Design and Development of Temperature Sensing Mechanical Actuator using Shape Memory Alloy

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ABSTRACT

Shape memory alloy (SMA) falls under the category of smart materials where a phase transition results in an actuating motion and has the capability of retaining its original shape based on difference in temperature. At present there exists no commercial product which employs a temperature sensing mechanical actuator. By exploiting the phase changing properties of this material, changes in temperature can be detected and hence finds several applications. In this proposed design, we utilize Nitinol SMA springs to actuate the lid of a container so that fluid can be dispensed at the optimum temperature. The compression of this spring at high temperatures causes actuation, thus closing the outlet valve. The same can be extended to several other practical scenarios where temperature based actuation is required.

KEY WORDS: Shape memory alloy, Nitinol, Temperature sensing, Mechanical actuator.

1. INTRODUCTION

There are various electronic temperature sensors available in the market. In order to design a mechanism based on difference in temperature, such electronic sensors have to be coupled with a separate mechanical actuator to achieve the desired output. This increases the complexity of the design which in turn affects the cost. Instead, if both the functions of the sensor and the actuator can be obtained from a single device, it will result in a much simpler design which is less bulky. SMA springs serve the purpose of both an actuator and a sensor. The advantages of these mechanical components over electronic devices can be exploited in a variety of practical scenarios where temperature based actuation is required.

In this proposed design, development of a container for storing hot fluid such as milk or water which can later be poured out for various uses once the temperature drops is suggested. The material to be chosen for the SMA spring depends on the application. In this work, we utilize a Nitinol (50% Nickel, 50% Titanium) SMA spring whose actuation temperature is 45^0C which can be employed in products like baby feeding bottles. The shape retention properties of the SMA springs above their actuation temperatures make them reliable components where effective actuation of the valve or the lid of a container is required (Tiwari, 2013).

Research is being carried out in the area of SMA based actuation in order to come up with novel mechanisms employing this material. In this present work, one such mechanism is proposed.

2. MATERIALS AND METHODS

Construction: The fundamental unique property of SMA and particularly Nitinol is that it possesses the ability to remember the austenitic phase despite several loading conditions. This property of shape retention, thus giving it the name of shape memory alloys, makes this material a viable alternative to electronic components in its ability to act as a temperature sensor. This material also possesses super elastic behavior beyond its elastic limit and this property also makes it adaptive for various applications. This present work involves the use of a Nitinol SMA spring with actuation temperature around 45˚C to actuate the valve in a container. There are several proposed designs that serve to achieve the same purpose of actuation, but the success of a design resides in its simplicity and ability to generate enough force for actuation (Chen Hsing, 1993). An important property of a SMA spring is that, when the temperature drops down below the actuation temperature, it will not return to its normal shape independently. For this purpose, a stainless steel spring of suitable dimension and stiffness is selected. The two springs are connected in such a way that when the SMA spring is compressed, the stainless steel spring is elongated. The valve attachment is a right angled structure consisting of thin plates. It is connected to both the springs and is placed between them. The valve is constructed in such a way that its axial movement is enough to seal or open the container depending on the use. The spring-valve system must be allowed to slide in a definite direction. A stepped shaft is employed over which the springs and the valve can exhibit axial movement to the extent required. A separate tube is also provided to pour the fluid into the container without disturbing the spring-valve arrangement. Other accessories for supporting the design such as adjustments for the spring-valve system and nuts of appropriate dimensions are also used. The entire set up is housed in a cylindrical case.

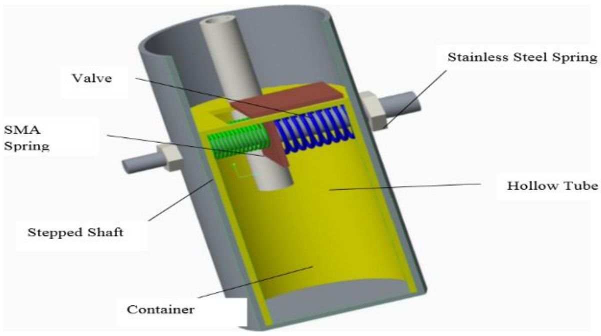

Figure.1. 3D model of the proposed design

Working: The shape memory alloy exhibits two stable phases, namely martensite and austenite. At room temperature, the used SMA material is in martensite phase. It is difficult to deform the material in the martensite phase. When the temperature increases above a certain temperature called the austenite start temperature (A_s), the material starts to convert into austenite. When the austenite finish temperature (A_f) is reached, the conversion to austenite is completed. In this austenite phase, the material will deform to the remembered shape. Thus the spring is made to contract when the temperature is increased beyond the actuation temperature. As the material cools down below the actuation temperature, the conversion from austenite to martensite starts at the martensite start temperature (M_s) and ends at the martensite finish temperature (M_f). A simple graph can be used to explain the processes resulting in the two phases.

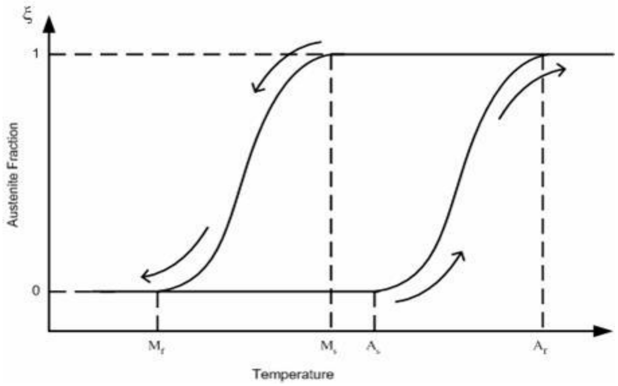

Figure.2. Phase transition of SMA (Leo and Donald, 2007)

The mechanism proposed in the current work uses the compression of the SMA spring at high temperatures when it is converted from martensite to austenite phase to actuate a valve and close the container. The hot fluid is poured into the container through the additional tube. The fluid level rises inside the container. When the fluid submerges the SMA spring, the spring is compressed if the temperature of the hot fluid is above the actuation temperature of the spring. This causes the stainless steel spring to expand and the valve to slide thus closing the container. This prevents the outward flow and hence the use of the hot fluid from the container. The additional tube can be closed using an appropriate cover. When the fluid cools down below the actuation temperature, the SMA spring will not come back to its normal shape on its own. At this point, the expanded stainless steel spring tries to return to its original shape thus pulling the SMA spring and the valve open. This opening of the valve can be used as a signal to identify when the hot fluid cools down to a useable temperature. The actuation of the spring does not depend on the value of the difference between the actuation and fluid temperature. Irrespective of the value of the difference in temperatures, the length by which the SMA spring compresses remains the same.

Applications: This proposed work has a wide range of applications. It can be viewed as a viable alternative for temperature sensors notably those that use electronics in various scenarios. The objective with which this present work was formulated is focused on a particular application, namely the development of a temperature sensing smart feeding bottle. This is to ensure that infants are not fed milk at high temperatures. This concept can thus be viewed as a tool to and can be extended to various other facets of product development such as in stent implants for biomedical applications and orthodontic braces (Brien, 2017).

3. EXPECTED OUTCOMES

For a Nitinol SMA spring of length 29 mm placed inside the container, the contraction is observed to be around 12 mm at temperatures higher than 45^0C. A graph is presented to illustrate the lengths of the SMA spring for various temperatures around the actuation temperature.

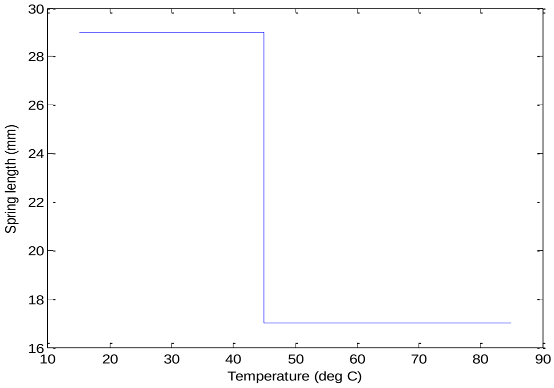

Figure.3. Spring Length vs Temperature

The spring maintains its original length of 29 mm until the temperature becomes 45^0C when it contracts to a length of 17 mm. The new length of 17 mm remains constant for temperatures above 45^0C. The dimensions of the valve and other components were arrived at considering the data regarding the SMA spring. Thus the valve should seal the container at temperatures higher than the actuation temperature.

4. CONCLUSIONS

The present work is concerned with the development of a container for storing fluid which employs a mechanism for actuating a valve using SMA spring. Experiments concerned with the data regarding the SMA spring have been performed.

A 3D model of the product has been developed using Creo 3.0 software. The development of the product is under way. Further research in this area can be utilized to improve the existing design and invent new mechanisms.

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