Determination of Natural Frequency for a CRPF beam embedded with SMA wires using FRF Analysis.

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Abstract

Owing to high specific strength and stiffness, composites find wide applications in automobile and aerospace industry. But conventional composites suffer from noise and vibration issues in many of the automotive and aircraft applications. In this paper, effect of embedded shape memory alloy wire (SMA) on the vibration characteristics of composites was studied. Experimental modal analysis was carried out on the carbon fibre reinforced epoxy composite beams (CFRP beam) embedded with shape memory alloy wire manufactured by hand lay-up process. Moreover, the natural frequency of the carbon fibre reinforced epoxy composite beam embedded with shape memory alloy wire was also calculated theoretically. Increased levels of pre-strain on shape memory alloy wire resulted in maximum increment in both natural frequency.
1 INTRODUCTION

A. COMPOSITES

Composite materials of high stiffness and strength to weight ratio and higher weight savings are used for high performance operations. Also several parameters of composite materials like fibre angle, number of layers, stacking sequence and fibre volume fraction can be tailored to efficiently meet the design requirements of strength and stiffness. Also, composite materials typically have a lower modulus of elasticity. As a result, when torque peaks occur in rotary application, composites can act as a shock absorber and decreases stress on part extending life. But composites generally suffer from noise and vibration problems and hence composite drive-shaft employed in supercritical operation undergo excess vibration and instability at resonant conditions. This leads to the need for a way to control its vibration while going through resonance condition. Reduced vibration levels can be achieved through passive and active control. Passive control involves structural redesign through use of external dampers and springs, whereas active control involves embedded actuator which reduce the vibration levels.

The need for external damper can be avoided through adapting active control techniques. Adaptive composites are structural materials that integrate actuating and sensing capabilities often under the form of embedded active materials. Active control improves the structure with actuators, sensors and some form of electronic control system which is programmed to reduce the measured vibration levels. Advance in smart materials have produced smaller and effective actuators and sensors with high integrity in structures. Many types of smart materials are well accepted for actuating and sensing devices: they include piezoelectric (PE), electrostrictive (ES), magnetostrictive (MS), Shape Memory Alloy (SMA), electrorheological and fibre optical materials.

Shape memory alloys are good candidates for conferring these adaptive capabilities. The concept of smart hybrid composites with embedded shape memory alloy elements/ SMA composites has attracted a wide interest. SMA composite materials are created by embedding SMA elements in the form of wires, ribbons or particles into matrix metals such as polymers, metals or composites. The physical properties of the matrix materials are either improved by
the SMA elements or can even be actively modified by controlling the progress of the martensitic transformation of the embedded pre-strained SMA elements. So, the objective of the work is to determine the natural frequency of a CFRP beam embedded with and without SMA wire and the effect of different levels of pre-strain on the natural frequency of CFRP beam with SMA wire through experimental modal analysis.

2 FABRICATION

A. SPECIMEN PREPARATION

A beam of 150*50*7 mm dimension was taken as reference geometry. On the basis of ease of manufacturing, hand-layup process has been chosen for manufacturing of the beam. Fig.1 shows a prepared specimen using hand-layup process. Carbon T 250 gsm fabric was cut according to the dimension of the beam. Curing of thermoset plastics is an exothermic process, as a rule of thumb. This might lead to activation of SMA wires during fabrication. Hence cold curing is selected and suitable hardener and resin (EH-758 &EP-306) is chosen. EP 306 resin, EH 758 hardener and EP 072 dilutor was taken in the ratio of 10:1:1 and mixed. The prepared mixture should be used before gel time of the resin is reached.

Cut carbon fabric layers are placed inside the mould. The prepared resin mixture is applied over alternate carbon layers of fabric. This process is repeated until the mid-level of the prepared mould is reached. Wires were positioned along the neutral axis of the mould and then the process of applying resin over alternate layers of carbon fibre fabric is repeated till the complete height of the specimen
is achieved. A roller should be rolled over the specimen immediately in order to remove air bubbles formed inside the specimen. Care must be taken to ensure that the SMA wires do not come into contact to avoid short circuiting during electrical heating. A suitable weight should be placed over the prepared specimen to ensure the flatness of the specimen while curing. Table 1 gives the information on geometrical properties of the specimen.

<table>
<thead>
<tr>
<th>TABLE I Geometrical properties of the specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of SMA wire in each specimen</td>
</tr>
<tr>
<td>Dimensions (l breadth)</td>
</tr>
<tr>
<td>Thickness (t)</td>
</tr>
<tr>
<td>Diameter of SMA wire (d)</td>
</tr>
<tr>
<td>Young’s modulus of CFRP</td>
</tr>
<tr>
<td>Young’s modulus of strain</td>
</tr>
<tr>
<td>Density of CFRP</td>
</tr>
<tr>
<td>Volume fraction of SMA wire (V SMA)</td>
</tr>
<tr>
<td>Volume fraction of fibre (V CFRP)</td>
</tr>
<tr>
<td>Volume fraction of strain (V strain)</td>
</tr>
<tr>
<td>Po’s strain (%)</td>
</tr>
<tr>
<td>Boundary Conditions</td>
</tr>
</tbody>
</table>

A. EXPERIMENTAL SETUP

Experimental modal analysis as explained in chapter 5 involves the use of vibration sensor, data acquisition, FRF analysis and modal parameter extraction. Experimental modal analysis is carried out according to ASTM C747-93 standard. This test method covers the measurement of the fundamental transverse, longitudinal, and torsional frequencies of isotropic and anisotropic carbon and graphite materials. These measured resonant frequencies are used to calculate dynamic elastic moduli for any grain orientations.
The specimen is constrained as a fixed beam with support condition as per ASTM C 747 standard and is shown in fig. 1. Three accelerometers are placed on the beam and impact hammer is used to provide input vibrations on the beam and the accelerometer picked up response from the beam till the vibration died out. DeweSoft data acquisition system conditions the signal and DeweSoft software determines the Frequency Response Function curve of the input and output signals.

SMA wire needs to be activated upon heating and hence a VI converter with suitable current rating is required to provide joule heating. A 24V DC generated power supply was used to provide joule heating. Generally the maximum value of current that can be passed through SMA wire without degrading the material is in the range of 3-4 amps. The activation temperature of SMA wire was found to be 75 deg Celsius.
Activation temperature of SMA wire was experimentally verified to be 75 deg Celsius and the activation time required to reach activation temperature for a single SMA wire by passing 1.5 amps under 2.5 volts was found to be 1.5 minutes. Alternate wire ends were connected to enable series connection of SMA wires. 5 amps current passing through SMA wire under 7.5 volts activated the SMA wires placed in CFRP beam in a time span of 5 minutes. Impact Hammer was used to induce input vibration on the specimen around the activation range and the response of the beam was recorded by three accelerometers placed equidistant on the specimen. DeweSoft data acquisition system conditions the signal and DeweSoft software determines the Frequency Response Function curve of the input and output signals.

3 RESULTS AND DISCUSSION

A. FUNDAMENTAL FREQUENCY UNDER UNACTIVATED CONDITION

FRF curve of an unactivated CFRP beam with 2% pre-strained SMA wire is shown in fig.5. The first fundamental frequency of an activated CFRP beam with 2% pre-strained wire was found to be 613 Hz. FRF curve of an unactivated CFRP beam with 4% pre-strained SMA wire is shown in fig.5. The first fundamental frequency of an unactivated CFRP beam with 4% pre-strained wire was found to be 613 Hz.
Figure.5 FRF of unactivated CFRP beam with 2% and 4% pre-strained SMA wire

FRF curve of an unactivated CFRP beam with 6% pre-strained SMA wire is shown in fig.6. The first fundamental frequency of an unactivated CFRP beam with 6% pre-strained wire was found to be 793 Hz.

Figure.6 FRF of unactivated CFRP beam with 6% pre-strained SMA wire

B. FUNDAMENTAL FREQUENCY UNDER ACTIVATED CONDITION

FRF curve of an activated CFRP beam with 2% pre-strained SMA wire is shown in fig.7. The first fundamental frequency of an activated CFRP beam with 2% pre-strained wire was found to be 732 Hz.
Figure 7 FRF of activated CFRP beam with 2% pre-strained SMA wire

FRF curve of an activated CFRP beam with 4% pre-strained SMA wire is shown in figure 8. The first fundamental frequency of an activated CFRP beam with 4% pre-strained wire was found to be 769 Hz.

Figure 8 FRF of activated CFRP beam with 4% pre-strained SMA wire.

FRF curve of an activated CFRP beam with 6% pre-strained SMA wire is shown in figure 9. The first fundamental frequency of an activated CFRP beam with 6% pre-strained wire was found to be 805 Hz. Percentage variation in natural frequency between theoretical and experimental results in activated and unactivated state is shown in Table 2 and Table 3 respectively.

Figure 9 FRF of activated CFRP beam with 6% pre-strained SMA wire.
TABLE II C. COMPARISON OF EXPERIMENTAL RESULTS WITH THEORETICAL RESULTS UNACTIVATED STATE

<table>
<thead>
<tr>
<th>S. No</th>
<th>Pre-strain (%)</th>
<th>Unactivated State</th>
<th>Theoretical Natural Frequency (Hz)</th>
<th>Experimental Natural Frequency (Hz)</th>
<th>% variation in Natural Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>725</td>
<td>613</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>725</td>
<td>613</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>725</td>
<td>793</td>
<td>9.57</td>
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</tr>
</tbody>
</table>

Theoretical frequency of all three CFRP beam with 2%, 4% and 6% pre-strained SMA wire under unactivated condition was found to be 725 Hz respectively. Theoretical frequency of an activated CFRP beam with 2%, 4% and 6% pre-strained SMA wire was found to be 760 Hz, 794 Hz and 825 Hz respectively.

Fundamental frequency of CFRP beam embedded with 2%, 4% and 6% pre-strained under unactivated SMA wire was found to be 613 Hz, 613 Hz and 793 Hz respectively.

Fundamental frequency of CFRP beam embedded with 2%, 4% and 6% pre-strained under activated SMA wire was found to be 732 Hz, 769 Hz and 805 Hz respectively.

TABLE III
D. COMPARISON OF EXPERIMENTAL RESULTS WITH THEORETICAL RESULTS ACTIVATED STATE
### TABLE IV
E. COMPARISON OF EXPERIMENTAL RESULTS BETWEEN UNACTIVATED AND ACTIVATED STATE

<table>
<thead>
<tr>
<th>8 No</th>
<th>Pre-strain (%)</th>
<th>Activated State</th>
<th>% variation in Natural Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Theoretical Natural Frequency (Hz)</td>
<td>Experimental Natural Frequency (Hz)</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>760</td>
<td>702</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>784</td>
<td>709</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>825</td>
<td>805</td>
</tr>
</tbody>
</table>

Percentage variation in natural frequency between experimental and theoretical values in unactivated state was found to be 15.5%, 15.5% and 9.37% for 2%, 4% and 6% pre-strained specimen respectively.

Percentage variation in natural frequency between experimental and theoretical values in activated state was found to be 3.68%, 59.2% and 2.42% for 2%, 4% and 6% pre-strained specimen respectively.
Percentage variation in natural frequency between unactivated and activated state was found to be 19.4%, 47.2% and 1.52% for 2%, 4% and 6% pre-strained specimen respectively.

4 CONCLUSION

Design and development of CFRP beam embedded with SMA wire with different levels of pre-strain has been completed and experimental modal analysis has been carried out successfully. Natural frequency of the CFRP beam embedded with SMA wire with 2%, 4% and 6% pre-strain was recorded experimentally and compared with calculated theoretical values for unactivated and activated state.

Experimental results were well in agreement with theoretical results. Higher fundamental frequencies were obtained for CFRP beam embedded with SMA wire pre-strained to higher values. This result shows a positive trend in increase of fundamental frequency which opens up the possibility of use of such composites in a wide area of applications.

References


