

AE3145 Laboratory #1

Geometric Dimension Measurements and Deflectometer Calibration

Purpose:

The purpose of this lab is to familiarize the student with some of the basic instruments and procedures used to measure dimensions and displacements. The student will also learn how to apply analytical techniques to analyze the resulting data and to present this information in meaningful ways.

Procedures:

Dimensional Measurement

The dimensional measurement portion of the lab will examine how to measure the geometric dimensions of several mechanical parts and to compute areas, perimeters and moments of inertia which are commonly required for analysis of structural members. These measurements will be made using the direct comparison method. You will use familiar linear scales (rulers) as well as vernier calipers and micrometers.

Each student group will be given several specimens with different shapes and/or cross sections.

- 1 The geometric dimensions of each specimen will be measured using three different length measuring instruments:
 - linear scale (ruler)
 - vernier caliper
 - micrometer
- 2 Using these measurements, the student will then calculate certain quantities particular to the specific object. These may include volumes, cross sectional areas, cross sectional centroids and area moments of inertia, or mass moments of inertia about a particular axis.

Displacement Measurement

Measurement of displacements is not easily carried out by direct comparison with a reference such as is done when using a micrometer. Instead, displacement measurements are generally made using precalibrated systems involving sensor-detectors, transducers, signal conditioners, and a recording device. We will calibrate a linear variable differential transformer (LVDT) or a strain gaged ring using a micrometer and then we will use these transducers to calibrate a sensitive pneumatic displacement gage.

- 1 You have before you two displacement transducers. One is a linear variable displacement transformer (LVDT), one of the most widely used kinds of displacement transducers. This transducer is actually a very small transformer in which a movable ferrous core is used to couple the primary windings to two differentially connected secondary windings. The rectified output from the secondary windings is proportional to the position of the core, and this is the basis for using the differential transformer as a displacement transducer. The lab

appendix has a brief description and more details are in the recommended lab textbook. The second is a ring gage fitted with electrical resistance strain gages. **NOTE: When using the LVDT's, please be very careful to observe the polarity and magnitude of the applied input voltage. A mistake could damage the LVDT.**

- 2 You also have a micrometer table (small table on precision bearings moved by a micrometer) that will be used in to calibrate the displacement transducers. Turning the micrometer barrel moves the table the distance displayed on the micrometer scale. Set up the table and clamp the displacement transducer to it. Arrange the table so that the transducer can be moved towards a fixed reference surface. After establishing the reference condition, record approximately 20 data points for the calibration curve. Make sure you consider both advancing and retracting displacements in order to assess hysteresis.
- 3 Next, use the calibrated displacement transducer to calibrate the Precisionaire pneumatic displacement instrument. This instrument is quite sensitive and will respond to very small displacements. Data acquisition will be difficult and time consuming! Gather about 10 or 15 data points using the micrometer table simply as a positioning table and not as a calibration standard (due to the high sensitivity of the Precisionaire transducer).

Data Analysis

The analysis of data from this experiment should include the following items as a minimum. Analyze and discuss any other issues raised by the lab TA's.

- 1 From the dimensional measurements of the given objects, find the volume of one object, the centroid and principal mass moments of inertia of another, and the area centroid and principal area moments of inertia of the third.
- 2 Estimate the uncertainties in the quantities computed in #1 using uncertainty analysis and making assumptions about the uncertainties in the primary measurements.
- 3 From the transducer calibration data, determine the appropriate calibration constants for each transducer using the method of least squares as implemented in the Excel spreadsheet program. Report and analyze only the slope and not the intercept (which can be removed in practice by re-zeroing the instrument).
- 4 Estimate the uncertainty in the slope measurements from #3 at a confidence level of 95% (determine the confidence limits around the computed calibration slope). You may want to consult the recommended lab text and the Microsoft Excel documentation.

Appendix A – Getting Off to a Good Start in AE3145

Here are some lab tips to help you get the best possible grades on these labs.

Tables:

- All tables should be neatly constructed following a logical order and clearly identifying the independent and dependent variables. Use only single input single output or two input single output tables.
- All data in the tables should have appropriate and consistent units given.
- All tables should be numbered and have titles that can be referenced.

Graphs:

- Make sure graphs are titled and all axes are labeled.
- Place graphs on the page after the data is presented in tabular form.
- The data that you actually take in the lab (the experimental data) should be shown as plot symbols; use different symbols for different data sets.
- Any theoretical curves should be shown as lines without symbols (use different line styles to differentiate more than one curve).
- Use a legend if more than one dataset is plotted in a single figure.

Other:

- In your report, answer ALL questions posed in the lab assignment as well as all questions added during the lab session.
- Follow the formats closely. Each major section should start a new page. Use headings for subsections. (MS Word has heading styles that can readily be used for this purpose).
- If you have questions, please contact the TA's by email at the addresses given at the start of the semester. If they cannot answer your questions, contact the course instructor by email.
- Don't wait too long to start on the report. You will start to forget details and conversations very quickly! Even making an attempt at a skeleton report may stimulate questions that can be addressed earlier rather than at the last minute!

Appendix B – Lab Report Outline

Lab Report formats can be highly varied but the general structure is well-defined. Corporations may have slight variations in the basic format, just like different journals have slight variations in styles for articles. The following is the minimum format requirements for the AE3145 lab reports. It closely follows the format for the AE3010 lab and is repeated on the lab web pages. If you have questions or want to make significant deviations, please consult with one of the lab TA's first.

- 1. Title Page**
- 2. Abstract** – A brief summary of the contents of the report, including the conclusions but not the numerical details unless they are extremely important (approximately 200 words).
- 3. Introduction**
 - a. Background information on the lab topic
 - b. List of objectives of the experimental work
 - c. Discussion of the underlying theory.
- 4. Instrumentation and Procedure**
 - a. Test apparatus design
 - b. Test specimen design or selection
 - c. Instrumentation
 - d. Uncertainty analysis or error analysis
 - e. Test procedures
- 5. Results and Discussion**
 - a. Data in tabular form (put most in appendix if more than 2 pages are required)
 - b. Data in graphical form
 - c. Calculations – include worked out samples of calculations carried out.
 - d. Comparison with theory
 - e. General implications
- 6. Error Analysis**
 - a. Sources of error and their evaluation
- 7. Conclusions**
- 8. Appendices** (don't continue section numbers; use A, B, or I, II, etc)

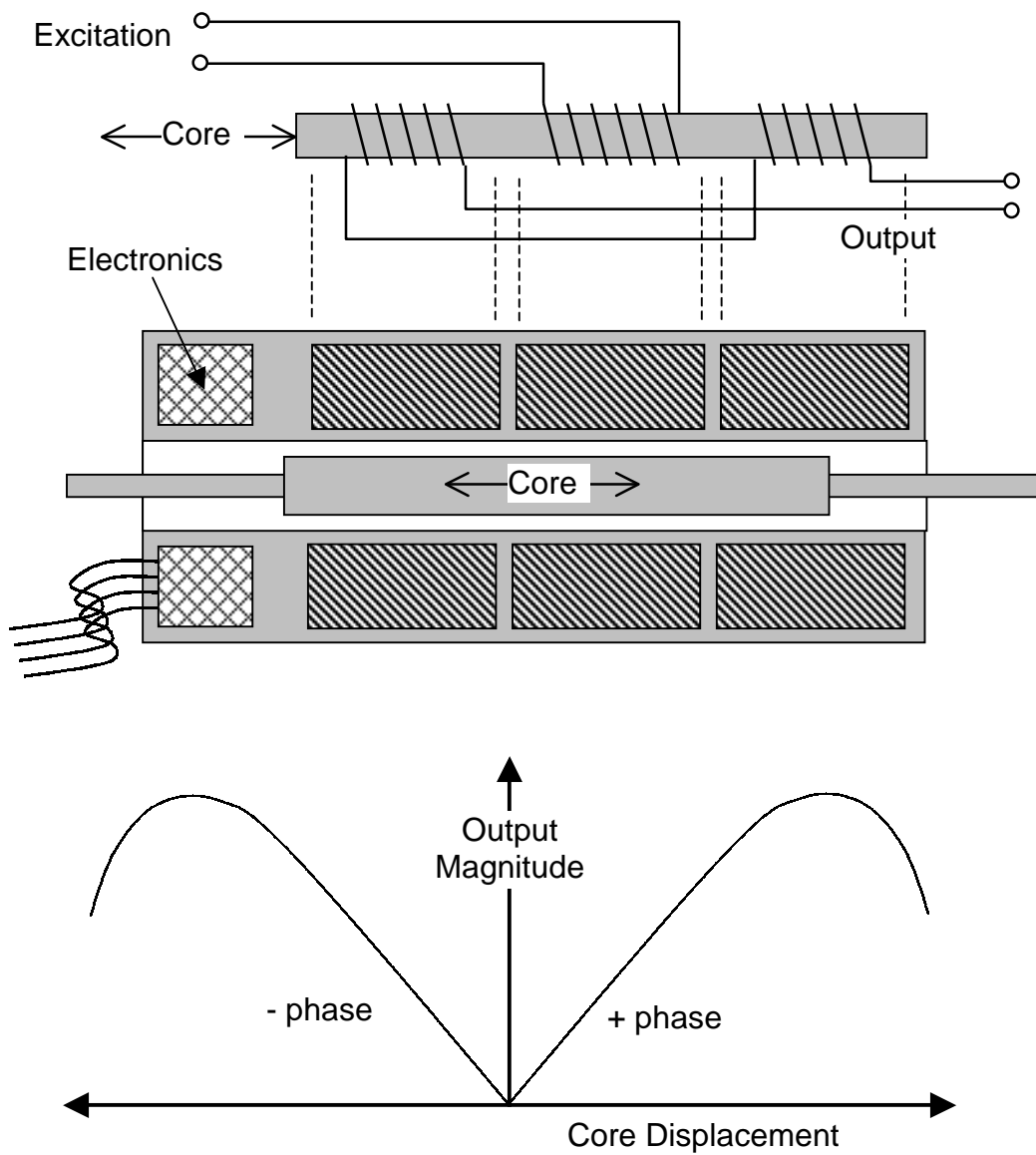
Appendix C – The Linear Variable Differential Transformer

One of the most useful of the many variable inductance transducers is the differential transformer or more specifically the so-called Linear Variable Differential Transformer or LVDT. This displacement transducer provides an output voltage proportional to the displacement of a ferrous core passing through the windings of the transformer. It is a mutual inductance device making use of a primary and two secondary windings arranged generally as shown in the figures below.

The primary winding is energized from an external AC source. For some designs such as those used in the lab, the external source is a DC source that powers an AC generator (oscillator) contained within the transducer body. The two secondary, or pickup, coils are connected together differentially in phase opposition. When the core is perfectly centered, the output of each secondary coil is equal in magnitude but opposite (0, 180 degrees) in phase and so they cancel exactly to yield a zero output. As the core is moved one way or the other, the magnitudes change and the phase indicates in which direction the motion is taking place (with a +/- 180 degree phase change).

Typical LVDT characteristics are shown in the figure below which shows electrical output versus core position. For purely AC devices, external signal conditioning is needed to generate the AC excitation (typically in the 1kHz to 5 kHz range) and to detect the output magnitude and phase angle changes. The more popular DC devices incorporate a small oscillator in the transducer body to provide the AC excitation and include the circuitry to condition the secondary coil outputs in order to provide a purely DC output signal. Because the zero position is often quite difficult to achieve, the transducer behavior near this region is usually less accurately defined than in the regions to either side. For excessive core displacements, the output begins to deviate from linearity as shown. In general, the range is primarily dependent on the length of the secondary coils and the core itself.

Purely AC devices are electrically very resistant to temperature changes and can operate under high levels of pressure or even nuclear radiation. For DC devices, the built-in signal conditioning circuitry often limits the application environment. Devices with ranges up to 12 inches or more are available. Devices that respond to rotary motion are also produced (often called RVDT's). Sensitivities to more than 50 volts per inch can be achieved. For very small displacement ranges, it is necessary to carefully control the core motion in order to minimize radial movement within the transformer body. For longer ranges, simple teflon lined core tubes are often used. Changing the core material will change the transducer sensitivity and require another calibration.



Mechanical and Electrical Construction of an LVDT Showing Typical Output Voltage Magnitude

Appendix D - Lab Problems

The following lab problems are designed to reinforce the lecture material presented on analysis of uncertainty in the measurement process. The following problems each involve computing an estimate of the uncertainty of the computed variable based on either bias or precision (random) uncertainties (or both) in the various independent variables and parameters.

1. The buckling load, P , for a pin-ended column is given by the well-known formula:

$$P = \pi^2 \frac{EI}{L^2} = \frac{\pi^2 Ebt^3}{12L^2}$$

where L =column length, b =cross section width, t =cross section thickness and E =modulus of elasticity. The weight of the column is simply: $W=\rho LA=\rho Lbt$ where ρ =weight density. Using this, it follows that the weight of a column that is designed to support an axial load of up to P without buckling is given by the formula:

$$W = \frac{L^2 \rho}{\pi} \left[\frac{12bP}{Et} \right]^{1/2}$$

If the bias uncertainties (at 95% confidence intervals) in the measurements of the variables used to compute W are estimated to be the following:

Variable	Value	Bias Uncertainty (95%)
L (length)	40 in.	±0.3%
b (width)	3 in.	±0.07%
t (thickness)	0.35 in.	±0.04%
E (modulus)	10.3e6 psi	±6%
ρ (density)	0.098	±3%
P (load)	594 lbs	±20 lbs

Find the uncertainty in W and compute the smallest weight estimate.

2. The deflection of a shallow spherical shell at the point of application of the load, P , (the apex) is given by:

$$u = \frac{\sqrt{3(1-\nu^2)}}{4} \frac{Pa}{Et^2}$$

The variables in this equation are measured to the accuracies shown and these are assumed to be measures of the precision (random) error:

Variable	Value	Precision Uncertainty (95%)
E (modulus)	10.6e6 psi	±8%
t	0.032 in	±0.004%
a (radius)	26 in	±2%
ν (Poisson's Ratio)	0.32	±0.03%
P (load)	200 lbs	±2 lbs

Determine the single measurement uncertainty at a 95% confidence for the deflection, u , neglecting any bias errors for this case. Remember that the computed precision uncertainty must be increased by an additional factor to account for the added uncertainty associated with a single sample ($N=1$) as shown in the notes. Determine the maximum deflection you might expect to measure at a 95% confidence level for this case.

3. The maximum deflection, d , at mid-span of a simply supported timber beam is limited by design codes to be no greater than, $d \leq L/240$, where L is the span in inches. The beam deflection under a uniform load, w , can be computed from beam theory to be:

$$d = \frac{5}{384} \frac{wL^4}{EI}$$

where E =modulus, w =uniform load (lbs/inch) and I_{yy} is the cross section area moment of inertia about the transverse (y) axis. Assume the following bias uncertainties in each of the variables shown:

Variable	Value	Bias Uncertainty (95%)
E (modulus)	1.8e6 psi	±200,000 psi
L (length)	250	±2 in
b (width)	5.50	±0.12 in
h (depth)	12.50	±0.12 in

Determine the uncertainty in the computation of the uniform load and determine the maximum value that would be allowed by code at a 95% confidence level.