

Jump Attenuation in a Non-Ideal System Using Shape Memory Element

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Abstract. The studies on the so-called smart materials have grown in the last years due to the diverse possibilities that these materials can provide. These types of materials have the ability to respond to an external excitation, altering its physical form, and being able to be considered as actuators. Among these materials are the Shape Memory Alloys (SMA), several metal alloys that are able to memorize a shape and recover it after a deformation through an increase of its thermal energy. In this paper, an actuator consisting of an SMA wire is used to attenuate the vibration and Sommerfeld effect of a non-ideal type oscillator. The temperature control of the actuator was carried out through the application of an electric current in the wire. Results are presented for different currents, with the objective of investigating the temperature variation for vibration control applications. The results showed that it is possible to apply SMA actuators to the attenuation of the Sommerfeld Effect as well as in the reduction of the total vibration of the system.

1 Introduction

Among the most common configurations in engineering designs, there are systems composed of a mechanical structure and some rotating excitation, e.g., a DC (Direct Current) motor. All these systems that have some rotating device are subject to mechanical vibrations that may be induced by an imbalance or poor alignment [1].

Sometimes, the methods of balance a system can be difficult or even unfeasible due to presented critical speeds. These velocities emerge when the angular frequency of the excitation shaft equals the natural frequency of the mechanical structure, being a characteristic effect of a non-ideal type system, where the motor (responsible for the vibration) is influenced by the behavior of the system, thus altering its normal functioning [1, 2].

In 1907, Sommerfeld performed an experiment composed of a cantilever beam with an unbalanced DC motor at its tip. Sommerfeld realized that when the angular frequency of the motor came close to the natural frequency of the system, the applied electrical voltage would stop corresponding to an increase of the rotation of the motor, where only the amplitudes of vibration increased. However, after the motor have passed through the resonance region, its rotation returned to function normally. This effect was called by Sommerfeld Effect and is one of the most characteristic effects of a non-ideal type system [2, 3].

The behavior of a non-ideal system implies an increase in the vibration amplitudes and loss of energy,

which can cause a reduction in useful life or a critical system failure, thus, such systems should be studied in advance to prevent this kind of situation in a real project [1, 3].

However, an opportunity that have emerged is the use of new materials that were previously unavailable, materials that little alter the project and can act in a way to attenuate, control or remove certain behavior of the structure, allowing the project barriers to be expanded. These are the so-called smart materials, which are a class composed of several materials that have the capacity to respond in a specific way to some type of excitation, and can be used as actuators and sensors. Among these materials, there are the Shape Memory Alloys (SMA), a group of metal alloys that can change and return to a memorized form by increasing their thermal energy [4-6].

The SMA materials have two different crystallographic phases. A phase called Austenite, referring to high temperatures and a phase called martensite, referring to the low temperatures. In the SMA material, the so-called martensitic transformation effect occurs, which is a transition between the two phases. This transition occurs at high speed and in solid state and the effects of shape memory and pseudoelasticity come from this transformation, which occurs due to temperature change and/or mechanical loading [4-6].

As stated, the effect of shape memory consists of the structural return of the material to a previous form through the increase of its thermal energy. The effect of

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pseudoelasticity occurs when the system is at a temperature above its austenite temperature and, in this condition, the system tends to return after deformed, performing mechanical work in the return [5-6].

In this way, this work presents the pseudoelastic effect of a SMA actuator used in a non-ideal oscillator in order to reduce its vibration and the jump effect that occurs in these types of systems. The built acquisition system was explained and experimental results were obtained for different electric currents applied in the actuator.

2 Experimental procedures

3.1 System built and instrumentation

The system built for the tests consists of a cantilever beam made of aluminum with an unbalanced DC (Direct Current) motor attached to its free end. For the motor unbalance, on its shaft was fixed an extension with a certain mass at its free end. When the motor works, this mass destabilizes and makes the system vibrate vertically (flexural vibration). Figure 1 presents the non-ideal system built for the tests.

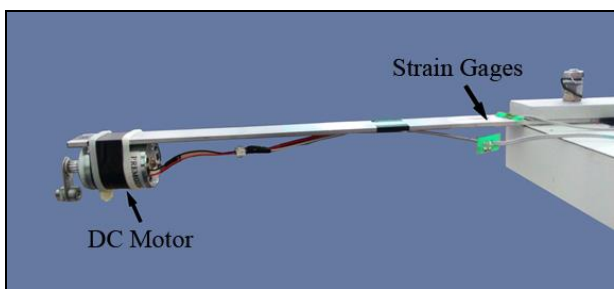


Fig. 1. Non-ideal oscillator.

In order to acquire the vibration of the system, it was used a strain gauge type sensor. This kind of sensor has an extremely low mass, not physically influencing the system and can be used for both static and dynamic system measurements. The principle of operation of a strain gauge occurs by the variation of its electrical resistance. When variations of its dimensions occur, the changes of its dimensions are transformed into electrical signals that can be measured and related to its real time physical deformation through a Wheatstone Bridge. The Wheatstone bridge is a common circuit used to discover an unknown electric resistance applying a determined voltage at one of its ends and reading the output voltage at another end. In this paper, two of the resistors of the bridge are strain gauges and the other two are normal resistors, all of them having the same electric resistance (120Ω). If the four resistances are equal (the strain gauges are not deformed), the voltage read is equal to the voltage applied, and it is said that the bridge is in equilibrium. If the electric voltage is different, then this variation can be used to relate to the deformation suffered by the structure.

As the electric signal of the Wheatstone bridge has a low magnitude, a signal amplifier circuit was built using an INA128P low power instrumentation amplifier of

Texas Instruments®. All instrumentation data were obtained with the use of a National Instruments Data Acquisition (DAQ) model 6212. electric current and rotation of the DC motor.

As power source, a nominal 24V DC motor was used. Figure 2 shows the torque/speed curve of the motor used.

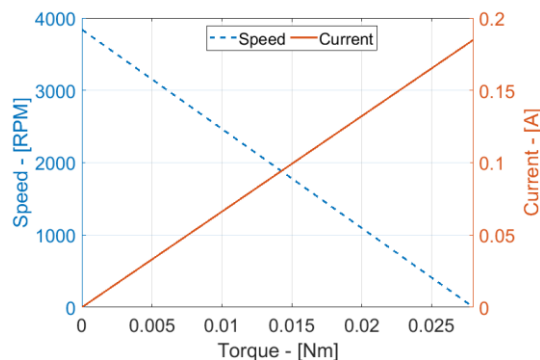


Fig. 2. Torque versus speed curve of the DC motor.

The Labview® software was used to process and save all the data acquired from the vibration, electric current in the SMA element and the rotation of the motor. Figure 3 shows the scheme of the data acquisition.

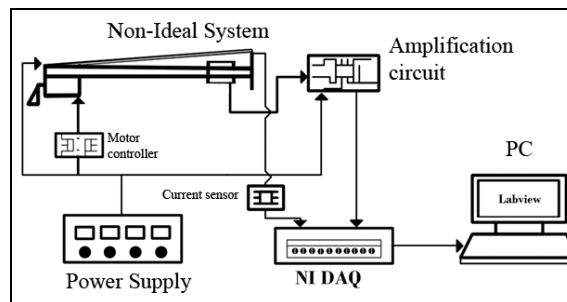


Fig. 3. Scheme used to obtain the results.

3.2 Tests performed

As previously stated, the objective of this paper is to use an actuator made of SMA to attenuate the Sommerfeld Effect (jump phenomenon) in a non-ideal type system. First, the natural frequency was found through a free vibration type excitation. In sequence was obtained the two types of graphs: the graphics of the jump phenomenon based on the angular frequency of the motor and the graphics of the jump due to the applied voltage in the DC motor. With these types of graphics, it is possible to analyze the amplitudes of the Sommerfeld Effect and the behavior of the motor during the vibration.

A SMA actuator was used as a tendon, applying a force in order to hold the system in vibration. The actuator was a Flexinol® wire with the properties shown in Table 1.

For activation of the SMA actuator, an electric current passed through the wire, thus, due to the Joule's

effect, the actuator tends to heat proportionally to the current that crosses it. However, due to vibration, the actuator changes its shape dynamically, hence, there are variations in its temperature during the dynamic operation of the system. This fact makes it difficult to obtain the exact temperature of the actuator, and then the electric current was used as the control parameter of the shape memory alloy actuator for the tests.

Table 1. Actuator parameters.

Properties	Value
SMA wire diameter (μm)	375
Austenite start temp. ($^{\circ}\text{C}$)	68
Austenite finish temp. ($^{\circ}\text{C}$)	78
Martensite start temp. ($^{\circ}\text{C}$)	52
Martensite finish temp. ($^{\circ}\text{C}$)	42

Seven different tests were carried out. The first one was the non-ideal system without the actuator. The other six consist of different electric currents applied to the actuator, whose tested electric current are of 500mA, 600mA, 700mA, 800mA, 900mA and 1A. These values were chosen because, for this actuator, 500mA was the first value that activated the actuator (temperature above the Austenite Start) and 1A was the last value that was able to activate the actuator at the same time that it did not physically deform the system before the tests. To avoid this behavior, electric currents that deformed the system before the tests were discarded.

4 Results and discussion

In order to obtain the natural frequency, the system was excited and then its vibration frequencies were analyzed with the use of a Fast Fourier Transform (FFT). Figure 4 shows the frequency that is most active in the system; this is one of the natural frequencies of the system.

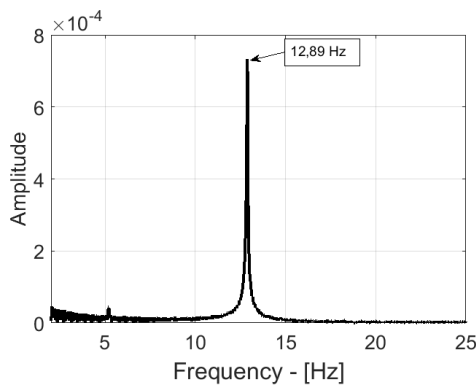


Fig. 4. Natural frequency of the electromechanical system built.

This frequency will be the expected point where the Sommerfeld effect occurs.

4.1 System without the SMA actuator

In this subsection, results for the jump effect are presented. Two types of graphs are displayed as results. The first type shows the response diagram frequency for the Sommerfeld effect. With these results, it is possible to observe the amplitude and angular frequency of the motor where the jump is occurring. The second type shows the jump effect in function of the voltage applied to the motor.

Figure 5 shows the jump according to the angular frequency of the motor for the system without actuator.

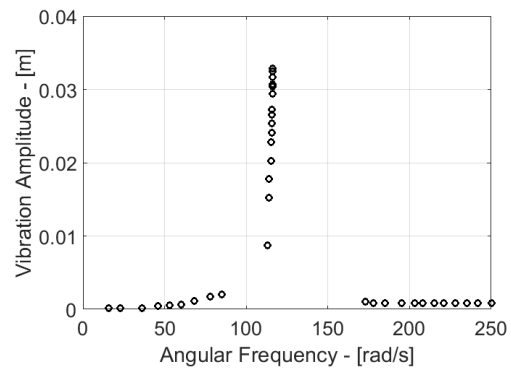


Fig. 5. Frequency response diagram for the Sommerfeld Effect - Without the SMA actuator.

Figure 6 shows the results for the jump phenomenon based on the voltage applied to the motor.

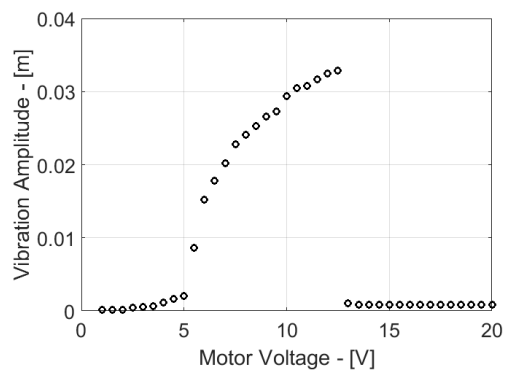


Fig. 6. Jump phenomenon due to the applied voltage in the DC motor - Without the SMA actuator.

The jump phenomenon occurs when the motor reaches 115 rad/s and 12.5 volts, after this point the system returns to normal operation. Due to the effect of the coupling between the motor and the structure, the system has its operation weakened and it is realized that between 6 and 12.5 volts all the increase of voltage in the motor serves almost solely to increase the amplitudes of vibration and not the rotation of the motor. This is the biggest problem in a non-ideal system.

4.2 System with the SMA actuator

Figure 7 shows the results for different parameters of the SMA actuator based in the angular frequency of the DC motor.

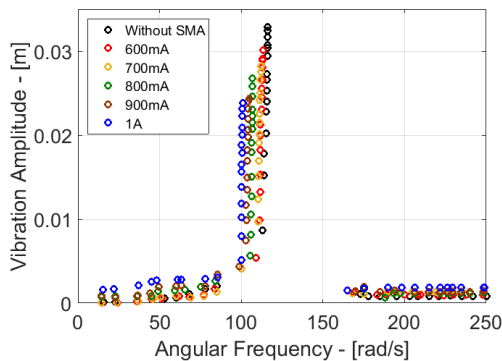


Fig. 7. Frequency response diagram for the Sommerfeld Effect.

Figure 8 shows the results for different parameters of the SMA actuator based in the motor voltage.

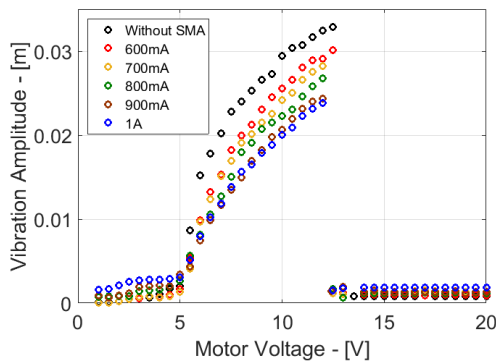


Fig. 8. Jump phenomenon due to the applied voltage in the DC motor.

Due to the force exerted by the actuator, the system has reduced its amplitudes of vibration. It is also observed that due to the mechanical alteration of the oscillator, the jump occurs each time before, with a lower motor voltage and consequently with a lower rotation. In these tests performed, even with the actuator with its maximum current, was not enough for the Sommerfeld effect to disappear.

Table 2 presents a summary of the results obtained for each parameter of the actuator used.

Table 2. Results summary.

Parameter in the actuator	Result in the system
600mA	Reduction of 16.20% in the positive peak of vibration
700mA	Reduction of 18.16% in the positive peak of vibration
800mA	Reduction of 23.18% in the positive peak of vibration
900mA	Reduction of 30.72% in the positive peak of vibration
1A	Reduction of 32.12% in the positive peak of vibration

4 Conclusions

This work presented an experimental method of attenuating the Sommerfeld effect of a non-ideal oscillator type system by coupling a Shape Memory Alloy (SMA) actuator. Non-ideal systems are systems where the source of excitation is influenced by its own performance, losing energy in the process that serves only to amplify the amplitudes of vibration.

As a control parameter, an electric current was passed through the actuator, which, through the Joule's effect, heated the wire and modified its physical properties. Five electric currents were tested: 600mA, 700mA, 800mA, 900mA and 1A. The results showed that the actuator does not need to reach austenite temperature to act on the system, although this is the temperature with the best results due to it is the temperature where the system has the highest energy available to perform work.

According to the force applied to the system through the actuator, the jump effect tends to occur at a lower motor voltage. This is an effect similar to change the stiffness and damping of the system. With the used actuator, it was possible to reduce the amplitude peak of the Sommerfeld effect by up to 32.12%. This is equivalent to reduce the vibration amplitudes of the system by the same value.

In all the performed tests, it was not possible to completely remove the Sommerfeld effect from the system. Future research may focus on the use of greater quantity and optimum positioning of the actuators, noting that the design of the system has a great influence on the Sommerfeld effect.

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