Design and fabrication of Shape Memory Alloy actuated Stewart platform for automated laser assist micro-machining application

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Abstract

In this work a Shape Memory alloy (SMA) actuated, automated Stewart platform has been designed and developed for laser based micro-machining setup. The Stewart platform are designed using SMA based actuators owing to their capability for precisely controlling displacement. The actuation studies were also performed through joule heating with linear displacement of 3 mm. The system is designed with a graphical user interface that can be integrated with the computer. The system has a capability to go have a displacement of 4 mm along the X and Y plane and 3 mm in the Z direction. The resolution is of the system is estimated to be around 0.2 mm and the accuracy will be up to 0.5 mm. The silicon wafer can be attached for the reflection of laser for micro machining. This platform is a parallel manipulator robot which converts linear motion into prismatic and two rotary axes in a planar motion. Design of Stewart platform equipped with Shape memory alloy spring and biased springs concentrically. This setup will be used for generating micro channels using lasers on the silicon wafer.

Keywords: Shape Memory Alloy, Micro machining, on-off controller

1. INTRODUCTION

The most novel mechanism used for flight simulators and position maintaining is Stewart platform or parallel manipulator. It is a classic example of a mechanical design that is used for positioning and orientating the platform with respect to a fixed base. Main application is to fulfill the requirement of high load carrying and precise positioning capability. Most of them available are actuated with hydraulics and pneumatics whose drawback is the control of position. The same platform can be used for the position control in other applications. Traditional actuators such as electric motors, hydraulic pump and pneumatic necessitate the use of large and heavy supported and are usually very noisy. Electric motors are bulky, revolve at very high revolution in which reduction gear is required to produce needed torque [1]. In recent decades, the parallel mechanisms have become attractive because they exhibit advantages in the manufacturing accuracy and speed. This plays an important role in developing the micro-scale positioning platform. Hassel Bach et al. have investigated several positioning platforms based on a parallel mechanism and emphasized the advantages of a parallel mechanism in the precision positioning field [2]. Yi et al. have designed and con ducted experiment on the stiffness of a platform consisting of several flexure hinges [3]. Dasgupta et al. have reviewed a parallel manipulator platform based on the Stewart–platform [4]. Various arrangements for stewart platform [5-9] have been studied to understand the behavior of platform. In this paper developed stewart platform is explained and experimentation of SMA spring performance were carried out to find important data such as speed of contraction, minimum and maximum weight that can be lifted and operating conditions. Fabrication and construction process of platform using SMA spring actuators was based on analysis of the experimental results. In the upcoming sections design, fabrication, experimentation and control strategy is discussed in detail.

2. DESIGN AND PRINCIPLE WORK

The design of the Stewart platform is developed in a mini scale of 50 mm * 50 mm * 8 mm and attain three degree of freedom with rotation on x and y axis and prismatic in z axis. The platform consist of similar 4 SMA and 4 biased springs coaxially. The springs are hinged at both ends of the platforms. One side of the platform is fixed like a cantilever beam. The platform is designed in a CAD model with hooks for mounting the springs and converted to stereo lithography format for 3D printing (fig.1). The bottom platform is hinged with the table and SMA springs are mounted first in to the designed hooks. The Biased springs are installed coaxially with SMA springs and wires are commonly grounded and the positive supply pins are connected to separate relays for the control for actuation.

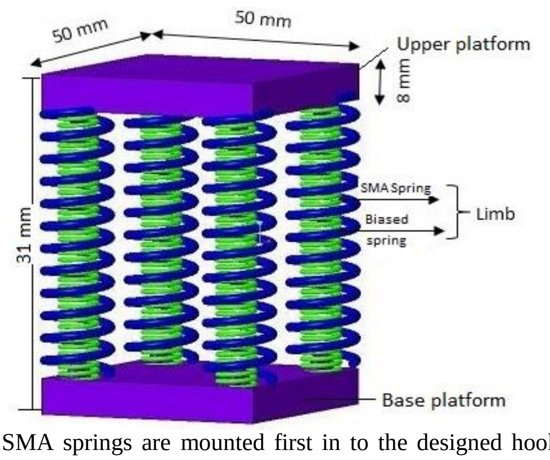

Figure 1: Design of Stewart Platform

3. NITINOL SPRING SELECTION

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The correct selection of Nitinol spring is very important as it will affect the performance and control of platform. In this study stewart platform must have low activation temperature property which only needs low current supply to the wire. It must also possess lifelong cycle and low resistance. Spring design for SMA and biased is shown in Fig. 2(a) and 2(b) respectively. Others factors that also contribute the spring selection are economical cost, delivery period, wire diameter, coil diameter and lifting capability. Based on all these parameters which is tabulated in next section Nitinol spring is selected.

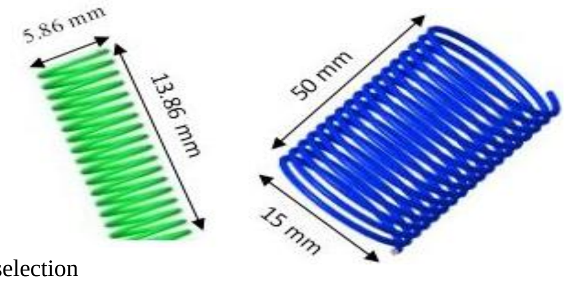

Figure 2: Spring design a) For SMA, b) For biased

4. FABRICATION

Used parameters for shape memory and biased spring are tabulated below:

Table.1: Parameters for SMA and Biased spring

S.NO	Parameters	Specification	
		SMA Spring	BIASED Spring
1	Length	13.86 mm	50 mm
2	Coil Diameter	5.86 mm	15mm
3	Wire Diameter	770 µm	1440 µm
4	Stiffness	0.341 N/mm	0.943 N/mm
5	Activation Temperature	70˚C	NIL
6	Number of Turns	18	18

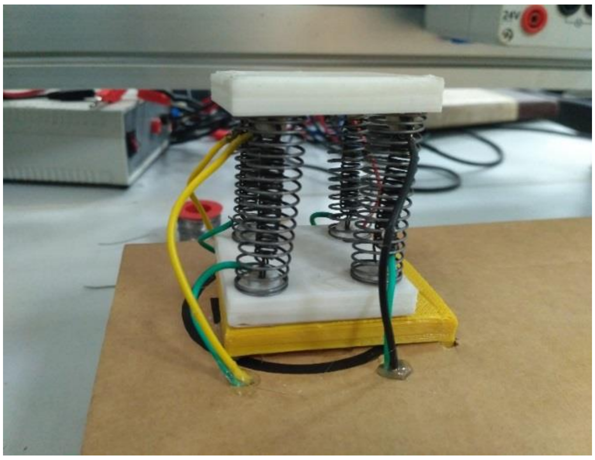

Figure 3: Fabricated Micro-positioning stage

The wires are commonly grounded and the positive supply pins are connected to separate relays for the control for actuation. The relays are actuated with a voltage of 5V from microcontroller.

5. EXPERIMENTAL SETUP

Fig. 4 shows the experimental setup with its components and connections. They work in a synergic way for the desired output. The Fig shows clearly that Labview program is the interface between all the components. The serial communication between Arduino, DAQ and PPS is done. The signal for actuation is synced for all the devices. The control of relay through Arduino to the SMA spring is switched by the GUI interface in the Labview Program. The LDS gets the feedback and the data is simultaneously recorded in 200 ms time interval. The power supply is attached to the relay and Arduino because they cannot be operated in the same potential for actuating the spring. The selection of springs to be actuated using the Arduino. The centralized system which is integrated computer with Graphical user interface (GUI) which the Atmel 328p in Arduino, Programmable power supply, and DAQ is connected. The Master command is from the GUI and the components connected acts like a slave. All the communication is done through a serial communication cable with different Baud rates. The actuation command is given from graphical user interface for the Arduino, PPS, and DAQ at the same time. The Laser displacement sensor (LDS) is connected to the DAQ for feedback. The GUI will supply analog signal for the PPS for the current parameter control. The maximum output range from the PPS will be 3V and 1.3 Amperes for the actuation. This is sufficient to joule heat the spring for actuation. Fig.5 shows the steps for fabrication of set up. The on-off controller is embedded with GUI for the control of current. The actuations tilt and movement of the platform due to the degree of freedom. The biased spring which acts as a load for making the SMA back to the position after the heat dissipation in natural cooling.

6. EXPERIMENTAL RESULT

To apply SMA spring actuator repeatable behavior is very important. The application mentioned above are driven by electric current and controlled LDS feedback. To measure the thermal cyclic behavior of SMA wire actuators it is required to heat the SMA spring many times while measuring the response. A thermal cycling test bench was developed for continuously monitoring the various parameters. Requirement for actuation of single SMA spring is 3 V and 1.3 Ampere. Experimentation is done for multiple cycles out of which only 5 cycles have been shown. Displacement and temperature corresponding to time plot have been shown in fig 6 (a) and fig 6 (b). Maximum 3 mm displacement is achieved for SMA spring after implementing on-off controller. Hysteresis curve for first cycle is shown in fig. 6 (c)

The SMA springs, initially at the room temperature, are in martensite phase. Thus, in the differential mechanism, when one SMA is activated, the other SMA produces a small resistive force. Following that, when the other SMA is activated (within 120 s), the opposite SMA that is already in a high temperature, produces a larger resistive force. Thus to reach to the same negative deflection as the previous case the passive spring should cool off reasonably. The cooling time however is longer, and it takes about 180 s which is almost 3 times longer than heating. The variation of module’s displacement when an external load is applied demonstrates the flexibility and low stiffness of the module. This property may be very useful in the application of the module in stages.

7. DISCUSSION AND CONCLUSION

The platform uses 12 Amperes for actuating the springs at the same time, but for control constraints the platform is given only 5 Amperes for all 4 springs. The average response time of the system is less than 3 seconds for different temperature environment.

Figure 4: Line Experimental set up positioning stage

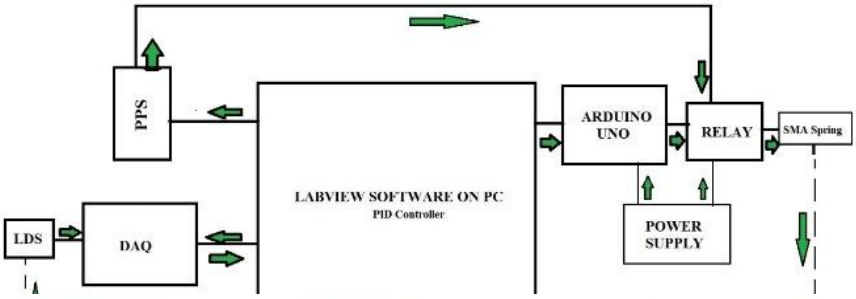

diagram of for actuating micro-

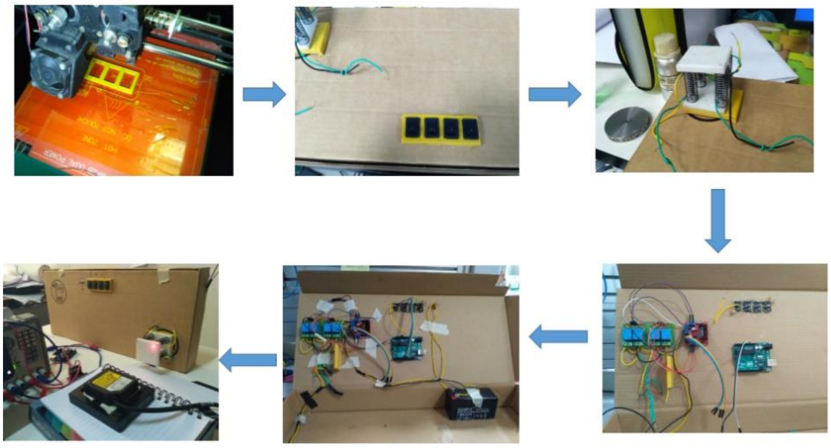

Figure 5: Fabrication of Experimental set up for actuation

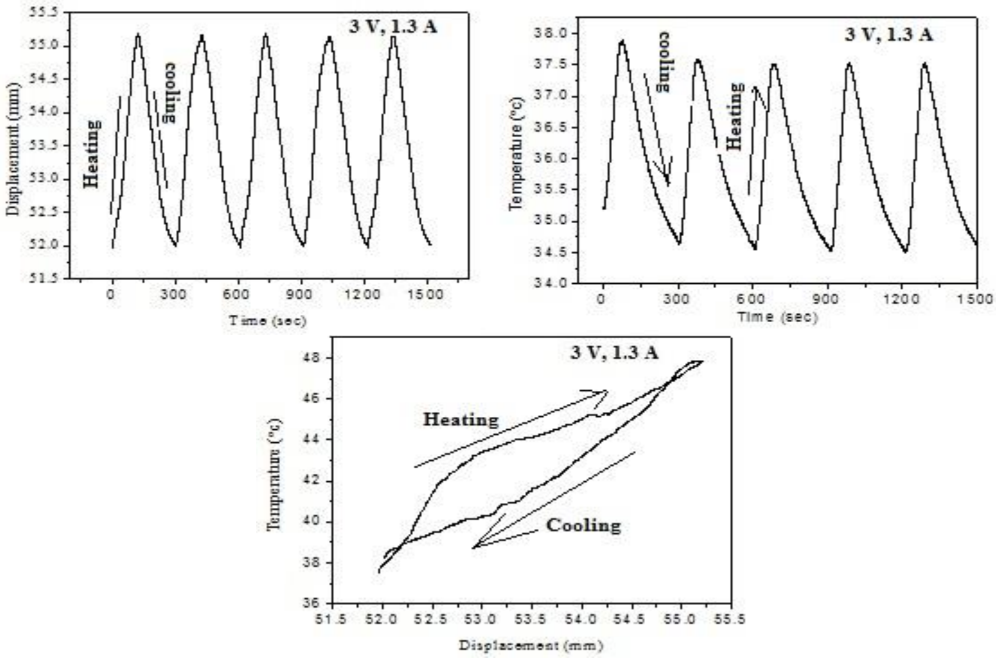

Figure 6: Plot between a) Displacement vs time, b) Temperature vs Time c) and Hysteresis curve

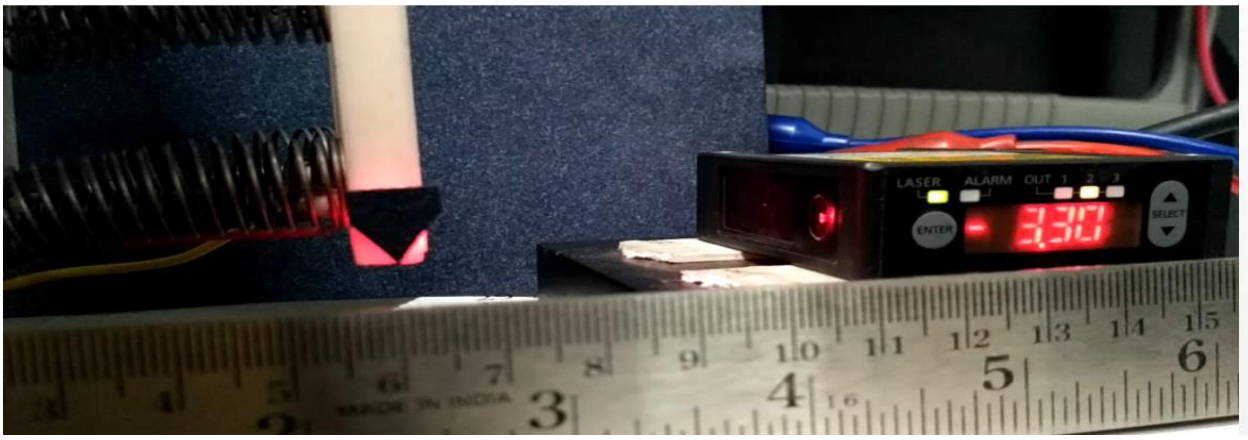

Figure 7: Monitoring of displacement using LDS

One leg at the time is actuated for higher displacement in a particular direction and two for a controlled direction with a limit. The combination of legs actuated in a sequence make them to move in a desired path. The on-off controller is implemented because the system is highly nonlinear, so to reduce the errors in the open loop system the closed loop control system take the role to rectify it.

Acknowledgements

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