International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: SJIF: 5.995
Available Online at www.journalijcar.org
Volume 7; Issue 1(G); January 2018; Page No. 9208-9211
DOI: http://dx.doi.org/10.24327/ijcar.2018.9211.1512

Review Article

DESIGN AND MANUFACTURING OF A SHAPE MEMORY ALLOY HELICAL SPRING ACTUATOR: A REVIEW

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A R T I C L E I N F O

Article History:
Received 11th October, 2017
Received in revised form 10th November, 2017
Accepted 26th December, 2017
Published online 28th January, 2018

Key words:
Shape memory alloy, manufacturing, design, actuator, and model.

A B S T R A C T

Shape memory alloy (SMA) provides a significant amount of actuation with an extremely small envelope volume with minimum noise levels. Mechanical properties of Ti-Ni alloys are very interesting for developing smart actuators manufactured from these non-conventional materials. Design and material properties for SMA has been discussed in the present work. The paper provides framework for manufacturing, designs and applications of shape memory alloy intelligent helical spring actuator. This paper will contribute through intelligent technique using temperature sensitive automation in mechanical system.

INTRODUCTION

Today the use of shape memory alloy (SMA) is growing rapidly. Shape memory alloys have proven their worth in solving engineering problems that in the past seem implausible. The main reason behind their importance today is that the shape memory elements provide a significant amount of actuation with an extremely small envelope volume. This statement becomes truer and their implementation even more important when looking at the direction where technology is heading [1]. A shape memory element can be actuated thermally or electrically. Not having to rely on moving parts for actuation, just the simple contraction of the material, makes them highly attractive for actuation where minimum noise levels are desired. Besides being an actuator they can also serve as thermal sensors and super elastic springs. Some existing applications use them as an actuator and a sensory device, thus minimizing space and cost for the designer. The most popular incarnation of shape memory alloys, Ni-Ti, is biocompatible [2]. It is also expected that computational tool will be used more widely in the design of SMA-based actuators. However, the computational method has not yet been established for the super elastic, large deformation analysis of SMA helical springs, which are used and expected as actuator devices [3]. Shape memory alloys present complex thermo mechanical behaviors related to different physical processes.

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The most common phenomena presented by this class of material are the pseudo elasticity, the shape memory effect, which may be one-way (SME) or two-way (TWSME), and the phase transformation due to temperature variation. Besides these phenomena, there are more complicated effects that have significant influence over its overall thermomechanical behavior – for instance: plastic behavior, tension-compression asymmetry, plastic-phase transformation coupling, transformation induced plasticity, thermomechanical coupling, among others. The remarkable properties of SMAs are attracting much technological interest, motivating different applications in several fields of sciences and engineering. Aerospace, biomedical, and robotics are some areas where SMAs have been applied [4]. SMAs have the capability to generate large strains associated with phase transformation induced by stress and/or temperature variations. During the phase transformation process of a SMA component, large loads and/or displacements can be generated in a relatively short period of time making this component an interesting mechanical actuator. Basically, SMA presents two possible phases: martensite and austenite. Martensitic phase may appear in variants induced by different kinds of stress fields [5-7]. Several alloys can develop strains associated with phase transformation but only those that can develop large strains are of commercial interest, as nickel-titanium (NiTi) and copper base alloys (CuZnAl and CuAlNi). According to studies, two steps transformation occurs due to the formation of nickel-rich precipitates during heat treatment in the matrix phase (8-9). The electrothermal driving characteristics of the two-way shape memory effect (TWSME) extension TiNi springs, which

can extend upon heating and contract upon cooling, were investigated with alternating and direct current (10-14). It was found that the response time (the time interval between the start and the end of the spring's shape change) and the maximum elongation greatly depend on the magnitude of the electrical current. The response time was large for a small electrical current and small for a high one. Brinson [15] formulated one-dimensional constitutive equation for SMA and applied it to the finite element analysis and others (16-20) formulated constitutive equations for SMA and some of them were applied to the finite element analysis of SMA devices. Brinson's one-dimensional constitutive modeling for SMA has been extended to consider the asymmetric tensile and compressive behavior and the torsional deformation (21). The incremental finite element analysis program has been developed by using the layered linear Timoshenko beam element equipped with the extended Brinson's constitutive modeling for SMA. The developed program the calculated results have corresponded well with the experimental results.
Mechanical properties of Ti-Ni alloys are very interesting for developing smart actuators manufactured from these non-conventional materials. In many technological applications these actuators need to generate force and to avoid the degradation of the shape memory effect caused by the martensitic stabilization processes (22-24). Several shapes might be used to obtain smart sensors/actuators, however helical spring shapes are more interesting.

During this wire drawing process are introduced a large concentration of linear crystalline defects. This large concentration of defects acts as an obstacle the occurrence of phase transformation through blocking of all variants of martensite (25-28). According to studies, two steps transformation occurs due to the formation of nickel-rich precipitates during heat treatment in the matrix phase (29-30). SMAs have the capability to generate large strains associated with phase transformation induced by stress and/or temperature variations during the phase transformation process of a SMA component, large loads and/or displacements can be generated in a relatively short period of time making this component an interesting mechanical actuator. In mechanical actuator, as in the thermomechanical cycles, SMA spring is heated by Joule effect as a consequence of electric current flow through the wire. This pushes the SMA spring and recovers the starting condition in the martensitic phase for the successive activation. The design of mechanical actuator using helical SMA spring is described in this work. Based on literature survey it was found that practical application of Ni-Ti SMA actuator is limited in mechanical components. The present work is to design shape memory alloy intelligent helical spring actuator for its applications in mechanical engineering.

Material and Design of one-way shape memory alloy helical spring

MATERIAL

Shape Memory Alloys (SMA) are a special type of materials which have a property that enables them to return to a pre-established shape when their temperature is increased from a lower initial condition .One of the commercial materials most frequently used to produce SMA is a metallic alloy composed of nickel and titanium (NiTi) or nitinol, which is that used in this study. The relation in the composition of this alloy is around 50% (Ni) − 50% (Ti), signifying that the behavior of the SMA is limited to NiTi alloys that have a near-equiatomic composition. Flexinol wire of (0.3- 1.0) mm diameter is available. When a sand shape-memory alloy is in its cold state (below A_s), the metal can be bent or stretched and will hold those shapes until heated above the transition temperature. Upon heating, the shape changes to its original. When the metal cools again it will remain in the hot shape, until deformed again.

Design spring parameters

Shape memory springs offer an increased amount of stroke at the expense of a reduced actuation force. The increased stresses that develop in the wire when setting this form can also potentially reduce its life considerable. The methodology to calculate shape memory spring also follows Waram's [31] procedure as outlined below:

A compression shape memory alloy spring will behave as shown in Figure 1, where at low temperature the spring will be compressed and when heated will extend with a pushing actuation.

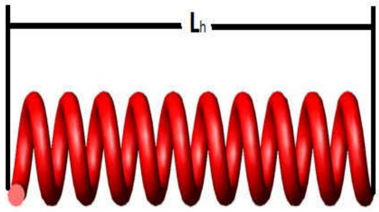

Figure 1 SMA compression spring

The expression for shear stress in a spring is described as:

$$\tau = \frac{8.F.D}{\pi.d^3}.K = \frac{8.F}{\pi.d^3}.C.K \quad \text{.....(1)}$$

The value F represents the axial load applied, D is the average diameter of the spring, d represents the wire diameter, K the correction factor applied, and C is known as the spring index:

$$C = \frac{D}{d} \quad \text{.....(2)}$$

The K value, also known as Wahl correction factor, corrects this shear stress to account for transverse and torsional shear stresses present in a spring:

$$K_w = \frac{4.C-1}{4.C-4} + \frac{0.615}{C} \quad \text{.....(3)}$$

Juvinall and Marshek [32] recommend the use of equation 16 for fatigue loading whereas equation 3, is often used for static loading only:

$$K_s = 1 + \frac{0.5}{C} \quad \text{.....(4)}$$

Wire diameters for the actuator for acceptable values of C ranging from 3 to 12:

$$d = \sqrt{\frac{8.F.C.K}{\pi.\tau}} \quad \text{.....(5)}$$

There are two factors that relate to the value of C in the design specifications: the cycle rate and the envelope volume of the actuator. Since the cycle rate is a function of the wire diameter, a value of C can be selected to accommodate a desired cycle rate. Shape memory alloy manufacturers usually provide actuation timetables for different wire diameters.

RESULTS AND DISCUSSION

Shape memory alloy helical spring is temperature and pressure sensitive. This can be used for design of mechanical actuator. In the following steps, the framework of an intelligent SMA spring actuator can be designed

a. Calculate various designed parameters: diameter of spring wire, coil diameter of spring, length of spring for the selected SMA material and for designed load using design equations.
b. Proceed for annealing of the spring to get hardened spring of desired length.
c. Set compression expansion length of the spring through experimental testing.
d. Apply on actual actuation application and see the error, if any.
e. In case of error the spring parameters to be modified and again repeat the procedure.

CONCLUSIONS

It is found that there is limited application of SMA in mechanical engineering. Various applications of helical spring SMA wire is reviewed. Materials and design process has been worked out. In this review paper, a framework of intelligent helical spring using SMA wire was framed for an actuator. The study is useful in design of actuator for automation.

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How to cite this article:

Prince Deshwal and M.L.Aggarwal (2018) 'Design and Manufacturing of A Shape Memory Alloy Helical Spring Actuator: A Review', *International Journal of Current Advanced Research,* 07(1), pp. 9208-9211.
DOI: http://dx.doi.org/10.24327/ijcar.2018.9211.1512

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