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SMA Actuation for Wrist Motion with Split-tube Flexures

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ABSTRACT

The research addresses alternate method of actuating a pseudo wrist motion intending to replicate a human supination/pronation motion. The actuation implemented was using a Shape Memory Alloy (SMA) wire as mimicry for a muscular action located within the boundary of the human forearm. Replacing the bone and other muscular structure which act as torsional resilience is the rigid Polyvinyl Chloride (PVC) Split-Tube Flexures. The design of the actuation method was experimented and simulated under laboratory conditions. A fixed size SMA wire was used throughout the experiment. The results gave an insight working of the split-tube flexures under linear angled forces and the behavior of SMA wires under different strain conditions. The study concluded that with use of SMA linear actuation, an angular motion could be achieved. Furthermore the research concludes that split tube flexures can be used as torsional resilience as to be able to return to the initial position, thus removing complex mechanisms.

Key words: Shape memory alloy, split tube flexures, torsional resilience

INTRODUCTION

Shape memory alloy (SMA) was used as a linear actuator to mimic a wrist like motion of an arm in one angular direction. In dynamic terms linear actuation was used to create an angular motion. The reasons behind this research were to create an angular motion which replicates a supination/pronation movement of the lower human arm as in Fig. 1. The exact dimension of wrist

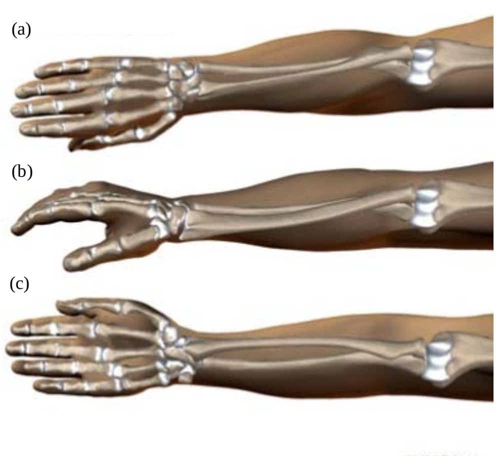

Fig. 1(a-c): Human forearm (a) Pronation, (b) Straight and (c) Supination movement (http://www.parkwayphysiotherapy.ca)

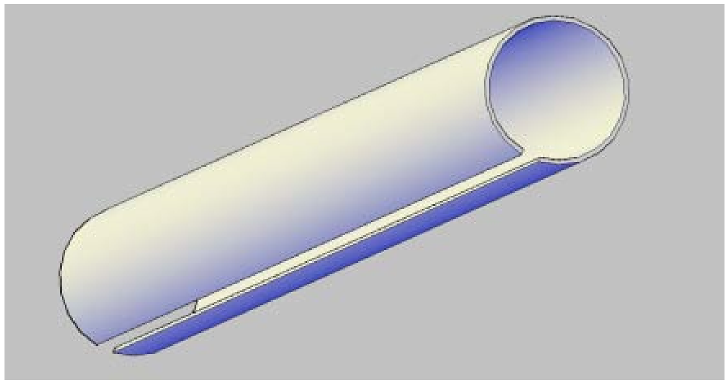

Fig. 2: Split tube flexures

and elbow sizes is different for each individual so a generalized dimension of the elbow and wrist was used. To mimic the torsional stiffness of the arm created by muscles and bones a split-tube flexural was used as in Fig. 2. The other purpose of the tube was to connect a pseudo wrist and elbow.

Actuators come in different form and sizes to accommodate the actuation needed. The common mode of actuation is powered by hydrauhc, pneumatic and motorized system. Shape Memory Alloy (SMA) is an actuator in sense, since it has the ability to return to its initial shape when there is a phase transformation from martensite to austenite when heated and reversed upon cooling. SMA is actually an alloy composed of two different materials mainly Nickle and Titanium in proportions determined by each individual manufacturer and goes by the name of Nitinol in the manufacturing industry. For the research conducted, a SMA wire produced by Dynalloy(http://www.dynalloy.com) which goes by the registered trade name Flexinol was used.

SMA is superelastic material and is able to sustain a large deformation at a constant temperature. When the deforming is released they return to their original undeformed state. Heating is the only way SMA retains its original shape. Since, heat is the property that determines the shape of metal, heat is the first property used to manipulate deformation. If SMA is subjected to the same heating and deformation, it will acquire Two-Way Shape Memory Effect (TWSME) training. SMA in wire form shortens in length when it is heated and due to its high ohmic resistance, the easiest way to heat SMA will be using electrical current or joule heating.

SMA creates a huge amount of force when it is under strain when heated due to its strength at high temperature austenite phase and as any normal material it has its limitations. Figure 3 displays a typical heating and cooling cycle of Nitinol under strain. Upon further study of Fig. 4 it would be noticed that between the heating and cooling cycle between transformations there is a void and it is not linear in transition. The void is caused by hysteresis of nitinol, where the cooling strain recovery does not follow the curve of the heating strain and this leads to slow dynamic response (Sreekumar *et al.*, 2007).

Sphit tube flexures (Speich and Goldfarb, 2000) is a tube which has been split as in Fig. 2, this actually creates an open section where the torsional stiffness (k_0) is less than for a close section. Though, the torsional stiffness is reduced, mechanical properties such as bending and compressive behavior remains the same, ultimately allowing the tube to be compliant in the desired axis of rotation but stiff about the other axes.

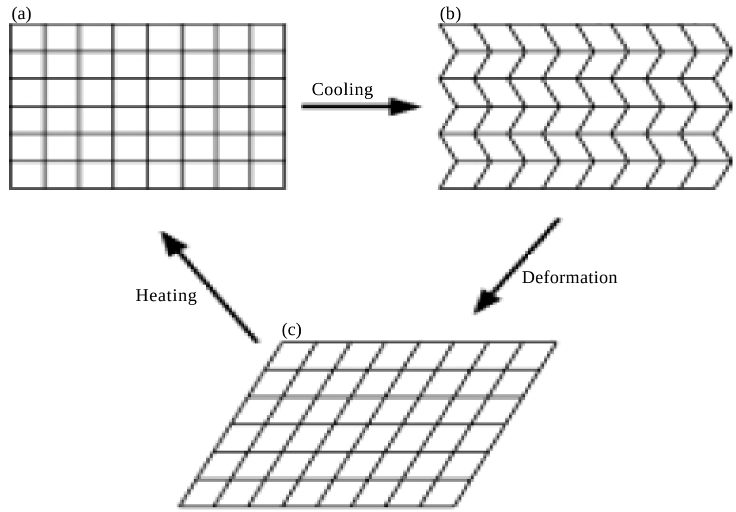

Fig. 3(a-c): Shape memory effects (a) Austenite, (b) Martensite (twinned) and (c) Martensite (de-twinned)

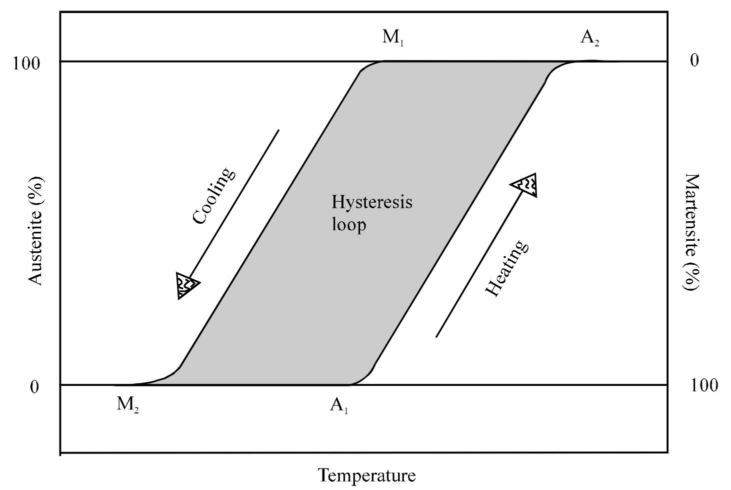

Fig. 4: Hysteresis loop of SMA

MATERIAL AND METHODS

Experiment setup and actuation design: The experiment model is as in Fig. 5. The experimental setup consists of disk B which represents the elbow with diameter of 80 mm and disk A 60 mm representing the wrist. The center skeletal is 20 mm PVC rigid tube with a thickness of 1.2 mm and length of 205 mm is split laterally to create a torsional flexural support and as a torsional resilience. The split-tube flexures has two functions, one as support between disk A and B mimicking the radius and ulna and second as a torsional resilience device which exerts a counter force when twisted on one direction. This acts like a torsion spring. The size of the split is 0.5 mm.

The Flexinol wire size of 0.254 mm was used, acting as a muscle and is affixed to a strain gauge (SGA, SGB and SGC) at disk B and attached at an helical angle of 120° to disk A with screws. Power is connected to the wires via cables to either end of the wires to actuate the wires by heating them with their own ohmic resistance.

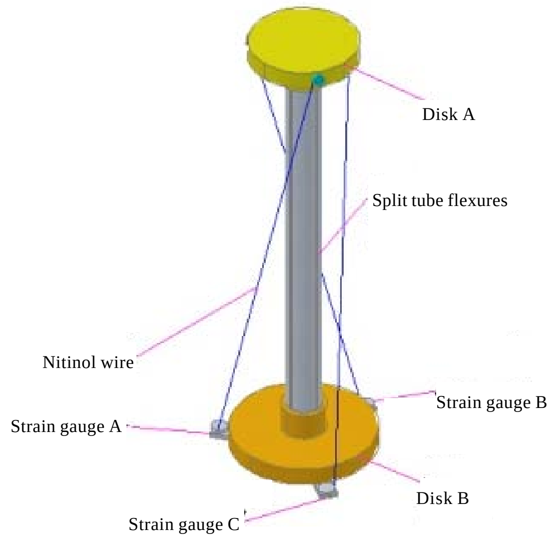

Fig. 5: Experimental model

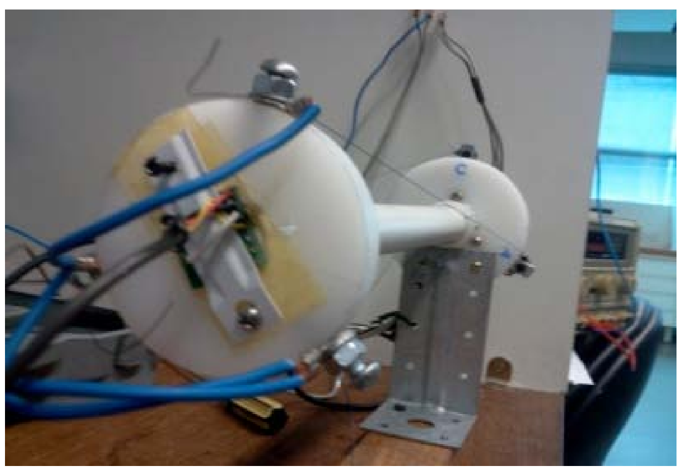

Fig. 6: Experimental setup

Measurement of force created by nitinol wire with strain gauge at disk B and measurement of angular twist is done with an accelerometer at disk A. There are three independent parallel nitinol wires which have been affixed in such manner with an angle distance of 120° from each other. Force in grams is measured independently for each wire. This actually creates a parallel force around disk A and in turn a torsional force on the split-tube flexures. All the measurements were recorded using a Dataq DI-158 and DI-145 data loggers with the necessary signal conditioners and amplifier. The finalized experimental setup is as in Fig. 6.

Split-tube flexures: Spht tube Flexures calculation (Howell, 2001) for three common of different materials available in retail outlets were analyzed, which were stainless steel, aluminum and rigid PVC. To calculate the angular deflection with reference to the torque was used from the Eq. 1:

$$k_0 = \frac{2\pi GRt^3}{3L}, T = k_0\theta, \theta = \frac{T}{k_0} \quad (1)$$

where, L denotes the length of the tube followed by R as the radius, t as the thickness, G as the modulus of rigidity as the torque and θ as the angular deflection. A fixed radius (R) of 10 mm, thickness (t) of 2 mm and a length (L) of 205 mm was used for the three materials.

RESULTS

The appropriate material to be used is the rigid PVC since it is able to create a large angular deflection with minimal torque and its ability to return to its original shape, whereas, the aluminum and stainless steel have insignificant angular deflection due to very high torsional stiffness as evident from the Fig. 7.

The magnitude of the forces along three SMA wires is found from the experimental setup shown in Fig. 8. The forces are measured by SGA, SGB and SGC referring to strain gauge transducers, where the SMA wires were attached. The pull force by an individual wire is greatest at location SGB with a force of 2325 grams followed by SGA at 1800 g and SGC took the lowest pull force of 1370 g at a maximum power consumption of about 3.22 watts per wire.

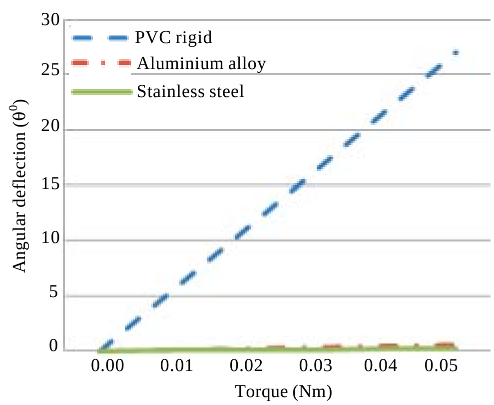

Fig. 7: Torque vs. angular deflection of different actuators

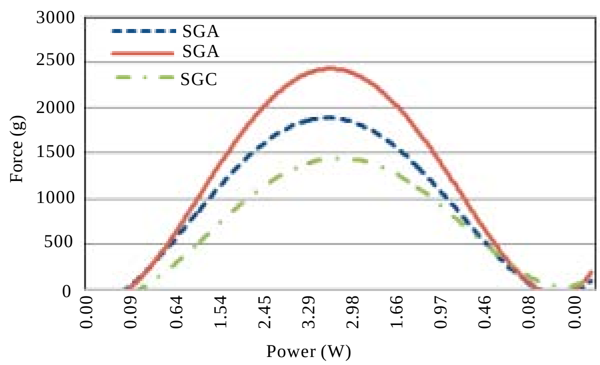

Fig. 8: Force vs. power graph for split-tube flexural

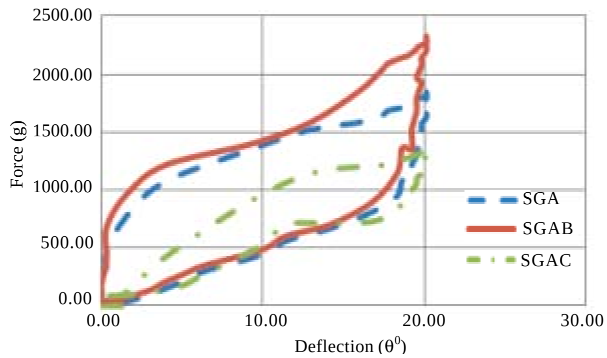

Fig. 9: Force vs. angular deflection of different wires

Figure 9 displays the maximum angular deflection obtained which was 20.1° when all the three wires were at maximum force. The graph displays the heating and cooling cycle of a typical SMA.

DISCUSSION

The three nitinol wires acted independently to counter any imbalanced forces as the split tube flexures faced a torsional force created by the wires. From this experiment it is possible to conclude that the tube in actual fact contorted when it was twisted causing imbalanced torsion across the thin walls of the tube. To suppress the contortion, the SMA wires independently acted as muscles to establish the needed forces to create the twist. Wire A and Wire B contributed the majority of the forces needed to create the twist due to the strain imposed on the wires connected to the strain gauge. In comparison to the same setup with a 0.254 mm Flexinol wires but using a U Aluminum channel instead of a split-tube flexures, the max force obtained was 2100 grams (Amirtham *et al*., 2012). The maximum deflection achieved was 55.91° at a power consumption of 4.92 watts. In the case above disk A has a diameter of 55 mm and disk B, 110 mm. The bigger diameter could have created a larger angular deflection since the diameter of disk B in the current setup is 80 mm.

CONCLUSION

Results from the finding conclude that it is feasible to create an angular motion based on the experimental device designed based on split-tube flexures. This research has successfully explored the possibility of replacing conventional actuators with SMA actuation to create pseudo wrist motion with the torsional resilience support of PVC split- tube flexures.

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