A New Multi-Range Force Sensor

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Abstract

In many robotic and industrial applications contact forces are generated that need to be controlled. Force and torque measurements are required to accomplish these tasks. This project was to develop a multi-range sensor that offers improved sensitivity over currently available sensors using materials that undergo phase transformations. A shape memory alloy, whose mechanical properties change with temperature, was used for this multi-range sensor development. Shape memory alloys are materials that exhibit a phase transformation when the temperature of the material changes. The material possesses a low temperature low strength martensitic phase and a high temperature high strength austenitic phase. In the martensitic phase these materials can undergo a certain amount of plastic deformation, which is reversible upon exposure to an elevated temperature. The ability of the material to exhibit large changes in the yield stress and the modulus of elasticity, as well as its ability to recover from certain plastic deformations are important to the proposed sensor design. The ability of the material to exhibit linear elastic deformation in both phases will result in enhanced sensing capability. A sensor developed of shape memory alloy will have the ability to measure contact forces in two different ranges. The sensor will be maintained in the martensitic phase for lower force range operations and heated to the austenitic phase for higher force range operations.

1 Introduction

The primary objective of this research was to investigate if it is possible to create a sensor that can measure contact forces in two different ranges. In today's applications to accomplish this task two different sensors have to be used. Force-measuring transducers are frequently known as load cells. A transducer is a device, which transforms one type of energy into another. A battery is therefore a transducer, as is an ordinary glass thermometer. To conduct our experiments we used a load cell to calibrate the sensor constructed with strain gages.

2 Important Components

The most critical mechanical component of a load cell is the spring element [1]. The function of the spring element is to serve as the reaction for the applied load and to focus the effect of the load into an isolated, uniform, strain field where strain gages can be placed for load measurement. Load cell spring elements are divided into three classes, according to the type of strain field used. These are: bending, direct stress, and shear. For our experiments, we used a bean-like configuration subjected to bending moments. If the bean is thin, the design will result in good temperature compensation. Other important components are the strain gages. The strain gages are thin metal–foil grids that can be bonded to the surface of a component. When the component is loaded, strains develop and are transmitted to the foil grid. The changes in the resistance of the foil grid are proportional to the load-induced strain.

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3 Design Considerations

Two major aspects were considered in order to design the sensor, its size and the material used to construct it. The material chosen for the sensor is NiTi, which is a shape memory alloy (SMA). This alloy is also a shape memory alloy. Shape memory alloys are materials that exhibit a phase and mechanical transformation when their temperature changes. At low temperatures, the material exhibit low strength while at high temperatures, the material has high strength. In theory, the sensor should be able to measure a particular force range at low temperatures and a large force range at high temperatures. After material selection the dimensions of the spring element had to be determined. For the application a multiple-bending element configuration was chosen. Based on the maximum force that will be applied to the SMA (the spring element) a force transducer with a 0 to 2.5 lbs range was selected. External force was applied to the center of the SMA with both ends clamped. The governing equation to determine the deflection the element is given by:

$$y_{max} = -Fl^3/192EI$$

were

y_{max} = the maximum deflection allowed
F = the applied force
l = the length of the SMA
E = the modulus of elasticity of the SMA
I = moment of inertia

Solving the equation for l the length of the SMA was found to be 3 inches. Only the length was determined because the width and the height were known specifications. Other design aspect taken into consideration was the method of heating the shape memory alloy. We decided to use thermoelectric heaters to accomplish this task. This will allow the shape memory alloy to reach the austenitic phase, which is the high temperature high strength phase. The temperature needed to reach the austenitic phase is in the range of 70 to 80° C. We were also interested in finding the time needed to change the temperature of the shape memory alloy. Time was an important factor for the experiment because it will allow for the collection of data in a reasonable amount of time. Using the ITI Ferro Tec reference manual [2] we determined the time needed to change the temperature of the shape memory alloy. The equation used was

$$t = (m)(Cp)(DT) / Q$$

were

t = time period for temperature change
m = weight of the material
Cp = specific heat of the material
DT = temperature change of the material
Q = heat transferred to or from the material

For our design this time was determined to be 57.06 seconds. This is the time it will take one thermoelectric heater to change the temperature of the shape memory alloy. To reduce this amount of time we decided to use two thermoelectric heaters in our design. Also, four strain gages were bonded to the surface of the shape memory alloy. These strain gages formed a full wheatstone bridge circuit. A thermocouple was also attached to the shape memory alloy to measure and control the temperature of the alloy. The software LabView was used to control the experiments. A strain gage indicator, a switch and balance unit, and a dc power supply were all used as part of the experiment.

4 Martensitic Phase

Initial experiments were conducted in the martensitic phase. During these experiments, several problems had to be overcome. The strain gage electric wires were replaced since the weight of the wire during the application of the force had an effect on the reading. Due to the low force values the transducer was design for, drag placed on the wires had a bearing on the strain gage reading. The original electric wires were affecting the strain indicator readings. Thin connections were used to overcome this problem. Also, because the thermocouple had a similar problem, we decided to modify the lead wires by removing the insulation. These changes improved the precision of the sensor. The sensor was loaded with force until the strain indicator had a reading of 750 micro strains. Readings were taken for both loading and unloading of the transducer. During the initial tests readings show that there was a sizable difference between the strain gage readings for the loading and unloading cases. With repetition of the tests these difference was considerably reduced. Also, during the initial readings, it took long time for the sensor to go back to its original position but as loading and unloading cycles were repeated, it became easier for the sensor to attain its original position (0 micro strains). This means that when loading and unloading sequence was performed the sensor stress-strain curve became linear. A straightening of the stress-strain curve is shown in Figure 1 and Figure 2. Series 1 represents loading and series 2 represents unloading. The values of loading and unloading are much closer in Figure 2.

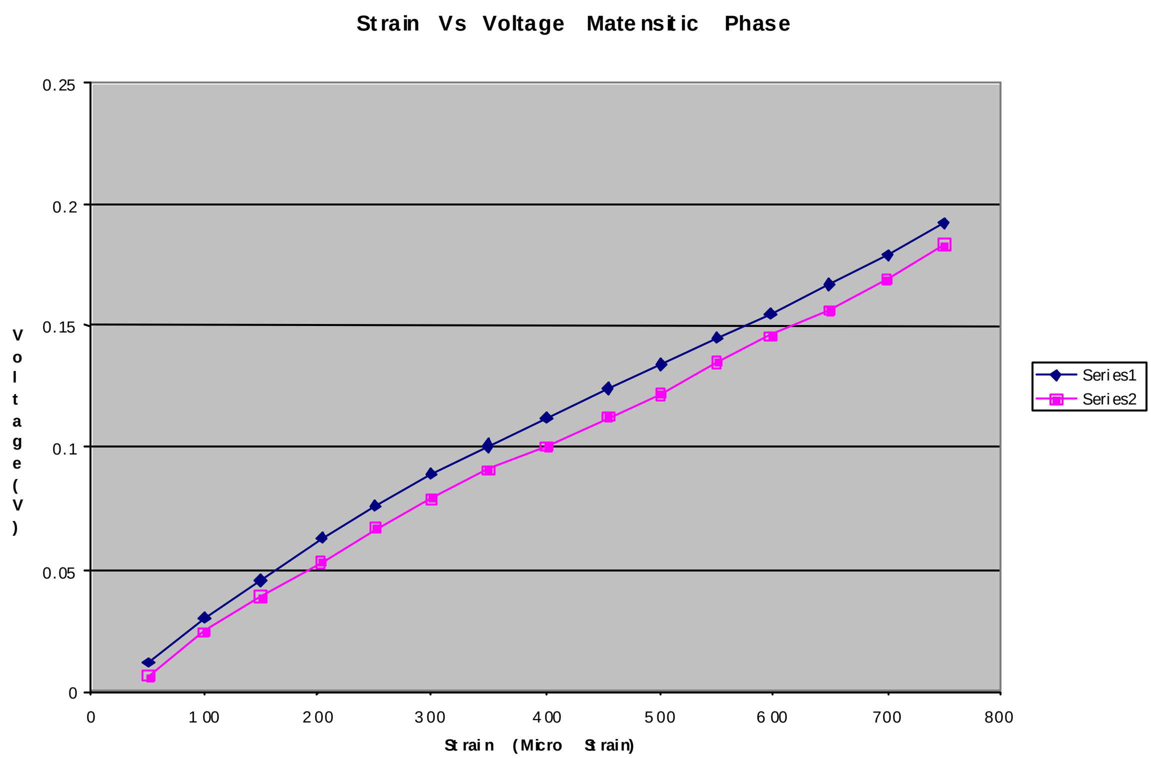

Figure 1

Figure 2

5 Austenitic Phase

For the sensor to be of practical importance, the same set of loading and unloading cycles has to be repeated for the austenitic phase. For the austenitic phase, the sensor had to be heated to a temperature of 70-80°C. Initially, the experiment was done using thermoelectric heaters. The experiment failed because the desired temperature could not be reached. Using two cartridge heaters we were able to heat the sensor to the desired temperature. In order for the sensor to be reliable a linear stress-strain had to be attained in the austenitic phase also. During the testing in the austenitic phase it was noticed that the strain on the indicator reading were not steady. The strain values were jumping up to 30 micro strains in value. Possible reasons for this behavior could be the adhesion of the strain gages to the SMA being affected by heat. New experiment needs to be done with better attachment of the strain gage to the SMA.

6 Conclusion

The basic knowledge for the design of a multi-force were obtained. The sensor could be trained to a linear relationship between stress and strain in the martensitic phase. The behavior of the sensor in the austenitic phase still needs to be investigated.

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