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New Progress in the Application of Shape Memory Alloys in Passive Control of Structural Vibration

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Abstract

The research of structural vibration control based on shape memory alloys has received widespread attention. In response to this problem, this article first introduces some of the main characteristics of shape memory alloys, elaborates the new development of shape memory alloys in the field of structural vibration control, and proposes key issues to be resolved in the future research.

Keywords

shape memory alloy; Features; Vibration control; review.

1. Introduction

Shape Memory Alloy (SMA). To date, more than 50 alloys have been discovered with shape memory effects. Shape memory alloys play an important role in aerospace, mechatronics, biomedical, automotive, vibration control, robotics, industry, civil engineering, and other fields due to their shape memory effects, superelastic properties, high damping properties, and electrical resistance properties. Super-elastic SMA has self-resetting performance and high damping characteristics. It is found that super-elastic SMA can suppress structural vibration caused by wind and earthquake, and can reduce the residual deformation of the structure. Using the shape memory effect of SMA, It plays an important role in structural repair. Using the characteristic that the elastic modulus of the SMA changes with temperature, the stiffness and damping characteristics can be adjusted to perform semi-active control. Use the main characteristics of SMA for structural vibration control to reduce property damage and hazards, thereby improving the safety and reliability of the structure. Based on recent research progress at home and abroad, this paper summarizes the main characteristics of SMA and summarizes the current research status and problems of SMA in structural vibration control.

2. Important Characteristics of Shape Memory Alloys Section Headings

2.1. Shape Memory Effect

The Shape memory effect (SME) refers to a material with a thermoelastic martensitic transformation that maintains a certain shape at a certain temperature. When it rises to a certain temperature, its shape returns to a high temperature before deformation. The shape of austenite, which retains the memory characteristics of the previous shape. The shape memory effect is mainly caused by temperature-induced martensite transformation. SMEs show various forms according to their alloy composition, heat treatment process, and mechanical training. According to the recovery of the alloy shape, they can be divided into one-way memory effect, two-way memory effect, and global memory effect [1].

2.2. Hyperelastic Properties

Super-elasticity refers to the fact that in a certain temperature range above ambient temperature, the applied stress exceeds the elastic limit, and after plastic deformation occurs,

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even if it is not heated during unloading, the strain will decrease as the external stress decreases, and the external stress is zero The strain also returns to zero, and the stress-strain curve shows a hysteresis effect [2], which is different from elastic deformation in nature and is called superelasticity, also known as phase-change pseudoelasticity. During the deformation process, the stress-strain curve is not a linear relationship, but a hysteresis ring shape, which has an energy dissipation effect. Therefore, using the super-elastic properties of shape memory alloys, various dampers can be developed to achieve the effect of reducing and controlling vibration.

3. Shape Memory Alloy for Passive Structure Control

The high damping characteristics of SMA materials during martensitic transformation and their pseudo-elastic hysteretic damping characteristics at high temperatures can be widely used in structural vibration-damping design [3]. In recent years, SMA-based passive control has been mainly applied in basic seismic isolation devices, SMA reinforced composite materials, stay cables, passive dampers, and concrete components embedded in SMA.

3.1. Base Isolation Device

Vibration isolation technology is to install some kind of vibration isolation device between the bottom of the structure and the top surface of the foundation to extend the vibration period to avoid the main energy band of the earthquake, thereby reducing structural damage and reducing casualties. Generally speaking, the vibration isolation technology can exert a good isolation effect in a far-field earthquake, but under the long-period pulsating motion of a near-fault earthquake, it has adverse effects. In recent years, more and more researchers have begun to explore the use of SMA composite isolation bearings to solve the above problems. Speicher [4] developed a quadrilateral articulated support system based on shape memory alloy and conducted an earthquake resistance test. The experimental results show that the shape memory alloy has a large strain recovery ability, and the deformation distribution of the shape memory alloy system at the structural height is more uniform than that of the traditional system. Huang Bin et al. [5] proposed a new basic isolation system composed of super-elastic shape memory alloy (SMA) coil springs and sliding bearings and verified the validity of the numerical model through multiple sets of ground motion excitation tests. Yang Haidong [6] put the SMA effectively and reasonably around the rubber bearing and developed the SMA intelligent vibration isolation bearing. Through simulation analysis and comparison, the ordinary laminated rubber bearing, SMA laminated rubber composite bearing, and SMA intelligent insulation are compared. The isolation effect of the three types of bearings of the seismic support found that the SMA smart isolation support has the best isolation effect. Dolce et al. [7] combined SMA wire with sliding support and proposed SMA-sliding support vibration isolation device, which verified its isolation effect in a reinforced concrete frame. SMA-rubber isolation bearings are also increasingly used. Ren Wenjie et al. [8] established a mechanical model of SMA-rubber composite bearings and pointed out that SMA wires can improve the mechanical properties of laminated rubber isolation bearings, and with the increase of pre-strained SMA wires, the residual of composite bearings Deformation, energy consumption and damping ratio all increase linearly. Chen Haiquan et al. [9] added a spring to the SMA-rubber bearing designed by Xue Suduo to improve the function of the SMA energy-consuming cable and designed a type II SMA-rubber bearing, which increased the isolation effect.

Friction Pendulum System (FPS) is effective dry friction sliding isolation device with high bearing capacity, high stability, high durability, self-reset capability, and low sensitivity to the frequency range of seismic excitation As well as the advantages of excellent isolation and energy dissipation mechanisms, it has gradually become isolation support with broad development prospects. However, under the long-term earthquake, the traditional FPS will cause a large displacement of the isolated structure and isolated support [10]. Liu Yudong et al.

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[11] proposed a new type of composite isolation bearing—SMA spring-friction bearing. By increasing the number of SMA springs, the stiffness and energy consumption of the bearing were increased. Yang Yi et al. [12] combined FPS and SMA cables to develop an SMA-FPS composite bearing. On the one hand, using SMA as a supplement to the FPS level recovery stiffness can effectively control the FPS displacement; on the other hand, To reduce the seismic response of an isolated structure, SMA's superelastic effect and high damping characteristics are used to consume energy. Zhuang Peng et al. [13] studied a new type of shape memory alloy spring-friction bearing. The bearing can provide a full hysteresis curve, strong energy consumption, and a certain reset ability. The effect on residual displacement is significant. Ozbulut [14] et al. Studied the seismic performance of a sliding base isolation system considering changes in ambient temperature, and studied the maximum displacement of the support for external temperatures of 0 ° C, 20 ° C, and 40 ° C, with an impact not exceeding 13%. This shows that SMA-friction bearings have relatively stable and excellent performance even when used outdoors.

In addition to SMA composite bearings, some researchers have combined SMA composite bearings and dampers to achieve better vibration isolation and isolation. Liu Haiqing et al. [15] combined the SMA composite bearing with magnetorheological damper, which can not only greatly reduce the horizontal side shift of the isolation layer, effectively protect the isolation device, but also enable the interlayers of the superstructure The displacement and acceleration responses are effectively controlled, thereby improving the shock absorption effect and reliability of the isolated building. Also, Zhan Meng et al. [16] reasonably combined SMA piezoelectric composite vibration damping device with two intelligent materials, shape memory alloy and piezoelectric ceramics, which have better energy consumption ability, stable performance, and strong adaptability. Good for vibration control of engineering structures.

3.2. Stay Cable

Due to the low mass and rigidity of the cable and its poor ductility, various vibrations are likely to occur under extreme weather and loads. Large vibrations will cause hidden safety hazards and shorten the life of the cable. The pseudo-elastic properties of shape memory alloys can effectively dissipate vibrational energy. Zuo et al. [17] designed an SMA damper and installed it on a stay cable, and studied the effect of the SMA damper on the damping effect of the model cable under free vibration and bridge deck vibration excitation. The SMA damper installed in the plane can reduce the attenuation time of free vibration in the stay cable by 50%, which can restrain the vibration response of the stay cable. Casciati et al. [18] wound the SMA on the cable to simulate its dynamic characteristics change, and chose the best configuration method to achieve the best vibration reduction effect. Dieng et al. [19] thin nickel-titanium shape memory alloy (SMA) wire as a damper, qualitatively, and quantitatively evaluated the efficiency of Ni-Ti dampers to reduce the vibration amplitude of civil engineering cables. Li et al. [20] studied the vibration damping performance of a shape memory alloy damper on stay cables using SMA's superelastic behavior to dissipate energy. This SMA damper can effectively reduce cable vibration. Wang Sheliang [21] proposed the SMA cable and studied the working principle and mechanical model of the control system of the SMA cable. Asgarian and Moradi [22] designed SMA cables of different configurations. Dieng et al. [23] used super-elastic SMA wire to make a damping device for vibration control of stay cables. Guangguang Yu [24] adopted a new type of self-resetting damper composed of a ring spring and SMA. The damper works in conjunction with a ring spring through an SMA cable. Both parts have both reset and energy dissipation characteristics.

3.3. SMA Smart Composite Structure

Intelligent materials such as shape memory stage gold (SMA) fibers, piezoelectric fibers, and optical fibers are mixed with advanced fiber-reinforced composite materials to make hybrids.

Developed intelligent structure with intelligent behaviors such as sensing function and driving function. It is an important breakthrough in the development of materials science and technology at the end of the 20th century. It marks the arrival of a multifunctional and intelligent era in material design. In the intelligent material structure system, SMA intelligent composite material structure has attracted more and more attention from the engineering community in the static and dynamic design of the structure due to its unique properties.

If the SMA is pasted or embedded in a composite beam, the high damping characteristics of the SMA material during the martensitic transformation and its pseudo-elastic hysteresis damping characteristics at high temperatures can be used to absorb the vibration energy of the composite laminate, thereby Suppress vibration of laminates. The structural SMA and the laminated board are integrated into one body and are widely used in passive control of structural vibration. Sun Shuang Shuang et al. [25] studied the vibration characteristics of SMA hybrid composite hollow laminated beams with composite hollow laminated beams embedded with pseudo-elastic shape memory alloy fibers. Research shows that pseudo-elastic SMA fibers can better achieve vibration suppression of laminated beams at higher temperatures. The vibration suppression effect of pseudo-elastic SMA fibers on laminated beams is significantly better than that of structural damping on laminated beams. Damanpack et al. [26] studied the vibration control performance of shape memory alloy composite beams under impact loads and proposed a numerical algorithm for solving nonlinear SMA constitutive models. The results show that the highly pre-strained SMA layer can control passive vibration at low temperatures. Zhang Jingye [27] studied the vibration model of a super-elastic SMA single-degree-of-freedom system and the influence of super-elastic SMA on the vibration characteristics of a composite cantilever beam based on the mechanical test of a super-elastic SMA wire and its constitutive model. Khalili et al. [28] proposed a nonlinear finite element model for analyzing the dynamic properties of SMA composite laminates considering the SMA transient phase transition and material nonlinearity and studied the vibration of laminates by pseudo-elastic SMA fibers Inhibitory effect. Zhang Xiaomei et al. [29] significantly improved the equivalent bending stiffness and static deformation characteristics of the shaft by using the martensitic phase transformation driving action of SMA wire. Hao Ying et al. [30] studied the lateral nonlinear vibration of an axially moving SMA laminated beam under uniform lateral load. The research shows that the main common amplitude-frequency response curve of the axially moving SMA laminated beam has a jump phenomenon. The axial velocity and axial load only affect the resonance frequency. The axial movement speed increases and the resonance frequency decreases. The external excitation amplitude increases, the hysteresis effect is obvious, and the common amplitude value increases.

4. Summary

This paper summarizes the current research status of SMA from passive vibration control, active control, and semi-active control. From the existing research, the main characteristics of SMA's superelasticity and shape memory effect are good for structural vibration control. However, SMA has few practical engineering applications, and most of them focus on theoretical analysis and model research. However, to truly apply SMA to the field of vibration control of actual engineering structures, the following issues need to be further studied:

(1) Combining SMA with other dampers, on this basis, carry out relevant experimental research to obtain a reasonable, stable, and reliable design solution.

(2) Experimental verification research. At present, the research on the vibration control of tall towers using the shape memory effect of SMA and the vibration control of wind turbine blades using the superelastic characteristics of SMA are mostly based on numerical calculations and simulation analysis. There are differences between theoretical and experimental results and

even simulation software Some actual working conditions cannot be simulated, so it is necessary to carry out experiments for comparison and verification.

(3) SMA as a driving material for active control has high requirements on the heating and cooling speed of SMA. In the study, the influence of factors such as temperature must be considered comprehensively to improve the temperature control efficiency of SMA.

(4) The types of SMA materials are constantly innovating, and SMA materials must be reasonably selected and applied in structural vibration control.

(5) When SMA is mixed in composite materials, the structural vibration control effect is related to the SMA layering angle, layering sequence, and martensite volume fraction. Whether it is numerical calculation or simulation analysis, the influence of these factors must be fully considered.

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