MAE 3340 Laboratory Exercise 1

Dimensional Metrology

Introduction:

Precise mechanical measurements are critical to the construction and assembly of mechanical components and systems. This laboratory exercise compares the resolutions and accuracies of several displacement measurement tools with gage block displacement standards traceable to NIST.

Equipment:

Measuring sensors for this lab include:

- Steel rules
- Vernier Calipers
- Dial Calipers
- Electronic Calipers
- Micrometers

Gauge Blocks: are "precision ground, lapped length measuring standards used as a reference for the calibration of measuring equipment used in machine shops, such as micrometers, sine bars, calipers, and dial indicators"[1]. Gauge blocks are the main means of length standardization used by industry. Gauge block accuracies are determined by grade as defined by the most recent ASME standards (ASME B89.1.9 2003). The gauge block set used in the MAE 3340 lab is a 'B' calibration standard, with tolerances *of* $\pm 8\,\mu in$[2]. Further information is available from NIST[3].

ASME (US)

Length Over –	Up to	Accuracy at 20°C (µinch) Grade 1	Grade 2	Grade 3	Grade B**
	1"	±2	+4 –2	+8 –4	+10 –6
1" –	2"	±4	+8 –4	+16 –8	+20 –12
2" –	3"	±5	+10 –5	+20 –10	+30 –18
3" –	4"	±6	+12 –6	+24 –12	+40 –24

**This grade is not specified by GGG-G-15C.

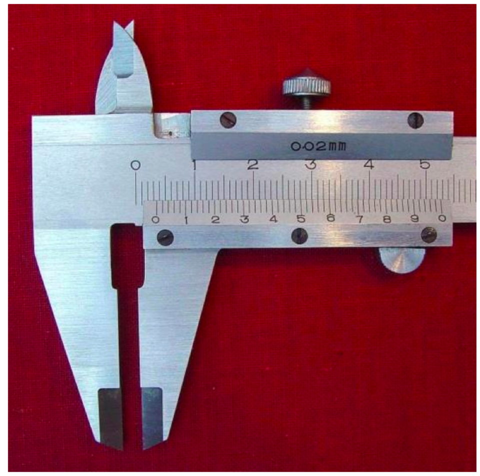
Table 1: ASME Standards for Gage Block Machining Accuracy

Micrometer: "a device incorporating a calibrated screw used widely for precise measurement of small distances in mechanical engineering and machining … Micrometers use the principle of a screw to amplify small distances that are too small to measure directly into large rotations of the screw that are big enough to read from a scale. The accuracy of a micrometer derives from the accuracy of the thread-form that is at its heart".[4]

The micrometer requires the user to adjust the spindle so that the measuring flats make secure, but not compressive contact with the part to be measured. Some micrometers have a torque-limiting ratchet to prevent over-torqueing. Reading a displacement measured by the micrometer is explained in the figure on the right[5]. In this figure, the measurement is 0.275" plus 0.001" for a 0.276" measurement.

MAE 3340, Instrumentation Systems

Calipers: "a device used to measure the distance between two opposing sides of an object. A caliper can be as simple as a compass with inward or outward-facing points. The tips of the caliper are adjusted to fit across the points to be measured, the caliper is then removed and the distance read by measuring between the tips with a measuring tool, such as a ruler"[8] or by directly reading the displacement with an embedded scale, as shown in the photo at right[9].



Definitions:

Sensor zero: The reading value of the sensor when the measured displacement is zero. Many sensors have a scale adjustment to mechanically or electrically set the zero. In other cases the value at zero must be recorded and subtracted from the final measurement.

Resolution: the smallest increment of change in the measured value that can be determined from the instruments scale. By using judicious interpolation, the actual resolution is smaller than the minimum scale used by the sensor. ***For analog sensors, select one half to one third of the minimum marked resolution.***

Repeatability: Defined as the variation in repeated measurements of the same quantity *(measurand)*. The repeatability of a sensor can be estimated by taking repeated measurements until a reasonably consistent set of data is gathered. The standard deviation of this data can be used to describe the repeatability uncertainty. (Remember that the zero value also has an uncertainty), where n=number of measurements (*samples*) taken, and x_i is an individual sample.

"Sample Standard Deviation"
"Standard Error" "sigma"
"random Error"

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\rightarrow U_{repeatability} \approx S_x = \sqrt{\sum_{i=1}^{n}\frac{\left(x_i - \bar{x}\right)^2}{n-1}}$$

Total Measurement Uncertainty: The uncertainty of each measurement will be a "Root Sum Squared" (RSS) combination of the resolution and the repeatability:

$$U_{total} = \sqrt{U^2_{repeatability} + U^2_{resolution}}$$

"sigma"^2

Operator Error: Students should also be aware of beware of operational errors, where the operator can have an impact in the measuring process by disturbing the sensor measurement. This is especially true with the dial indicators. *Operator error is considered to be a systematic error that cannot be removed from a measurement set, once taken*. Be sure you know how to use the devices!

Laboratory Exercise:

This exercise compares the resolutions and accuracies of steel rules, micrometers, and calipers and with gage block displacement standards traceable to NIST. This objective is to compare the measurement of multiple sets of gauge blocks using these sensors and determine whether or not the sensor accuracy lies within the expected error limits.

Each student team will use up to 5-6 gauge blocks with varying dimension, make sure you record the nominal dimension of each block you receive. Each student in the group will measure each block using (in order)

- Steel Rule
- Vernier Caliper
- Dial Caliper
- Electronic Caliper
- Micrometer

A) Populate the example Table 2 below for each block (there should be at least 2 readings per student for each device, add columns as necessary. As required students may perform necessary calculations "off line" after lab. Modify Table as required to fit all data. There should be a table for ***each*** gage block measured. Compare the calculated uncertainty in the data of Table 2 to the values listed by Table 1.

Table 2: Example Data Table for Individual Gage Block Measurements

Nominal Gage Block Dimension: +Uncertainty: -Uncertainty:	Student 1	Student 2	Student 3	Student 4	Student 5	$\bar{X}$	$U_{repeatability}$	$U_{resolution}$	U_{total} **Root-Sum-Squared**
Steel Rule									
Vernier Caliper									
Dial Caliper									
Electronic Caliper									
Micrometer									

Students will build their own spreadsheet file here!

OK to Attach .xlsx Spreadsheet file here

B) Once each individual gauge block has been measured by each student using each instrument, take blocks together and "wring" them together to form a single measurement gauge. The uncertainty of the single gauge block dimension is determined the columns of Table 1 for the "B" standard. The uncertainty for two wrung block is calculated by a "Root Sum Squared" (RSS) method:

$$U_{total} = \sqrt{U_{block1}^2 + U_{block2}^2}$$

This value will be compared to the total measurements uncertainty calculated in the table below.

Select 4 combinations of "wrung" gage blocks, and each student will measure these combinations using each of the above instruments. Populate the example Table 3 below. There should be a table for ***each*** "wrung" combination measured.

Table 3: Example Data Table for Individual Gage Block Measurements

Nominal "Wrung" Gage Blocks Dimension: +Uncertainty: -Uncertainty:	Student 1	Student 2	Student 3	Student 4	Student 5	$\bar{X}$	$U_{repeatability}$	$U_{resolution}$	U_{total}
Steel Rule									
Vernier Caliper		***Students will build their own spreadsheet file here!***							
Dial Caliper									
Electronic Caliper									
Micrometer									

References.

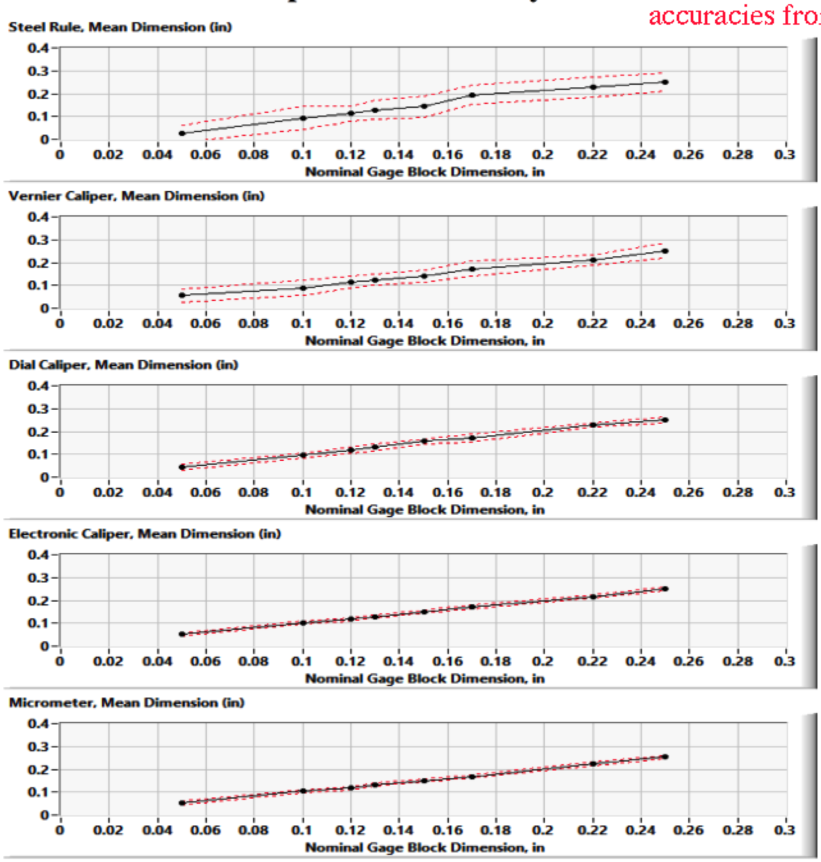
1. http://en.wikipedia.org/wiki/Gauge_block
2. Mitutoyo General Catalog, 2010
3. NIST Monograph180a "The Gauge Block Handbook"
4. http://en.wikipedia.org/wiki/Micrometer
5. Photograph taken by Glenn McKechnie, licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license.
6. http://en.wikipedia.org/wiki/Dial_indicator
7. Photograph taken by Glenn McKechnie, licensed under the Creative Commons Attribution-Share Alike 2.0 Generic license.
8. http://en.wikipedia.org/wiki/Caliper
9. Photograph from ArtMechanic, distributed via GNU Free Documentation License

Lab Report Format:

1. Team Name/Section #
2. **Individual Student Name:**
3. **Executive Summary:**
4. ***Fully Populated* Data Tables for All Data (See Table 2 and Table 3 Examples)**
5. **Graph of Results.**
    a. Plot the measured "mean" dimensions from each gage block trial for each instrument. The measured data should be plotted on the Ordinate (y-axis), and the nominal dimension value should be plotted on the Abscissa (x-axis).
    b. Be sure to include the dependent value error bars or uncertainty boundaries.
    c. Plot the data in ascending order of dimension. It is recommended that you plot the data on a separate graph for each measurement instrument. Be sure to include the "wrung" data measurements and the corresponding uncertainties on each plot.
    d. See example summary plot below. Be sure that your plots are large enough to be legible!
6. **Compare the observed uncertainty boundaries to the manufacturing uncertainties of the gage blocks.**
    a. What can you conclude?
    b. Does the true value (as determined from the gauge block) lie within each error band for each sensor?
    c. Discuss this topic in your report.

Compare the calculated uncertainty boundaries to the expected gauge block accuracies from Table 1.

Example Data Summary Plot



Mean Value of a Random Sample

• The mean value (μ) of a random population is what is commonly Referred to as the "average" … *it is the most likely value to occur* … more on this in the next section

… for a sample of n members $\{x_i\}$, selected at random from the population we can Represent the *mean* by the *"Sample mean"* $\bar{x}$

$$\mu \approx \bar{x} = \frac{x_1 + x_2 + x_3 + \ldots x_n}{n} = \sum_{i=1}^{n} \frac{x_i}{n}$$

• For error quantification … *mean error can be considered as bias*

Standard Deviation of a Random Sample

• A random sample will always vary about the mean .. And a Quantification of this variability is referred to as the "***standard Deviation***" σ … *the square of the standard deviation is called the* ***"variance"***

… for a sample of ***n*** members, selected at random from the population we can true variance by the "sample variance" S_x

$$\sigma \approx S_x = \sqrt{\frac{\left(x_1 - \bar{x}\right)^2 + \left(x_2 - \bar{x}\right)^2 + \ldots \left(x_n - \bar{x}\right)^2}{n-1}} = \sqrt{\sum_{i=1}^{n} \frac{\left(x_i - \bar{x}\right)^2}{n-1}}$$

• … *standard deviation is used to quantify the random error In a measurement*

Overall Measurement Uncertainty

• The overall uncertainty of a measurement will be a combination of the bias uncertainty and the precision uncertainty

• If we can account for the bias we take it out … otherwise bias is modeled as an uncertainly

• The overall uncertainty is the Root-sum-square (RSS) of the Bias and random uncertainty + other *independent* classifiable errors like hysterysis, calibration, etc.

$$U_{total} = \sqrt{\mu_{bias}^2 + \underbrace{\sigma_{random}^2}_{\text{“repeatability”}} + u_{hysteresis}^2 + u_{resolution}^2} \ldots etc$$

Graphical Presentation of Data (1)

A graph should be used when it will convey information and portray significant features more efficiently than words or tabulations.

Graphs should:

1) Require minimal effort from the reader in understanding and interpreting the information it conveys
2) The axes should have clear labels that name the quantity plotted, its units, and its symbol
3) Axes should be clearly numbered and should have tick marks for significant numerical divisions. Typically, ticks should appear in increments of 1, 2, or 5 units. Not every tick need be numbered. Too many will clutter the axis.
4) Use scientific notation to avoid placing too many digits on the graph.

Graphical Presentation of Data (2)

5) When plotting on logarithm axes, place ticks at powers of 10 and minor ticks at 10, 20, 50, 100, 200, etc.

6) Axes should usually include 0.

7) The choice in scales and proportions should be commensurate with the relative importance of the variations shown in the results.

8) Use symbols, Not dots, for data points. Open symbols should be used before closed. ***When allowed USE COLOR!***

9) Either place error bars on the plot that indicate uncertainty or use symbols that are the size of the uncertainty.

10) When several curves appear on the same plot, use different line styles to distinguish them. Avoid using colors.

Graphical Presentation of Data (3)

11) Minimize lettering on graphs

12) Labels on the axes and curves should be oriented to be read from the bottom or from the right. Avoid forcing the reader to rotate the figure to read it.

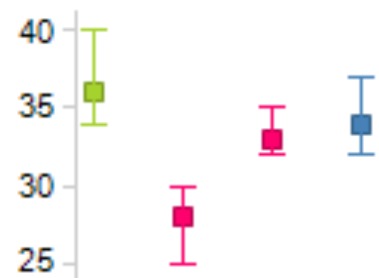
13) The graph should have a descriptive but concise title.

14) When plotting points collected from multiple trials use "error bars" to show the accuracy range for each sample.

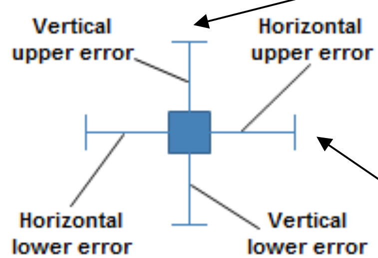
Bottom Line- You want to communicate information to your reader. The burden to get your point across falls to you. The chances of successfully communicating your point are improved considerably when you make it easy on the reader. Never think of your plot as pretty graphics. If that is all it is, you should remove it.

Graphical Presentation of Data (5)

Average	Upper Error	Lower Error
36	4	2
28	2	3
33	2	1
34	3	2



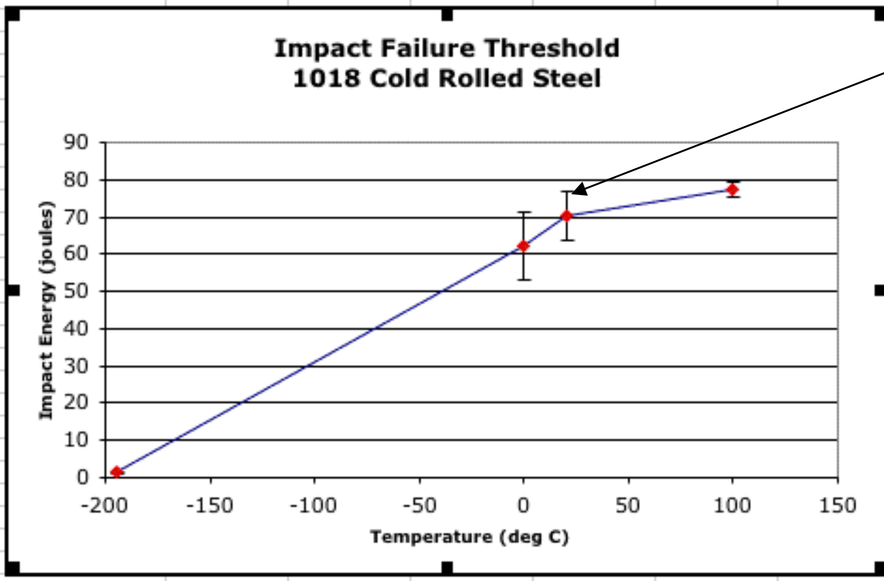
Error in Dependent Variable



Error in Independent Variable

Graphical Presentation of Data (6)

	Temperature (C)			
	-195	0	20	100
Impact Energy	1	52	48	74
(joules)	1	58	66	82
	2	82	74	72
	1	35	86	80
	2	84	78	79
Mean	1.4	62.2	70.4	77.4
Standard Deviation	0.5	20.8	14.4	4.2
Standard Error	0.2	9.3	6.5	1.9



$\pm$Error (U_{total}) in Dependent Variable

Graphical Presentation of Data (7)