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Design and Development of a New Rotary Actuator based on Shape Memory Alloy and Permanent Magnet System

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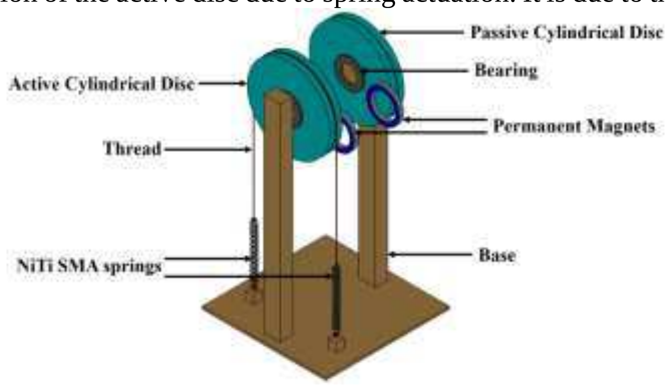
Abstract

This paper presents the design concept of a new family of rotary actuators based on shape memory alloy (SMA) springs and permanent magnet systems. The proposed actuator is so designed that it could operate even in vacuum. The developed novel actuator operates silently [3] and precisely through the help of direct current (DC) power supply. The involvement of SMA based spring results in smart and smooth operation. Figure 1 depicts the proposed permanent magnet based novel rotary actuator. The actuator consists of an active and a passive cylindrical disc positioned at a fixed height from the base and separated with a certain distance. Two NiTi (Nitinol – 50% Nickel, 50% Titanium) SMA springs connected the active disc to the base with the help of a thread, as depicted in Figure 1, for bi-directional rotation of the active disc. The SMA spring contracts when then DC power supply is delivered across it. The rotation of the active disc is possible with the power supply, furthermore, the direction of rotation of the disc would be in the active SMA spring direction (that is, whichever direction spring energizes, the disc would rotate in that side). This action is due to the contraction of the active SMA spring. At the same time, the other SMA spring elongates due to the force exerted by the actuation of the active spring. Since, permanent magnets are attached to both the discs as depicted in Figure 1, the passive disc rotates by rotation of the active disc due to spring actuation. It is due to the magnetic force between the magnets.



(a) Isometric view

(b) Right view

Figure 1. Proposed permanent magnet based SMA operated actuator.

The proposed actuator has been designed such that there exists no physical contact between the active and passive cylindrical discs. The actuator operates even when both the discs are positioned in different environments. The separation between the discs (or magnets) is a significant parameter, as the force of attraction between two permanent magnets is inversely proportional to the square of the distance between them. The force exerted by two magnetic poles is given in accordance with Equation (1).

$$F = \frac{\mu q_{m1} q_{m2}}{4\pi r^2} \tag{1}$$

where, F (Newton) is the force between two magnetic poles of magnitudes q_{m1}, q_{m2} (ampere-metre) separated by a distance r (metre). μ (Tesla metre per ampere) is the permeability of intervening medium.

The SMA based actuators are extremely light in terms of weight and undergo simple actuation. To conduct the experiment, SMA springs are actuated by the Joule heating process. As, direct current is supplied through the SMA spring, the spring heats up due to its resistance. As temperature rises, SMA undergoes phase transition from the martensitic state to austenitic state by varying its crystal orientation from monoclinic to the body-centered cubic crystal structure respectively [1]. For several applications, traditional bulky actuators are being substituted by SMAs, because of multiple advantages such as light-weight, high power per unit mass, low voltage activation etc. [2]. The precision, accuracy and sensitivity characteristics of the proposed actuator primarily depend on the following parameters:

1. Distance between the magnets and
2. Magnitudes of the magnetic poles.
3. Radius of the cylindrical disc
4. SMA spring contraction rate

Proper selection of magnets can overcome the issue of the first two parameters. The remaining two parameters are based on the design considerations. By varying the radius of the cylindrical discs and the SMA contraction rate, the desired characteristics of the proposed actuator can be obtained.

The angle of rotation (θ) of the cylindrical disc (of radius R) achieved due to the length of contraction (L) of one of the SMA spring can be represented by Equation (2).

$$\theta = \frac{360 \times L}{2\pi R} \text{ (in degrees)} \qquad (2)$$

As angle of rotation is inversely proportional to the radius of the cylindrical disc, it can be stated that better sensitivity of the actuator can be achieved with increase in radius of the disc and vice-versa. Also, enhanced sensitivity could be accomplished with reduced contraction rate of SMA spring.

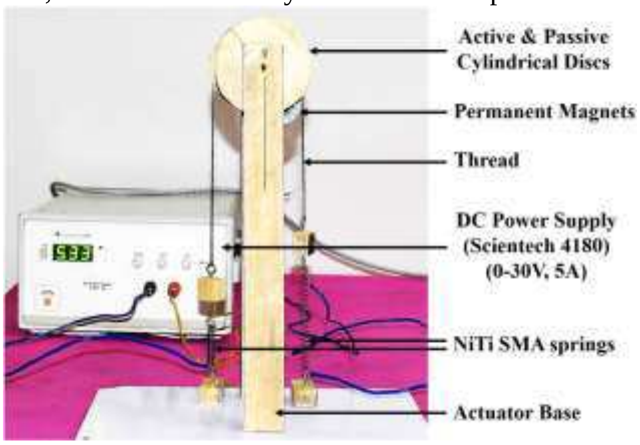


Figure 2. Experimental Setup of the proposed novel actuator.

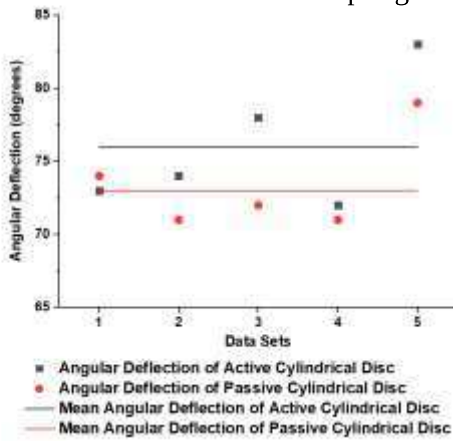


Figure 3. Angular deflection of the active and passive cylindrical disc.

Five sets of experiments were conducted to rotate the proposed actuator bi-directionally. The experimental setup of the developed novel actuator is presented in Figure 2. Direct current was supplied to one of the SMA spring and the angular rotation of the cylindrical discs was measured. Similarly, current was also supplied to the other SMA spring and the angular deflection in opposite direction was measured. Figure 3 presents the graph of the experimental data. The experiment results mean angular rotation of 76^0 and 73.4^0 for the active and passive discs with a standard deviation of 4.52^0 and 3.36^0 respectively.

Since one magnet is attached to each disc, owing to the immense gravitational force exerted by the magnet, the discs are unable to achieve full rotation. Therefore, for improved efficiency, multiple smaller permanent magnets can be fixed near the circumference of each of the disc.

References

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