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Investigations onControl of CuAlNi/Polyimide Bi-Morphs by Using PID Controller

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Abstract

Shape Memory Alloy thin films developed on flexible substrate has shown immense potential towards developing MEMS systems. Parameters such as substrate thickness, composition and the structural properties play a vital role in realizing the shape memory effect. A study on the influence of quaternary material for improving the ductility of CuAlNi shape memory alloy is reported. Further, to utilize the developed bi-morphs in application, control of the displacement is vital. Applications such as aerial robots, circuit breaker and temperature sensing requires precise control of the b-morphs. This can further be advanced into micro-valves when its displacement is controlled in the micro-scale.Comparative study between the response of the CuAlNi and CuAlNiMn bi-morph to PID controlis investigated. The parameter used forcontrol is current and a closed loop system is created for the control using a sensor feedback and a programmable power supply.The control mechanism followed here is PID on a trial and error basis. The Ziegler Nichols method was followed to study the PID parameters. The theoretical values were compared to the trial and error based PID system. The errorhas been maintained as low as .02mm for both the different bi-morphs, which can be further reduced in the future. The response of the bi-morphs to the control system varied with parameters like the current range, voltage, thickness of the sheet.

Keywords:SMA, Control system, PID.

1. INTRODUCTION

Shape Memory Alloy bimorphs have a wide scope of application because of their flexed actuation especially in micro-actuation systems. SMA Bimorphs have been competing with the piezoelectric bimorphs, though the latter leads in the number of applications and reliability. In contrary to this, SMA bimorphs of different compositions are being developed for better utilization. One such composition is CuAlNi and its upgraded composition CuAlNiMn. . As it is known, the SMA changes from martensite to austenite on heating, hence temperature is used to control the displacement of the bimorphs as described in [1]. The proposed control is based on Joule's heating. The current is the parameter of control. The closed loop system was created for the control of the polyimide using a sensor feedback and a programmable power supply. The system was set up in a laboratory environment.

PID (Proportional-Integral-Derivative) was chosen as it is the most basic control system currently opted. A PID controller continuously calculates an error value as the difference between a desired setpointand a measured process variable and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively) which give their name to the controller.

In general, several patented loop tuning methods are in use. Though tuning a closed loop control system seems to be conceptually trial and error, it is hard to estimate the environmental factors now and then. The biggest difficulty faced in the manual loop tuning was the environmental factors as this is a 2cmx2cm SMA bimorph.

Factors such as the current rating of the power supply used would also impact the heat generated on the bimorph. Hence, this study was completely performed in the laboratory environment under constraints.

2. DESIGN AND ANALYSIS

The SMA bimorph used was a standard size of 2cmx2cm, in the shape of a cantilever beam. The Joule heating technique is completely utilized by the resistance in the alloy which resulted in the heat generation. As said in [1], the heat generation resulted in the change of orientation i.e. displacement.

The parameter to be controlled for the bimorph is its displacement. The displacement is produced as the result of exhibition of the SMA property with respect to temperature. The temperature in this case of Joules effect, is produced by current. Thus the parameter to be controlled is current. The control system can be hence lined up as per the Fig 2.

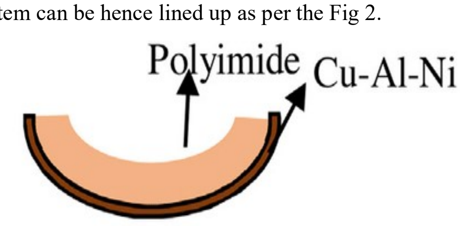

Fig 1.Bimorph

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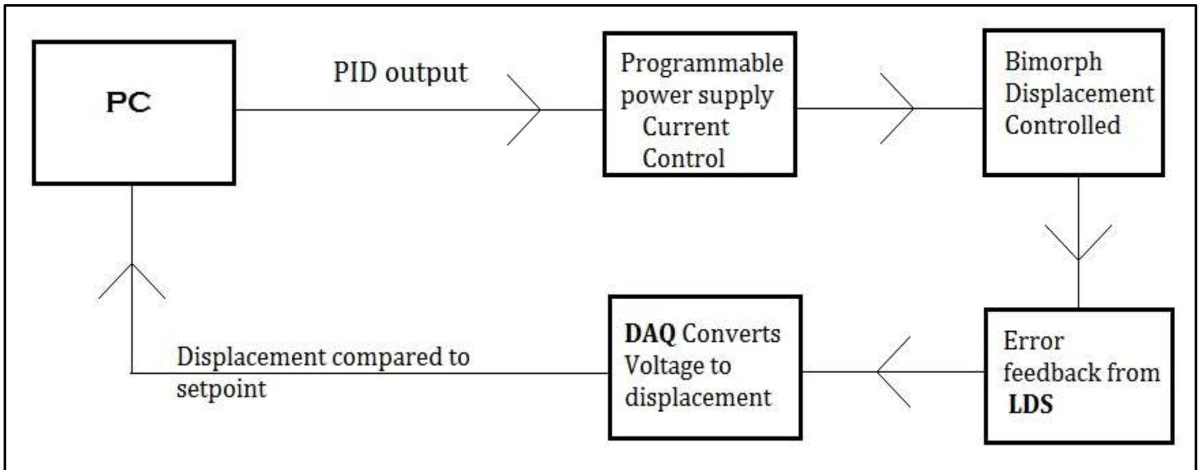


Fig 2. The control sequence

3. EXPERIMENTAL SETUP

The entire setup goes around the concept of Joule's effect .i.e. the amount of heat produced is proportional to the electrical resistance of the wire when the current in the circuit and the time of current flow is constant.

$$i.e.\ H \propto R\ (when\ i\ and\ t\ are\ constant)$$

Here, 'H' is the heat generated in Joules and 'R' is the resistance of the material.

The power supply given had to be controlled at 2V - 4V and 0.3A - 1A. The standard power supplies available were not efficient and hence a complete control system with designed where a programmable power supply was used. The other devices used were : Arduino UNO, DAQ, Relay module, Laser Displacement Sensor, PC with LabVIEW software.

The Fig 5 gives the layout of the experimental setup. RIGOL Programmable Power Supply was used for the same purpose. The VI generated by the LabVIEW was run on the computer system continuously to provide the required control. Since the bimorphs follow Joules effect, the heat control was done by the current supplied from the RIGOL Programmable Power Supply. The power supply was interfaced to the PC by means of Ultra Zigma.The bimorph when actuated, the displacement was to be studied and so the Laser Displacement Sensor of micron level accuracy was used. It provided the output in terms of Voltage and the Data Acquisition(DAQ) Agilent 34970A was used to read the data and there by convert the voltage to displacement. The DAQ was interfaced to the computer by means of Keysight's Connection expert The displacement data was read and the error compensation was done by the PID control system on the Computer(LabVIEW).Though the VI generated values were used to control the current, the on and off control was given by means of an Arduino UNO development board connected to a 5v-230v relay. Hence a GUI(Graphical User Interface) was created for controlling the bimorph.

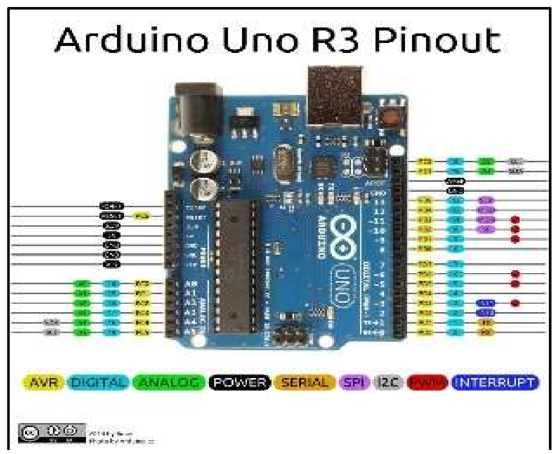


Fig 3. UNO

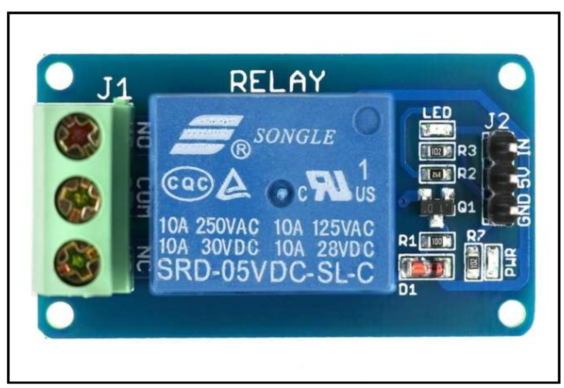


Fig 4. Relay

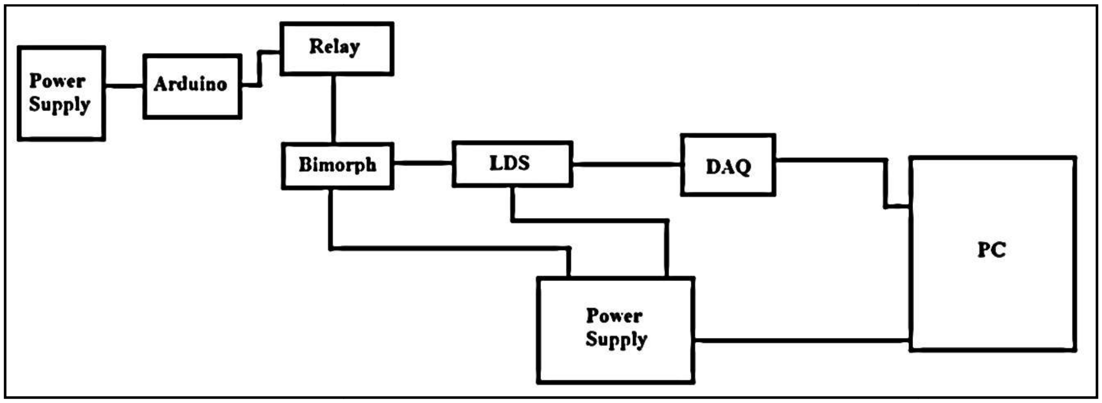
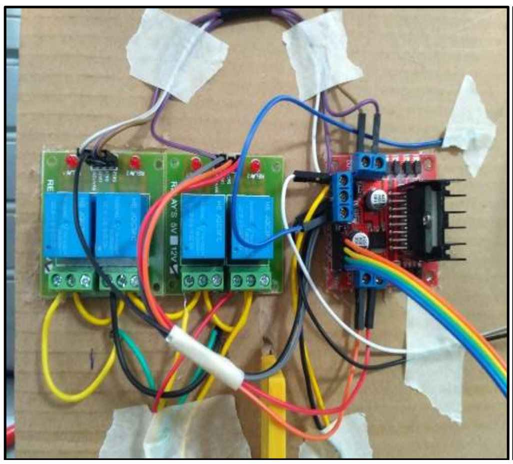


Fig 5. Line diagram of the setup



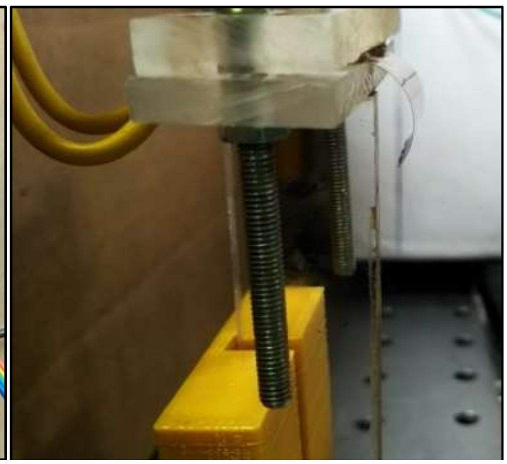


Fig 6. Setup **Fig 7.Bimorph stand**

4. EXPERIMENT AND RESULTS

Strain recovery can also be used for the control but the drawback was the effect of temperature on the strain gauge. The microstrain studied for the bimorph compared to the linear displacement by LDS were almost the same but strain gauge didn't prove to be sufficient to control. Every scan was taken at a span of 200ms and the graph generated was as follows.

The system was designed to control the current and so as to control the displacement as per the need.

PID in real time as discussed before involves three parameters: K, T_i, T_d.

Using the standard form, in contrast with other implementations (for example, when the derivative term is taken from output):

$$u(t)=K_p e(t)+\frac{Kp}{Ti}\int t_0 e(\tau)d\tau+K_p T_d\frac{de(t)}{dt}$$

Alternative definitions can include *Ki=KpTi*and *Kd=KpTd*. Also, the derivative term can be modified in order to reduce issues with high frequency noise - e.g. a low pass filter.

For a 75micron Kapton coated with 100mg of CuAlNi, the control was difficult because of quicker cooling rate of the SMA. Hence the improvised SMA bimorph of material CuAlNiMn was also studied. Comparatively, the control was implemented with ease for the latter because of the better displacement.

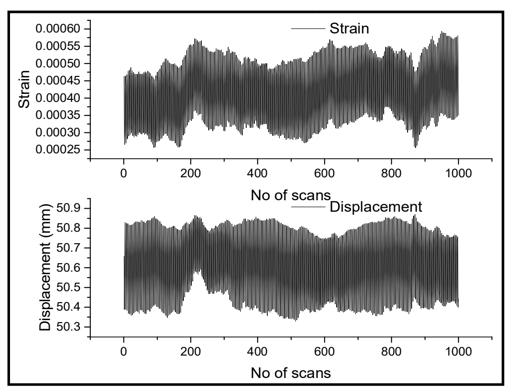


Fig 8.Strain vs.Time and Displacement vs. Time

The Gain value Kp was increased until the displacement reached the set point and then the Ti was increased in order to increase the precision and then the Td was increased to reduce the

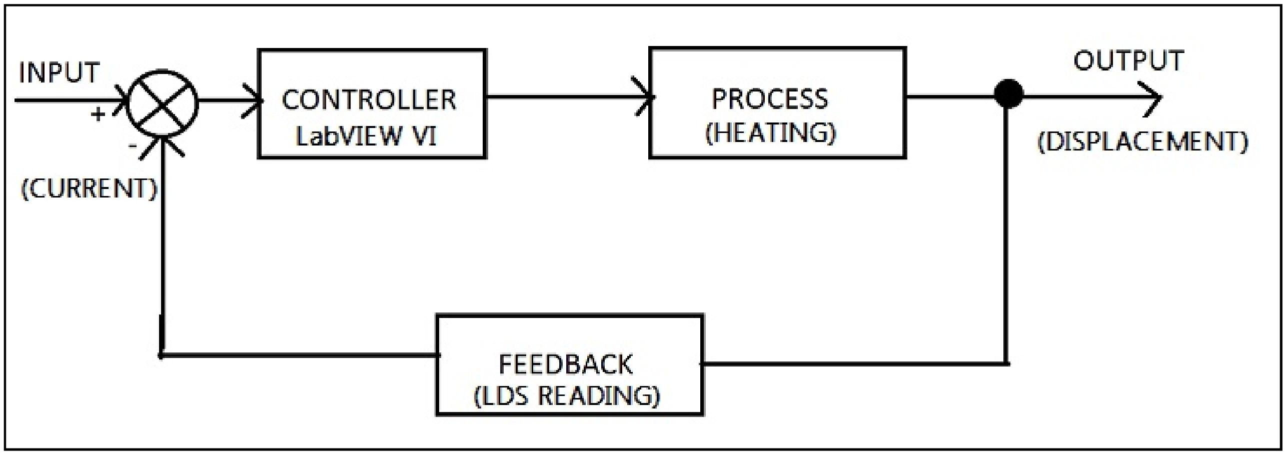


Fig 9.Control System

overshoot. In a similar fashion the controller parameters were designed for the other SMA bimorphs too.

By Zeiger Nichol's method the displacement of CuAlNiMn bimorph was tried.The gain Kp was increased from 1 till it produced a quasi-semi stability.

From the observations, the gain K_p = 9.8 has been chosen as the critical gain. The ultimate period for the oscillation was obtained from the plot.The ultimate time (Critical time period,T_u) for the oscillation was found as 5s. i.e the Time gap between two consecutive peaks of the displacement plot.

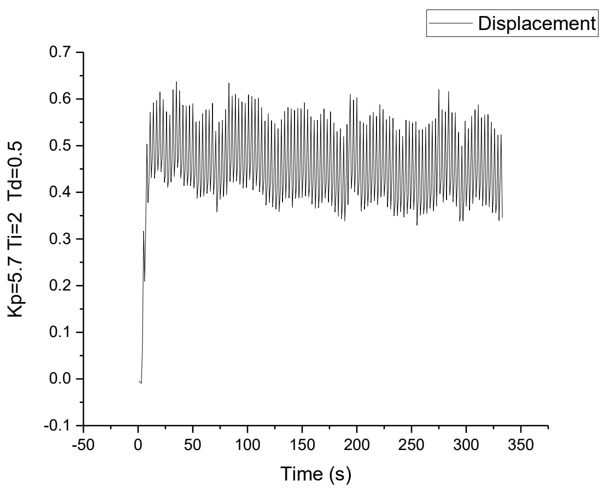


Fig 10. Displacement vs. Time

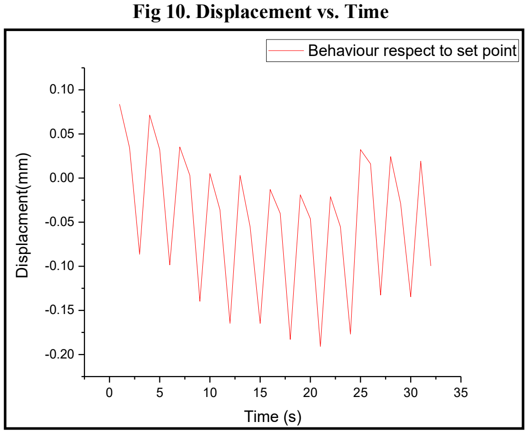


Fig 11. Displacement(Error) vs. Time

5. CONCLUSIONS

The data thus obtained proves to confirm that the CuAlNi bimorph is controllable and can be used in applications like aerial robots and micro-valves were control is essential. Further study on better displacement measurement system, can result in a better control over the system. Self-tuning PID can also be set up and more precision in control and stability can be obtained. The environmental factors has a vast impact on the material property and thus improvisation on the material composition will help in the material property enhancement.

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