Date of lab:

Precalculations – Individual Portion Mechanical Measurements Lab: Measurement of Mechanical Quantities



1. (7) In the eddy current dynamometer setup, a clever device is used to directly measure torque. As seen in the sketch to the right, mass *m* is attached to a wheel of radius *R*, and is lifted up as torque $T_{applied}$ is applied (counterclockwise) to the wheel. Gravity provides a constant downward force W = mg, but the moment arm (torque arm) *r* increases as the weight moves up in elevation, causing an increase in the counteracting (clockwise) torque $T_{counteracting}$. The wheel is stationary when $T_{applied} = T_{counteracting} = T$, which is read directly on the torque scale built into the instrument. Derive an expression for torque *T* as a function of weight *W*, radius *R*, and angular displacement θ , showing all your algebra for full credit.



2. (6) From the analysis above, does torque increase *linearly* or *nonlinearly* with angular displacement θ ? Explain.

3. (7) The scale on the eddy current dynamometer torque gage reads torque in units of oz-in (force in ounces multiplied by moment arm in inches). If the reading is 130. oz-in, what is the torque in Newton-meters? If the shaft rotation rate is 1750 rpm, calculate the shaft power in watts. For full credit, show all your work, including unit conversions for both calculations. *Note*: Save your equations, because you will need them to do this lab.

Cover Page for

Lab 11

Lab Report – Group Portion

Mechanical Measurements Lab: Measurement of Mechanical Quantities

Name 1:	Section M E 345
Name 2:	Section M E 345
Name 3:	Section M E 345
[Name 4:	Section M E 345]
Date when the lab was performed:	

Group Lab Report Score (For instructor or TA use only):

Lab experiment and results, plots, tables, etc.	/ 50
Discussion	/ 30
TOTAL	/ 80

Lab Participation Grade and Deductions – The instructor or TA reserves the right to deduct points for any of the following, either for all group members or for individual students:

- Arriving late to lab or leaving before your lab group is finished.
- Not participating in the work of your lab group (freeloading).
- Causing distractions, arguing, or not paying attention during lab.
- Not following the rules about formatting plots and tables.
- Grammatical errors in your lab report.
- Sloppy or illegible writing or plots (lack of neatness) in your lab report.
- Other (at the discretion of the instructor or TA).

Name	Reason for deduction	Points deducted	Total grade (out of 80)

Comments (for instructor or TA use only):

Lab 11, Mechanical Measurement Lab Page 2

Mechanical Measurements Lab: Measurement of Mechanical Quantities

Author: John M. Cimbala; also edited by Mikhail Gordin and Savas Yavuzkurt, Penn State University Latest revision: 31 January 2013

Introduction and Background (*Note*: To save paper, you do *not* need to print this section for your lab report.) Instruments of various kinds have been invented to measure *mechanical quantities*, such as position (or

displacement), velocity, angular velocity, acceleration, force, torque, and shaft power. Many of these instruments are discussed in detail in the related learning module. In this lab, you get some hands-on experience with several of these instruments. There are seven experimental stations set up for this laboratory. Lab groups rotate between the seven stations (in any order); each lab group must complete all seven experiments within one lab period. *No group should spend more than about 20 minutes at any one station.* Occasionally, your group may have to wait a few minutes for an open station. A short description of each experimental setup is given below:

Linear displacement measurement - LVDT

One way to measure displacement is with a *linear variable differential transformer*, also sometimes called a *linear variable displacement transducer* (both abbreviated *LVDT*). An LVDT is an electrical-magnetic device in which a ferromagnetic *core* or *plunger* moves within electrical coils. When supplied with an AC voltage input, the coils produce an AC *output* voltage that varies with position of the core. Over a certain range, the output voltage of the transformer (typically either the rms value or the peak-to-peak amplitude) can be calibrated *linearly* with displacement of the plunger. In this experiment, the calibration curve for a commercial LVDT will be generated. An accurate mechanical traversing system (micrometer calibration stand) is used for the calibration.

Linear displacement measurement - Ultrasonic transducer

Another method for measuring displacement or thickness is with sound waves, using devices called *ultrasonic transducers*. The principle of operation is very simple: the time it takes for a sound wave to travel through the material is measured, and the distance of travel is calculated by multiplying this measured time by the known speed of sound in the material. In this lab, the *pulse-echo* mode of operation is used. In our device, a piezoelectric crystal is used as both the transmitting and receiving sensor. Ultrasonic transducers are particularly useful for thickness or depth measurement when limited spatial access to the sample is available. The sound speed through a solid object is a function of the material and sometimes also the geometry. Therefore, in some cases, ultrasonic transducers can be used to identify unknown materials. For example, if the thickness of the object is measured with some other instrument, the ultrasonic device can be used to measure the speed of sound in the material, which can then be used to help identify the material. Ultrasonic transducers can also be used to determine the presence of internal voids or cracks. This type of testing belongs to a large category called *non-destructive testing*, or *NDT*. In this lab, an ultrasonic transducer is used to measure the thickness of some metal and plastic specimens.

Linear displacement measurement - Laser displacement meter

A convenient way to measure displacement *with no physical contact* is with a *laser displacement meter*. The device transmits a laser beam, and a photodetector senses the beam after it reflects off an object. Electronics inside the laser displacement meter infer the distance to the object by sensing changes in the angle of the reflected beam. The laser displacement meter used in this laboratory has an operating point of 80.0 mm (3.15 inch), with a measurement range of $\pm 20 \text{ mm} (\pm 0.78 \text{ inch})$ away from this operating point. Outside of this range, the instrument displays an error. In this experiment, each student measures the thickness of his/her fingers.

Angular velocity measurement - Tachometers

The angular velocity of a rotating shaft can be measured by a variety of devices, both *contacting* and *noncontacting*, and both *mechanical* and *electronic*. All such devices are called *tachometers*. In this experiment, a *tachometer calibrator* is used to provide rotating shafts of known rpm. This device consists of an electric motor spinning at constant rpm, coupled with a transmission box (gear box) that provides several other rotating shafts of known constant rpm. Several tachometers are used in this lab, including a purely mechanical contacting *dial gage tachometer*, a *contacting electronic tachometer*, and a *noncontacting stroboscopic tachometer*.

Torque and shaft power measurement - Prony brake dynamometer.

In this experiment the output (torque, rpm, and shaft power) of an *AC induction motor* is measured with a *prony brake dynamometer*. In this device, power from the electric motor is absorbed by purely *mechanical friction* in a braking mechanism. The *load* on the motor is controlled by adjusting tension in a brake band, thereby changing the torque. Shaft rpm is measured with a tachometer, and force is measured with a mechanical spring force gage (a

common fish scale). Torque is calculated by multiplying the measured force by its moment arm, or *torque arm*, which is also measured.

Torque and shaft power measurement - Cradled DC motor dynamometer.

In this experiment the output (torque, rpm, and shaft power) of an AC induction motor is measured with a *cradled DC motor dynamometer*. In this device, power from the electric motor is absorbed by a DC motor running "backwards" as a *generator*. The load on the motor is controlled by adjusting the electrical resistance of a resistor bank connected to the generator, thereby changing the torque. Shaft rpm is measured with a tachometer, and torque is measured directly with a mechanical spring torque gage. (This gage is really just a force gage, but the units on the scale are those of torque – the torque arm is known and fixed in the experimental setup, and thus torque is directly proportional to force.)

Torque and shaft power measurement - *Eddy current dynamometer*.

In this experiment the output (torque, rpm, and shaft power) of an AC induction motor is measured with an *eddy current dynamometer*. In this device, power from the electric motor is absorbed by a *fluctuating magnetic field*. The load on the motor is controlled by adjusting the electromagnetic field strength, thereby changing the torque. Shaft rpm is measured with a tachometer, and torque is measured directly with a torque gage. The scale on the torque gage is calibrated to the torque produced by gravity acting on a weight that increases the moment arm as it rises in elevation.

Objectives

- 1. Become familiar with the electrical input, output, and calibration of an LVDT.
- 2. Use an ultrasonic transducer to measure the thickness of several samples.
- 3. Apply a laser displacement meter to measure the thickness of students' fingers.
- 4. Obtain hands-on experience with several kinds of tachometers.
- 5. Obtain hands-on experience with three types of dynamometers.
- 6. Investigate the torque, shaft speed, power, and efficiency characteristics of AC motors.

Equipment

- For the *LVDT* experiment:
 - LVDT with removable core
 - o mechanical traversing system (micrometer calibration stand)
 - o function generator
 - o hand-held micrometer
 - o digital oscilloscope
 - o somebody's room key
- For the *ultrasonic transducer* experiment:
 - o ultrasonic transducer transmitting and receiving electronics instrument
 - o ultrasonic transducer head
 - digital oscilloscope
 - hand-held micrometer
 - o specimens of various materials and thicknesses:
 - aluminum (nominally 1/4 inch thick)
 - aluminum (nominally 1/2 inch thick)
 - aluminum (nominally 3/4 inch thick)
 - brass (nominally 1/2 inch thick)
 - cold rolled steel (nominally 1/2 inch thick)
 - Lucite (Plexiglas) (nominally 7/8 inch thick)
 - lubricating oil
 - paper towels (to wipe up any mess from the oil)
- For the *laser displacement meter* experiment:
 - o laser displacement meter with digital readout
 - laboratory test stand
 - DC power supply, set to 12.0 V

- For the *tachometer* experiment:
 - goggles (eye protection *must* be worn around rotating machinery)
 - o tachometer calibrator
 - o contacting mechanical dial gage tachometer
 - o contacting electronic tachometer
 - o stroboscopic tachometer
 - vibrating cantilever beam tachometers (two of them just for rough estimates)
- For the *prony brake dynamometer* experiment:
 - o goggles (eye protection *must* be worn around rotating machinery)
 - AC induction motor
 - o prony brake dynamometer
 - o ruler or tape measure
 - o contacting electronic tachometer
 - stroboscopic tachometer
- For the *cradled DC motor dynamometer* experiment:
 - o goggles (eye protection *must* be worn around rotating machinery)
 - o AC induction motor
 - o cradled DC motor dynamometer
 - o 2 digital multimeters (DMMs)
 - o contacting electronic tachometer
- For the *eddy current dynamometer* experiment:
 - goggles (eye protection *must* be worn around rotating machinery)
 - \circ AC induction motor
 - o eddy current dynamometer
 - o stroboscopic tachometer (you may use if you prefer, but the optical tachometer is easier)
 - optical tachometer (make sure a strip of reflecting tape is on the shaft, or the optical tachometer will not work properly)

 V_0 to ch. 2

-0

oscilloscope

Procedure

Separate procedures are provided below for each of the seven experiments. Wiring diagrams and other details are provided for completeness, but in most cases, the experiments have already been set up and wired.

Procedure for the LVDT Experiment

- 1. Connect the output of the function generator to the first channel of the oscilloscope as sketched to the right. Adjust the output voltage to approximately a 3.00 V peak-to-peak sine wave at 2500 Hz. This same AC supply voltage will later be applied to the inner, main coil of the LVDT.
- 2. Adjust the time (horizontal) scale of the oscilloscope so that 4 or 5 periods of the sine wave are clearly visible on the screen.
- 3. Apply this same voltage to the input lines (main coil) of the LVDT. Use a tee connection (parallel) so that this voltage can be monitored on the oscilloscope as well.



Red wire

Yellow/red wire

- 4. Connect the red and black output lines from the LVDT to the second channel of the oscilloscope, as sketched.
- 5. Verify that the LVDT is working by manually lifting up the core. If working properly, the peak-to-peak output voltage should change as the core is moved up and down.
- 6. (1) Adjust the micrometer traverse as necessary to locate the *null point* of the LVDT, which occurs when the core is exactly in the middle of the unit. At this point the output should theoretically be zero, but in practice, there may be some minimum non-zero null voltage. Record both the micrometer reading and the peak-to-peak voltage reading this point will be assigned as the null point, i.e., zero displacement. *Note*: Adjust the vertical scale (volts/div.) for channel 2 to maximize the accuracy of the reading.

Micrometer reading at null point = _____ mm

Peak-to-peak voltage reading at null point = _____ V

7. *Note*: You may put a small mark (with a pencil, not a pen!) on the traverse crank to aid in counting crank turns. The micrometer traversing screw is designed such that the core moves 0.50 mm for every full 360 degree turn of the crank. Carefully count four turns such that the core is displaced 2.00 mm *upwards*. Record the peak-to-peak output voltage at this point in the table below at a traverse displacement of 2.00 mm.

Core displacement (mm)	Peak-to-peak voltage (V)
0	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	

8. (1 for #6,7,8) Continue in increments of 2.00 mm (4.00, 6.00, 8.00 ... mm) until the core is displaced 20.00 mm (2.000 cm) upwards. Adjust the vertical scale as necessary, especially when the oscilloscope warns that the signal is *clipping*.

- 9. (1) For upward displacement of the core, record the *phase* of the output voltage relative to that of the input voltage. In other words, do the phases match, or are they 180° out of phase? *Note:* The oscilloscope should be set to trigger on the signal coming directly from the function generator.
- 10. (1) Return to the zero displacement point, and repeat for *downward* core displacement. Assign *negative* values to these displacement readings since they fall below the zero setting. (The peak-to-peak output voltage is, of course, always positive.) *Note*: In the interest of time, the increment between data points can be twice as large (4.00 mm, or eight complete turns of the crank) on the negative side. Record in the table below.

Core displacement (mm)	Peak-to-peak voltage (V)
0	
-4	
-8	
-12	
-16	
-20	

- 11. (1) For downward displacement of the core, record the *phase* of the output voltage relative to that of the input voltage do the phases match, or are they 180° out of phase? *Note:* The oscilloscope should be set to trigger on the signal coming directly from the function generator.
- 12. (2) Plot displacement (vertical axis in units of mm) as a function of LVDT peak-to-peak output voltage (horizontal axis in units of volts).

See attached, Figure number _____

13. (1) For the positive side only, perform a straight line calibration curve fit (linear regression analysis) of displacement as a function of peak-to-peak voltage. Record the coefficients (intercept and slope).

Intercept for least-squares best-fit straight line = _____

Slope for least-squares best-fit straight line = _____

14. (1) Return to the displacement corresponding to a peak-to-peak output voltage of 200 mV. Insert the flat part of somebody's room key between the core and the traverse so that the core is displaced by the thickness of the key. Record the peak-to-peak voltage.

Peak-to-peak voltage reading for the thickness of a key = _____ V

15. (1) Using the voltage reading obtained when the room key was inserted, calculate the key's thickness from your calibration curve. Show your equation and calculations here.

Thickness of the key computed from the LVDT reading = _____ mm

16. (1) Using the hand-held micrometer, measure and record the thickness of the key (at or near the same point at which the sample's thickness was measured by the LVDT). *Note*: If your micrometer has units of inches, convert to mm.

Micrometer measurement of the thickness of a key = _____ mm

17. (1) Compare the thickness of the room key computed from the LVDT measurement to that measured directly with the hand-held micrometer. What is the percentage error between the two readings?

Percentage error = _____ %

Procedure for the Ultrasonic Transducer Experiment

- 1. Verify that the ultrasonic transducer head is connected to the Transmit/Receive (T/R) connector on the front panel of the transmitting/receiving electronics instrument. Also make sure that the plastic protective cover is off. Turn it on (the power switch is on the *back*).
- 2. Turn on the oscilloscope, and verify that Channel 1 is connected to the back of the transmitting/receiving electronics instrument the connector labeled *Signal*.
- 3. The times to be measured are on the order of a few *microseconds*, so adjust the oscilloscope appropriately. A time setting of 1.00 microseconds per division and a voltage setting of 1.00 volts per division are suggested to start. These settings may need to be adjusted later for better accuracy.
- Set the *PRF* (pulse rate) to about 5, set the *Damping* (noise reducer) to about 5, and set the *Gain* (amplifier) to about 5. Set the *Pulse Height* (sound level) to Low, set the other *Gain* (output) to Full, and set the *Mode* (type of pulse) button up.
- 5. Place the nominally 1/2-inch aluminum specimen on the table, and place a drop of oil on the top of the aluminum specimen. (The oil helps to create a better contact.) Place the transducer face (the shiny metal part of the transducer with smaller diameter) on the oil and move it in circles to spread the oil around. *Firmly* hold the face of the transducer against the top surface of the specimen as sketched.



- 6. Observe the oscilloscope trace. You may have to adjust the horizontal position and/or the trigger knob on the oscilloscope (the trigger should be set to a negative voltage). When adjusted properly, it should look like the trace sketched. The first pulse (negative) represents the transmitted sound wave. The next pulse (positive, then some ringing) represents the first reflection from the other side of the sample. The subsequent pulses represent further reflections, which are of no concern here.
- 7. To test the system *qualitatively*, repeat for the other two aluminum specimens. If the instrument is working properly, the time increment should decrease by about a factor of two for the 1/4-inch plate, and should increase proportionately for the 3/4-inch plate.
- 8. (2) For each specimen, record the time increment between the transmitted pulse and the first reflected pulse. The cursor feature on the oscilloscope is useful for this purpose. *Note*: Adjust the time scale of the oscilloscope as necessary to get the best possible time resolution. It also helps to use the horizontal position adjustment to move the trace to the left or right of the screen so that better time resolution is possible.

Specimen	$\Delta t \ (\mu s)$	Calculated <i>h</i> (mm)	Measured h (mm)	Percent error (%)
1/4-inch aluminum				
1/2-inch aluminum				
3/4-inch aluminum				
1/2-inch brass				
1/2-inch steel				
7/8-inch Lucite				

9. (1) Calculate the thickness h of the metal specimens (show your calculations here). The speed of sound in aluminum is approximately 6300 m/s, that of brass is 4700 m/s, that of steel is 6100 m/s. Record the calculated h values in the above table.

- 10. (1) Using the hand-held micrometer, measure the thickness of each specimen, and enter the measurements in the above table. *Note*: If your micrometer has units of inches, convert to mm.
- 11. (1) For each of the metal specimens, calculate the percentage error in thickness, assuming that the reading from the hand-held micrometer is exact, and enter the results in the above table.
- 12. (2) From your measurements, calculate the speed of sound in Lucite, showing your calculations below.

Calculated speed of sound in Lucite = _____ m/s

Procedure for the Laser Displacement Meter Experiment

- 1. Verify that the DC power supply is connected as follows:
 - 1. Red wire to the positive voltage supply.
 - 2. Black wire to the negative voltage supply (not ground).
- 2. Turn on the DC power supply if it is not already on. *Note: The manual states that readings are not stable and reliable until the unit has been on for about 10 minutes. For this reason, the power supply should remain on at all times during a lab session.*
- 3. Adjust the voltage output of the power supply to 12.0 VDC. The laser displacement meter uses a few watts, so the current control should be turned all the way up to ensure that enough power is supplied to the unit.
- 4. The laser displacement meter should be <u>on</u> at this point, with the red spot from the laser beam visible on the table surface.

Note: If a reading is not displayed, hold down the Enter (\downarrow) button for several seconds to re-set everything to the default settings. This should clear up the problems, hopefully.

- 5. If the reading is not zero, push the <u>zero button</u> on the laser displacement meter to zero the reading.
- 6. Stick a coin, key, someone's Ipod, pencil, or some other thin object on the table such that the laser spot hits the object. The display should show a non-zero reading (*the units on the display are mm*).
- 7. A student volunteer is needed. Measure and record the thickness *h* of all four of his/her fingers on both hands (do not measure thumbs). For consistency, insert your finger such that the laser beam spot is exactly in the middle of your fingernail. Try to exert the same amount of pressure with each finger. To eliminate any potential psychological influence on the reading, have someone *else* read the thickness for *your* fingers, while you are not looking. Record the thickness of all eight fingers, being sure to distinguish between right hand and left hand fingers.

Finger	h (mm), student 1	h (mm), student 2	h (mm), student 3	h (mm), student 4
	(right left)	(right left)	(right left)	(right left)
	handed	handed	handed	handed
Left-hand pinky				
Left-hand ring				
Left-hand middle				
Left-hand pointer				
Right-hand pinky				
Right-hand ring				
Right-hand middle				
Right-hand pointer				

8. (5 for #7,8) Repeat for each person (up to four total) in the lab group. Also, for each person, circle his/her dominant hand in the above table – is he/she right-handed or left-handed?

Procedure for the Tachometer Experiment

- 1. Turn on the tachometer calibrator unit. Notice the rpm labels stamped for each rotating shaft. **Safety note:** Watch your hands and hair when around the tachometer, as it has swiftly-rotating shafts!
- 2. In the following steps, *each* student in the group should get a chance to use *each* of the tachometers. In addition, use two calibrator shafts for each tachometer I call the rpm's N_1 and N_2 in the table below.

Tachometer	N ₁ (rpm), calibrator	N ₁ (rpm), measured	Percent error (%)	N_2 (rpm), calibrator	N ₂ (rpm), measured	Percent error (%)
Contacting						
Stroboscope						

- 3. Insert the rubber cone-shaped end of the contacting electronic tachometer into one of the rotating shafts. After the shaft of the instrument gets up to speed, push and hold the button on the instrument to take a reading. Enter your readings into the table, and calculate the percent error for each case.
- 4. (3 for #3-6) Repeat with the noncontacting stroboscopic tachometer. Due to ambient lighting, it is easiest to use the strobe tachometer if you pick the 1000 rpm and 1800 rpm shafts. *Note*: Do not run the strobe continuously, or it gets too hot! Note that there are two frequency adjustment knobs a course knob and a fine knob. Adjust until the shaft appears to stand still at or near the calibrator rpm.
- 5. (3) Experiment with the strobe set at integer fractions of the known rpm so as to experience the inherent uncertainty (aliasing) associated with using only one reading of a stroboscopic tachometer. Record your results for an aliased case. Draw some sketches to explain why there is aliasing.

Actual (calibrator) rotation rate = _____ rpm

Observed aliased (stroboscopic tachometer) rotation rate = _____ rpm

6. (2) Place the vibrating contact tachometers on top of the calibrator and observe their behavior. Comment on it below.

7. When finished, turn off all instruments.

Procedure for the Prony Brake Dynamometer Experiment

1. (1) With the motor *off*, measure the torque arm of the dynamometer. Convert to meters for consistency in units.

Torque arm = _____ m

Split Phase

Motor Control

Rotor

Main winding

on off

- 2. Make sure the motor controller unit is wired as shown to the right.
- 3. Loosen the band so that there is minimal friction applied, but **do not completely loosen the belt**. Loosening the belt entirely will cause the surge protector to turn off.
- 4. Turn on the AC motor.
- 5. Measure and record (in the table below) the force (load) on the fish scale and the rpm (using a contacting electronic tachometer). *Note*: The force should be zero (or very close to zero) when the brake band is slack.
- 6. Tighten the band slightly so that 100 g of load (on the fish scale) is applied to the motor. Again record both load and rpm. (*Note*: The fish scale has units of grams, which is actually *mass*, not force, so be careful with units! You will need to calculate the force based on the measured mass reading.)
- 7. (4 for #6,7) Repeat for several loads. Make adjustments slowly (a 100 g increment is suggested) so that at least ten conditions are measured. Record all results in the table below.

Load mass (g)	Load force (N)	N (rpm)	ø (rad/s)	Torque, T (N·m)	Power, P (W)

- 8. Bring the motor as close to stall conditions as possible. *Note*: Do not run near stall conditions for more than a few seconds, since this is hard on the AC motor, and can cause it to overheat.
- 9. <u>Read the following sentence in its entirety before proceeding</u>: Tighten the belt until the motor stalls, and then *immediately* loosen the band to un-stall the motor.
- 10. (1) Calculate torque and shaft power. Generate a plot of shaft power versus torque, shaft power versus rpm, and torque versus rpm.

See attached, Figure numbers _____

11. When finished, turn off the motor.

Procedure for the Cradled DC Motor Dynamometer Experiment

- 1. Note: Be careful not to touch any wires or contacts when the power is on electrical shock can result.
- 2. Both DC current *I* going *through* the resistor bank, and DC voltage *V* measured *across* the resistor bank will be measured. Note that the current meter is *in line* between the armature and the resistor bank, while the volt meter is *across* the resistor bank. Verify that the wiring is as sketched below.



3. (1) In this setup, the spring scale is calibrated directly in torque units. With the motor *off*, record the torque (and its units) indicated on the spring scale. It should be zero or close to zero since there is no load.

Measured torque T (and units) at zero load with motor off = _____

- 4. Adjust the resistor bank so that *no* resistor is connected all switches off. (This is actually infinite resistance, which means zero loading.)
- 5. (1) Turn on the AC motor, and measure the rpm with the contacting electronic tachometer.

Measured *N* at zero load = _____ rpm

6. (1) Record the torque indicated on the spring scale, along with its *units*. It should still theoretically be zero since there is no load. However, there is some friction inside the generator, so the torque will actually be non-zero.

Measured torque T (and units) at zero load with motor on = _____

7. (1) Record the voltage and current. The current should be close to zero, again since there is no load.

Measured voltage at zero load = _____ V

Measured current at zero load = _____ A

8. Turn on the first resistor (1000 ohms) to provide some load on the motor. Record resistance, rpm, torque, current, and voltage in the table below.

R (O)	N (rnm)	Ø (rad/s)	Torque, T (N-m)	Current, I	Voltage, V	Shaft power (W)	Dissipated Power (W)	Efficiency $n(\%)$
(32)	(ipiii)	(140/3)	I (I I II)	(11)	(•)	power (11)		<i>1(</i> / 0)

- 9. Turn on the next resistor to increase the load on the motor. *Note*: the resistor bank switches must be turned on *sequentially* (clockwise) around the box; any closed switch downstream of an open switch is ineffective. Calculate the total resistance of the resistor bank, based on the circuit diagram (*Note*: The resistors are in *parallel*, not series.) Again record resistance, rpm, torque, current, and voltage in the above table.
- 10. (2 for #8,9,10) Repeat for all 16 loads by turning on the resistor switches sequentially until all of them are on (maximum load). For each case, record rpm, torque, current, and voltage in the table.
- 11. (1) For each row in the table, calculate the shaft power, the power dissipated by the resistor bank, and the efficiency η of the generator. *Note*: Use P = VI to calculate the dissipated power through the resistor bank. Define the *efficiency of the DC generator* as *the power dissipated by the resistor bank divided by the shaft power of the motor*.
- 12. When finished, turn off the motor and all other instruments.

Procedure for the Eddy Current Dynamometer Experiment

1. Of the three dynamometers, this one is the easiest to use. First check the wiring as in the sketch below:



- 2. The watt meter is connected *in series* with the AC power line going to the switch box for the motor. Thus, the watt meter measures the actual power being supplied to the motor also the power *used* by the motor.
- 3. Turn the knob on the Magtrol power supply box all the way down (counterclockwise) so that there is minimal initial load on the motor (zero or near zero torque). This knob controls the field winding of the eddy current dynamometer.
- 4. Turn on the watt meter box and the Magtrol power supply box. Turn on the AC motor with the white switch on the small switch box. (The red switch is to turn the motor off.)
- 5. Measure the shaft rpm with the stroboscopic tachometer, and/or with the optical tachometer. (*Note*: The optical tachometer does not work unless there is reflective tape on the shaft.) Choose one of these to use for the remainder of this experiment. *Note*: Do not run the strobe continuously, or it gets too hot!
- 6. On the table below, record the rpm, the torque, and the input power supplied to the AC motor (as indicated by the watt meter). *Note*: For the weight used in this lab, use the *top* scale of the torque gage. The torque should be zero (or nearly zero) when no load is applied. Calculate the shaft power, and record it in the table. Some unit conversions may be required.
- Calculate the efficiency of the AC motor. Here, the *efficiency of the AC motor* is defined as *the shaft power* divided by the input power. Some unit conversions may be required. (You can attach an EXCEL Table if you wish) Table No:

N (rpm)	w (rad/s)	Torque T (oz·in)	Input Power (W)	Shaft power (W)	Efficiency η(%)

- 8. (4 for #7,8) Turn the Magtrol power supply control knob up a little to add some load (approximately 50 oz-in of torque) to the motor, recording rpm, torque, and input power on the above table. Repeat for loads in 50 oz-in increments of torque (50, 100,150,...). Go up to the maximum torque, where the motor is almost ready to stall. *Do not stay at the high torque conditions too long, as this can cause overheating of the motor*.
- 9. (1) Test for *hysteresis* by taking readings while *decreasing* the torque back to zero loading. To save time, you can skip every other reading on the way down (take half as many data points as you took on the way up).
- 10. When finished, turn off all three switches.

Discussion Questions

- 1. <u>LVDT</u>
 - (a) (3) How can you tell if the core is on the positive or negative side of the zero point? Explain.
 - (b) (2) Was the positive side of the LVDT calibration nearly *linear*?
- 2. (3) <u>Ultrasonic transducer</u> What is the greatest source of error in this kind of measurement?
- 3. (2) <u>Laser displacement meter</u> Is finger thickness correlated with a person's dominant hand? Specifically,
 (a) If a person is *right-handed*, are the fingers in his/her right hand *thicker* than those on his/her left hand?
 (b) If a person is *left-handed*, are the fingers in his/her left hand *thicker* than those on his/her right hand?
- 4. (4) <u>Tachometers</u> Which kind of tachometer had the best accuracy? The worst accuracy? Which is easiest to use?
- 5. (4) <u>Prony brake dynamometer</u> At what rpm does the AC motor produce maximum shaft power?
- 6. (2) <u>Cradled DC motor dynamometer</u> How efficient is the cradled DC motor, when acting as a generator?
- 7. Eddy current dynamometer –
 (a) (2) Was there any appreciable *hysteresis*? Explain.
 - (b) (2) At what rpm does the AC motor produce maximum shaft power?
 - (c) (2) At what rpm does the AC motor operate at maximum efficiency?
 - (d) (4) Is the rpm corresponding to maximum shaft power the same as that corresponding to maximum efficiency? Why or why not?