P17341: Precision CTE Testing Apparatus

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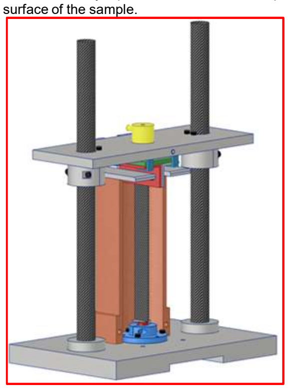
Project Overview

The scope of this project was to create a coefficient of thermal expansion (CTE) test apparatus that would be capable of suspending test coupons via magnetic levitation. CTE is defined as strain (change in length/starting length) divided by temperature. Heat is applied to the coupon, which in turn will cause it to expand. This expansion is measured using a non-contact capacitance sensor, and temperature is recorded using attached thermocouples.

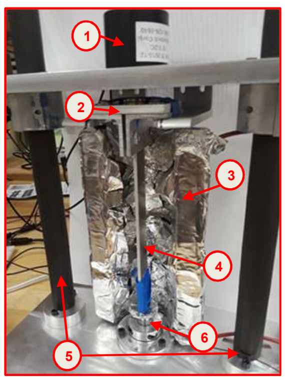
In addition to the structure itself, it was also necessary to provide a detailed explanation and quantification of the error sources. This would allow for a measure of how effective the new system is compared to systems currently in place, and provide an idea of what the most significant sources of error are. Future work would focus around reducing or eliminating the most significant sources of error.

System Design

The test coupon is oriented vertically, secured at one end, and levitated through the use of the electromagnet located in the top plate. The two support rods are constructed from a near-zero CTE composite materials, and the top and bottom plates are constructed from aluminum. The height of the top plate can be adjusted by loosening the two support collars, and then tightening them at the desired height. Heat is applied to the sample by a resistive heater tape inside an insulating thermal shroud. The shroud is split into two halves in order to allow for easy replacement of the test sample, and is controlled by a thermocouple on the surface of the sample.



CAD Model of Structure

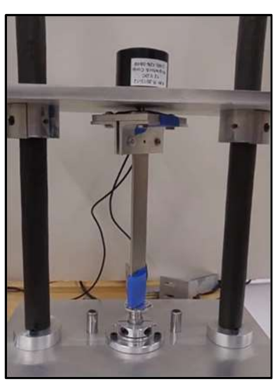


Final Assembled Structure

1: Electromagnet
2: Sample clamp w/ embedded permanent magnet
3: Thermal shroud (one half shown)
4: Sample coupon
5: Composite support rods (2x)
6: Capacitive displacement sensor in mounting flange

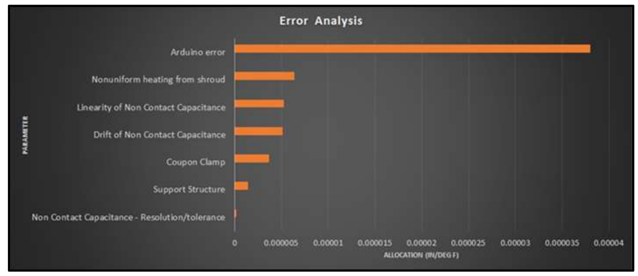
Initially, a smaller prototype structure was 3D printed, which was capable of levitating a magnetic ball. However, the electromagnet was unable to handle the greater mass of the test coupon clamp, and produced a significant amount of heat due to the current draw. When moving to the final structure, a larger electromagnet was purchased. In addition to having a better lifting capacity, the larger electromagnet required less current to pick up the clamp. This meant that significantly less heat was produced when in operation.

3D Printed Prototype Levitating a Magnetic Ball



Final Structure Levitating Clamp and Test Coupon

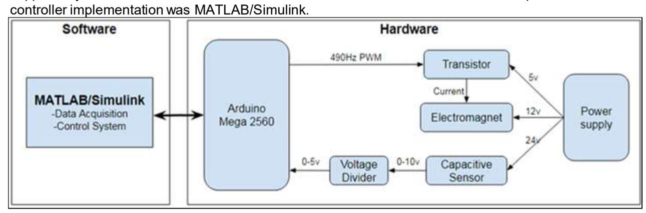
Error Budget



The most significant source of error comes from the resolution of the analog to digital converter that measures the output signal from the displacement sensor. Sensor error parameters, effects from nonuniform heating of the sample, and expansion effects in the structure followed. Several parameters that were considered but ended up being negligible included: temperature effect from the electromagnet heating the sample, consistency of magnetic field, electrical noise in connectors, and interference of magnet in sensor readings.

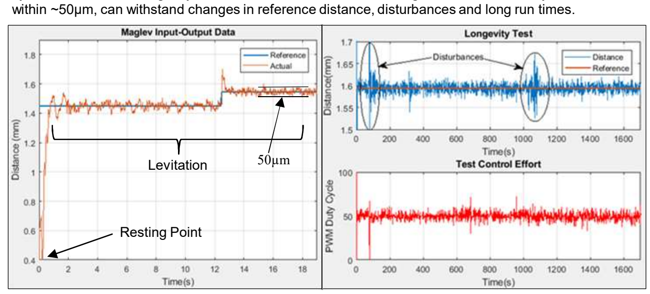
Electrical Components

The electrical system design uses a combination of hardware and software. The hardware portion of the system includes the electromagnet, diode, transistor, feedback sensor, Arduino Mega 2560, 15k and 10k resistors, and a 100μF electrolytic capacitor. The electromagnet is powered on a $12V_{DC}$ rail that is switched on and off through use of a MOSFET and pulse width modulation (PWM) signal supplied by the Arduino microcontroller. The software that was used for data acquisition and PID controller implementation was MATLAB/Simulink.

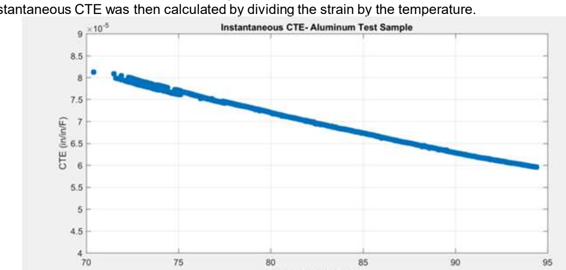


Results

The electrical system enabled the clamp and coupon to levitate. The figures below show how the system reacts to an initial reference distance, how it reacts to a change in reference, and how the system withstands a longevity test with added disturbances. The figures show that the system is stable within ~50μm, can withstand changes in reference distance, disturbances and long run times.



The aluminum test coupon was heated to 90°F, and then allowed to return to room temperature. Deflection data was taken from the cap sensor, converted to inches, and used to calculate strain. Instantaneous CTE was then calculated by dividing the strain by the temperature.



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Slide 1

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James Fisher, 11/30/2017