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ORIGINAL PAPER

Experimental Investigation of Shape Memory Alloy (Sma) – Force And Angle Analysis

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ABSTRACT

This paper presents the investigation of the effect of 0.508 mm diameter shape memory alloy (SMA) wires on the 150 mm Stewart platform and the relationship between Stewart platform and SMA wire using response surface methodology techniques. This Stewart platform has a parallel structure including a fixed plate and a moving plate. The plate is linked together with 6 SMA and a mechanical spring is located in the centre part. Currently, DC motors are the most widely applied actuators employed in the design of prosthesis devices which do not use lightweight, strong and cheap actuators as an important mechanical system and this is where SMAs play a key role. SMAs are the latest generation of the actuators which has the capability to restrict the freedom of movement when external forces are applied. The possible application was ankle/foot rehabilitation exercise for Range of Motion (ROM). This paper documents the work resulting in the development of Stewart platform producing 24.8° range of motion (ROM) in comparison to the other researchers' findings with a limited of ROM up to 20°, showing an improvement of the current work with the previous work.

INTRODUCTION

A Swedish by the name of Olander (Ölander 1932), was the first to discover a transformation that takes place in Shape Memory Alloy (SMA) in the solid state in the year 1932. Later found that an alloy called gold-cadmium (Au-Cd) had the capabilities to return to its original configuration when heated after being plastically deformed when cool. Greninger and Mooradian (GRENINGER and MOORADIAN 1938) were the first to observe the characteristics of SME (Shape Memory Effect) in Copper and Zinc (CuZn) and Copper and Tin (CuSn).

A decade later, Kurdjumov and Khandros (Kurdjumov and Khandros 1949) and Chang and Read (Chang and Read 1951) discovered what was later known as the memory effect whereby, a fundamental phenomenal takes place which is known as a behavior of martensite phase governed by the principle of thermoplastic.

Different type of smart materials with different features and characteristic and having SMA as one of the functional intermetallic has been developed by researchers (Fletcher 1996, Krishnan, Nagarajan et al. 2006, Krishna, Nagarajan et al. 2011, Krishnan, Nagarajan et al. 2012, Nagarajan, Krishnan et al. 2013, Abdul-Rani, Krishnan et al. 2017). The major advantages of SMA actuators are their simultaneous sensing and actuation capabilities. They are capable of returning to some formerly fixed size and shape when subjected to appropriate thermal actuation, which is known as Shape Memory Effect. Their distinguishing characteristic includes High power density, high thermal conductivity, pseudo elasticity, high tensile strength and possession of two district phase with different resistivity. Further properties like steerability, good kink resistance and less sensitiveness to magnetic resonance made shape memory alloy a suitable in medical applications (Morgan 2004). NiTi, also called Nitinol is a typical SMA material mostly employed in industrial applications.

Stewart platform is one of the mechanical design moving platforms classified as a parallel manipulator. It consists of end-effectors with 6 degrees of freedom, and of a fixed base, linked together by at least two independent kinematic chains from a parallel robot is as shown in a line sketch in Figure 1. Actuation takes place through and simple linear actuators (Gogu 2004). Generally, it has 6 spherical joints at the base, 6 prismatic joints to create linear motion on six legs and 6 spherical joints at the moving platform to result in 6 DOF robots. This is named as 6 SPS mechanism. The 6 degree of freedom movement means a translational, prismatic, rectilinear and rotational degree of freedom at Rx, Ry, and Rz.

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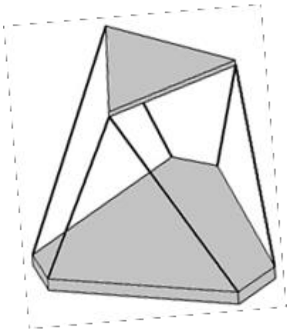

Figure 1. Basic Schematic of Stewart Platform (Speich and Goldfarb 2000)

MATERIALS AND METHOD

This research study proposed a Stewart platform design using the six Spherical-Prismatic-Spherical (SPS) configurations. SPS configuration consists of the lower and upper platforms connected by spherical joints (hook) and SMAs wires as prismatic actuators. This SPS configuration was selected because it can produce acceptable displacement angle ranging from 19.8° to 24.8° which can promote ROM motion for Foot/Ankle rehabilitation.

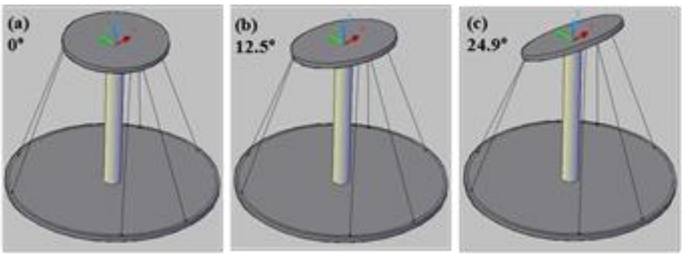

Figure 2. 150 mm Stewart Platform Actuated by SMA: (a) at 0°, (b) at 12.5° and (c) at 24.9°

Figure 2 present the positions of 150 mm Stewart platforms respectively when actuated by 0.584 mm SMA wires.

Methodology

The major components of the strut apparatus are top platen. The top platen moves in the vertical direction along the height of the column. This enables the clear height between the top and the bottom platen to allow SMAs to be tested. Once the desires achieved, the top and bottom nuts are tightened to anchor the platen to the supporting column. Figure 3 presents the strut apparatus setup.

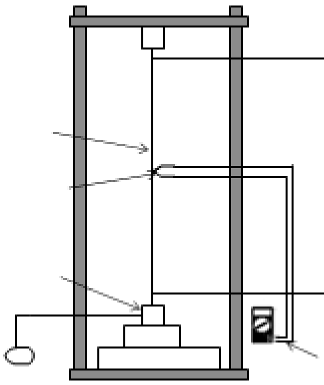

Figure 3. Strut Apparatus –Schematic

Experimental investigation on the displacement, force developed by the SMA actuators and the force required for the large deflection of the central pillar of the mechanism is presented in this chapter. In order to investigate the relationship between force and deflection of the upper platform, a 3-axis Micro-electromechanical system (MEMS) accelerometer has been mounted on the moving platform to measure the angle. Three numbers of force sensors have been used with the strain gauge to measure the force developed by the SMAs. Calibration of the force sensor (Strain gauge) was accomplished with known weights (50 N to 950 N). The accelerometer was calibrated for the sagittal plane using a CNC rotary indexing table (Mazak–VARIAXIS 630-5X).

RESULTS AND DISCUSSION

Force analysis - 150 mm Stewart Platform actuated by 0.508 mm diameter wire

Figure 4 presents the experimental effect of temperature on the force when using 150 mm Stewart platform with SMA diameter of 0.508 mm. From Figure 4, it can be seen an increase of force when the temperature increases from 30ºC to 50ºC. The increase in force when the SMA was subjected to temperature, which will increases force.

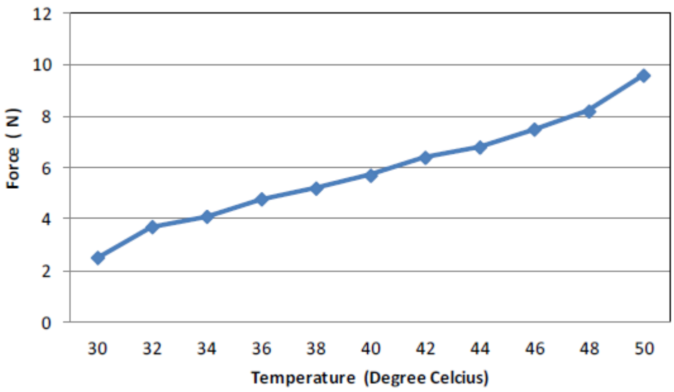

Figure 4. Experimental Effect of Temperature on Force using 150 mm Stewart Platform with SMA Diameter of 0.508 mm

Figure 5 presents the predicted versus actual plot for 150 mm Stewart platform SMA diameter of 0.508 mm. From the Figure 5, it can analyze that the distribution of the data points fits well the model.

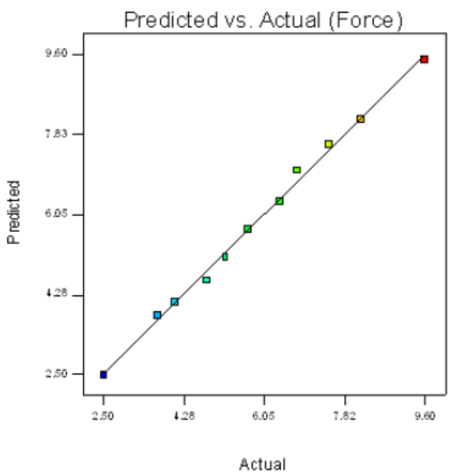

Figure 5. Predicted Vs Actual Force for 150 mm Stewart Platform SMA Diameter of 0.508 mm

Figure 6 presents the 3D surface response of force for using 150 mm Stewart platform with SMA diameter of 0.508 mm. The increase in force with increase in temperature and current can be seen clearly from Figure 6.

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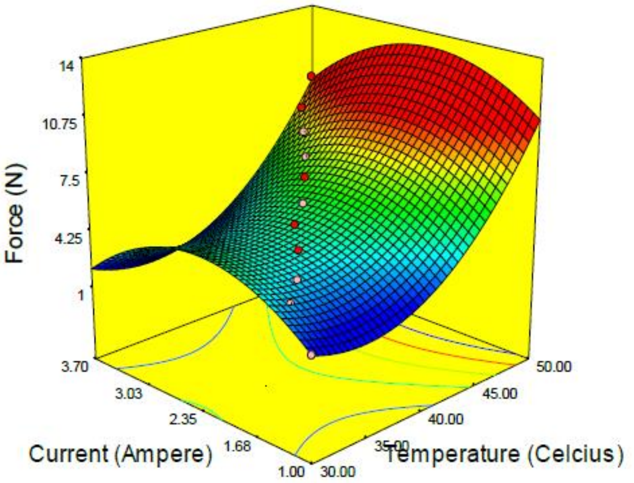

Figure 6. 3D Plot for Force using 150 mm Stewart Platform with SMA Diameter of 0.508 mm

Platform Angle analysis - 150 mm Stewart Platform actuated by 0.508 mm diameter wire

Figure 7 presents the effect of varying temperature on the platform angle when using 150 mm diameter Stewart platform with a wire diameter of 0.508 mm.

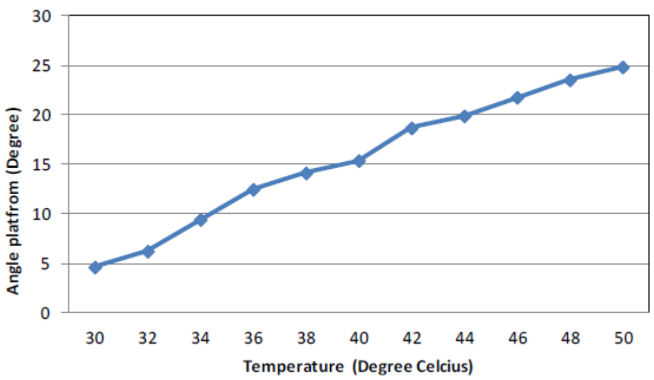

Figure 7. Experimental Effect of Temperature on Angle using 150 mm Stewart Platform with SMA Diameter of 0.508 mm

As the temperature increases from 30ºC to 50ºC, the platform angle is increasing and the maximum angle produced is 24.8°. This increase of the platform angle when the temperature increase is due to shortening of the SMA wire which is caused by the effect of temperature. The temperature shift causes the SMA material to transit from Martensite (low base temperature) to Austenite (high base temperature) which causes a platform angle to deflect.

Figure 8 shows the Predicted versus actual platform angle for 150 mm Stewart platform SMA diameter of 0.508 mm. From the Figure 8, it is observed that the data points fall into the fitted line and this implies that shows how well the data fit the model.

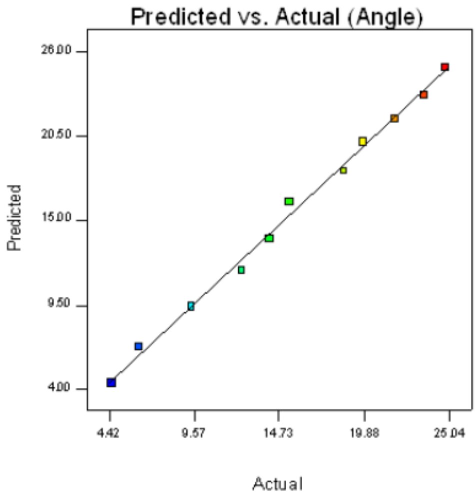

Figure 8. Predicted Vs Actual Force for 150 mm Stewart Platform SMA Diameter of 0.508 mm

Figure 9 presents the 3D- plot for platform angle using 150 mm Stewart platform with SMA diameter of 0.508 mm. At 30°C and 1 Ampere current the platform angle is low. As the temperature increases, the platform angle increased as shown in Figure 9.

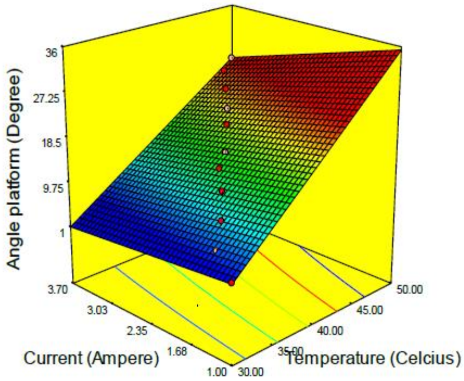

Figure 9. 3D Plot for Force using 150 mm Stewart Platform with SMA Diameter of 0.508 mm

CONCLUSION

In this research it is established that the use of Stewart platform actuated by SMA improves the range of motion (ROM) for patient Foot/Ankle rehabilitation in biomedical applications. A promising option for the Foot/Ankle of patients is a Stewart platform actuated by SMA performed concentrically (ankle plantar flexion during SMA relaxation) or ankle dorsi flexion during SMA contracting) as external forces are applied by the SMA wire. The 150 mm Stewart platform actuated by Ø 0.508 mm SMA wire produced maximum platform angle of 24.8° with a force of 9.6 N and coefficient of determination R2 of 99.56 %. The developed Stewart platform actuated by Ø 0.508 mm SMA wires produced range of motion of ±24.8° which is acceptable range to promote dorsi/plantar flexion. As compared the developed Stewart platform with Takemura et al (Takemura, Onodera et al. 2012) and G.Liu et al (Liu, Gao et al. 2006), findings of ±20° and +20°/ – 17.5° respectively for dorsa and plantar flexion which is limited Range Of Motion (ROM).

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