*Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 48 **(4D)** 161-164 (2016)*

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Improving Cycle Time of Ni-Ti Shape Memory Alloy Actuators Using a Novel Cooling Technique

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Received 28rd August 2016 and Revised 17th October 2016

Abstract: Shape Memory Alloy (SMA) actuators require long cycle time due to slow cooling. Therefore, they are not suitable for applications that require fast operation. The research reported in this paper presents a novel technique of SMA actuator cooling. Using this technique, the Nickel-Titanium (Ni-Ti) based SMA wire actuator of diameter 0.15 mm was placed inside a PolyTetraFluoroEthylene (PTFE) tube of 0.5 mm outside diameter. The tube was filled with a grease to achieve faster cooling. The actuation behaviour was investigated in ambient air and in grease filled PTFE tube under various actuation currents. Compared to ambient air cooling, this technique resulted in up to 50% reduction in cooling time.

Keywords:*SMA actuator, fast cooling, heat sink, PTFE tube*

1. INTRODUCTION

(Ölander 1932), discovered Shape Memory Alloysin however, they got recognition in 1962 when William Buehler and Federick Wang discovered Shape Memory Effect (SME) in Nickel-Titanium (Ni-Ti) based alloy (Buehler. *et.al.,* 1963). (Kauffman. *et. al.,* 1997). These alloys are named as Shape Memory Alloys (SMAs) because of their ability to remember pre deformed shape. SMAs exist in two different phases, a high temperature phase called Austenite and a low temperature phase called Martensite, and three different crystalline structures (Sun. *et .al.,* 2009). (Mihálcz. *et. al.,* 2001). as shown in (Daudpoto. *et. al.,* 2012). **(Fig. 1) .**

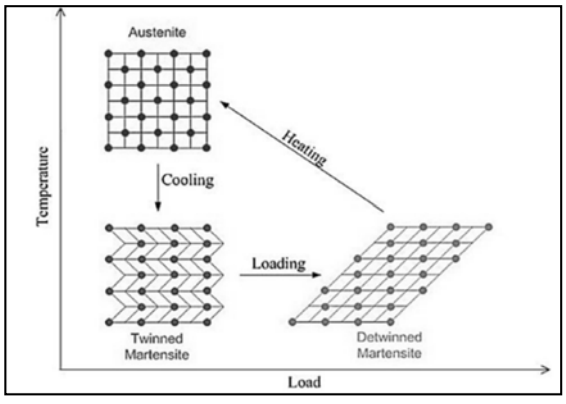


Fig.1. Phase Transformation in SMAs [6]

Phase change is function of change in temperature. However, in both phases SMA remains in solid form. SMAs have higher value of Young's modulus in Austenite phase, whereas SMA is softer in Martensite phase with lower value of Young's modulus (Teh. 2008). Various SMA properties like silent and clean operation, simplicity of design and ease of miniaturization, have attracted researchers to use them as actuators (Dynalloy. 2011). (Featherstone. *et. .al.,* 2004). in a variety of applications like consumer products and industrial applications (Wu. *Et .al.,* 2000). structures and composites (Furuya. 1996). automotive (Butera. *et. al.,* 2007). aerospace (Bil. *et. al.,* 2013). biomedical (Petrini. *et. .al.,* 2011). and robotics (Kheirikhah. *et. al.,* 2011). (Eren. *et. al.,* 2002). However, these actuators require long times. This results in longer cycle times (up to 10 s). This long cycle time has limited the use of SMAs. Some techniques for faster cooling have been reported in literatrure. A brief review of these techniques is given below.

Andrew Russell and Robert B. Gorbet (Russell. *et. al.,* 1995). developed a mobile heat sink mechanism which had a two-wire differential type configuration. The heat sink was connected with the shaft at centre. When the one wire was heated it contracted and made the shaft to rotate and as a result the heat sink moved towards the other wire, whose current supply was disconnected at the moment, making it cool. The system is provided with a friction clutch mechanism. The proposed methodology is complex and may not be applicable in miniature applications. (Loh. *et.al.,* 2006). used stainless steel tube as a heat sink. They placed two SMA wires each of 0.3 mm diameter and 500 mm long (when non strained) inside a stainless steel tube. The wires were used to actuate a prosthetic hand when supplied 50-70V using pulse width modulation. (Cheng.

et.al., 2015). applied water circulation around the SMA spring eclosed in a soft silicone tube. Although water circulation works but the system may not be suitable for miniature applications as water circulation can be achieved by a pump, also for water special sealing arrangements are required. (Loh. *et.al.,* 2005). tested the 750 mm long and 0.3 mm diamter SMA wire jacketed around by silicone grease inside a copper tube. The wire was made to lift up a mass of 3 kg. The authors observed quick cooling of wire when used in sink than that of in air. Copper tube being rigid may affect system's flexibility.

However, the cooling methods reported in literature result in design complexity, thus reduce the engineering prospects of SMAs.In this paper, a light-weight heat sink is proposed which decreases the cooling time without affecting stroke length. The heat sink consists of grease filled inside a PTFE tube. The actuator was tested at different actuation currents. PTFE material was used due to its resistance to corrosive reagents, non adhesiveness, non flammability, flexibility, low coefficient of friction and stability at high temperatures (Teflon. *et.al.,* 2016).

2. MATERIALS AND METHODS

2.1. Materials: Following material was used in the research presented here.

*Actuator***:** A 0.15mm diameter Flexinol wire manufactured by Dynalloy Inc was used. Table 1 gives the various properties of Flexinolwire used in the research.

Table 1: Properties of SMA Actuator

Manufacturer	Commercial Name	Diameter (mm)	Length (mm)	Composition	Maximum Strain (%)	Transformation Temperature (°C)
Dynalloy Inc	Flexinol	0.15	80	Ni. 55 to 56% Ti 44 to 45%	8	90

*Tubing:*A 80mm long and 0.5mm diameter PolyTetraFluoroEthylene (PTFE) tube, manufactured by AdTech, was used to encase grease and actuator.

*Coolant:*High Temperature Synthetic base grease (NLGI-3) was used as coolant. It was ensured that PTFE tube was completely filled with grease without any air bubbles. The coolant was filled inside the PTFE tube with the help of a syringe, as shown in **(Fig.2)**

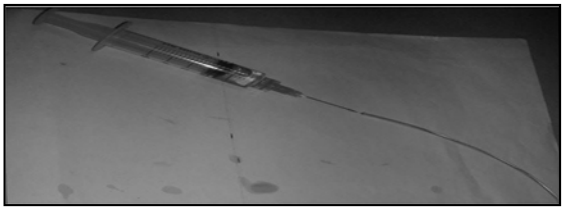


Fig.1. Grease Insertion In PTFE Tube

*Experimental Setup:*The experimental setup comprised of Laser displacement sensor, National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS) prototyping board, myRIO, power supplies, load cell, current sensor and Lab VIEW software for data acquisition, as shown in **(Fig. 3).**

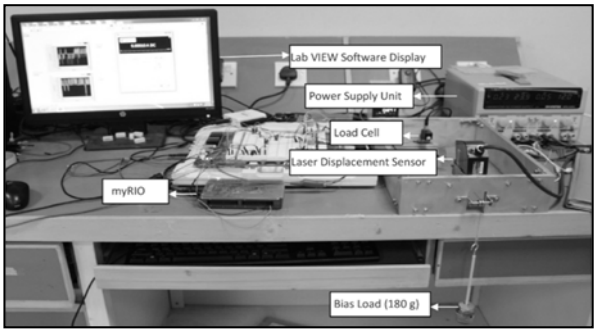


Fig.2. Experimental Setup

2.2. Method: The proposed heat sink comprised of PTFE tube and grease, as shown in **Fig.4.** The grease was filled into the PTFE tube via a syringe and SMA wire was inserted into the PTFE tube.

Since thermal conductivity of grease (0.79 W $m^{-1}K^{-1}$ is higher than that of air (0.0257 W $m^{-1}K^{-1}$) the grease cooling will result in faster heat dissipation from SMA when compared to air cooling.

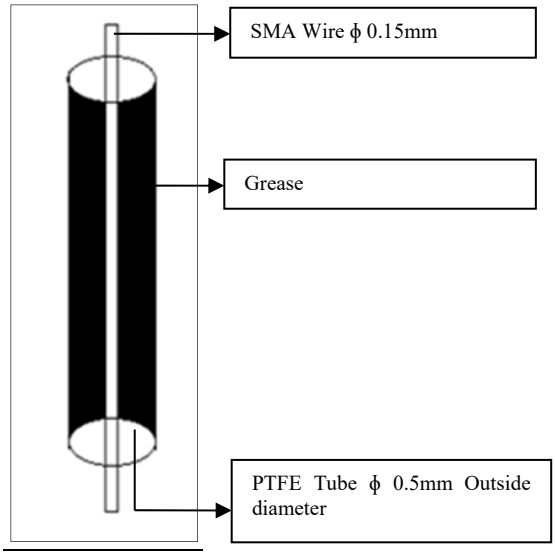


Fig.3. Crossection view of heat sink

3. RESULTS AND DISCUSSION

3.1. Ambient Air Cooling: The wire in ambient air was actuated at 210mA, 310mA and 410mA for 1 second. The response of SMA actuator in ambient air at different current supplies.

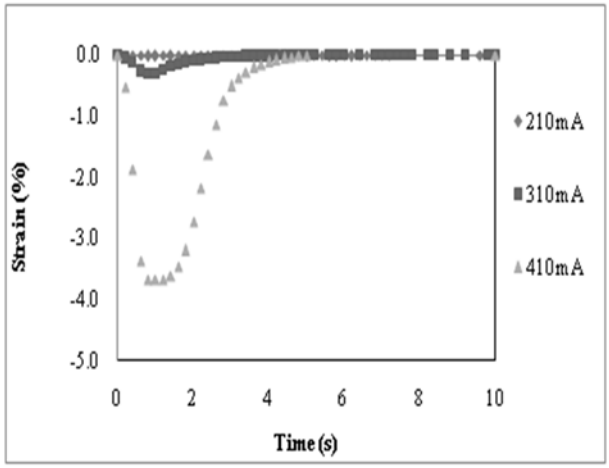


Fig. 4. Actuator strain in Ambient Air

The negative sign on vertical axis represents the contraction in actuator. When the SMA was supplied with 210mA current supply for 1 second, no strain was observed in the wire, however small strain of about 0.311% was observed at 310 mA. With 410mA actuation for 1 second, 3.68% strain was recorded in the SMA wire, the wire cooled off in 2 seconds.

The supply of current accros the actuator results in Joule heating. This heating power is given by following equation.

$$P = I^2R \qquad \text{Eq. (1)}$$

Here,
P = Heating Power in Watt
I = Current accros actuator in Ampere, and
R= Resistance of actuator in Ohm
As seen in Eq. (1), the higher currents result in higher heating power, hence larger strains in the actuator.

3.2. Grease Cooling

Grease cooling was carried out by inserting grease and actuator in the PTFE tube. The actuator was supplied 210mA, 310mA, 410mA, 500mA, 615mA, 720mA and 810mA each for for 1 s. The cycle time was set at 10s out of which 1 second was for actuation and remaining 9s for relaxation. **(Fig. 5)** shows the strain in grease cooled actuator.

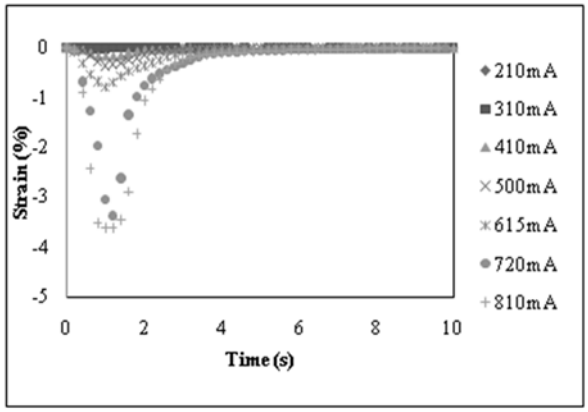


Fig. 5. Actuator strain in Grease for 1 s actuation

No strain in SMA wire was observed at 210mA and 310mA, because the heat supplied to the wire during actuation was lost to the sink. However, some strain was recorded at 410mA, 500mA, and 615mA because some of the Martensite was converted to Austenite. Whereas, at 720mA and 810mA, strains recorded were 3.38% and 3.6%, respectively. The wire cooled off in 1 second when actuated with current of 720mA, however, the wire relaxed in 1.4 seconds for 810mA actuation.

To investigate the effect of heating time on the grease cooled actuator, it was decided to supply 210mA, 310mA, 410mA, 500mA, 615 mA, and 720mA currents for 2 seconds. Fig. 6. gives the actuator strains for 2 s actuation.

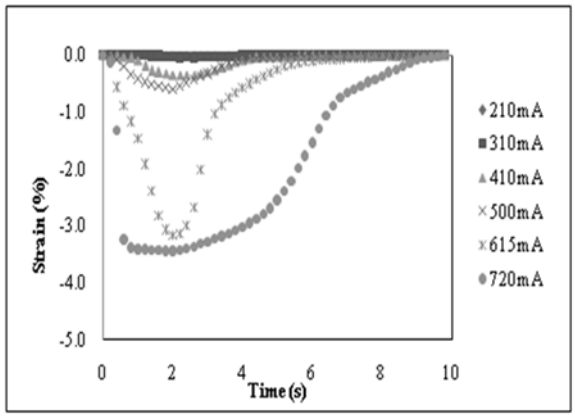


Fig. 6. Actuator strain in Grease for 2 s actuation

Since most of the heat was lost to grease at 210mA and 310mA, therefor no strain was recorded. However, 0.35% strain was induced when actuated with 410mA for 2 seconds and 0.6% strain was induced at 500mA supplied for 2 seconds.

The SMA wire strained by 3.174% when actuated for 2 seconds with supply of 615 mA. The wire relaxed in 2.5 seconds. However, 3.4% strain was observed in wire when actuated for 2 seconds with supply of 720mA. The wire cooled off in 6 seconds. As it can be observed that when actuated for 1 second with 810mA gave more strain than that of 720mA for 2 seconds, and the cooling time was 3.75 times less than that of actuated with 720mA for 2 seconds. This was because large portion of heat was dissipated to the grease and that reduced the viscosity of grease and affecting its heat conductivity properties. Since thermal conductivity of PTFE tube is less than that of metallic tube, the heat remained inside the sink for larger time.

4. CONCLUSION

In this research Shape Memory Alloy (SMA) actuator of 0.15 mm diameter was tested in ambient air and synthetic grease in a PolyTetraFluoroEthylene (PTFE) tube. It was found that, for same current, grease cooled actuators underwent smaller strain as compared to ambient air cooling. However, the grease cooled actuators were cooled faster as compared to ambient air cooled actuators. For similar level of strain the grease cooled actuators required higher level of actuation current. However, the cooling time was improved by 30% in case of grease cooled actuators. It is therefore concluded that for faster cooling, grease cooled actuators may be preffered over ambient air cooled actuators

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