Journal of Sound and Vibration 423 (2018) 212–229

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Non-symmetric forms of non-linear vibrations of flexible cylindrical panels and plates under longitudinal load and additive white noise

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ARTICLE INFO

Article history:
Received 9 August 2017
Received in revised form 29 December 2017
Accepted 28 February 2018

Keywords:
Non-symmetric modes
White noise
Parametric vibrations
Transitional processes
Finite difference method

ABSTRACT

Parametric non-linear vibrations of flexible cylindrical panels subjected to additive white noise are studied. The governing Marguerre equations are investigated using the finite difference method (FDM) of the second-order accuracy and the Runge-Kutta method. The considered mechanical structural member is treated as a system of many/infinite number of degrees of freedom (DoF). The dependence of chaotic vibrations on the number of DoFs is investigated. Reliability of results is guaranteed by comparing the results obtained using two qualitatively different methods to reduce the problem of PDEs (partial differential equations) to ODEs (ordinary differential equations), i.e. the Faedo-Galerkin method in higher approximations and the 4th and 6th order FDM. The Cauchy problem obtained by the FDM is eventually solved using the 4th-order Runge-Kutta methods. The numerical experiment yielded, for a certain set of parameters, the non-symmetric vibration modes/forms with and without white noise. In particular, it has been illustrated and discussed that action of white noise on chaotic vibrations implies quasi-periodicity, whereas the previously non-symmetric vibration modes are closer to symmetric ones.

1. Introduction

Real engineering systems are subjected to numerous internal and/or external noisy excitations. White noise influences the dynamic regimes of deterministic systems, implies new types of dynamical behaviour, changes the character of bifurcations and, consequently, has an important impact on accuracy, durability and stability of the working regimes of engineering constructions. Flexible cylindrical panels with rectangular planforms, working as independent structural elements of complex constructions, are widely employed in the aviation, rocket and cosmic industries, ship-building and cars factories as well

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https://doi.org/10.1016/j.jsv.2018.02.065

as in energy and chemical machine-building or measurement devices. In the above mentioned constructions, structural elements are subjected to various external loads and work in the environments with time-dependent properties (stochastic impact or sound pressure). Therefore, there is a strong need for a complex and reliable investigation of the influence of external noise on the behaviour of the considered structural systems.

To model stochastic properties of the external matter, one can implement white noise. As it is known, behaviour of non-linear dynamical systems may be sensitive even to a very small change of the initial conditions, and hence also to noisy fields.

In the available literature, one can find a vast amount of works devoted to the modelling of complex dynamics of mechanical systems. However, the influence of noisy fields on the complex vibrations and bending forms of mechanical structural members is rather marginally studied. On the other hand, it has been illustrated that stochastic inputs play an essential role in the behaviour of dynamical systems found in physics, biophysics, chemistry, biology, medicine or economy [1–10].

Despite noise-induced vibrations can be found in biological, chemical and human cognition systems, there is a little research devoted to the study of the influence of noise on the non-linear dynamics of mechanical systems and, in particular, of structural mechanical members.

It is well known that noise is present in every experimental study and in real-world problems (street noise, loud music, radio and TV, etc.). It is usually believed that noise destroys the order of a structure. In Ref. [11] it has been shown that introduction of noisy terms to the van der Pol and Lorenz equations can destroy either periodic or chaotic orbits. However, according to the recent results, noise can under certain conditions induce ordering in non-linear systems far from equilibrium configurations.

An optimal level of noise can improve synchronization between the input and output of a dynamical system or can change the transition in a non-equilibrium system. The so-called noise-induced vibrations imply the transition to a new state, which is sometimes qualitatively different from the considered one (see, for instance, [4,12,13]).

Generally, in engineering-oriented sciences, one can find numerous works devoted to investigate the influence of noise on dynamic regimes of the 1-DoF (degree-of-freedom) systems. In Ref. [14] it has been shown that a white noise-induced transition of the van der Pol oscillator from a limit cycle to the stationary state is proportional to the product of the characteristic energy of self-oscillations and the friction coefficient.

Corapella and Costabile [15] demonstrated noise-induced transitions in the pendulum with randomly vibrated suspension. It has been shown that if the noise intensity is below/above the critical value, the oscillations are absent/present. It is also worth mentioning that noise-induced oscillations are also exhibited in practical engineering problems, since the noise-induced transition appears in open subsonic submerged jets [16].

It is well recognized in physical and chemical dynamical systems that noise can stabilize/destabilize steady states of radio circuits [17], enzyme systems [18] and spatially distributed systems [19].

Brand et al. [20] demonstrated experimentally that external noise can suppress the onset of the spatial turbulence and, in particular, they showed that for sufficiently high noise intensity a transition from the spatially homogeneous state to turbulence can be achieved via intermittency.

Lefever and Turner [21] detected the location of a Hopf bifurcation in the parameter space, which can be postponed or advanced by multiplicative coloured noise.

Kai et al. [22] investigated the influence of external multiplicative noise on the electrohydrodynamic instability in nematic liquid crystals. It has been demonstrated that different types of noise yielded minor quantitative changes comparing to white noise. An increase in the noise intensity implied the first instability occurrence, whereas destabilization effects were detected for sufficiently long correlation times of noise.

Kautz [23] presented a certain type of equivalence between the deterministic chaos and white noise. Namely, he found that a phase loop working in a chaotic regime can generate high-level white noise.

Huh and Kai [24] reported noise-induced threshold shifts and phase diagrams in electroconvections in a neumatic liquid crystal by controlling the noise frequency band for white and coloured noise.

More recently, Foukzon [25] presented a non-perturbative analytical approach to study quantum chaos in dynamical systems with an infinite number of degrees of freedom.

The so far carried out review of the state-of-the-art illustrates the influence of noise on the non-linear dynamics of systems from outside the field of mechanics and mechanical systems. However, from a point of view of mathematical modelling, the studied systems can (in many cases) be equivalent to noise-excited mechanical dynamical systems in terms of either the governing non-linear ODEs (lumped mass mechanical systems) or non-linear PDEs (continuous mechanical systems). This also means that the developed theory of bifurcation and chaos can be extended to the mechanical systems driven by either white additive or coloured noise.

In what follows, we refer to some works aimed at studying robustness of the classical scenarios of transition from regular to chaotic dynamics in the presence of noise. A role of external noise in the scenario of transition from regular to chaotic dynamics has been studied by Eckman [26]. It has been shown that out of three well knows scenarios, only the Ruelle-Takens scenario has not been influenced by the action of low-level noise. The influence of noise on a strange chaotic Lorenz attractor has been studied numerically by Zippelius and Lucke [27]. The noise lowered the threshold of transition into turbulence, which agrees with one's intuition. The Feigenbaum and the Pomeau-Manneville scenarios also exhibited sensitivity to small noise, what has been shown by Mayer-Kress and Haken [28].