

Lab 1: Pressure Transducer Calibration and Hysteresis

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I. Introduction

This is a report on the data collected in session one on Wednesday, January 24th that analyzes the pressure and current recorded from both the transducer and manometer while varying the flow velocity in the wind tunnel. Two sets of data were recorded, one while increasing flow velocity, and one while decreasing the flow velocity. Over the course of the report, these two sets of data will be compared and hereafter referred to as simply 'increasing' or 'decreasing'.

II. Manometer Pressure Calculation

Manometer pressure values, were calculated in Pascals using equation (1), where h is the recorded height of the manometer, adjusted for the initial offset. The density of water used was 997.71 kg/m^3 , while the gravitational constant used was 9.81 m/s^2 .

$$P_{\text{manometer}} = \rho_{\text{water}}gh \quad (1)$$

III. Analysis of Data for Hysteresis

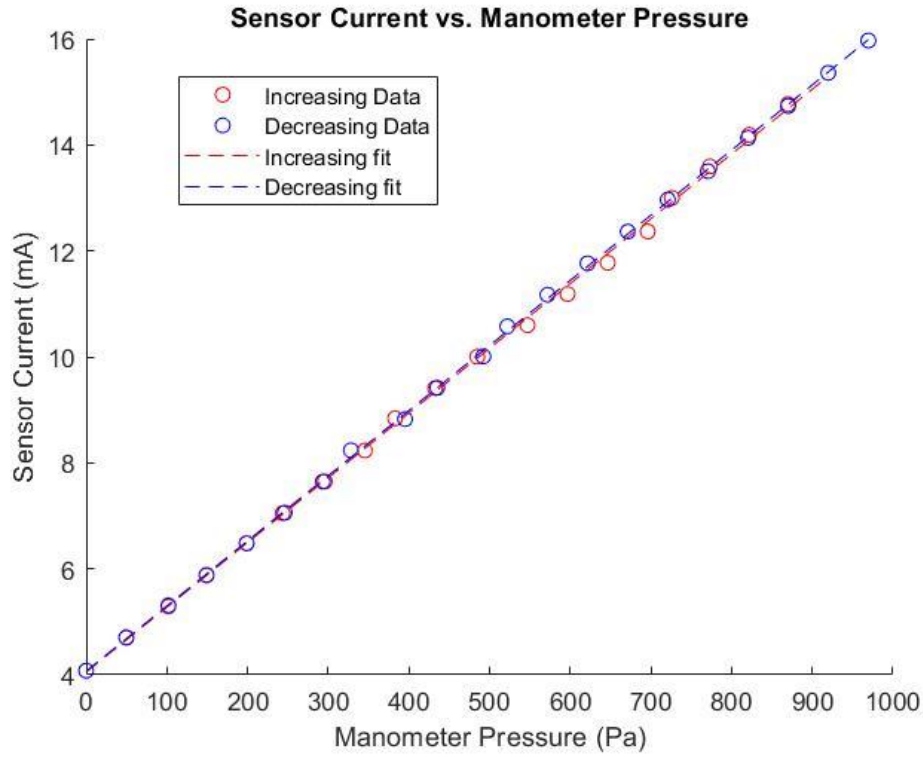


Figure 4. Sensor Current vs. Manometer Pressure. Shows the linear regressions for both the increasing and decreasing data sets when plotting current against pressure. The slopes of the regression lines are the calibration factors, which, if close, mean that the system is well calibrated and there is little or no hysteresis.

The calibration factors of the increasing (2) and decreasing (3) data sets are represented by the slope of the corresponding line of best fit in Fig. 4, which plots sensor current against manometer pressure.

$$y = 0.0122 * x + 4.0518 \quad (2)$$

$$y = 0.0123 * x + 4.0695 \quad (3)$$

These two slopes differ only by 0.816%, as shown through the percent difference equation (4), indicating that if hysteresis is present, it is minimal. The slopes here are represented by variable m .

$$^3\text{Percent difference} = \frac{|m_{\text{increasing}} - m_{\text{decreasing}}|}{\left| \frac{m_{\text{increasing}} + m_{\text{decreasing}}}{2} \right|} \quad (4)$$

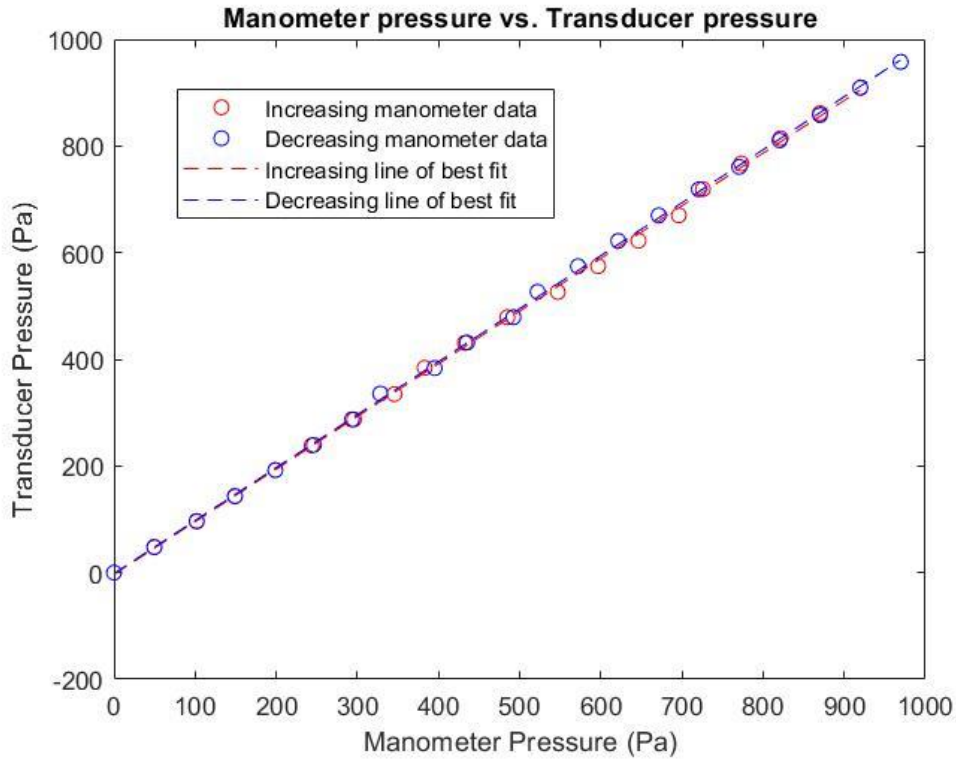


Figure 1. Manometer Pressure vs. Transducer Pressure. Shows the linear regressions for both the increasing and decreasing data sets when plotting manometer pressure against transducer pressure. The slope of the linear lines should be equal to one if there is no discrepancy between the sets of data

Fig. 1, which plots transducer pressure readings against the manometer pressure readings, reinforces the idea that the data lacks hysteresis. The linear regression slopes should equal one in this case if the transducer data are identical to the manometer data, but as the data are not identical, the slopes as shown by equations (5) and (6) instead equal 0.9874 and 0.9933, for the increasing and decreasing sets, respectively. While these calibration factors are not exactly equal to one, they are extremely close, each being only a couple hundredths off, illustrating the negligibility of the data variation.

$$y = 0.9874 * x - 3.3743 \quad (5)$$

$$y = 0.9933 * x - 1.7110 \quad (6)$$

To be thorough, if calculated using the lines of best fit for the calibration curves in Fig. 4, there is approximately only 0.567% hysteresis for the entire data set. To calculate approximate hysteresis, the lines of best fit for the increasing and decreasing data sets were used as a basis. The midpoint between the first and last data point was found with the midpoint equation (7), and then the hysteresis was calculated with the hysteresis percentage equation (8).

$$x_{midpoint} = \frac{x_{max} - x_{min}}{2} + x_{min} \quad (7)$$

$$^{1,2,4}Hysteresis\ Percentage = \left| \frac{y_{midpoint\ upper} - y_{midpoint\ lower}}{y_{max} - y_{min}} \right| * 100 \quad (8)$$

Where values were not the same between increasing and decreasing sets, the average of the two was used. The y-values for the upper and lower midpoints refer to the linear regressions, and as shown in Fig. 4, the upper

regression corresponds to the decreasing data set. The x-value for the midpoint was used to calculate both midpoint y-values in junction with the linear regression equations (2) and (3). The values used for the calculations are as follows, with the x-values being pressure in Pascals, and the y-values being current in milliamps:

$$x_{max} = 919.8325, \quad y_{max} = 15.36, \quad x_{min} = 0, \quad y_{min} = 4.0785$$

$$y_{midpoint\ upper} = 9.727, \quad y_{midpoint\ lower} = 9.663$$

It should be noted that total hysteresis is typically calculated with two parallel lines, and in this case the lines of best fit are not parallel; however, the lines differ only slightly, so they were used for this approximate hysteresis calculation. With the variation in the calibration factors at a near-negligible level already, an estimation of hysteresis is suitable. Calculation shows that hysteresis is not present, as the percentage is small enough that other factors are likely the cause of the inconsistencies between the increasing and decreasing data sets.

IV. Sources of Error

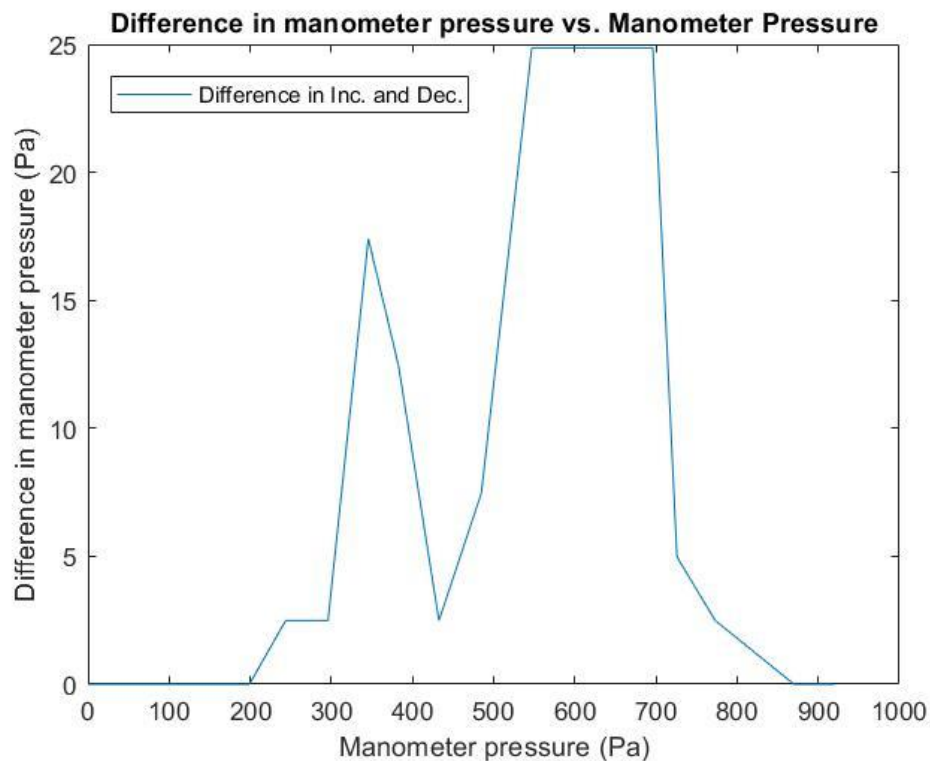


Figure 3. Manometer Pressure Difference. Displays the total (absolute value) difference in manometer pressure plotted against manometer pressure to show the discrepancy between the increasing and decreasing data sets.

Knowing the method of data collection involved reading from the manometer and adjusting propeller tilt, which both were not entirely exact, the low level of hysteresis can likely be attributed to human error and slight variations in flow. In Fig. 3, the difference in the manometer readings from increasing to decreasing can be seen to increase significantly at around the 600 Pascal mark. This difference does not take the transducer into account,

and as it is only comparing the manometer readings, it shows that primarily the variation in the data occurred because of the human-recorded manometer data.

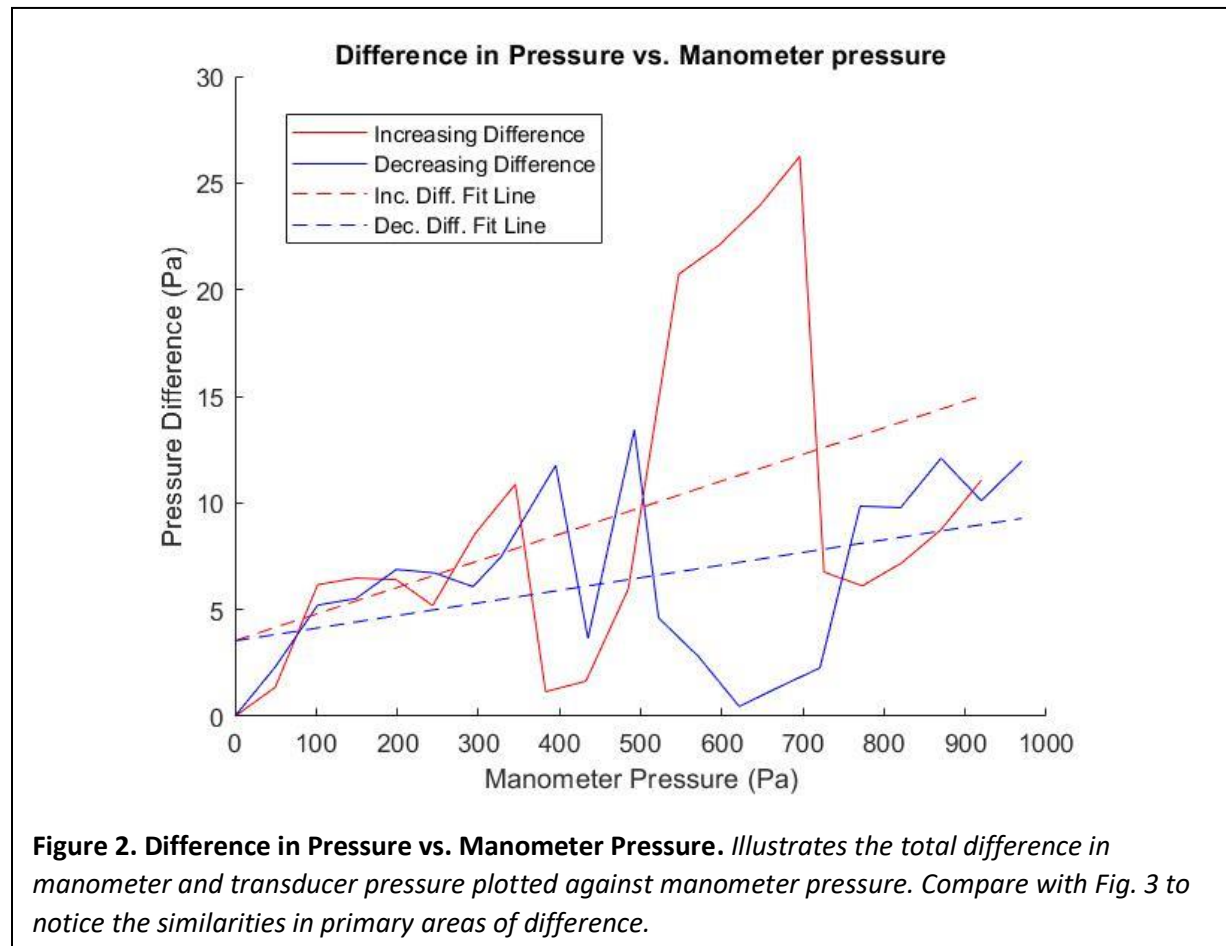


Fig. 2 also shows a difference in pressure reading, but instead compares the difference between the transducer and manometer readings. In combination, the figures portray that there was some inaccuracy in the transducer readings, but the inaccuracy can be mainly attributed to the manometer error, as the same spike in difference can be seen at around the 600 Pascal mark.

V. Accuracy of Transducer Calibration

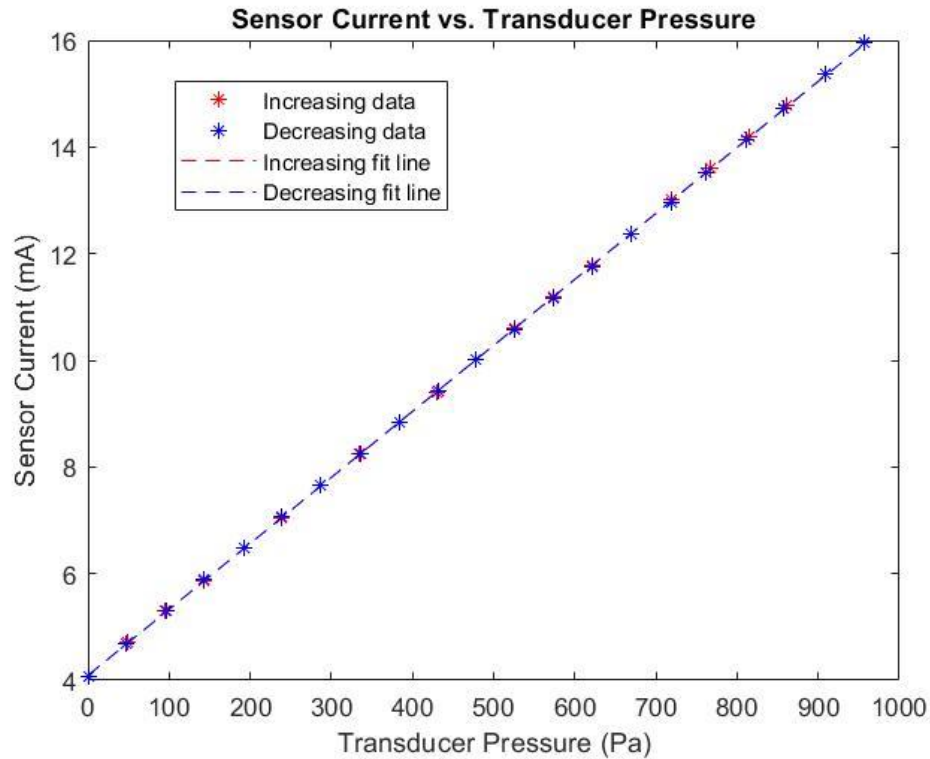


Figure 5. Sensor Current vs. Transducer Pressure. *Compares the two almost identical linear fits of the increasing and decreasing data recorded from the transducer, indicating correct calibration.*

Looking at the transducer readings alone, represented in Fig. 5, there is almost no distinction between the two lines of best fit, each having almost the same slope, which further indicates that the main source of error was in the manometer readings. Lack of distinction between the two calibration factors for the transducer data also indicates that the device is calibrated correctly, as it displays even less of a sign of hysteresis than that of the manometer data. The linear fit equations for the increasing and decreasing transducer data are represented by equations (9) and (10), in which the slopes are equal, and the intercept values differ by only two-thousandths.

$$y = 0.0124 * x + 4.0933 \quad (9)$$

$$y = 0.0124 * x + 4.0910 \quad (10)$$

VI. Appendix

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% Loading data and sorting in ascending order
incdat = sort(load('inc.dat'),'ascend');
decdat = sort(load('dec.dat'),'ascend');

% Extracting manometer heights and adjusting for initial height reading and
% adjusting to correct units (inches to meters, 1 inch = .0254 m)
hinc = 0.0254*(incdat(:,2) - incdat(1,2)); % data already sorted so that zero reading
is first element
hdec = 0.0254*(decdat(:,2) - decdat(1,2));
% Calculating Manometer Pressure (rho*g*h, where rho is the density of water in SI
and g is the gravitational constant)
rho = 997.71; % kg/m^3
g = 9.81; % m/s^2
pcalc = @(h) rho.*g.*h; % anonymous function for below calculations
ipress = pcalc(hinc);
dpress = pcalc(hdec);

% Extracting transducer pressure readings and converting from psf to N/m^2
% 1psf = 47.88026 Pa
transi = 47.88026*(incdat(:,1));
transd = 47.88026*(decdat(:,1));

%% Pressure Plots
% Plotting manometer pressure vs. sensor pressure
figure(1)
plot(ipress,transi,'ro')
hold on
plot(dpress,transd,'bo')
% Lines of best fit
linfiti = polyfit(ipress,transi,1);
linfitd = polyfit(dpress,transd,1);
fitLinei = polyval(linfiti,ipress); % polyval for applying it to the data
fitLined = polyval(linfitd,dpress);
% Plotting those lines and graph details
plot(ipress,fitLinei,'r--')
plot(dpress,fitLined,'b--')
legend('Increasing manometer data','Decreasing manometer data','Increasing line of
best fit',...
'Decreasing line of best fit');
title('Manometer pressure vs. Transducer pressure')
ylabel('Transducer Pressure (Pa)');
xlabel('Manometer Pressure (Pa)');

% Plotting difference between increasing and decreasing as compared to
% transducer readings and plotting (mano - trans)
figure(2) % new figure for differences
hold on
diffi = abs(ipress - transi); % difference in increasing (manometer - transducer),
absolute value for difference
diffd = abs(dpress - transd); % difference in decreasing
plot(ipress,diffi,'r');
plot(dpress,diffd,'b');
title('Difference in Pressure vs. Manometer pressure');
xlabel('Manometer Pressure (Pa)');

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ylabel('Pressure Difference (Pa)');
diffifit = polyfit(ipress,diffi,1);
diffdfit = polyfit(dpress,diffd,1);
diffiLine = polyval(diffifit,ipress);
diffdLine = polyval(diffdfit,dpress);
plot(ipress,diffiLine,'r--');
plot(dpress,diffdLine,'b--');
legend('Increasing Difference','Decreasing Difference','Inc. Diff. Fit Line','Dec.
Diff. Fit Line');
%% Plotting difference between increasing and decreasing pressures from manometer
alone
% shows human error
diffmano = abs(ipress - dpress(1:20)); % only first 20 elements of dec. pressure
values to match the 20 inc. vals
figure(3)
plot(ipress,diffmano);
xlabel('Manometer pressure (Pa)');
ylabel('Difference in manometer pressure (Pa)');
title('Difference in manometer pressure vs. Manometer Pressure');
legend('Difference in Inc. and Dec.');
```

%% Sensor Current vs. Manometer Pressure

% Getting values for current from data file, with current in mA

% (1e-3 mA = 1 A)

incAmps = (incdat(:,3)); % mA in the third column

decAmps = (decdat(:,3));

% Current vs. Pressure plot

figure(4)

hold on

plot(ipress,incAmps,'ro'); % Increasing data plot

plot(dpress,decAmps,'bo'); % Decreasing data plot

% Fit lines and plotting

ampfiti = polyfit(ipress,incAmps,1); % Increasing fit

ampfitd = polyfit(dpress,decAmps,1); % Decreasing fit

ampLinei = polyval(ampfiti,ipress); % Increasing line

ampLined = polyval(ampfitd,dpress); % Decreasing line

plot(ipress,ampLinei,'r--');

plot(dpress,ampLined,'b--');

% Graph details

ylabel('Sensor Current (mA)');

xlabel('Manometer Pressure (Pa)');

title('Sensor Current vs. Manometer Pressure');

legend('Increasing Data','Decreasing Data','Increasing fit','Decreasing fit')

%% Extra Credit: Sensor Current vs. Transducer Pressure Readings

% Transducer pressure vs sensor current plot

figure(5)

plot(transi,incAmps,'r*')

hold on

plot(transd,decAmps,'b*')

% Fit lines and plotting

transampfiti = polyfit(transi,incAmps,1);

transampfitd = polyfit(transd,decAmps,1);

plot(transi,polyval(transampfiti,transi),'r--');

plot(transd,polyval(transampfitd,transd),'b--');


```
% Transampfiti and transampfitd have the same slope, which means that the
% transducer is correctly calibrated. There is only slight deviation
% between the lines of best fit, that's why the blue dotted line seems to
% almost completely cover the red dotted line.

% Graph details
xlabel('Transducer Pressure (Pa)');
ylabel('Sensor Current (mA)')
title('Sensor Current vs. Transducer Pressure');
legend('Increasing data', 'Decreasing data', 'Increasing fit line', 'Decreasing fit line');
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VII. References

- ¹Morris, K.A., "What is Hysteresis?," Department of Applied Mathematics, University of Waterloo, Waterloo, Ontario, URL: https://uwaterloo.ca/applied-mathematics/sites/ca.applied-mathematics/files/uploads/files/morris_hysteresis_final.pdf
- ²Sethna, J.P., Kuntz, M., Dahmen, K., Perkovic, O., Kartha, S., Krumhansl, J.A., Roberts, B.W., Shore, J.D., "What's Hysteresis?," *Avalanches, Hysteresis and Noise*, Cornell University, Ithaca, New York, 1999, URL: <http://www.lassp.cornell.edu/sethna/hysteresis/WhatIsHysteresis.html>
- ³WebAssign, "Percent Error and Percent Difference," 2013, URL: http://webassign.net/question_assets/ncsucalcphysmechl3/percent_error/manual.html
- ⁴ "Explanation of hysteresis calculation," Missouri University of Science and Technology, Rolla, MO, Word Document URL: <http://web.mst.edu/~cottrell/ME240/Resources/Calibration/Explanation%20of%20Hysteresis%20calculation.doc>