The effect of shape memory alloys in vibration suppression of a cantilever beam


Department of Mechanical Engineering,
Worcester Polytechnic Institute, Worcester, MA 01609, USA
Email: jsalichs, cirrus, mnnoori, davoodi@wpi.edu

Abstract

Experiments were conducted to investigate the effect of the shape of Nitinol strips on shifting the natural frequency of a cantilever beam. Nitinol belongs to a group of metallic materials known as Shape Memory Alloys (SMA). Nitinol strips were attached to the cantilever beam in order to reduce the vibration of the beam upon activation. The results show that Nitinol strips with curved memory are more effective than straight strips in shifting the natural frequency of the system.

1 Introduction

Shape Memory Alloys (SMA) are a group of metallic materials that have the ability to return to a previous shape when subjected to heat. The SMA material used in this experiment consisted of an alloy of Nickel and Titanium known as Nitinol. This material can be deformed at lower temperatures and when subjected to higher temperatures it recovers its original memory. This memory effect is known as Shape Memory Effect (SME). The SME occurs because of the change in the crystal microstructure of the material from martensite (low temperature crystal microstructure) to austenite (high temperature crystal microstructure), Davoodi[3]. Shape Memory Alloys have different types of SME known as one-way and two-way memory. The one-way memory results when the material recovers its original shape only when subjected to heat. The two-way memory results when the material
recovers its original shape upon heating and cooling. It is important to mention that the stiffness and elastic modulus of the material change when it is subjected to phase transformation. These property changes are responsible for the vibration mitigation abilities of the material.

Many applications have used SMA for vibration mitigation and structural control. Both passive and active damping applications of SMA were initially proposed in 1988, Beards[2]. Kelly and Nims at the Earthquake Engineering Research Center at Berkeley were the first to investigate the applications of SMA for seismic resistant design, Aiken[1]. Davoodi and his colleagues, Davoodi[4], studied the feasibility of using SMA for controlling the amplitude and natural frequency of structures during high level of excitation. A review of applications for SMA can be found in Shakeri[5].

2 Experimental Procedure

Different memories and configurations of SMA materials were investigated for the application of vibration control. Nitinol strips were attached to a cantilever beam. The dynamic response of the system was obtained for free vibration when the material was not activated and when it was activated. Electric current was passed through the strips to heat them up and thus activate them. An accelerometer was attached at the end of the cantilever beam and the response was displayed on a digital signal analyzer.

Two different memories for the Nitinol strips were used: straight and curved. By using different memories for the SMA material, the response of the system can be improved because of the change in the stiffness of the material. The natural frequency of a system can be shifted more using the same amount of material but a different shape. In addition, two different types of attachments were used: Nitinol strips attached to one side or both sides of the cantilever beam.

In order to know when the Nitinol was completely activated (austenite finish) the time response of the SMA material when subjected to heat was investigated. A 5 amps current at 10 volts was used to heat up the strips. The time to reach the austenite start temperature (29.4 C) was 3.6 seconds and the austenite finish temperature (48 C) was 14.6 seconds. These results were based on a room temperature of 26C.

A cantilever beam with a concentrated mass at the end was designed. Six SMA strips with straight memory were attached at the top of the cantilever beam in pairs. Each pair consisted of two Nitinol strips
in pmauci. in auuiuon, me pairs were connected electrically in series. The natural frequency was obtained at different temperatures, at 26°C (when the material was not activated) and 58°C (when the material was completely activated). Then, one pair of SMA strips was taken out of the configuration and the same procedure was repeated until just one pair of Nitinol material was at the top of the cantilever beam. The above procedure was repeated with curved memory strips.

In the second part of the experiment configuration of the Nitinol strips was changed. Two pairs of SMA strips with straight memory were attached at the bottom and another one at the top of the cantilever beam. The response of the system was obtained for free vibration. Then, one pair at the top of the beam was taken out and the same procedure was repeated until one strip was left at the top and another one at the bottom of the cantilever beam. Finally, the experiment was repeated again using SMA strips with curved memory instead of using straight memory strips. The SMA strips with curved memory were attached to the system by forming a U with respect to the beam.

3 Experimental Results

The natural frequency of the cantilever beam was shifted when the Nitinol strips were activated regardless of the shape of the strips (straight or curved) or the attachment configuration. Figure 1 shows the percentage of change of the natural frequency of the system using different number of strips. This change in natural frequency is due to the increase in the Nitinol’s stiffness. As it is shown the effect of the curved memory on the natural frequency is more pronounced than the straight memory. The reason is that the Nitinol strips are acting as a pre-stressed spring. In addition, by attaching the Nitinol strips at both sides of the beam the natural frequency is shifted to a higher value than when the strips attached only at the top of the beam (no matter what memory was used). It is important to note that the effect of using different memories is more pronounce than the effect of using different attachment configurations. The maximum shift in natural frequency is 25.7%. This is obtained with 6 strips with curved memory at both sides of the beam. By using the strips with straight memory a maximum of 3.1% shift in natural frequency can be obtained using 4 strips at both sides of the beam.
Discussion and Future Work

The use of SMA with different memories is an efficient way to improve the vibration mitigation abilities of this material. SMA with curved memory shifted the natural frequency of the system to a higher value than the straight memory. Also higher values for the natural frequency can be obtained by attaching curved memories to the cantilever beam. It is important to note that the property that causes this shifting in the natural frequency of the system is the change in stiffness of the material.

The use of SMA in different configurations is another way to control vibrations with the same amount of material. The results showed a change in the natural frequency of the system when using SMA material at both sides of the beam rather than attaching them only to one side. However, the maximum shift in natural frequency can be obtained by using a combination of both effects: change in memory and attachment configuration.

Further research is needed to study the effect of the mass ratio of Nitinol to the structure. The result of such study will show how to get the most effect out of a specific amount of SMA material. Developing analytical models helps to gain better idea of the effect of the SMA before experiment. In addition, more experiments should be done on the effect of temperature on damping ratio of SMAs in order to use it along with frequency shifting in vibration suppression.
Acknowledgments

Special thanks to Memry Corporation for supplying the SMA material for this investigation. Also thanks to Bob Taylor, Mr. Steve Derosie, Mr. Todd Billings, and Mr. Jared Eaton.

6 References


