MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 41/1986

Nonlinear and Random Vibrations

14.9. bis 20.9.1986

Die Tagung fand unter der Leitung der Herren W. Schiehlen, Stuttgart, und W. Wedig, Karlsruhe, statt. Von den 37 Teilnehmern kamen 18 aus der Bundesrepublik, die übrigen aus der DDR, der Schweiz, aus Österreich, England, Frankreich, Israel, Kanada und den USA. Wegen dieser internationalen Beteiligung wurden alle 29 Tagungsvorträge in englischer Sprache gehalten und diskutiert.

Mit dem Thema "Nonlinear and Random Vibrations" wurden Fachkollegen sowohl der Mathematik als auch der Mechanik angesprochen, die sich entweder mit nichtlinearen deterministischen Schwingungen oder mit zufälligen Schwingungen beschäftigen. Der Übergang zwischen beiden Gebieten ist durch das zunehmende Interesse an chaotischen Bewegungen fließend geworden. Es hat sich in der Tat auch gezeigt, daß die mathematischen Methoden sehr verwandt sind. So werden z.B. die Lyapunov Exponenten sowohl zur Charakterisierung chaotischer Bewegungen als auch zur Stabilitätsuntersuchung stochastischer Systeme herangezogen.

Die einzelnen Vorträge können folgenden Problemgruppen zugeordnet werden: Identifikationsverfahren zur Modellierung, zur Parameter- und Zustandsschätzung mittels adaptiver Filter; Stabilitäts- und Bifurkationsprobleme zur Ermittlung des Lyapunov Exponenten oder der Momentenstabilität; Sensitivitätsanalyse nichtlinearer Systeme mittels statistischer und harmonischer Linearisierung; Untersuchungen chaotischer Bewegungen mittels numerischer Simulation und asymptotischer Methoden; Zuverlässigkeits- und First-Passage-Probleme bei nichtlinearen Systemen.

Vortragsauszüge

S. T. ARIARATNAM:

Stochastically Perturbed Hopf Bifurcation

The influence of small stochastic parametric perturbations on dynamical systems (2-Dimensional) exhibiting Hopf bifurcation is discussed. It is found that the bifurcation point is shifted. In fact as the system parameter is increased, there is a first bifurcation point corresponding to the vanishing of the Lyapunov exponent and the response probability distribution spreads outwards from a delta function, the distribution still remaining unimodal. But as the parameter is increased further, there is a point at which the distribution density becomes bi-modal and corresponds to a sharper bifurcation with the system "oscillating" about a definite non-trivial amplitude.

L. ARNOLD:

Lyapunov Exponents of Stochastic Flows with Application to Stability

Given a stochastic differential equation on a smooth Riemannian manifold M

$$dx_t = X_o\,(x_t)\,dt + \sum_{i=1}^{m} X_i\,(x_t)\circ dw_t,\quad X_o(x,\omega) = X\varepsilon M$$

$$\Omega \;= \{\omega\varepsilon C\,(R^+,\,R^m):\,\omega(o) = o\},\quad P = \text{Wiener measure on } \omega$$

The following results are reported:

(i) With probability 1, the mapping $x \to X_t(x)$ defines a flow (or cocycle) of diffeomorphismus of M (Elworthy, Kunita).

(ii) The linearized flow $(Tx)_t\,(x,\omega)$ on the tangent bundle satisfies the multiplicative ergodic theorem, i.e. there are, provided the base flow $x_t(\omega)$ is ergodic, Lyapunov exponents $\lambda_d \leq \ldots \leq \lambda_i$, $d = \dim M$, which do not depend on (x,ω) (Carverhill)

Examples are presented for which the Lyapunov exponents can be explicitly calculated. Applications to stability, bifurcation and chaos are given.

E. BROMMUNDT:

How Should the Theories be Changed to Reach Better Agreement with Experimental Observations?

(i) Experiment or numerical calculation cannot distinquish between rational and irrational numbers.

(ii) All experiments or numerical calculations yield results for/from finite time intervals only.

It is, to my opinion, for these reasons that up to now there does not exist, e.g., a strict definition of a chaotic motion basing on f (t) alone. To overcome such difficulties it is necessary to change the underlying assumptions in the pertinent "mathematical theories". In the special case mentioned above it might be advisable to introduce into the space A of (H. Bohr) almost periodic functions (cf. Riesz/Nagy, Vorles. über Funktionalanalysis, p. 239 ff) a weighted inner product like $(f,g): = \int_{-\infty}^{+\infty} W(t)\, f(t)\, \bar{g}(t)\, dt$

with a weighting function $W(t)>0$ which decreases sufficiently fast for $t \to \pm\infty$.

As an example we take the Gauss weight

$$W(t): = 1/\sqrt{2\pi}\sigma \,.\, \exp\,(-t^2/2\sigma^2), \sigma>0.$$

When this is done, the corresponding norm takten for two basis elements

$$e_\nu: = e^{j\nu t} (\nu \text{ real}) \text{ leads to}$$

$$||e_{\nu_1} - e_{\nu_2}||^2 = 2\,\{1 - \exp\,(-(\nu_1 - \nu_2)^2\, \sigma^2)/\sqrt{2\pi}\sigma\}$$

which tends to zero for $\nu_1 \to \nu_2$ continuously. This has the consequence that A_σ becomes separable, the set e_ν with $\nu \in$ all rational numbers forms a commutable basis.

Now, there arise many questions. For example:

(1) Which appropriate orthonormal system should be introduced into the space of T-periodic functions. (Looked upon as a subspace of A_σ?)

(2) How must the Fourier (integral) transform be modified? (Does it contain periodic functions without "δ-functions"?)

(3) When the rational ν's are represented binary numbers, are chaotic motions f(t) just almost periodic functions characterized by specially structured grouping of their Fourier coefficients c_ν in an expansion for $\Sigma c_\nu e_\nu$? - the "fractals" being the outcomes of some geometrically decreasing sequences of fractional ν's?

Similar questions arise in other fields of mathematics when the points (i), (ii) are taken care of.

J.F. DUNNE

Nonlinear Oscillator Responses to Narrow-Band Excitation

A prediction method is presented outlining a practical solution to the threshold crossing problem for oscillator responses to narrow-band excitation. The method is based on the combination of two well-established techniques: namely, equivalent linearisation and the Fokker-Planck-Kolmogorov method. In combined form this technique generates an optimised FPK equation of low dimension for which solutions are feasible.

Predictions are compared with measured crossing statistics via simulation and results are concentrated within the regions of high nonlinearity and narrow-band excitation. Evidence is shown, how under these conditions, motions are highly sensitive to excitation intensity. Important implications for reliability assessment follow form this sensitivity.

I. ELISHAKOFF

Remarks on Free Vibrations of Structures with Different Tension and Compression Moduli.

Some aspects of nonlinear free vibration of bimodular structures behaving dissimilarly in tension and compression are ducidated. It is shown that, in general, the character of the vibration is governed by the breakpoint in the restoring force graph: when the latter is outside the coordinate origin, the vibration is nonisochronous, i.e. dependent on the vibration halfthrow's; when these two points coincide, there is no such dependence. An exact solution is given for the case where the graph is a combination of a straight line and a cubic.
In addition, such a bilinear approximation is suggested which both retains the nonisochronicity property and agrees surprisingly well with the exact solution.
The study has been performed with Prof. V. Birman of the University of New Orleans and Prof. Charles Bert of the University of Oklahoma.

K. HENNIG

Some Problems of Stochastic Stability for Nonlinear Continuum Vibrations

The structural stability of geometrically nonlinear shallow shells excited by wind has been investigated. Three types of models are considered.
The first is a deterministic equation with the influence of the mean value of wind velocity. By some methods of functional analysis typical solutions are given and stability properties are examined.
The second is an equation with influence of the stochastic process of wind. We presented and discussed a scheme for constructing limits of stability.

In the third case stability is investigated by the theory of markov processes.
For special parameters of a shallow membran shell critical wind velocities are calculated and discussed.

C. S. HSU

Random Vibration Analysis of Nonlinear Systems by Generalized Cell Mapping

For the generalized cell mapping method, the continuous state space is discretized into a collection of large number of cells. Each cell may then be identified by an N-tuple of integers. In the framework of a cell state space, the evolution of a dynamical system is recast to a cell-to-cell mapping.
In generalized cell mapping a cell may have multiple image cells, with each cell assigned with a definite probability. The evolution of the dynamical system is then given in terms of a Markov chain. Once the transition probability matrix is given, then the persistent groups (or the invariant sets of cells), the invariant probability distributions of the persistent groups, transient cells, domains of attraction of the persistent groups, the absorption probabilities of transient cells into the persistent groups, and the absorption times of transient cells into the persistent groups can be determined. The method is originally developed for global analysis of nonlinear systems. It can deal with chaos and fractal boundaries very effectively. The method can also be applied to stochastic systems. The stochasticity can be in excitation or in the system coefficients. All the stochastic information can be incorporated into the transition probability matrix, and

the computed results form the Markov chain will give the influence of the stochasticity on the system behavior. Some examples were shown. The results show that the generalized cell mapping gives very good results when compared with known exact solutions or long time simulation results.

R. KALLENBACH

A Covariance Method for Parameter Identification of Time-Continuous Systems

A method for the parameter identification of linear and nonlinear time-continuous systems with stationary, stochastic input and output processes is considered. The input and output signals are processed in known linear filters. Stationary covariance relations between these signals allow identification of unknown system parameters. The method is developed in detail for systems with incomplete state measurements. As example, the parameter identification of a robot arm is presented.

U. KIRCHGRABER

Monotone Twist Maps

Based on recent work of Mather, Aubry, Moser and Bangert we present some new developments in the theory of discrete dynamical systems generated by so-called monotone twist maps. These considerations shed some new light on such classic topics as Birkoff periodic orbits and the Moser Invariant Curve Theorem for perturbed twist maps, and partially extend these results to a broader class of systems.

A. KISTNER

A Comparison of Nonlinear Filtering Methods

A nonlinear filtering method proposed by Sorenson (K.W. Sorenson: A Nonlinear Perturbation Theory for Estimation and Control of Time-Discrete Stochastic Systems, Ph. D. Thesis, UCLA 1966) is reexamined and enlarged to work with non-scalar time-discrete problems. The algorithm uses terms up to second

order of appropriate Taylor series expansions of the measurement and system equations, the first terms of Gram-Charlier series expansions of the filtering densities, the first terms of the series expansions of exponential functions appearing in the calculations, and the quasi-Gaussian assumption for computing approximations of highter order moments needed.
For the problems of reconstructing the states of a noise driven van-der-Pol oscillator from disturbed measurements, the performance of different versions of the Sorenson filter is compared to that of the corresponding Kalman filter.

W. KLIEMANN

Are Almost Sure Exponentially Stable Stochastic Systems Stable

For a stochastic system of the form $\dot{x} = A(\xi_t)x$, where ξ_t is an ergodic diffusion process on a compact manifold, we discuss the stability properties. In particular, the almost sure Lyapunov exponent λ, the moment Lyapunov exponents $g(p)$, $p\varepsilon R$, and their relations are analyzed. For small p, $g(p)$ determines λ via $g'(o) = \lambda$, while for large p, $g(p)$ describes the large deviation behavior of the system: If $\lambda<o$, i.e. almost sure exponential stability, $P\{ \frac{|x(t,x_o)|}{|x_o|} \geq K\} \sim e^{\alpha t}$, where $K>o$ is a constant and $\alpha = \min_{p\varepsilon R} g(p)$.
If $\alpha>-\infty$, i.e. $\gamma^+>o$ for $\gamma^+ = \lim_{p\to+\infty} \frac{g(p)}{p}$, then with exponentially decaying positive probability the system will exceed any given bound $K>o$, while for $\gamma^+<o$ (i.e. $\alpha = -\infty$) the stochastic system behaves like an exponentially stable deterministic system, i.e. $x(t,x_o)$ stays below an easily computable threshold $c > |x_o|$ with probability one.

F. KOZIN

Linearization by Adaptive Filtering

Linearization remains an important mean of approximating the statistical properties of the response of non-linear systems to random excitations. The common procedure is to apply the concept of statistical linearization. However, this method does not lead to the "best" linear approximation in some suitable sense because, in general, the underlying probability measure of the non-linear response is unknown. One would like to obtain the best approximation in a least square sense by determining the Wiener optimum filter. It appears that a procedure for determining such an optimum linear approximation is through adaptive filters such as least mean square and normed least mean square filters. In one lecture we have discussed the exact conditions on the convergence of such adaptive filters by translating the problem to that of a stochastic stability formulation. Convergence to the Wiener filter is established on an almost sure basis and numerical simulations of non-linear discrete equations are presented illustrating the ideas.

P. KRÉE

White Noise, Distributions on the Wiener Space and Random Vibrations

It has been noted that the Kuo-Watanabe lifting theory of S' on the Wiener Space (1982) gives a direct proof of Rice formula. Since Sobolev Spaces theory on Gaussian Spaces applied to the white noise space gives also recently (Ustunel, Ustunel-Kerzeioglu, Nuarhat) an extension of Ito's calculus, we have also recalled how this theory has been built up:

1971-1972: cylindrical distributions (Cecil B. de Witt and P.K.)
1973-1976: Derivations operators ∇, $\tilde{\nabla}$, δ for these distributions (L. Schwartz, P.K.) and Calculus in Sobolev Space (Mirella Krée, B. Lascan, P.K.)

Note incidentally that the Malliavin Calculus (1976-1978) does not use Sobolev Spaces and that the corresponding differential calculus does not concern equivalence classes of functions.

E. KREUZER

Stochastic Behavior in Harmonically Driven Nonlinear Oscillators

Recent developments in mechanics have revealed widespread occurrence of stochastic behavior in deterministic nonlinear dynamic systems. Such stochastic or chaotic solutions have been looked for and found in a great

variety of systems-mechanical, electrical, etc. - by computer solutions and by experimental measurements. These results suggest, that most non-linear dynamic systems with phase space dimension three or more have some stochastic or chaotic and some regular motion. By understanding stochastic behavior in deterministic mechanical systems with few degrees of freedom one may gain insight of more complex systems and even of turbulent motion of fluids.
In this talk harmonically driven nonlinear oscillators are studied and methods for analysis and characterization are discussed.

C. MÜLLER

Approximate Methods for the Analysis of Limit Cycles of Stochastically Excited Nonlinear Systems

Methods of Harmonical or Statistical Linearization are well-known in the analysis of nonlinear dynamic systems in the case of the existence of limit cycles or in the case of stationary stochastic responses of systems with noise excitation. On the opposite, the combined method of Harmonical and Statistical Linearization usually fails in the analysis of stochastically disturbed limit cycles. Therefore, some modified approximate methods are represented:

(i) Harmonical Linearization in combination with a subsequent covariance analysis based on Statistical Linearization;
(ii) Taylor expansion technique;
(iii) Gauss + Sine probability density function approach.

Particularly, method (i) leads to good results. The problems of justification and accuracy of these methods are discussed noting that there are only few results such that a lot of research work is still necessary in this field.

H. G. NATKE

On Structure Identification of Nonlinear Systems

System Identification is a part of modelling. If it is based on an prespecified structural model then system identification is reduced to parameter estimation. Therefore and for a detailed and physically interpretable description of the dynamic behaviour of a mechanical system a structural model is needed. It follows that the first step in system identification is the structure identification.

At first, the system nonlinearities must be detected and secondly, one has to decide whether they must be modelled. Detection methods are discussed. If the nonlinearity is severe the hirarchical decision process in determination of the structural model is described. A review of identification methods dealing with nonlinear systems was presented. It is common to choose a model with given "power of nonlinearity". Restricting the model class to polynomials procedures are discussed to estimate in addition to the coefficients the power of the polynomial taking into account noise corrupted measuring data. Finally, the problem formulated is discussed in a more general manner including the complexity of the model within the optimization.

J. B. ROBERTS

First-Passage Time for Randomly Excited Non-linear Oscillators

An approximate method of computing first-passage probabilities for non-linear oscillators subjected to stationary wide-band random excitation is discussed. The method is based upon an approximation of the energy envelope of the oscillator response as a one-dimensional Markov process, governed by an appropriate diffusion equation. The adoption of suitable absorbing and reflecting boundary conditions enables the evolution of the first-passage probability to be computed. An efficient and simple algorithm for the numerical solution of the governing diffusion equation is outlined which is based on an implicit, finite-difference approximation. Numerical results for the mean first-passage time are compared with the results of a finite-difference numerical solution of the exact two-dimensional Pontriagin-Vitt equation for this statistic.

G. I. SCHUELLER

Nonlinear Damping and its Effects on the Reliability Estimates of Structures

As in deterministic investigations, the assumptions concerning the structural damping models significantly influence in the stochastic case as well the calculated response quantities. Moreover, since the damping characteristic of structural materials is nonlinear, the calculated reliabilities are also significantly influenced by these nonlinearities, i.e. by their modeling. In this presentation an attempt was made to investigate various material damping models with respect to their physical interpretation and their applications to stochastically excited mechanical systems. This includes statements on the probability distribution of load effects, maxima of the response, exceedance probabilities of thresholds, fatigue failures, etc. The analysis includes the statistical uncertainty of the damping parameters in the nonlinear damping models and its effect on the resulting reliability estimates.

J. SKRZYPCZYK

Analysis of Statistical Linearization of Nonlinear Dynamic Systems Described by Random Integral Equations Over Locally Compact Abelian Groups

The purpose of the present report is to present the accuracy analysis of dynamic systems described by nonlinear integral equations defined over a locally compact Abelian group. Nonstationary dynamic system is considered as well as a nonstationary one. The technique of generalized harmonic analysis of noncommutative causal operators form $L^1(G;L(R^n,R^n))$ is used to analyse special Banach algebras of integral operators being limiting filters. Bounds on the statistical linearization error between the exact and approximate solutions are given. Existence conditions of mean-square continuous exact are considered too. To compare presented statistical linearization methods with other methods of linearization as:

tangent method, equivalent method, mean-square method etc. the accuracy of a simple nonlinear second-order mechanic system with the white noise type input is presented in details.

L. SOCHA

The Sensitivity Analysis in Stochastic Vibrations

The concept of stochastic sensitivity in linear and a class of non-linear continuous stochastic dynamical systems is considered. New definitions of moment and output sensitivity measures are introduced. Detailed applications for linear systems with stochastic coefficients under noise excitations and for a non-linear oscillator are analysed. The cases of white and coloured noise are considered. In the second part of the lecture the definitions and criteria of stochastic insensitivity are established. A few examples are given to illustrate the results obtained.

W. SZEMPLINSKA-STUPNICKA

Jump Phenomena and Chaotic Motion in Nonlinear Oscillators

Two types of nonlinear, dissipative, forced oscillators are considered: I-oscillators with three equilibrium positions, II-oscillators with single equilibrium positions. Behaviour of the systems is studied by means of approximate analytical methods and by computer simulation. The considerations are aimed at finding a relation between phenomena known in the approximate theory of nonlinear vibrations and a distinctly new type of steady state irregular solution called chaotic motion. Results presented allow to interpret chaotic motion as a transition state between two types of periodic resonances. Thus the zones of chaotic behaviour replace classical "jump phenomena", when system parameters exceed certain critical values.

J. SZOPA

The Stochastic Sensitivity and the Application to Vehicle Model

The method of stochastic sensitivity functions/SSF/in the case when the parameters are stochastic processes is developed.
There have been constructed equations for SSF. The SSF have been used for approximating an arbitrary solution. This approximation converge and by using it the time required for computer calculation is shortened. The mean values and variances for several vehicle model moving over random profile by using this method were calculated.

H. TROGER

Bifurcations of the Equilibrium at Multiple Eigenvalues and Adjacent Nonlinear Oscillations of a Spherical Double Pendulum

The loss of stability of the downhanging equilibrium position of a spherical double pendulum with elastic end-support c and elastic joints is studied under the action of a compressive follower force P. The analysis of this problem is possible only due to the fact that the system possesses a rotational and reflectional symmetry, i.e. it is O(z)-symmetric.
Varying c we, generically, get either a Hopf or a divergence bifurcation at loss of stability. However, there exists a critical value c_c where both modes of instability occur simultaneansly. Furthermore we show that the amount of damping in the joints has an influence on the structure of the critical eigenvalues. The bifurcation equations for these singular cases are derived and their steady state solutions are discussed. Finally physical interpretations of the mathematical solutions are given.

A. TYLIKOWSKI

Dynamics and Stability of Nonlinear Systems Subjected to Poissonian Impulse Excitations

The work is concerned with random vibration problems which occur in systems subjected to impulse excitations. The excitations are assumed to be a sequence of δ-Dirac impulses arriving in times which obey the Poisson probability low. Impulses of force are independent on the arrival times and have an arbitrary probability distribution. Using the generalized Itô formula sufficient conditions implying the uniform stochastic stability of a simple one degree of freedom system with a cubic nonlinear term subjected to the parametric impulse excitations are established. The vibration of the nonlinear system subjected to a random external excitation is investigated. The stochastic linearization technique and the generalized FPK equation are used to obtain a characteristic function and moments of system response probability distribution. A digital simulation method is applied to verify the results obtained.

J. WALLASCHECK

<u>On the Correlation Between Velocity and Displacement in Continuous Mechanical Systems</u>

For those mechanical systems which are described by partial differential equations of the form

$$\left(\mu \frac{\partial^2}{\partial t^2} + d_1 \frac{\partial}{\partial t} + \{ 1 + d_2 \frac{\partial}{\partial t} \} L_x \right) w(\vec{x},t) = f(\vec{x},t)$$

and boundary conditions $B_{\vec{x}}\, w(\vec{x},t) = 0,$
where $f(\vec{x}, t)$ is the realisation of a stationary random field process with zero mean and correlation function

$$E \{ f(\vec{x}_1,t_1)\, f(\vec{x}_2,t_2) \} = F(\vec{x}_1,\vec{x}_2)\, R(t_1-t_2)$$

the conditions on $F(\vec{x}_1,\vec{x}_2)$ are established so that velocity and displacement are orthogonal random variables, i.e.

$$E \{ w(\vec{x}_1,t)\, \dot{w}(\vec{x}_2,t) \} = o$$

holds. In that case the covariance method for continuous systems that was developed by Wedig (1979, Ing. Archiv) can be applied to yield a closed form solution for the covariance functions of the systems response.

W. WEDIG

Moment's Stability of Nonlinear Stochastic Systems

For linear systems with harmonic coefficients there is always a transformation which transforms the time-variant differential equations into a time-invariant form. The same holds in the stochastic case where the parametric excitation is generated from white noise by shaping filters.

The contribution introduces this stochastic transformation of the drift-terms based on multidimensional Hermitian operators and associated orthogonal function spaces. The procedure leads to infinite determinants the convergence of which is proofed by means of the necessary and sufficient conditions of H. v. Koch.

Nummerical applications show some new effects of low-pass and band-pass parametric excitations. The infinite determinants are evaluated by scalar two-step recursions leading to monotone instability properties in case of low-pass excitations. For band-pass parameters oscillatory instabilities are occuring with mode jumping phenomena in different regions of the parametric excitation frequency.

J. WICK

The Influence of Jumps and Bumps of a Non-Linearly Damped Car

A model for a road-vehicle-system is developed from measured datas. This gives results in a good agreement with the experiments, if the excitation by the road is not to strong. For higher amplitudes we observe phases where the tire has no contact to the road. To describe this situation, the model must modified. Unfortunately a direct measurement of the tire is not available. The model will be checked indirectly and the influence of jumps and bumps are studied.

H. WINDRICH

Analysis of Stochastically Disturbed Limit-Cycle Systems

The analysis of stochastically excited nonlinear mechanical systems leads to the equation of Fokker, Planck and Kolmogorov (F.-P.-eq.). It is known that exact solutions of the F.-P.-eq. can be found only in very special cases. Nonlinear one-degree-of-freedom-systems can be adjoined to those nonlinear systems which allow to solve the F.-P.-eq. exactly. The corresponding solution of the F.-P.-eq. represents an approximation of the probability density of the original system. This method is illustrated by means of an example. Moreover the possibility is discussed to make this procedure applicable for the investigation of multi-degree-of-freedom-systems. Additionally linearization methods are discussed.

F. ZIEGLER

Random Vibrations of Yielding Structures

Already the single-degree-of-freedom elastic-plastic oscillator when excited by a non-stationary random driving force poses an "awkward" problem. By approximating the two-sided barrier formulation through a boundary problem of absorbing the elastic part of the kinetic energy at the yielding limit and considering two states, the elastic one within the barriers and the plastic drift process, the latter can be calculated separately.

A multi-degree-of-freedom structure (a shear wall building forced by the ground acceleration of an earthquake input) is considered. Splitting the deformation in the linear and nonlinear parts, a linear time-invariant system is driven by the external forces and the plastic drift process. Modal analysis transforms the system to n-"uncoupled" oscillators. Linear statistics of level crossings renders the ingredients of power balances.

(1) Elastic kinetic energy at the barrier equats the sum of the work of the forces at the yield limit (dissipated) and the work of the external forces during the yielding time interval.

(2) The difference of the power of external forces and those of the modal excitation equats the dissipated power.

(1) renders the drift, (2) renders the effective modal envelope function (time- and frequency dependent) of proper modulation of the input power-spectral density.

Preliminary results are published by Irschik & Ziegler in Nuclear Engineering and Design 1985 and by Irschik in Acta Mechanica 1985.

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