Non-random vibration analysis based on non-stochastic process model

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Abstract

Committed to provide an effective mathematical tool for time-varying uncertainty quantification of structural dynamic analysis when inadequate information can be derived for stochastic process modelling, we proposed a non-stochastic process model and corresponding non-random vibration method. Only upper and lower bounds of the time-varying uncertain parameters are required for non-stochastic process modelling. A self-correlation function is defined for interval variables at any two different time points of a non-stochastic process. With correlation information, the dependent non-stochastic process can be transformed into an independent one, which will significantly facilitate the subsequent uncertainty analyses such as dynamic reliability analysis, etc. Correspondingly, by combining the non-stochastic process model with classical mechanical vibration, a non-random vibration method is developed for dynamic response bounds of structures under external excitations. The dynamic responses of both single degree-of-freedom (SDOF) and multiple degree-of-freedom (MDOF) systems are provided, in the form of upper and lower bounds. Several numerical examples are investigated, including damped and undamped systems, under stationary or non-stationary excitation forces, and some interesting and reasonable phenomena are observed.

Keywords: Non-stochastic process, Time-varying uncertainty, Non-random vibration, Dynamic response analysis

Introduction

Time-varying uncertain parameters such as wind excitations on bridges or road excitations on vehicles are widely exist in engineering. Traditionally, the stochastic process and random vibration methods [Crandall (1958)] are adopted for quantification of a time-varying parameter and corresponding mechanical vibration analysis. However, prohibitively huge data are required to obtain the precise values of the characteristic parameters that needed for stochastic process modelling, which is often very costly or relatively difficult to obtain in engineering [Bendat and Piersol (2000)]. Hence in this work, a novel non-stochastic process method is developed, where only the upper and lower bounds of the time-varying uncertain parameters are required, as shown in Fig. 1. A non-stochastic process can also be recognized as a time-varying interval. Some important characteristic parameters and a correlation quantification function are proposed for description of a non-stochastic process. Based on the correlation information, a technique to transform the dependent process into an independent one is provided.

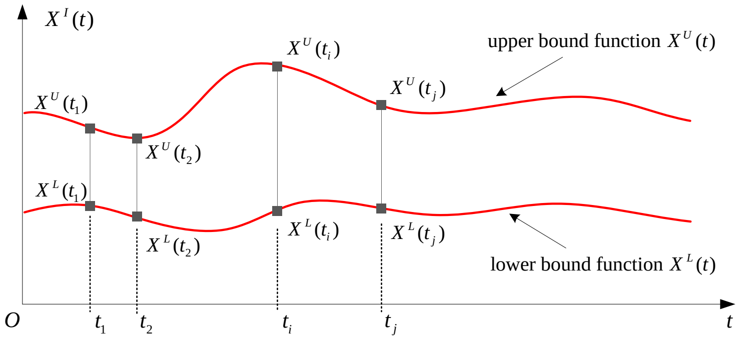

Figure 1. Non-stochastic process model

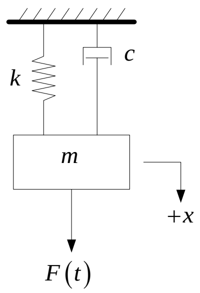

Figure 2. SDOF system

By applying the proposed non-stochastic process method to mechanical vibration, the non-random vibration method is presented. In non-random vibration, an external force or excitation is described as a non-stochastic process. Therefore, the structural responses such as displacement and velocity are also time-varying uncertain processes with upper and lower bounds. Based on existing results of the mechanical vibration analysis [Timoshenko et al. (1974)] where the excitations are deterministic, we provided the response bounds of the single-degree-of-freedom (SDOF) and multiple DOF spring-mass-damper systems for our non-random vibration problems.

Results and discussions

Figure 2 shows the SDOF spring-mass-damper system, in which the external force $F(t)$ is nondeterministic and modelled as a non-stochastic process. The correlation between interval variables at different time points is assumed to be a function which depends on the time interval τ, which is denoted as $r(\tau)$. Various types of the correlation function are discussed and corresponding responses such as displacement and velocity functions are compared. Figure 3 shows the bounds of displacement $x(t)$ under different kinds of correlation functions. From Fig. 3 we can see, the bounds under different correlation cases are all enveloped within the bounds calculated when $F(t)$ is an independent process, i.e., $r(\tau)=0$. Furthermore, we can also find that for the damped system the response bounds tend to be steady with time elapse.

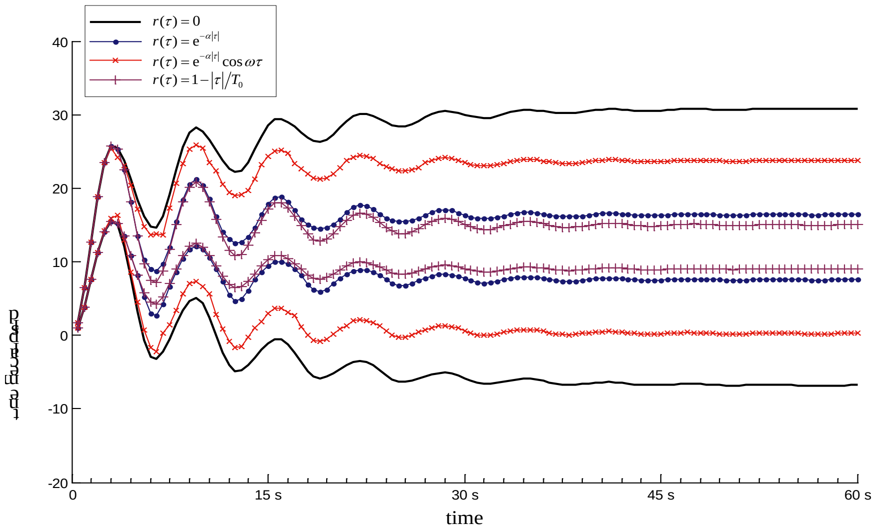

Figure 3. Displacement response bounds of the SDOF system in different correlation cases

Conclusions

A novel non-stochastic process model and corresponding non-random vibration method is proposed for time-varying uncertainty analysis of structures. When calculating the responses for complicated structures, the proposed model requires only the upper and lower bounds of a time-varying uncertain parameter. The technique to transform the dependent non-stochastic process into an independent one is provided, and the bounds of the transformed independent process are deduced. Subsequently, the non-stochastic process method is applied for non-random vibration analysis to compute the dynamic response bounds of SDOF and MDOF systems. The study of the non-stochastic process model and corresponding non-random vibration method illustrates a possible and feasible way for time-varying uncertainty analysis when inadequate information can be obtained.

References

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