Report

An individual, short report is due at NOON on the next Friday of classes from each student for this lab. The report will consist of only the requested plots and calculations in the “Outside Lab” items in each section. Use heading to identify the section and clearly label each item. (no what was learned etc). For example

Section 7.1
Plot: $\omega_{\text{handheld}}$, $\omega_{\text{encoder}}$ vs. $\omega_{\text{ideal}}$
Plot: $(\omega_{\text{handheld}} - \omega_{\text{ideal}})$ vs. $\omega_{\text{ideal}}$
Plot: $(\omega_{\text{encoder}} - \omega_{\text{ideal}})$ vs. $\omega_{\text{ideal}}$

Include the usual header information (name, partners, etc) but not “What was learned” etc.

Procedures

7.1 Angular Velocity Transducers

This section of the laboratory will examine three different methods for measuring the rotational speed of a motor’s shaft. The different sensors that you will use are:

1. Optical Tachometer
2. Incremental Encoder
3. Magnetic pickup

These are all shown in Figure L7-1 below.

In the first example, a handheld tachometer is pointed at an optical reflective tape on the shaft coupling. The shaft speed in rpm is read directly off of the display on the front of the tach.

In the second example, a commercial incremental encoder is used. It has a resolution of 360 slots per revolution and is attached to the end of the DC motor/tachometer. The output of this device can be read with the VirtualScope. You can also use the frequency counter (on the lab bench) to make this reading. Both devices provide the speed in events per second. To convert that reading into the motor speed in rpm, use the following formula:

$$\text{Motor's } \frac{\text{rev}}{\text{min}} = \frac{\text{slots}}{\text{sec}} \times \frac{1 \text{ rev}}{360 \text{ slots}} \times \frac{60 \text{ sec}}{\text{min}}.$$

Finally, a circular plate with ferrous metal “gear-teeth” has been installed on the shaft of the motor and is used to generate pulses as the teeth pass an external, fixed magnetic pickup coil. There are 30 teeth on the plate and thirty “spaces.” As such, 30 pulses are generated for each revolution of the plate. Those pulses are translated into the speed in rpm, which can be read on the readout at the front of the experimental setup.

The process for testing these rotary velocity transducers is as follows:

1. Set the speed controller to a desired (low) setting.
2. \(\Rightarrow\) Measure the rotational speed of the shaft using each of the transducers listed above:
   - Handheld tachometer (direct reading in RPM)
   - Incremental encoder frequency in Hz from VirtualScope or the frequency counter. If you use VirtualScope, make sure there are between 5 and 20 complete cycles on the screen.
   - Magnetic gear pickup readout (direct reading in RPM)

3. Change the speed setting and repeat step #2.

4. \(\Rightarrow\) Continue step #3 until at least 10 different motor speeds (including the maximum speed) have been tested and the data has been recorded for the report.

5. \(\Rightarrow\) Outside Lab:
   - Treat the angular velocity from the magnetic gear pickup readout as ideal \((\omega_{\text{ideal}})\) and plot the other 2 directly measured speeds \((\omega_{\text{handheld}}, \omega_{\text{encoder}})\) on the vertical axis of one plot.

6. Plot the deviations \((\omega_{\text{handheld}} - \omega_{\text{ideal}})\) vs. \(\omega_{\text{ideal}}\) and \((\omega_{\text{encoder}} - \omega_{\text{ideal}})\) vs. \(\omega_{\text{ideal}}\) on a second plot.
7.2 Accelerometer and LVT Experiment

A single axis accelerometer, a linear velocity transducer (LVT), and a magnetostrictive displacement sensor are mounted to a translating rack assembly as shown below in Figure L7-2. Four springs are used to center the rack on the frame. A small DC motor drives a disk with which has several holes in a non-symmetric pattern. The rotation of the disk with these holes creates an unbalance in the disk, which leads to large vibrations in the plate as the disk rotates (similar to the effect on an automobile produced by an unbalanced wheel or the condition on a washing machine produced by an unbalanced load). All three sensors can be used to measure the amplitude of the vibration caused by the unbalance. Your assignment is to use the accelerometer and displacement sensor signals to calibrate the LVT. To do this, you will test the system at a minimum of three different motor speeds and record the corresponding acceleration and displacement signals. Based on either of those two signals, you can calculate the corresponding velocity, by assuming a sinusoidal response. You can then use that data together with the LVT output to compute a gain for the LVT.

![Vibration Test Apparatus](image)

Figure L7-2. Vibration Test Apparatus

You will use VirtualScope to read the three signals. However, because of noise in the system, the accelerometer and LVT signals must be filtered. A filter with a corner-frequency of 20 Hz has been constructed for you in the lab. By knowing the excitation frequency, you can compute the corresponding gain of the filter at that frequency. You can then back-calculate the actual accelerometer and LVT signals at that frequency. In addition to that signal-processing, the accelerometer and displacement sensor also require external power supplies. The displacement sensor runs off of a 24 V DC signal that is provided by a power supply on the bench next to the data acquisition PC. The accelerometer signal is fed into an ICP power supply which then provides the signal that is to be filtered. The ICP power supply gain should be set to x100, such that the unfiltered accelerometer signal is 1 V/g. The unfiltered displacement transducer signal is 2.5 V/inch.
The procedure for this experiment is:

1. Make sure that the ICP power supply (the small white and blue box) is turned on, that the accelerometer is connected to Channel 1, and that the gain for Channel 1 is set to 100x.

2. Make sure that the ICP power supply output (Channel 1) is applied to one of the passive low-pass filters on the breadboard. The LVT signal should be applied to the input of the other low-pass filter. The displacement sensor output should be applied to the breadboard, but does not require any filtering.

3. Make sure that the three cable pairs (yellow and black, orange and black, and green and black) from your data acquisition break-out box are recording the three signals on the breadboard. Record which channel is measuring what signal.

4. Using the DC power supply (LOKI), increase the voltage applied to the motor until the motor starts turning. Observe your signals using VirtualScope. Adjust the voltage until a speed of approximately 5 Hz is reached. You can use Measurement in VirtualScope to help you with this. You may want to double-check your speed readings using the optical tach. If you do, make sure that you convert your readings from rpm to Hz.

5. Record the motor speed and the corresponding signal amplitudes for each of the sensor signals. Note that the displacement transducer may have a significant DC offset. As such, you may want to record representative signal traces for each speed.

6. Increase the voltage applied to the motor for at least two more voltage levels (four more would be nice). At each level, repeat Step 5. Test for motor speeds from approximately 5 Hz to approximately 15 Hz.

Outside Lab:

1. Provide time-traces for each excitation frequency (motor voltage). Plot the outputs of all three signals in each trace.

2. For each excitation frequency (motor voltage), determine the acceleration and displacement amplitudes in m/s² and m.

3. Determine the velocity amplitude based on your results of (2).
7.3 “Build Your Own Encoder”

As explained in class lectures, the basic operation of an encoder can be incorporated through the use of a photosensitive transistor and a light-emitting diode (LED).

Two circuit configurations are possible and are shown below in Figure L7-6. In both cases, the LED is connected through and external resistor $R_1$ to a power supply, $+V$. The purpose of $R_1$ is to ensure that excessive current is not passed through the LED. A functioning LED typically drops 0.7 V. In order to maintain, say 20 mA of current using a 5 V supply, a resistance $R_1 = (5-0.7)/0.02 = 215 \, \Omega$ is required. The functioning LED will then emit infrared light. A phototransistor then conducts or does not conduct, based on the amount of IR light impinging on the transistor. A picture of the phototransistor and the LED is shown in Figure L7-7. Television remotes and other controls use similar LED/transistor pairs.

![Figure L7-6. Two encoder configurations.](image)

![Figure L7-7. Infra-red LED and photo-transistor.](image)
The photo-transistor can be utilized in either of the two configurations shown in Figure L7-6. In both cases, an infra-red LED is used to “excite” a photo-sensitive transistor. When the light from the LED falls upon the transistor, it goes from non-conducting to conducting. The operation is not linear, but it is not exactly binary (“on-off”) either. That is, a small amount of light impacting the transistor base will result in a small amount of current being conducted through the transistor and a large amount of light will result in a large current. The relationship is not linear; for example, in some cases, doubling the light may result in a ten-fold increase in current being conducted, up to the saturation of the transistor.

In case (a), the transistor is preceded by a resistor, R2. As with the diode side of the circuit, the resistor may be used to limit the current through the transistor. More importantly, however, when the transistor is excited and conducts, the resistor provided a voltage drop that serves to reference Vout with respect to V+ and ground. The voltage dropped over the transistor is relatively small, such that, as the transistor conducts, Vout should transition from V+ to a voltage “near” ground. If the transistor does not conduct, no voltage is dropped over R2 and Vout is equal to V+.

In case (b), the principle of operation is very similar to that of case (a). In (b), however, as the transistor conducts, Vout will transition from “near” ground to V+. If the transistor does not conduct current, then Vout will be “near” ground.

For this experiment, you will be wiring the LED and photo-transistor according to the schematics shown in Figure L7-6 and using the combination to measure the rotational speed of an AC motor. The AC motor will have a disk attached to the motor shaft with a series of holes in its perimeter as shown in Figure L7-8. Your job will be to position the LED and photo-transistor on opposite sides of the wheel such that the spinning holes provide a regular interruption of the IR light emitted to the photo-transistor from the LED. You will be able to determine the angular velocity of the motor by counting the frequency of the voltage pulses showing up as Vout and by counting the total number of holes in the rotating disk.

You will be provided with the appropriate R1 and R2 resistors in the laboratory. Use the +5 V supply from your breadboard power supply as V+. To improve the response of the LED/photo-transistor combination, you will be provided with a block of wood with a slot for the rotating disk and with holes for the LED and photo-transistor, as shown in Figure L7-8. Because the photo-transistor is not a completely “on-off” device, you should be able to see varying amplitudes of Vout as you slide the block back and forth along a tangent to the rotating disk. (This will be more apparent as you examine the set-up in the lab.)
The procedure for this experiment is:

1. Wire the LED and photo-transistor and test the response. Use the DMM to read $V_{out}$ as you place the LED and photo-transistor in close proximity. Note – both devices are directional, so as you point them toward each other and at different angles, you should get somewhat different responses.

2. Place the LED and photo-transistor in the holes in the wooden block. Make sure that you have enough length in your wires so that you won’t pull your leads out of the breadboard.

3. Start the AC motor by plugging it into the workbench power strip. Switch to measuring $V_{out}$ with VirtualBench.

4. Position the wooden block, together with the LED and photo-transistor such that you can slide it back and forth and make the block holes line up with the holes in the rotating disk.

5. Slide the block back and forth and determine the position of maximum response. Set VirtualBench such that you can observe a sufficient number of cycles of $V_{out}$ so as to determine the angular velocity of the rotating disk. Save the data for use in your laboratory report.

6. Slide the block away from the “optimal” position so that you read progressively smaller $V_{out}$ signals. Save the data from two additional positions.

7. Calculate the angular velocity of the rotating disk.

8. Provide plots of $V_{out}(t)$ for the three different block positions.
7.4 Measurement of Linear Acceleration

The last experiment (illustrated in Figure L7-9) involves the use of an analog accelerometer and an incremental encoder to determine one of the natural frequencies of the spring-mass-damper system shown in Figure L7-1. The natural frequency will be the frequency at which the system will oscillate when released from some non-zero initial condition. It will also be the frequency at which the response amplitude for a sinusoidal input will be the largest.

Figure L7-9. Spring-mass-damper system.

A set of color PowerPoint slides will be provided in the lab to describe the operation of the Educational Control Products Model #210 spring-mass-damper system. A rotary incremental encoder is attached to each mass via a pulley and cable arrangement in order to measure the linear position of the mass. The sensitivity of the encoder arrangement is 2250 counts per inch of motion.

Once the encoder counts are converted to displacements, the acceleration can be obtained by numerical differentiation (as opposed to numerical integration) using the central difference formula

$$\ddot{x}_{\text{enc}} = \frac{x_{i+1} - 2x_i + x_{i-1}}{(t_{i+1} - t_i)(t_i - t_{i-1})},$$

where

- $x_{i+1} =$ position at time $t_{i+1}$,
- $x_i =$ position at time $t_i$, and
- $x_{i-1} =$ position at time $t_{i-1}$.

An Analog Devices #ADXL05EM-1 accelerometer (datasheet on the ME 360 website) will be mounted to either the second or third mass. The sensitivity of the accelerometer is 0.500 volts/g. Note that this accelerometer has a 2.5 volt DC offset. An equation for computing the acceleration from the accelerometer voltage, $V_{\text{acc}}$ is
\[ \ddot{x} = (V_{\text{acc}} - 2.5V) \left( \frac{1g}{0.5V} \right) \left( \frac{9.8 \text{ m}}{s^2} \right) \]

Use *VirtualScope* to collect data from the accelerometer.

**Procedure:**

1. Start and set it to collect data from the “yellow” channel. Set the timebase to 500 ms/div and the vertical sensitivity to 500 mV/div. Set the yellow triangle to the bottom of the screen using the V. Position knob.
2. Start the ECP32-210 software and follow the steps in the color PowerPoint slides.
3. Test the spring-mass-damper at the following frequencies. Record the $V_{\text{P-P}}$ measurement from *VirtualScope* for each frequency tested.

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<thead>
<tr>
<th>Test Frequency</th>
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<tr>
<td>4.0 Hz</td>
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<tr>
<td>4.5 Hz</td>
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4. Re-run the frequency that gives the largest largest $V_{\text{P-P}}$ (largest acceleration), and save the data from both the ECP32-210 software and *VirtualScope*.

**Outside Lab:**

1. Make a single plot of the two acceleration vs. time measurements (one from the encoder on the ECP Model #210 system, one from Analog Devices accelerometer) for the specified mass. Use approximately 2 seconds of information from the mid-range of the collected data.