DIY Affordable, Low-Resolution Stylus Profilometer

Hannah Bickham, Emilee Dicken, Natalie Jaecks, Niklaus Zora, Nadia Hannon, Claire Sexton, Colby Jeffus, Sulaiman Kazi, Danielle Pettinger, Nathaniel Heathman, Ryan Benavides, Jacob Grodin, Kristin Norris, Abhishek Routray, Yu-Chuen Chang, Tanya Hutter and Michael Cullinan
Walker Department of Mechanical Engineering, The University of Texas at Austin, Austin, Texas 78712, USA

APPENDIX D: Electronics Diagrams and Instructions

Supply List:

a. SHNITPWR 24V DC Power Supply 24 Volt 5A 120W (1)
b. Adjustable LM2596S DC-DC Buck Converter Reduced Voltage Regulator Power Module (1)
c. DROK Micro Boost Voltage Converter DC 4.8-35V to DC ±15V Positive Negative Dual Output (1)
d. Arduino Uno REV3 (1)
e. Arduino-to-PC USB connector (1)
f. ADS1115 A/D 16-bit Converter (1)
g. SparkFun Motor Driver - Dual TB6612FNG (1)
h. TE Connectivity DC-EC 050 Linear Variable Differential Transformer (1)
i. 100 ohm resistors (2)
j. Bemonoc 12V DC Low Speed 60 RPM Gear Motor with Encoder (1)
k. Breadboard(s) [quantity depends on size of breadboard]
l. Jumper wires (60)
m. Personal Computer with USB port and Arduino IDE compatibility (1)

Useful Tools:

a. Multimeter (1)
b. Soldering Kit (1)
c. Pliers (1)
d. Digital Calipers (1)

Instructions for Assembly:

1. Acquire each required electronic part and assemble with jumper wires and a breadboard (or normal solid wires and PCBs if desired) as shown in the following wiring diagram:

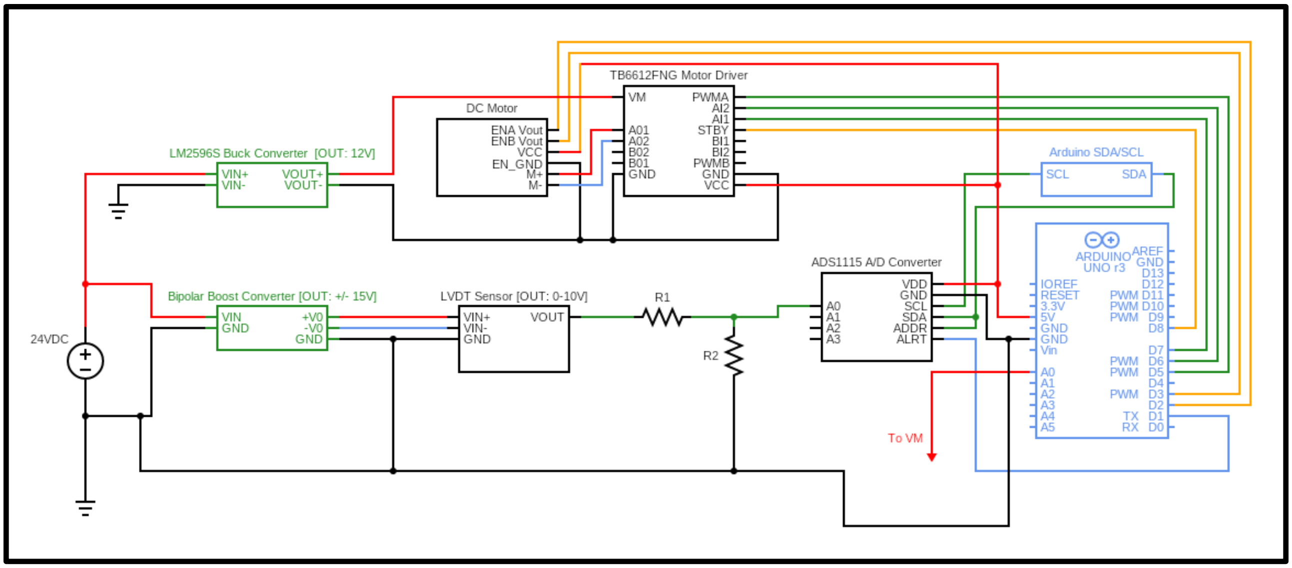

Figure D.1. Circuit Wiring Diagram

2. The buck converter modules must be tuned to their proper voltages.
   a. With a small flathead screwdriver, turn the metallic knob clockwise or counterclockwise.
   b. The OUT LED display will display the output voltage the buck converter is set to.
   c. Specific questions can refer to the documentation that is provided with the buck converter modules.
3. The LVDT sensor must be handled with EXTREME CARE.
   a. DO NOT OPERATE THE LVDT WITHOUT THE CORE PLACED IN THE OPERATIONAL RANGE. AN EJECTED CORE OR DISPLACED CORE CAN CAUSE A SUBSTANTIAL DROP IN INPUT IMPEDANCE RESULTING IN PERMANENT OVERHEATING DAMAGE TO THE SENSOR.
   b. Ensure that each LVDT lead is connected correctly in the circuit. Double and triple check this each time it is operated or rewired.
   c. When testing or diagnosing problems in other parts of the circuitry, it is highly recommended that you completely detach and de-energize the LVDT sensor.
   d. If the option is available to you and the limitations of an open core are cumbersome, it is strongly recommended to consider a “captive-core” LVDT option that prevents damage in the above manners.
   e. In the prototype LVDT:
      i. Red wire goes to the +15 Bipolar Boost Converter terminal
      ii. Black wire goes to the -15 Bipolar Boost Converter terminal
      iii. Green Wire goes to the signal common bus.
      iv. White wire goes to the voltage divider resistance network as the output voltage of the LVDT sensor.

4. Power Supply
    a. The power supply AC-DC transformer can be connected directly to the outlet. It should be placed on a breadboard's power bus and connected to the Bipolar Boost converter and the step down buck converter.
5. Arduino and A/D Converter
    a. The Arduino UNO R3 must derive power from the computer USB port.
        i. IT MUST NOT SHARE POWER WITH THE 24 V ACDC Transformer. THIS WILL DAMAGE THE ARDUINO.
    b. The A/D Converter requires a 0-5 VDC supply voltage to operate correctly. Do not alter the wiring connections outlined in the above figure.

Calibration Instructions:

Before the LVDT sensor can be used, it must be properly calibrated. There are two steps to the calibration process: (1) Null voltage calibration and (2) sensitivity calibration for correction. After the sensor is calibrated, the profilometer will be ready for scanning setup and operation.

1. Set up the profilometer to take LVDT vertical readouts only with the “ReadSingleValue” Arduino Script.
2. Upload the Code to the Arduino and open the Serial Monitor.
3. Detach needle assembly and prepare to move the core to the factory rated null position.
4. Measure from the top of the stylus assembly lead screw down to the top of the core to find where core position must be moved to.
5. With a multimeter, measure the DC voltage from the white LVDT output lead (red multimeter probe) to the green LVDT signal common (the black multimeter probe).
6. Begin the test by testing the factory-rated null position. If the voltage is 0 (or very near 0), then the null is found and no further action is necessary. If not, a procedure is established to quickly find the null.
7. Digital calipers will be used to measure the amount of upper screw exposed past the endstop. The LVDT core will not be moved in relation to the screw during the test. Measure and record the thickness of the endstop.
8. The endstop can be rotated to expose more or less screw, thus changing the internal core position. To calculate the position in relation to the outer body of the LVDT, use this equation:

$$CorePosition = RatedCorePosOnScrew - (ScrewLengthExposed + EndStopThickness)$$

This equation will give the exact position within the outer body that the LVDT core must be placed.

9. Place CorePosition at 0, then proceed to approximately 0.5 mm past the rated stroke range of the LVDT.
    a. For example, with a stroke range of +/-1.25 mm, extend the CorePosition value (by increasing or decreasing ScrewLengthExposed) by 1.25 mm.
    b. This will be the starting point for the test. On each side of the maximum stroke range, take a voltage reading.
    c. Depending on the outcome of the trial, the “bracket” that the null will be in will decrease. Eventually, the test will narrow to a thin band of possible positions. This will be the effective null position.
    d. It should be noted that the null may not be reached exactly. A voltage reading within approximately 500 mV is sufficient for a proper reading.
10. Each trial will use a root finding bracketing method to find the null.
    a. First trial will begin at maximum and minimum of testing range.

b. Each trial will consist of a readout from above and below the theoretical null.
c. Range will be eliminated according to the following outcomes:
    i. Voltage on one side is (+) and the other is (-)
        1. Result: Null is in this range, choose new values with lesser difference (i.e. closer together) and test again.
    ii. Voltage on both sides is (+)
        1. Result: Null position is above this range, lower voltage range becomes max distance value. Decrease lower bound distance to return to negative value.
    iii. Voltage on both sides is (-)
        1. Result: Same as two but now have a new minimum value.
    iv. Voltage on one position is 0
        1. Result: Found exactly!

11. Once the null position is found, the sensor calibration can begin. The calibration relates the digital readout to the actual position and corrects any inaccuracies that may exist.
    a. NOTE: MOST LVDT MANUFACTURERS CONDUCT THEIR OWN LINEAR CALIBRATION TEST. THIS DATA IS USEFUL TO MEASURE AGAINST, BUT SHOULD BE VERIFIED BY ANOTHER CALIBRATION.
12. For this testing, readouts will be taken from multiple positions in relation to the null voltage. The length of screw exposed, voltage reading, A/D Converter bit reading, and profilometer position readout should all be recorded.
    a. A spreadsheet is recommended for this data collection process, either Excel or Google Sheets.
    b. Ensure that the correction_factor and bit_noise values in the Arduino code are set to 1 and 0 respectively before proceeding. The next test will determine these values.
13. Begin with the null position and record data. The bits recorded with “ReadSingleValue” code is noise and represents a baseline bias. This bit value must replace the bit_noise quantity in the “FinalizedProductCode” in the Arduino script.
14. Further readings should be recorded at desired increments and placed in a spreadsheet.
    a. In the spreadsheet, reference all positions to the null (i.e. null is 0). The difference between the null distance read by the calipers and the null distance read by the program composes the ‘error’ in the profilometer.

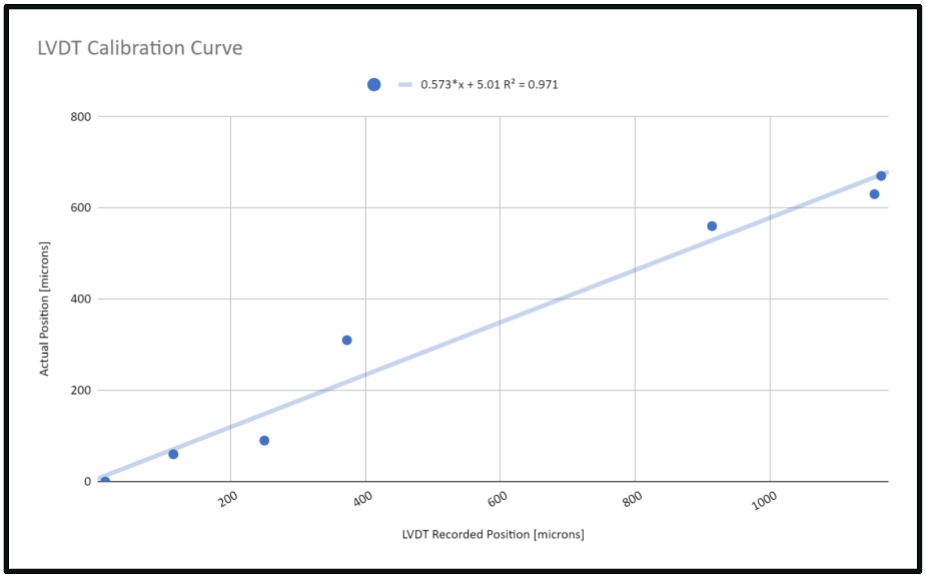

Figure D.2. LVDT Calibration Curve

   b. Map the two values against one another with the profilometer reading on the x-axis and the caliper-recorded measurement on the y-axis. The figure above shows what the calibration curve should look like.

15. Using spreadsheet software, a linear regression can be created with the data. The slope of this curve provides the correction_factor value for the Arduino code. Input this value to the script after conducting the experiment.
    a. This value corrects any scaling issues. The figure above shows that the real value is only 57% of what the profilometer reads out. Ideally, the correction_factor should approach unity.

<u>Instructions for Use</u>

1. The profilometer must be operated within accepted ranges or data will be invalid.
2. Begin by uploading the “PID_gains” script to Arduino. Using the Serial monitor and included instructions, the motor can be controlled in real time to move the stage back and forth.
   a. Note: This step is only necessary if the stage startpoint is not desired. If the stage is starting in a desirable position, skip this step.
3. Next, upload the “ReadSingleValue” script to the Arduino. Ensure the calibrated values previously recorded are placed in the script.
4. Lower the stylus tip to the material surface with the z-axis handle until the readout from the serial monitor shows the middle of the range. (If the full range is 600 microns, place the tip at 300 microns.)
   a. WARNING: NOTE THAT THE MATERIAL BEING TESTED MUST FALL WITHIN A CERTAIN RANGE. SEE THE FIGURE BELOW AND ONLY USE MATERIALS THAT ARE ABOVE THE LINE

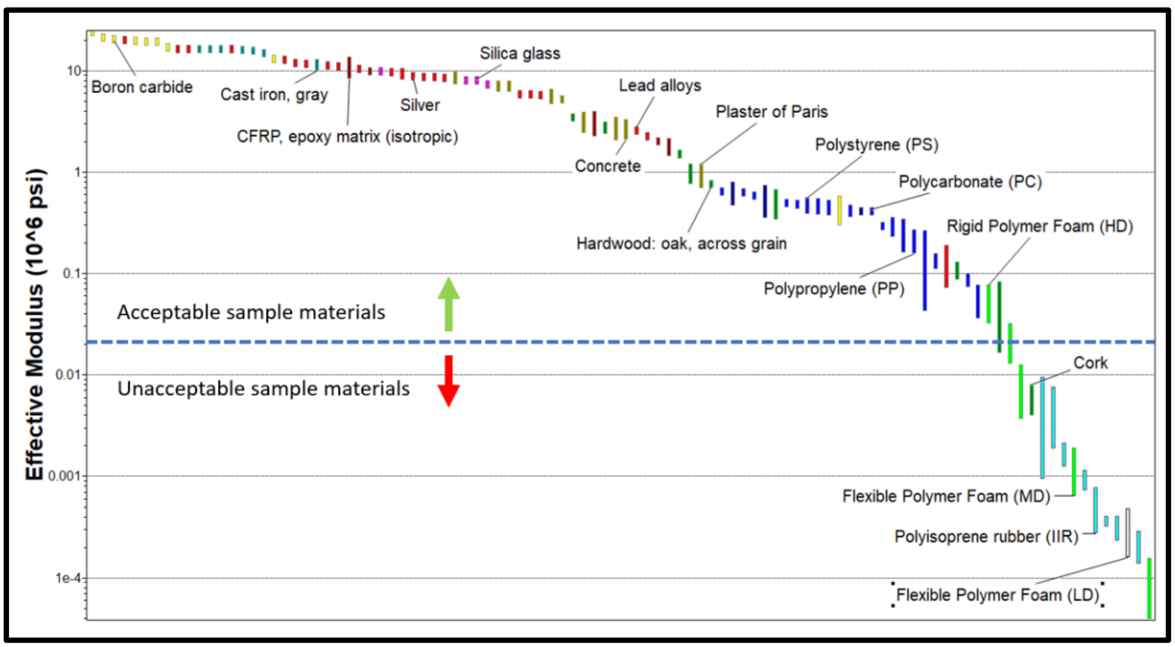

Figure D.3. Allowable Materials Curve

5. Lock the z-axis in place with the set screw and upload the “FinalProductCode” script to the Arduino.
6. Open the “Python_control.py” script in the Spyder console.
7. Double check the length of scan and scanning speed desired.
   a. Do not exceed a speed of 1.0 rad/s for the scan. The data at a higher rate of speed will be highly inaccurate.

8. If acceptable, simply press “Run” on the python code after ensuring all circuitry is plugged in and connected.
9. The scan will complete and a .csv file will be placed in the python file directory.
   a. It is recommended to process this data in an Excel spreadsheet or Google Sheet.
   b. Data must be processed and analyzed carefully. After the scan’s end the position recordings will be set to 0.
   c. If the voltage drops negative (outside the range of the LVDT) the bits counted by the A/D converter will maximize. This data is invalid.
   d. Data that reaches the maximum value recordable may not be accurate, as clipping will occur as the voltage exceeds what the A/D converter will read.