analysis of multibody systems with friction requires the reaction forces in addition to the equations of motion. According to Coulomb's law of adhesive friction the equations of motion and the equations of reaction forces remain decoupled while for Coulomb's sliding and mixed friction a nonlinear coupling of both systems of equations may appear. The method of solution is discussed for various cases and demonstrated by examples.

FATIGUE

(Also see No. 587)

84-734

Computer-Aided Verification of Fatigue-Machine Performance

T.M. Maheady and W.T. Broush

Westinghouse Electric Corp., R&D Ctr., Pittsburgh, PA, Exptl. Tech., 7 (12), pp 19-23 (Dec 1983) 7 figs

Key Words: Fatigue tests, Test equipment and instrumentation, Computer-aided techniques

Computer-aided techniques for the calibration of fatigue testing machines is described.

84-735

Variable Load Fatigue Report (10th): Speed of Testing and the Exclusion of Low and High Stress Peaks

M.N. Kenefeck

Motor Industry Res. Assn., Nuneaton, UK, Rept. No. 1982/1, 54 pp (1982)
MIRA-83

Key Words: Fatigue tests

Variable load fatigue tests were carried out on small laboratory specimens in order to determine the effect of the speed of testing and the effect of removing low peaks and high peaks from the loading signal. The primary purpose of this work was to decide whether realistic tests on components can be carried out more quickly, simply by speeding up the application of the load, and whether some simplification of the applied load in variable load tests on components is possible without serious loss of realism.

84-736

Static and Dynamic Stiffness Reduction of Graphite/Epoxy Composite Laminates under Fatigue Loading

H.A. Whitworth

Ph.D. Thesis, The George Washington Univ., 197 pp (1983)
DA8324493

Key Words: Layered materials, Fatigue life

An investigation has been conducted into the effect of fatigue loading on the stiffness and strength degradation of composite laminates. A set of fatigue tests was conducted on two orientations of graphite/epoxy laminates. Both static and dynamic stiffness were continually monitored during the fatigue tests, for a wide range of stress levels, and the results presented for each stress level tested. Residual strength tests were also performed on some laminates during this test program.

WAVE PROPAGATION

(Also see Nos. 683, 691, 692, 693, 694, 695, 696, 697, 699, 700, 701, 703, 704, 705, 706, 707, 708, 710, 711, 712, 713, 714, 715)

84-737

Ultrasonic Shear Wave Properties of Soft Tissues and Tissuelike Materials

E.L. Madsen, H.J. Sathoff, and J.A. Zagzebski

Dept. of Medical Physics and Radiology, Univ. of Wisconsin, Madison, WI 53706, J. Acoust. Soc. Amer., 74 (5), pp 1346-1355 (Nov 1983) 15 figs, 1 table, 23 refs

Key Words: Shear waves, Wave attenuation, Wave propagation, Bioengineering

Determinations of shear wave speeds of sound and attenuation coefficients are reported for soft tissues, a silicone rubber reference material, and a gel used in manufacturing ultrasonically tissue-mimicking materials. Fresh bovine tissues were investigated, including calfskin, liver, cardiac muscle, and striated muscle.

84-738

The Thermal Pulse Decay Technique for Measuring Ultrasonic Absorption Coefficients

K.J. Parker

Dept. of Electrical Engrg., Univ. of Rochester, Rochester, NY 14627, J. Acoust. Soc. Amer., 74 (5), pp 1356-1361 (Nov 1983) 6 figs, 11 refs

Key Words: Wave absorption, Temperature effects

The classic method for measuring absorption coefficients of materials requires a determination of the temperature rise within a medium during ultrasonic irradiation. Serious errors may result from a viscous heating effect around the required thermocouple probe, and from heat lost by conduction to surrounding, cooler regions. A thermal pulse-decay technique is proposed and evaluated which allows for the separation, in time and space, of the viscous heating artifact and the true absorptive heating of a medium.

84-739

Propagation of Stress Pulses in a Periodically Layered Elastic Composite

A.K. Ghosh, S.C. Lakkad, and P. Ramakrishnan

Reactor Analysis and Studies Section, Bhabha Atomic Res. Centre, Bombay, India, J. Sound Vib., 91 (2), pp 155-160 (Nov 22, 1983) 4 figs, 2 tables, 8 refs

Key Words: Composite structures, Stress waves, Wave propagation, Wave attenuation

A transfer matrix analysis of a periodically layered elastic composite is presented. Numerical analysis of propagation of a rectangular stress pulse reveals attenuation and development of a stress of an opposite sign, and these results are shown as functions of location and pulse-width.

84-740

Dispersion of Extensional Waves in Fluid-Saturated Porous Cylinders at Ultrasonic Frequencies

J.G. Berryman

Lawrence Livermore Natl. Lab., P.O. Box 808, L-200, Livermore, CA 94550, J. Acoust. Soc. Amer., 74 (6), pp 1805-1812 (Dec 1983) 4 figs, 28 refs

Key Words: Wave dispersion, Cylinders, Porous materials, Fluid-filled media

Ultrasonic dispersion of extensional waves in fluid-saturated porous cylinders is studied by analyzing generalized Pochhammer equations derived using Biot's theory. Cases with open-pore surface and closed-pore surface boundary conditions are considered.

84-741

Characterization of Volume Scattering Power Spectra in Isotropic Media from Power Spectra of Scattering by Planes

R.C. Wang, J.O. Nilsson, and J.P. Astheimer

Dept. of Electrical Engrg., College of Engrg. and Applied Science, The Univ. of Rochester, Rochester, NY 14627, J. Acoust. Soc. Amer., 74 (5), pp 1555-1571 (Nov 1983) 7 figs, 8 tables, 21 refs

Key Words: Power spectra, Wave scattering

Relations between the power spectrum of scattering by a plane and by a volume of a statistically isotropic random medium are developed from two basic expressions. One gives the power spectrum of scattering by an n-dimensional isotropic medium as a one-dimensional transform of a rotationally symmetric correlation function of medium variations. The other describes the power spectrum of scattering by an (n-k)-dimensional cross section as a projection of the power spectrum in n-dimensional space. The results are used to determine the power spectrum of scattering by a volume from the power spectrum of scattering by a plane within the volume and also to relate the moments of power scattered in spaces of various dimensions.

84-742

Scattering by Weakly Nonlinear Objects

D. Censor

Ben-Gurion Univ. of the Negev, Beer Sheva 84105, Israel, SIAM J. Appl. Math., 43 (6), pp 1400-1417 (Dec 1983) 32 refs

Key Words: Wave scattering

A consistent scattering theory is developed for systems involving nonlinear objects. Weak nonlinearity is assumed, such that harmonic generation is present, but shock wave formation is excluded. Mathematically this is described by constitutive relations in the form of Volterra series. For periodic waves, this procedure facilitates algebraic constitutive relations and dispersion equations in the transform space. Using wave solutions from the linear theory, various boundary value problems are discussed. Plane interfaces are considered, displaying well known properties relevant to new technological applications. Scattering from cylinders and spheres is also discussed.

84-743

The Scattering Integral Equation for Surfaces Containing Curvature Discontinuities

N.N. Bojarski

16 Pine Valley Lane, Newport Beach, CA 92660, J. Acoust. Soc. Amer., 74 (6), pp 1880-1882 (Dec 1983) 1 fig, 7 refs

Key Words: Wave scattering, Sound waves, Electromagnetic waves

The conventional formulations of the acoustic and electromagnetic scattering integral equations, which are valid only for surfaces with continuous and differentiable curvature, are generalized to surfaces containing curvature discontinuities. It is argued that these generalizations are essentially a generalization of the 1859 and 1882 Kirchhoff integration of the scalar and vector wave equations, respectively, as well as a generalization of the 1938 Stratton-Chu integration of Maxwell's equations.

84-744

Properties of Acoustic and Electromagnetic Transmission Coefficients and Transfer Matrices of Multilayered Plates

K.P. Scharnhorst

Naval Surface Weapons Ctr., White Oak, Silver Spring, MD 20910, J. Acoust. Soc. Amer., 74 (6), pp 1883-1886 (Dec 1983) 1 fig, 8 refs

Key Words: Plates, Layered materials, Wave transmission, Sound waves, Electromagnetic waves

With the aid of certain symmetry properties of the elementary transfer matrices of acoustic and electromagnetic field vectors in single layers of absorbing materials, the transformation properties of the system transfer matrices of bonded stacks of absorbing layers under the operation of reversal of the direction of incident radiation are derived.

EXPERIMENTATION

MEASUREMENT AND ANALYSIS

84-745

Differentiation and Integration of Continuous Experimental Data

D.G. Berghaus and T.O. Woods

School of Engrg. Science and Mechanics, Georgia Inst. of Tech., Atlanta, GA, Exptl. Tech., 7 (11), pp 22-27 (Nov 1983) 8 figs, 7 refs

Key Words: Testing techniques, Differential equations, Integral equations

A cam follower experiment is used to illustrate differentiation and integration methods and to show their problems and features.

84-746

Vibration Analysis (Analyse des Schwingungsverhaltens)

Indus. Anzeiger, 105 (6), pp 31-33 (1983) 6 figs, 1 ref

(In German)

Key Words: Vibration measurement, Holographic techniques

The fundamentals of holographic technology are briefly described and its application in the measurement of various objects is explained. The advantages of the procedure are enumerated.

84-747

Machinery Vibration Monitoring and Analysis – A Maintenance Tool

R.L. Eshleman

Vibration Institute, 101 W. 55th St., Clarendon Hills, IL 60514, "Coil Winding," Proc. of Intl. Coil Winding Assn., Inc., Oct 3-6, 1983, pp 76-80, 9 figs, 2 tables, 7 refs

Key Words: Vibration analysis, Vibration monitoring, Monitoring technqiues, Failure detection

This paper concerns the use of machinery vibration measurements as a maintenance tool. Measurements, analysis, criteria, and monitoring and analysis techniques are discussed. The process of fault identification in machinery using vibration analysis is reviewed. Examples of vibration signatures of common machine problems are given.

84-748

Advanced Programmable Alphanumeric Calculator Vibration Analysis

L.A. Van Gulick
Lafayette College, Easton, PA, ASME Paper No. 83-DET-54

Key Words: Vibration analysis, Computer-aided techniques

Advanced programmable alphanumeric calculators are shown to be capable of carrying out vibration analyses in support of preliminary design activities. The value of their special programming features and simple interactive execution procedures are demonstrated.

84-749

Multiple Input Estimation of Frequency Response Functions: Excitation Considerations

R.J. Allemang, R.W. Rost, and D.L. Brown
Univ. of Cincinnati, OH, ASME Paper No. 83-DET-73

Key Words: Frequency response function

The current approach to the estimation of frequency response functions using multiple inputs is reviewed. Background and example applications are provided for various excitation signal types that are consistent with the multiple input estimation of frequency response functions.

84-750

Use of "Corner Microphones" for Sound Power Measurements in a Reverberation Chamber

T.W. Bartel, S.L. Yaniv, and D.R. Flynn
Natl. Engrg. Lab., Natl. Bureau of Standards, Washington, DC 20234, J. Acoust. Soc. Amer., 74 (6), pp 1794-1800 (Dec 1983) 7figs, 1 table, 22 refs

Key Words: Acoustic measurement, Measurement techniques, Sound power levels

A comparison was made between acoustic measurements conducted with microphones mounted in a reverberation chamber and similar measurements using microphones located in the room interior away from the room boundaries. Measurements of broadband and discrete-frequency sound pressure and of reverberation time were included.

84-751

A Stochastic Analysis for Cross-Spectral Density Method of Measuring Acoustic Intensity

C. Mathur
Structural Dynamics R&D, Beech Aircraft Corp., 9707 E. Central Ave., Wichita, KS 67201, J. Acoust. Soc. Amer., 74 (6), pp 1752-1756 (Dec 1983) 3 figs, 13 refs

Key Words: Sound measurement, Measurement techniques, Acoustic intensity method, Cross spectral method, Two microphone technique, Stochastic processes

A stochastic analysis for the cross-spectral density method of measuring acoustic intensity is presented. The analysis is based on the theory of linear mean-square estimation as applied to stochastic processes and its generality is preserved through the use of some concepts from the theory of multidimensional stochastic processes. A general theoretical expression, in terms of spatial-correlation and cross-spectral density functions between two closely spaced microphones, is obtained for estimating acoustic intensity.

84-752

Effects of Static and Dynamic Stress on the Piezoelectric and Dielectric Properties of PVF_2

S.W. Meeks and R.Y. Ting
Underwater Sound Reference Detachment, Naval Res. Lab., P.O. Box 8337, Orlando, FL 32856, J. Acoust. Soc. Amer., 74 (6), pp 1681-1686 (Dec 1983) 9 figs, 19 refs

Key Words: Piezoelectricity, Experimental test data

The effects of hydrostatic pressure and pressure cycling on the piezoelectric properties of polyvinylidene fluoride (PVF_2) have been experimentally investigated by using an acoustic reciprocity technique. The hydrostatic piezoelectric constants and the relative dielectric constant were measured as a function of pressure and pressure cycling for both voided and nonvoided PVF_2 samples. The dynamic response of these materials to high-amplitude pressure pulses having a rise time of 1-3 ms was also determined.

84-753

Rapid Solutions to the Transient Response of Piezoelectric Elements by Z-Transform Techniques

R.E. Challis and J.A. Harrison
Dept. of Biophysics and Bioengineering, Chelsea College, London S.W.3, UK, J. Acoust. Soc. Amer., 74 (6), pp 1673-1680 (Dec 1983) 9 figs, 1 table, 8 refs

Key Words: Piezoelectricity, Transient response, Laplace transformation

Calculation of the transient response of piezoelectric elements by analytical means is only possible for a small range of exciting functions for which simple Laplace transforms exist. Calculation tends to be tedious due to the large number of terms which must be evaluated. A method is presented by which the Laplace transformed three-port model of a piezoelectric element is approximated by a discrete time system by application of the z-transform. A recurrent time domain solution is developed and this is applied in the manner of a digital filter to a variety of exciting functions.

DYNAMIC TESTS

(Also see Nos. 734, 780)

84-754

Selection of Shaker Specifications in Seismic Qualification Tests

C.W. De Silva

Carnegie-Mellon Univ., Pittsburgh, PA 15213, J. Sound Vib., 91 (1), pp 21-26 (Nov 8, 1983) 3 figs, 3 refs

Key Words: Shakers, Specifications, Seismic tests, Qualification tests

A procedure that can be employed to determine suitable exciter specifications for seismic qualification tests is developed. Estimates for force, power, and stroke ratings of exciter are obtained by this procedure, the mass and the damping ratio of test package and the response spectrum of the excitation signal being used. Either an acceleration required response spectrum (RRS) or a velocity RRS may be used in this procedure to specify the dynamic environment for the test. Two numerical examples are presented.

84-755

Review of Support Interference in Dynamic Tests

L.E. Ericss n and J.P. Reding

Lockheed Missiles and Space Co., Inc., Sunnyvale, CA, AIAA J., 21 (12), pp 1652-1666 (Dec 1983) 38 figs, 81 refs

Key Words: Supports, Wind tunnel testing, Dynamic tests

The interference of supports in wind tunnel testing is discussed focussing on testing at moderate angles of attack, including static support interference and dynamic support interference. The special difficulties encountered in static and dynamic tests at very high angles of attack is also dealt with.

DIAGNOSTICS

84-756

Studies on the Vibration and Sound of Defective Rolling Bearings (Second Report: Sound of Ball Bearings with One Defect)

T. Igarashi and S. Yabe

Technological Univ. of Nagaoka, Kamitomioka-cho, Nagaoka, Niigata, Japan, Bull. JSME, 26 (220), pp 1791-1798 (Oct 1983) 10 figs, 7 tables, 10 refs

Key Words: Diagnostic techniques, Sound measurement, Bearings, Roller bearings, Ball bearings

An investigation was undertaken to establish a procedure for diagnosing defects in rolling bearings from their vibration and sound. The sound of a rolling bearing with one dent in the race surface of the inner or outer ring or in the ball surface was studied. A method to locate the defect and determine its size was established.

84-757

On Stream Solution of a Prototype 8000 HP Motor Instability Problem

P.C. Monroe, Jr. and D.J. Salamone

Exxon Chemical Americas, Baytown, TX, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 53-71, 52 figs, 11 tables, 5 refs

Key Words: Motors, Failure analysis, Case histories

This paper presents a typical field problem that maintenance engineers in petrochemical plants encounter. Two 4000 hp through-drive electric motors were totally destroyed when the inboard coupling failed. The paper goes into detail on new bearing design and installation, motor mechanical and hot optical alignment, and start-up data. All of the design and fabrication of the bearings was done while the unit was running, and the bearings were installed during a normal scheduled downtime.

84-758

The Effects on the Dynamic Performance of Hydrostatic Drives - Application in the Selection and Diagnosis of Components (Einflüsse auf das dynamische Verhalten hydrostatischer Fahrantriebe -- Anwendung auf Baugruppenauswahl und - diagnose)

M. Schuszter and V.G. Binh

Hochschule fur Verkehrswesen "Friedrich List" Dresden, German Dem. Rep., Hebezeuge u. Fördermittel, 23 (10), pp 297-299 (1983) 11 figs, 3 refs (In German)

Key Words: Fluid drives, Diagnostic techniques

Parameters which have a considerable effect on the dynamic behavior of hydraulic drives are investigated and the possibilities for the reduction of dynamic loading are discussed. The parameters investigated were the reduced pump drive moment, reduced inertia moment of the pump group, reduced inertia moment of the hydromotor group, spring constants of the mechanical drive, and drive wear.

BALANCING

84-759

Armature Balancing - Automatic Positioning of the Workpiece

G.K. Grim

Balance Technology, Inc., Ann Arbor, MI, "Coil Winding," Proc. of Intl. Coil Winding Assn., Inc., Oct 3-6, 1983, pp 128-131, 6 figs

Key Words: Balancing techniques

A dynamic balancing machine measures unbalance amount and angular position. In the past, methods of measuring angular position depended upon pre-marking the workpiece, and upon operator skill and accuracy. With the method presented here, an unmarked workpiece can be measured in a conventional balancer and stopped with the point of unbalance aligned with the marking system and the center of the correction area marked. An operator may then handle the workpiece and add or remove material at exactly the right location.

84-760

Utilization of Gaging in the Balance Process

D.R. Weidner

Micro-Poise Div., Ransburg Corp., 3939 W. 56th St., Indianapolis, IN 46208, "Coil Winding," Proc. of Intl. Coil Winding Assn., Inc., Oct 3-6, 1983, pp 134-138, 4 figs

Key Words: Balancing techniques

The application of basic gaging methods to the balance correction process is discussed.

84-761

Quality of Rigid Rotor Balancing on Elastic Supports: Definition Rigidity

R. Bigret

Alsthom-Atlantique Co., France, ASME Paper No. 83-DET-74

Key Words: Balancing techniques, Rigid rotors, Rotors, Elastic foundations, Standards and codes

The developments presented in this paper are related to the standard ISO 1940 presently being revised and AFNOR E 90600, which gave a definition of rigid and flexible conditions and procedures to determine permissible unbalances for which the quality of balancing is evaluated.

84-762

Modal Balancing of Flexible Rotors without Test Runs: An Experimental Investigation

P. Gnielka

Institut f. Luft-und Raumfahrt, Technische Universitat Berlin, Berlin, Germany, J. Sound Vib., 90 (2), pp 157-172 (Sept 22, 1983) 8 figs, 2 tables, 13 refs

Key Words: Modal balancing technique, Balancing techniques, Rotors, Flexible rotors

In all methods of balancing flexible rotors currently in use (modal balancing and influence coefficient techniques) test masses and test runs are required for the calculation of correction masses. In the modal balancing procedure suggested by Gasch and Drechsler a simple identification method is used to find the generalized unbalances without test runs. In this paper the balancing procedure is reported and extended to multibearing rotors with initial shaft bow. Systematic experiments done on two test rotors are described.

MONITORING

(Also see No. 747)

84-763

A Technical Approach to the Maintenance and Overhaul of Gas Turbines

C.D. Hall

Dow Chemical, U.S.A., Freeport, TX, Turbomachinery Symp., Proc. of the 12th, Texas A&M Univ., College Station, TX, Nov 15-17, 1983, pp 73-80, 21 figs

Key Words: Monitoring techniques, Gas turbines

Conventional approaches to maintenance of large machines are effective, but often create problems in the areas of record keeping, access to knowledge gained from previous experience, lack of intimate knowledge of individual machines' operating characteristics, and availability of expert advice for emergency repairs. An alternative approach of an in-house, multidisciplinary maintenance team is discussed. This approach includes the specialty areas of lubrication, dynamic balancing and vibration, optical alignment, metallurgical engineering, welding technology, non-destructive testing, mechanical analysis, and mechanical engineering.

84-764

Simulation of Stress Induced Sound Emission by Means of an Instrument having Pseudostochastic Signal Generation (Simulation spannungsinduzierter Schallemission durch ein Gerät mit pseudostochastischer Signalerzeugung)

G. Dörfel, G. Kirchhoff, and V. Schöps

Zentralinstitut f. Festkörperphysik und Werkstofforschung Dresden, E. Germany, Feingerätetechnik, 32 (10), pp 457-459 (1983) 6 figs, 14 refs

(In German)

Key Words: Monitoring techniques, Acoustic emission

A test signal generator for the development and monitoring of the indication electronic equipment for acoustic emission signals for materials testing is presented. The simulation of the stochastic amplitude variation and the stochastic sequence of the emission bursts is described.

84-765

Vibration Monitoring Using a Computer Network Approach

T.P. Harrington, S.P. Roblyer, and H. Toffer

UNC Nuclear Industries, Richland, WA, ASME Paper No. 83-DET-72

Key Words: Monitoring techniques, Computer-aided techniques

This paper briefly discusses the history of vibration monitoring, covers data collection techniques currently in use, and then discusses the satellite station approach. A discussion of the hardware and software components of the satellite stations and minicomputer and a description of the communications network are then given.

ANALYSIS AND DESIGN

ANALYTICAL METHODS

84-766

Element Choices for Explicit and Implicit Nonlinear Finite-Element Computation. ISPRA Courses on Structural Dynamics - Lecture Notes

G.L. Goudreau

Lawrence Livermore Natl. Lab., CA, Rept. No. UCRL-89172, CONF-830582-1, 30 pp (May 1983) Structural Dynamics Mtg., May 16, 1983, Ispra Italy

DE83013041

Key Words: Finite element technique, Finite difference technique, Computer programs

The confrontation of the finite element technology with the awesome number crunching required for the nonlinear problem has forced a new assessment. The intent of this study is to review choices in the context of the two and three dimensional implicit and explicit Lagrangian codes developed in the Methods Development Group. The explicit DYNA2D and DYNA3D and implicit NIKE2D and NIKE3D of Hallquist form the focus of this discussion.

84-767

Bounds and Estimates for the Linearly Perturbed Eigenvalue Problem

W.D. Raddatz

Ph.D. Thesis, Georgia Inst. of Tech., 135 pp (1983) DA8322562

Key Words: Eigenvalue problems

The problem of bounding and estimating the discrete portion of the spectrum of a linearly perturbed self-adjoint operator, M(x) is considered. The results presented have numerous practical application in the physical sciences, including problems in atomic physics and the theory of vibrations of acoustical and mechanical systems.

84-768

Practical Reduction of Structural Eigenproblems

M. Paz

Civil Engrg. Dept., Univ. of Louisville, Louisville, KY, ASCE J. Struc. Engrg., 109 (11), pp 2591-2597 (Nov 1983) 32 refs

Key Words: Eigenvalue problems, Reduction methods

This paper presents a modified Guyan reduction method which decreases errors in the calculation of the eigenvectors of the system and which does not require matrix inversions. It also shows that a simple iterative process could be used to further improve the eigenvalue solution of the system.

84-769

Approximate Backbone Curves for Non-Linear Systems with Several Degrees of Freedom

F. Badrakhan

College of Engrg. and Petroleum, Kuwait Univ., Kuwait, Intl. J. Nonlin. Mech., 18 (5), pp 385-394 (1983) 7 figs, 8 refs

Key Words: Nonlinear systems, Multidegree of freedom systems, Normal modes

The concept of forced normal modes for linear damped systems is extended to nonlinear systems. It is used together with the first harmonic method in order to establish an approximate but rapid method for the determination of backbone curves for nonlinear systems having several degrees of freedom.

84-770

The Response of Multidegree-of-Freedom Systems with Quadratic Non-Linearities to a Harmonic Parametric Resonance

A.H. Nayfeh

Dept. of Engrg. Science and Mechanics, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA 24061, J. Sound Vib., 90 (2), pp 237-244 (Sept 22, 1983) 2 figs, 11 refs

Key Words: Multidegree of freedom systems, Harmonic excitation, Parametric excitation, Nonlinear systems

An analysis is presented of the response of multidegree-of-freedom systems with quadratic nonlinearities to a harmonic parametric excitation in the presence of an internal resonance.

84-771

An Experimental Study of Signal-to-Noise Ratio Losses Due to OR-ing

W.A. Struzinski and J.C. Bloom

Code 3213, Naval Underwater Systems Ctr., New London, CT 06320, J. Acoust. Soc. Amer., 74 (5), pp 1418-1421 (Nov 1983) 4 figs, 1 table, 13 refs

Key Words: Signal processing techniques, Data processing, Signal-noise ratio

The OR-ing device is a device used in signal processing systems which picks the single channel with the most energy. OR-ing experiments have been conducted to determine the signal-to-noise ratio loss when OR-ing N bins of data and to compare these results with some of the recently published theoretically derived losses. This paper discusses the details of the OR-ing experiment hardware and software, as well as the results obtained to date.

84-772

On the Oscillations of Musical Instruments

M.E. McIntyre, R.T. Schumacher, and J. Woodhouse

Dept. of Applied Mathematics and Theoretical Physics, Univ. of Cambridge, Cambridge, CB3 9EW, UK, J. Acoust. Soc. Amer., 74 (5), pp 1325-1345 (Nov 1983) 16 figs, 82 refs

Key Words: Musical instruments, Nonlinear systems, Time domain method, Vibration analysis

The time-domain description of musical and other nonlinear oscillators complements the more commonly used frequency-domain description, and is especially advantageous when studying large-amplitude oscillations for which nonlinearity may be severe. Efficient time-domain simulations may be easily set-up on a small computer. The simplest relevant model is described here and demonstrates some of the basic nonlinear behavior of the clarinet, violin, and flute families with very little programming effort.

STATISTICAL METHODS

84-773

The Effect of Random Errors on a Large Statistical Energy Analysis Model

R.J.M. Craik

Dept. of Bldg., Heriot-Watt Univ., Edinburgh EH1 1HX, UK, J. Sound Vib., 91 (1), pp 57-64 (Nov 8, 1983) 3 figs, 1 table, 2 refs

Key Words: Statistical energy analysis, Error analysis

The framework of analysis known as Statistical Energy Analysis has many important applications particularly in systems where detailed information is not available. As a result of the approximations made, to simplify the calculations, random errors can be introduced into the SEA model. For large systems this gives rise to uncertainty in the energy levels. It is shown that the effect of these errors on the model depends on the shape of the model.

84-774

Statistical Errors for Non-Linear System Measurements Involving Square-Law Operations

J.S. Bendat

J.S. Bendat Co., 833 Moraga Dr., Los Angeles, CA 90049, J. Sound Vib., 90 (2), pp 275-282 (Sept 22, 1983) 1 fig, 3 refs

Key Words: Statistical analysis, Power spectral density function, Error analysis

This paper develops normalized random error formulas for special bispectra estimates and associated frequency response function estimates in finite memory square-law systems. Error formulas are also derived for output spectrum estimates from these nonlinear systems and for associated nonlinear coherence functions. These formulas are used to evaluate such measured nonlinear results as well as to design experimental programs.

PARAMETER IDENTIFICATION

84-775

Structure Detection and Model Validity Tests in the Identification of Nonlinear Systems

S.A. Billings and W.S. F. Voon

Sheffield Univ., UK, Rept. No. RR-196, 30 pp (Oct 1982)

N83-31409

Key Words: System identification techniques, Nonlinear systems

A structure detection test which distinguishes between linear and nonlinear dynamic effects in the system response is derived. Model validity checks which indicate deficiencies in estimated nonlinear models are also presented.

84-776

Evaluation of System Identification Methodology and Application

B.J. Hsieh, C.A. Kot, and M.G. Srinivasan

Argonne Natl. Lab., IL, Rept. No. ANL-83-38, 98 pp (May 1983)

NUREB/CR-3388

Key Words: System identification techniques, Parameter identification technique, Nuclear power plants

As part of an assessment of the role of dynamic testing in the design of nuclear power plant structures, the state of knowledge concerning system identification methodologies and applications is evaluated. In general, it is found that system identification is limited to parameter estimation for a priori chosen models.

OPTIMIZATION TECHNIQUES

84-777

Optimization with Frequency Constraints – Limitations

M.P. Kamat, V.B. Venkayya, and N.S. Khot

Dept. of Engrg. Science and Mechanics, Virginia Polytechnic Inst. and State Univ., Blacksburg, VA

24061, J. Sound Vib., 91 (1), pp 147-154 (Nov 8, 1983) 5 figs, 9 refs

Key Words: Optimization, Frequency constraints

After outlining an efficient algorithm for designing minimum weight structures for a specified frequency of vibration, the limitations of designing such structures are stressed. It is shown that the amount of material that would be necessary for an optimum bar or a beam of a fixed configuration (length and boundary conditions) to attain an arbitrarily prescribed frequency can be disproportionately high, yielding a design that is completely impractical.

DESIGN TECHNIQUES

(See No. 782)

COMPUTER PROGRAMS

84-778

Submerged Shock Response of a Linearly Elastic Shell of Revolution Containing Internal Structure. User's Manual for the ELSHOK (Elastic Shock) Code

R. Vasudevan and D. Ranlet

Weidlinger Associates, New York, NY, Rept. No. DNA-TR-81-184, 144 pp (May 1, 1982)
AD-A131 282

Key Words: Computer programs, Shells, Shells of revolution, Submerged structures, Shock response, Modal analysis, Doubly Asymptotic Approximation

Presented herein is a user's manual for the ELSHOK computer code. This computer program calculates the transient response of a submerged ring-stiffened shell of revolution, with or without internal structure, to an underwater shock wave having an arbitrary direction of impingement. Linearly elastic structures are considered, and the surrounding fluid is treated as an infinite acoustic medium.

84-779

Nastran-Forced Vibration Analysis of Rotating Cyclic Structures

V. Elchuri, G.C.C. Smith, and A.M. Gallo

Bell Aerospace Textron, Buffalo, NY, ASME Paper No. 83-DET-20

Key Words: Computer programs, Forced vibration, Rotating structures, Vibration analysis

Theoretical aspects of a new capability developed and implemented in Nastran Level 17.7 to analyze forced vibration of a cyclic structure rotating about its axis of symmetry are presented. Fans, propellers, and bladed shrouded disks of turbomachines are some examples of such structures.

GENERAL TOPICS

TUTORIALS AND REVIEWS

84-780

Activities of the Institute of Sound and Vibration Research

Southampton Univ., UK, 45 pp (1983)
N83-33687

Key Words: Test facilities

Research in fluid dynamics and acoustics, vehicle noise, audiology and human effects, industrial noise, and noise and vibration control is summarized. Aircraft noise, underwater acoustics, damping of fiber reinforced materials and finite element methods are discussed.

84-781

Dynamic Behavior of Machine Tools (Dynamisches Verhalten von Werkzeugmaschinen)

M. Weck and H. Helpenstein

Aachen, W. Germany, Indus. Anzeiger, 105 (6), pp 13-17 (1983) 8 figs
(In German)

Key Words: Machine tools, Design techniques

A design catalog is described containing solutions for the dynamic analysis of machine tools, based on the finite element technique. As a representative component a machine stand is used.

CRITERIA, STANDARDS, AND SPECIFICATIONS

84-782

A Suggestion of Removing the Term Earthquake Intensity from the Aseismic Code

Hu Yu Xian

J. Bldg. Structure, 4 (1), pp 32-39 (1983)

CSTA No. 624-83.13

Key Words: Standards and codes, Seismic design

The function of earthquake intensity in the aseismic code in China is reviewed. It points out the contradiction between the fundamental idea of intensity and the parameters for ground motion in the current code and it is believed that the use of earthquake intensity restrains the improvement in revising the code.

USEFUL APPLICATIONS

84-783

An Analysis of the Mechanism of Reduction of Residual Stresses by Vibration

A.R. SotoRaga

Ph.D. Thesis, Georgia Inst. of Tech., 149 pp (1983)

DA8324413

Key Words: Vibratory stress relief

The use of vibratory methods to reduce stresses in structures is examined. The main objective of this study is to seek a better understanding of the mechanism of the reduction of residual stresses of materials undergoing cyclic loading.

AUTHOR INDEX

TECHNICAL NOTES

J.G.M. Kerstens, P.A.A. Laura, R.O. Grossi, and L. Ercoli
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J. Sound Vib., 89 (2), pp 291-293 (July 22, 1983) 1 fig, 2 tables, 5 refs

D.J. Inman and I. Orabi
An Efficient Method for Computing the Critical Damping Condition
J. Appl. Mech., Trans. ASME, 50 (3), pp 679-682 (Sept 1983) 1 fig, 8 refs

J.G. Gale and C.E. Smith
Vibrations of Suspended Cables
J. Appl. Mech., Trans. ASME, 50 (3), pp 687-689 (Sept 1983) 5 figs, 6 refs

G.C. Johnson
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J. Appl. Mech., Trans. ASME, 50 (3), pp 689-691 (Sept 1983) 7 refs

Y. Narita
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J. Appl. Mech., Trans. ASME, 50 (3), pp 691-692 (Sept 1983) 1 fig, 4 tables, 7 refs

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Sound Radiation from Finite Length Axisymmetric Ducts
J. Sound Vib., 90 (2), pp 286-290 (Sept 22, 1983) 6 figs, 12 refs

I.S. Raju and C.L. Amba-Rao
Free Vibrations of a Square Plate Symmetrically Supported at Four Points on the Diagonals
J. Sound Vib., 90 (2), pp 291-297 (Sept 22, 1983) 3 figs, 5 tables, 7 refs

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Vibration of Triangular Plates
AIAA J., 21 (10), pp 1472-1475 (Oct 1983) 3 figs, 3 tables, 9 refs

K.A. Edwards, R.C. Tobin, and L.L. Koss
Selective Excitation of Modes of Vibration by Means of a Laser
J. Sound Vib., 90 (3), pp 452-455 (Oct 8, 1983) 3 figs, 3 refs

W. Pekala and J. Szopa
Response of Shock Isolators with Linear and Quadratic Damping under Random Excitation
J. Sound Vib., 90 (3), pp 449-451 (Oct 8, 1983) 2 figs, 2 refs

O. Dyrlund
A Note on Statistical Errors in Acoustic Intensity Measurements
J. Sound Vib., 90 (4), pp 585-589 (Oct 22, 1983) 5 figs, 3 refs

G. Trevino
On the Bispectrum Concept for Random Processes
J. Sound Vib., 90 (4), pp 590-594 (Oct 22, 1983) 1 fig, 22 refs

M.S. Shipton
Noise Attenuating Characteristics of TDH-39 Earphones Fitted with MX-41/AR Ear Cushions
J. Sound Vib., 91 (2), pp 315-317 (Nov 22, 1983) 2 tables, 5 refs

E.H. Dowell, T. Ueda, and P.M. Goorjian
Transient Decay Times and Mean Values of Unsteady Oscillations in Transonic Flow
AIAA J., 21 (12), pp 1762-1764 (Dec 1983) 5 figs, 6 refs

CALENDAR

MAY 1984

1-3 Mechanical Failures Prevention Group 38th Symposium [National Bureau of Standards, Washington, DC] Gaithersburg, MD *(Dr. J.G. Early, Metallurgy Div., Room A153, Bldg. 223, National Bureau of Standards, Washington, DC 20234)*

8-10 Acoustical Society of America, Spring Meeting [ASA] Norfolk, VA *(ASA Hqs.)*

7-10 30th International Instrumentation Symposium [Instrument Society of America] Denver, CO *(Robert Jarvis, Grumman Aerospace Corp., Mail Stop T01-05, Bethpage, NY 11714)*

10-11 12th Southeastern Conference on Theoretical and Applied Mechanics [Auburn University] Pine Mountain, GA *(J. Fred O'Brien, Director, Engineering Extension Service, Auburn University, AL 36849 - (205) 826-4370)*

JUNE 1984

3-7 29th International Gas Turbine Conference and Exhibit [ASME] Amsterdam, The Netherlands *(ASME Hqs.)*

26-28 Machinery Vibration Monitoring and Analysis Meeting [Vibration Institute] New Orleans, LA *(Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 W. 55th St., Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254)*

JULY 1984

21-28 8th World Conference on Earthquake Engineering [Earthquake Engineering Research Institute] San Francisco, CA *(EERI-8WCEE, 2620 Telegraph Avenue, Berkeley, CA 94704)*

AUGUST 1984

6-9 West Coast International Meeting [SAE] San Diego, CA *(SAE Hqs.)*

19-25 XVIth International Congress on Theoretical and Applied Mechanics [International Union of Theoretical and Applied Mechanics] Lyngby, Denmark *(Prof. Frithiof Niordson, Presdent, or Dr. Niels Olhoff, Executive Secretary, ICTAM, Technical University of Denmark, Bldg. 404, Dk-2800 Lyngby, Denmark)*

SEPTEMBER 1984

9-11 Petroleum Workshop and Conference [ASME] San Antonio, TX *(ASME Hqs.)*

11-13 Third International Conference on Vibrations in Rotating Machinery [Institution of Mechanical Engineers] University of York, UK, *(IMechE Hqs.)*

30-Oct 4 Power Generation Conference [ASME] Toronto, Ontario, Canada *(ASME Hqs.)*

OCTOBER 1984

7-11 10th Design Automation Conference and 18th Mechanisms Conference [ASME] Cambridge, MA *(Prof. Panos Papalambros, Mechanical Engineering and Applied Mechanics, The University of Michigan, Ann Arbor, MI 48109 - (313) 763-1046)*

8-12 Acoustical Society of America, Fall Meeting [ASA] Minneapolis, MN *(ASA Hqs.)*

9-11 13th Space Simulation Conference [IES, AIAA, ASTM, and NASA] Orlando, FL *(Institute of Environmental Sciences, 940 E. Northwest Hwy., Mt. Prospect, IL 60056 - (312) 255-1561)*

15-18 Aerospace Congress and Exposition [SAE] Long Beach, CA *(SAE Hqs.)*

17-19 Stapp Car Crash Conference [SAE] Chicago, IL *(SAE Hqs.)*

22-25 Symposium on Advances and Trends in Structures and Dynamics [George Washington University and NASA Langley Research Center] Washington, DC *(Prof. Ahmed K. Noor, Mail Stop 246, GWU-NASA Langley Research Center, Hampton, VA 23665 - (804) 865-2897)*

DECEMBER 1984

3-5 International Conference on Noise Control Engineering [International Institute of Noise Control Engineering] Honolulu, Hawaii *(William W. Lang, Chairman, INTER-NOISE 84, P.O. Box 3469 Arlington Brnach, Poughkeepsie, NY 12603)*

3-6 Truck and Bus Meeting and Exposition [SAE] Dearborn, MI *(SAE Hqs.)*

9-13 ASME Winter Annual Meeting [ASME] New Orleans, LA *(ASME Hqs.)*

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 Park, NC 27709

SAE: Society of Automotive Engineers
400 Commonwealth Dr.
Warrendale, PA 15096

SEE: Society of Environmental Engineers
Owles Hall, Buntingford, Hertz.
SG9 9PL, England

SESA: Society for Experimental Stress Analysis
14 Fairfield Dr.
Brookfield Center, CT 06805

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

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 example below.

> 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 the practical applications that have been explored [3-7] indicate that . . .

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, number or issue, 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).
4. Lin, C.C., Reissner, E., and Tsien, H., "On Two-Dimensional Nonsteady Motion of a Slender Body in a Compressible Fluid," J. Math. Phys., 27 (3), pp 220-231 (1948).
5. Landahl, M., Unsteady Transonic Flow, Pergamon Press (1961).
6. Miles, J.W., "The Compressible Flow Past an Oscillating Airfoil in a Wind Tunnel," J. Aeronaut. Sci., 23 (7), pp 671-678 (1956).
7. Lane, F., "Supersonic Flow Past an Oscillating Cascade with Supersonic Leading Edge Locus," J. Aeronaut. Sci., 24 (1), pp 65-66 (1957).

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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