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# Topology optimization of damping layers in shell structures subject to impact loads for minimum residual vibration

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ABSTRACT

This paper studies optimum distributions of damping material in shell structures subject to impact loads by topology optimization. The optimization aims at reducing the residual vibration responses after the application of impact loads. In particular, the dependence of both structural forced vibration and residual vibration on the damping layer distribution is considered by transient dynamic responses based optimization approach. Until now, optimum distributions of damping material are always carried out based on frequency domain responses or structural dynamic characteristics. But for the studied problem, transient responses based optimization is more straightforward when the impact loads are known. When involving transient responses, the calculations of structural responses and sensitivities are always difficult and time-consuming. To deal with these problems, we use an integrated square performance measure of residual vibration as the objective function, which can be greatly simplified by Lyapunov equation, and use an efficient adjoint method to calculate the sensitivities. The topology optimization is implemented using the common solid isotropic material with penalization (SIMP) method. Numerical examples are carried out to illustrate the validity and utility of the proposed approach, and the numerical results also show the advantages of transient dynamic responses based optimization for the studied problem.



## 1. Introduction

Residual vibration is the free vibration after the application of external loads [1–2]. Fig. 1 shows the displacement response of a simple one degree of freedom system subject to an impact load. The solid curve and dotted curve are the responses of forced vibration stage and residual vibration stage, respectively. For many mechanical systems, excessive structural residual vibration is of important concern, such as, robots [3], cranes [4], solar panels [5] and vibration isolate systems [6]. Many active and passive approaches [7,8] are proposed to suppress structural residual vibrations.

This research will investigate residual vibration reduction of shell structures subject to impact loads by optimizing the distribution of attached damping material. Shells are widely used in engineering applications, and many researches have proposed approaches to control its vibrations. For shell structures, attaching damping material [9–11]on its surface to reduce

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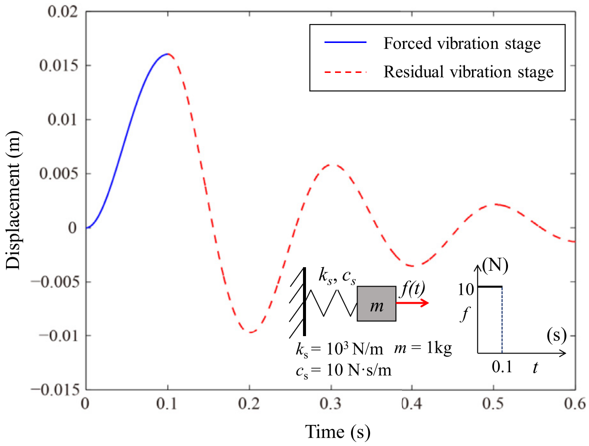


**Fig. 1.** Structural vibration response of structure subject to impact.

the dynamic response is a widely used passive approach, because it is relatively economical and simple in implementation and provides high damping effects over a wide range of frequency and temperature [11]. Full coverage of damping layer treatment is usually not practical due to added mass and material consumption. Thus, it is highly desirable to optimize the distribution of the damping material for achieving the best overall damping efficiency.

The damping material layout design can be solved as a structural topology optimization problem. Topology optimization [12–15] is a computational technique used for determining the layout, or topology. Zheng et al. [16] dealt with topology optimization of shells with constrained damping layer for maximizing the sum of the modal damping ratios, which are approximated with the modal strain energy method. Kang et al. [17] investigated the optimal distribution of damping material in vibrating structures subject to harmonic excitations. They also extended their work to simultaneous optimization of the damping material and host layers [18] and piezoelectric material distributions [19]. Kim et al. [20] adopted topology optimization to maximize the damping effect (i.e. the modal loss factor) subject to constraint on maximum allowable volume of damping material. El-Sabbagh and Baz [21] studied optimum distribution of viscoelastic material to maximize the modal damping ratio (MDR) for a certain volume of material. Takezawa et al. [22,23] dealt with topology optimization technique to find optimal damping material distributions to reduce the resonance peak response in the frequency response problem. Alfouneh and Tong [24] studied maximization of single and multiple modal damping ratios (MDR). Zheng et al. [25] investigated the topology optimization of passive constrained layer damping treatment patched on thin shells with respect to sound radiation. Chen and Liu [26] propose a topology optimization method for designing a viscoelastic cellular material with prescribed properties, aiming at improving the modal damping performance of the PCLD. The above-mentioned works used the well-known SIMP approach and mathematical programming to obtain optimum topology. Other approaches also had been applied to find optimum damping material distributions [27–30].

Most of the above-mentioned works investigate optimal damping material distributions for improving frequency domain responses or structural dynamic characteristics, and only a few works study transient dynamic responses [19]. This is because that, the optimization of transient responses involves the time variable, which makes the calculation of structural responses and sensitivities much more complicate and time-consuming. But, for the studied problem, transient responses based optimization is more straightforward when the impact loads are known. Thus, the objective of this research is to develop efficient method for the optimization of damping material distributions based on transient dynamic responses.

To overcome the time-consuming calculations of transient vibration responses, an integrated square performance measure is proposed to be the objective function. This function is used as a measure of structural residual vibrations [31–34],

$$J = \int_{T_d}^{\infty} \left( \dot{\mathbf{u}}(t)^T \mathbf{Q}_{\dot{\mathbf{u}}} \dot{\mathbf{u}}(t) + \mathbf{u}(t)^T \mathbf{Q}_{\mathbf{u}} \mathbf{u}(t) \right) dt \tag{1}$$

where, $\mathbf{u}(t)$ and $\dot{\mathbf{u}}(t)$ are the displacement and velocity vectors, respectively, $\mathbf{Q}_{\mathbf{u}}$ and $\mathbf{Q}_{\dot{\mathbf{u}}}$ are the positive definite or semi-positive definite symmetric weighted matrices, which are used to specify the locations of evaluation points in optimization. This measure can be applied in many cases, such as evaluating the residual vibrations of a specific location or domain or the relative deformations of two specific locations. The benefit of measure $J$ in Eq. (1) is that, the calculation of $J$ can be greatly simplified by Lyapunov's second method [35].

Several sensitivity analysis approaches [36–39] have been proposed to calculate the sensitivities for the measure in Eq. (1). Most approaches [36–38] are built based on the assumption, the initial excitations of residual vibration are independent of