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Stochastic Linearization Method for Prediction of Extreme Response of Offshore Structures

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ABSTRACT

The standard stochastic linearization method applied to a nonlinear dynamic system is based on a mean square deviation measure to derive the equivalent linear parameters. Experience indicates that the resulting equivalent linear system may have approximately the same mean square response as the original nonlinear system. For predicting extreme response, however, this procedure is not equally suitable. In the case of strong nonlinearities in the dynamic model, application of the standard method of stochastic linearization may lead to significant overestimation of extreme responses. In the present paper are described some initial efforts to develop stochastic linearization methods applicable for prediction of extreme response levels.

INTRODUCTION

The problem of estimating the response statistics of nonlinear dynamic systems has been a subject of research for several decades. Considerable progress has been made, but from a practical point of view the general results are still too weak to provide accurate estimates of exceedance probabilities for use in the design process of nonlinear structures subjected to random excitation.

A number of simplified procedures have been proposed for estimating specific response quantities of nonlinear systems. In particular, the method of stochastic linearization is extensively used. The attractive feature of this type of procedure is the replacement of the initial nonlinear dynamic system by a linear one. General experience indicates that the standard method of stochastic linearization leads to estimates of the response variance that are often fairly accurate. However, for the purpose of predicting the large response levels, expressed for example through exceedance probabilities and extreme values, this method leads in many cases to overly conservative estimates. Hence, for the purposes of design, the standard method of stochastic linearization is not adequate. As the feature of replacing nonlinear equations of motion by linear equations is very attractive, it is appropriate to ask the question: Can a linearization procedure be established such that the resulting extreme response predictions are in agreement with those of the original nonlinear dynamic system?

In this paper we shall present some initial efforts to develop a stochastic linearization procedure specifically designed for predicting large responses. This work has been carried out as a subtask of BRITE PROJECT P-2146, "Rational Procedures for Advanced Nonlinear Analysis of Floating Structures," in its turn a subproject of an extensive research programme launched within the EEC countries under the acronym BRITE. The P-2146 is a cooperative project among the Danish Hydraulic Institute, Fincantieri, Registro Italiano Navale (RINA) and Tecnomare.

NONLINEAR EQUATION OF MOTION

In this paper the following (normalized) equation of motion describing the response of a compliant offshore structure will be assumed:

$$\ddot{X} + f(X,\dot{X}) = F(t) \qquad (1)$$

Here $f(X,\dot{X})$ is a nonlinear function of displacement and velocity. $F(t)$ denotes the (normalized) excitation force and $X(t)$ the corresponding displacement response. In offshore applications, usually the nonlinear function $f(X,\dot{X})$ can be expressed as:

$$f(X,\dot{X}) = g(\dot{X}) = h(X) \qquad (2)$$

so that the damping and restoring force terms can be separated. For the sake of illustration and explicit derivations, it is assumed in this paper that the functions $g(\dot{X})$ and $h(X)$ are given by the relations:

$$g(\dot{X}) = \gamma\dot{X}\,|\dot{X}| \qquad (3)$$

and

$$h(X) = \omega_0^2\, X(1 + \alpha X^2) \qquad (4)$$

where γ, $\omega_0{}^2$ and α are positive constants. As mentioned above, the work presented in this paper aims at developing rational methods for replacing Eq. 1 by the following linear, time-invariant dynamic model:

$$\ddot{X} + \beta_L\,\dot{X} + \omega_L^2\,X = F(t) \qquad (5)$$

where β_L and ω_L^2 are positive constants, so that the extreme response predicted by using Eq. 5 is a reasonably accurate estimate of the extreme response obtained from Eq. 1. To this end, it is appropriate to give a brief discussion of the usual way of carrying out a stochastic linearization.

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