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Temperature compensation in viscoelastic damper using magnetorheological effect

Yi Zhong [a], Jianwei Tu [b,*], Yang Yu [c], Jiayun Xu [b], Dongmei Tan [b]

[a] *School of Information Engineering, Wuhan University of Technology, Wuhan, Hubei 430070, China*
[b] *Hubei Key Laboratory of Roadway Bridge and Structure Engineering, Wuhan University of Technology, Wuhan, Hubei 430070, China*
[c] *Jiangsu Province Metallurgical Design Institute Co. Wuhan Branch, LTD of Shenwu Group, Wuhan, Hubei 430070, China*

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ABSTRACT

The viscoelastic damper is an effective passive vibration control device, however, its viscoelastic material experiences considerable thermal softening when subjected to higher temperatures, limiting its development and application. In an effort to cope this problem, this paper proposes the development of a new-type viscoelastic damper using the magnetorheological (MR) effect to compensate for the thermal softening effect of viscoelastic material. The new damper is manufactured and the performance is tested, verifying that its MR effect can effectively make up for the performance deficiency of traditional viscoelastic dampers in high temperature. The mechanical model of the new damper is devised and its parameters are identified through the performance test data. The compensation strategy is presented and the thermal compensation controller based on pulse width modulation technology is developed. The compensation experimental results show that this new-type viscoelastic damper will not be influenced by environmental temperature, it can maintain the optimal energy dissipation performance in various temperature conditions.

1. Introduction

The viscoelastic damper is an effective passive vibration control device which increases structural damping and dissipates seismic energy by shear hysteretic deformation of viscoelastic material. The earliest viscoelastic damper was developed by Minnesota Mining and Manufacturing Company [1]. It was composed of 3 steel plates with viscoelastic material in between. The relative movement between the plates causes reciprocating shear deformation of the viscoelastic material layer, absorbing and dissipating energy accordingly. BRC viscoelastic damper was developed by Shimizu Company in Japan which was made up of multilayer steel plates with viscoelastic material in between. Its number of layers could be chosen reasonably on the basis of required damping force, and viscoelastic material absorbed a large amount of external energy during transmitting shear force [2]. So far, viscoelastic dampers have been applied in a lot of practical situations. The Twin Towers of World Trade Center in New York was the first building to be installed with viscoelastic dampers [3,4]. The viscoelastic dampers were also installed in the Building of Columbia in Seattle to resist wind-induced vibration, etc [5,6].

Although the viscoelastic damper was already used in some practical buildings, this technology has not been applied and

* Corresponding author.

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popularized on a large scale because of the fatal weaknesses of the viscoelastic material. According to a large number of experimental studies of various types of viscoelastic dampers, viscoelastic material is sensitive to temperature. With temperature going up, the storage modulus of this material drops quickly, and so does the loss modulus, which causes energy-dissipating capacity of viscoelastic damper to decrease rapidly. In addition, storage modulus of viscoelastic material decreases rapidly with the drop in frequency, which further restricts the application of viscoelastic damper into the civil engineering structures subjected to vibrations in low frequency range. The shear-type viscoelastic damper was studied by Zhou et al. [7] and the experimental data indicated that when temperature went from 17 °C up to 40 °C, the storage modulus and loss modulus of the viscoelastic damper decreased by 9.7% and 17.5% respectively, while loss factors increased at first and then decreased with temperature going up. When temperature increased from 25 °C to 40 °C, energy dissipation of each circle decreased to a great degree by 16.8%, which meant temperature had remarkable influence on dissipation capacity of viscoelastic damper. Three viscoelastic dampers of different sizes were tested by Chang et al. [8–10] and found that when environmental temperature increased from 24 °C to 42 °C, their energy-dissipating capacity decreased by 73%, 71%, and 60%, and stiffness decreased by 70%, 68%, and 34% respectively which explained that stiffness and energy-dissipating capacity of the damper decreased significantly with temperature going up. Empirical formula of the storage modulus and loss modulus was obtained by conducting regression analysis of experimental data [11–13]. Simple harmonic vibration test was conducted with long time, high frequency and low amplitude on the viscoelastic damper [14–17] and found that internal temperature increment of viscoelastic material caused by long-time loading had a notable influence on damper performance. In order to precisely simulate the influence of temperature and frequency on viscoelastic damper performance, a theoretical analysis model was established [18,19], on the basis of which the obtained hysteretic curve was able to be consistent with testing data. Shaking table test of steel frame installed with viscoelastic damper was performed under different environmental temperature [20–22], which showed the structural additional damping decreased apparently with temperature going up.

A great number of studies have been made to reduce the influence of temperature on the performance of viscoelastic damper. A wall-type viscoelastic damper with a digital temperature control device was developed by Nobuhiko et al. [23] which adjusted the damper temperature to remain about 20 °C. But this device was rarely used because it was heavy and complicated. The special viscoelastic damper was made from connection of two types of viscoelastic material suitable for high temperature and low temperature respectively by Sui et al. [24], discovering this damper could maintain preferable performance over a wide temperature range, but inferior to the viscoelastic damper made from one single material under optimal temperature.

It is well-known that there is no limits to elasticity and viscosity of viscoelastic material. The increasing temperature turns its elasticity character to viscous character, namely, the thermal softening effect. As a smart liquid material, magnetorheological (MR) fluid is transformed from free-flowing liquid to semisolid state swiftly by increasing external magnetic field. The external magnetic field can turn the viscous character of MR fluid into elastic character, namely, the MR effect. In this case, can MR effect be used to make up for temperature softening effect of viscoelastic material? It is a feasible idea obviously, based on which a new type viscoelastic damper is proposed and developed in this paper, while accomplishing its performance test and establishing its mechanical model. The second section of this paper demonstrates the performance test of traditional viscoelastic dampers. The third section introduces the fundamental principles, the mechanical model and the performance test of the new-type viscoelastic damper. The fourth section presents the compensation strategy of thermal softening effect and the development of compensation controller.

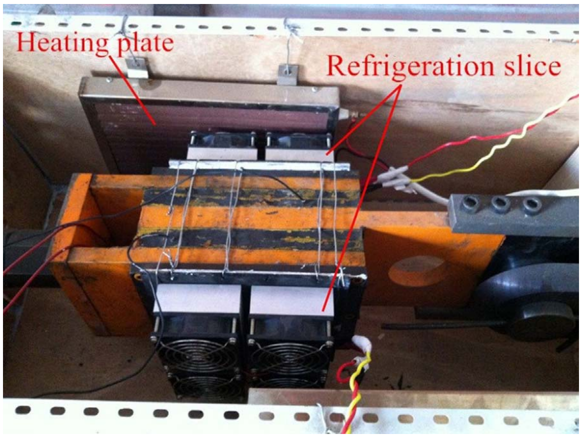

Fig. 1. The temperature change device.