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Numerical uncertainty analysis of active and passive structures in the structural design phase

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Abstract

The active approach is nowadays well developed and widely used for various kinds of structures for vibration control or compensation. However, it makes the structure more complex than a passive structure. In this study, active and passive beam structures with the same designed size are compared with regard to uncertainty analysis of the system. The purpose of the comparison is to find a comprehensive way to decide whether an active or a passive approach should be used in the structural design phase. An active beam structure used in this study is a beam structure with one sensor, one actuator, and one controller. The controller is designed to reduce the structural vibration. An active beam structure with a properly designed controller can reduce the structural vibration without changing the structure's physical dimensions. In contrast, a passive approach can also reduce the structural vibration without additional electric energy for active components, e.g., by changing the material. The comparison of the active and the passive beam structure is based on a beam structure with the same boundary conditions. It is well known that after manufacture and assembly the input parameters of the structure do not exactly correspond to the designed values. Therefore, the input parameters are assumed to be normally or uniformly distributed according to the manufacture tolerance class. They are varied according to the Monte Carlo method to compare the vibration reduction ability of the active and the passive approaches. Finally, uncertainty analysis supports the decision if an active or a passive approach should be used in the structural design phase.

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Keywords: uncertainty analysis; active structure; passive structure; Monte Carlo method

1. Introduction

Nowadays lightweight structures are widely used in engineering, architecture, and many other design tasks. In order to control or reduce the structural vibration of lightweight structures, active approaches are well developed and widely used. However, it makes the structure more complex than a passive structure. In this study the vibration reduction ability of active structures is compared with that of passive structures to investigate whether an active or a passive approach should be used in the structural design phase. It is well known that the input parameters such as geometric and position parameters vary due to uncertainty in manufacture and assembly processes. Consequently, the uncertainty analysis of the structural behavior must be carried out to ensure a reliable prediction of the performance.

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Uncertainty can be distinguished into epistemic uncertainty and aleatory uncertainty. The epistemic uncertainty is a reducible uncertainty that arises from a potential deficiency of knowledge on structure input parameters [1]. The possibilistic methods are feasible in case of epistemic uncertainty analysis and are usually used in the design phase when limited information on the density functions of the input parameters is provided. The commonly used methods are interval analysis and fuzzy analysis with α-cuts. By use of these two methods, extreme values of the intervals or extreme values of the fuzzy sets can be found. However, both of these methods risk to omit the global extremes [1] or to overestimate the uncertainty in some cases [3,4]. In contrast to the epistemic uncertainty, the aleatory uncertainty is a irreducible uncertainty that arises from a variability of the structure input parameters [1]. The probabilistic methods are feasible in case of aleatory uncertainty analysis by quantifying the statistical characteristics of the structural output variables. The commonly used method is the Monte Carlo method [1,3]. It generates random samples according to the known distribution of the input parameters and estimates the statistical characterization of the output variables after performing simulations of the random samples [3]. Even though it is time consuming for most applications, due to its generality and ease of implementation it is still an invaluable method to quantify the aleatory uncertainty [3].

In this study a beam structure is used as a reference structure. It is introduced in Section 2 as well as the corresponding feasible passive and active approaches. Furthermore, only the aleatory uncertainty is taken into account. Therefore, the Monte Carlo method is chosen and the results are discussed in Section 3. By comparing the results it is concluded in Section 4 whether an active or a passive approach should be selected in the structural design phase.

2. The Beam Structure

The beam structure to be investigated is a beam structure with one clamped end and one free end. An external vertical harmonic force $F_{\text{ext}}(t) = 1 \cdot \sin(\omega_{\text{ext}} \cdot t)$ N is set at the free beam end in the z-direction and acts as an excitation force (Fig. 1). Only the bending deflection is considered and the gravity is neglected. Therefore, it is modeled to be an Euler-Bernoulli beam [5]. The beam length, the beam width, and the beam thickness are repesented by L_{B}, W_{B}, and T_{B}. The beam material in the initial configuration, also named Configuration No. I, is assumed to be a magnesium alloy. Its Young's modulus and density are represented by E_{B} and ρ_{B}.

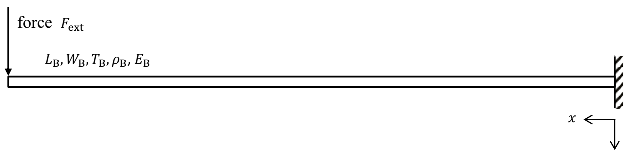

Fig. 1. The passive beam structure in side view.

2.1. The passive approach

The passive approach used in this study to reduce the vibration of the beam structure is a change of selected material for the beam design, because it requires no additional mass or material. In Configuration No. II, the beam is assumed to be an aluminum alloy, as it have a higher Young's modulus than magnesium alloys.

The second-order modal equation in z-direction of the passive beam structure used in this study is given by

$$\mathbf{M} \cdot \ddot{\mathbf{q}}(t) + \mathbf{D} \cdot \dot{\mathbf{q}}(t) + \mathbf{K} \cdot \mathbf{q}(t) = \mathbf{\Phi}(L_{\text{B}}) \cdot F_{\text{ext}}(t) \ . \tag{1}$$

The differential equation can be converted into the transfer function between the force $F_{\text{ext}}(t)$ and the displacement at the free beam end $\mathbf{q}(t)$ for the frequency analysis. The terms $\mathbf{M}$, $\mathbf{D}$, $\mathbf{K}$, and $\mathbf{\Phi}(L_{\text{B}})$ are calculated as follows:

The vertical displacement of the beam end in z-direction $w(x,t)$ is separated into the spatial solution $\mathbf{\Phi}(x)$ and the temporal solution $\mathbf{q}(t)$ for the eigenmodes 1 through n:

$$w(x,t) = \mathbf{\Phi}(x)\mathbf{q}(t) = \sum_{i=1}^{n} \Phi_i(x) q_i(t) \ . \tag{2}$$

The spatial solution for the i-th mode is given by

$$\Phi_i(x) = \sinh(\beta_i x) - \sin(\beta_i x) - \frac{\sinh(\beta_i L_{\text{B}}) + \sin(\beta_i L_{\text{B}})}{\cosh(\beta_i L_{\text{B}}) + \text{ocs}(\beta_i L_{\text{B}})}(\cosh(\beta_i x) - \cos(\beta_i x)) \quad [5]. \tag{3}$$