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Probabilistically-robust nonlinear control of offshore structures

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ABSTRACT

A controller design for offshore structures is discussed in this study. Stochastic simulation is considered for evaluation of the system's performance in the *design stage*. This way, nonlinear characteristics of the structural response and excitation are *explicitly* incorporated into the model assumed for the system. Model parameters that have some level of uncertainty are probabilistically described. In this context, the controller is designed for optimal reliability, quantified as the probability, based on the available information, that the performance will not exceed some acceptable bounds. This treatment leads to a robust-to-uncertainty design. The methodology is illustrated in an example involving the control of a Tension Leg Platform in a random sea environment. Multifold nonlinearities are taken into account for the evaluation of the platform's dynamic response and a probabilistic description is adopted for characterizing the random sea environment.

KEY WORDS: Control of offshore structures; Tension Leg Platform; robust control; model uncertainty; stochastic simulation; random sea.

INTRODUCTION

Under severe sea and wind conditions, offshore structures, such as jacket-type or tension leg platforms, may experience large response amplitudes that affect their serviceability and structural integrity. Active and passive control techniques have been considered for reduction of the effects of such dynamic loadings (Ahmad and Ahmad, 1999; Alves and Batista, 1999; Nakamura, Kajiwara, Koterayama and Hyakudome, 1997; Suhardjo and Kareem, 2001). Most of the studies in offshore structure control have adopted linear methodologies for the controller design, typically H_2 control. The models, though, that are used for the prediction of the behavior of offshore structures typically involve various types of nonlinearities. In particular, nonlinearities may come from (a) modeling the dynamic response of the structure (for example, in the case of Tension Leg Platforms, as discussed in Angelides, Chen and Will (1982)) and also from (b) characterizing the excitation forces acting on the structure (for example, the spectrum for random sea environment or the wave particle kinematics (Goda, 2000)). One of the main challenges in controller design for offshore applications has been the explicit consideration of these nonlinearities.

Enhanced linearization techniques have been suggested for addressing the second type of nonlinearity when applying linear control methodologies (Suhardjo and Kareem, 2001). This approach has the potential to adequately capture important nonlinear characteristics of the response; but for complex systems the application is usually not straightforward. The first type of nonlinearity, which is more important, is commonly ignored. The controlled system is usually designed based on a linear model, that does not take into account nonlinear characteristics (Ahmad and Ahmad, 1999; Alves and Batista, 1999). Only the performance of the system is evaluated using, at a later stage, a nonlinear model (Ahmad and Ahmad, 1999). This approach leads to a sub-optimal design in terms of the actual system performance.

Another challenge related to offshore structure control has been the efficient description of the uncertainties involved in the system model. In maritime applications, like most other engineering applications, there are model properties that involve some level of uncertainty (for example the characteristics of the sea environment). This uncertainty can be quantified by a probabilistic description of the model parameters (Mathisen and Bitner-Gregersen, 1990; Papadimitriou, Beck and Katafygiotis, 2001). Such an approach logically incorporates the available knowledge about the system into the model and allows for a robust-to-uncertainty design. Typically, though, a nominal model is adopted when designing the controlled system, using the most probable values for the model parameters. No uncertainty for these values is taken into account.

The current study considers a controller design for offshore applications that addresses both aforementioned challenges. Simulation is used for evaluation of the model response at the controller design stage, which allows for *explicitly* taking into account nonlinear characteristics of the system. Uncertainty about the model parameters is treated by assigning probability density functions (PDFs) to them. In this context, reliability criteria are used to evaluate the performance of the controlled system and for the controller optimization. An efficient algorithm is discussed for the latter. The methodology is illustrated in an example involving the control of a Tension Leg Platform in a random sea environment. The control force is provided by tuned mass dampers, placed inside the columns of the platform's hull. Both passive