University of New Hampshire
Department of Mechanical Engineering

ME 747 – Lab # 4
(16 Oct 2017)

Accelerometers and Force Sensors: Modeling and Calibrating, Measuring Vibration

Purpose:

In this lab experiment, you will calibrate and model a potentiometer accelerometer, a piezoelectric accelerometer, and a piezoelectric force sensor. The potentiometer transducer uses a proof mass, leaf springs, magnetic damping, and a Wheatstone bridge arrangement to convert acceleration to an output voltage.

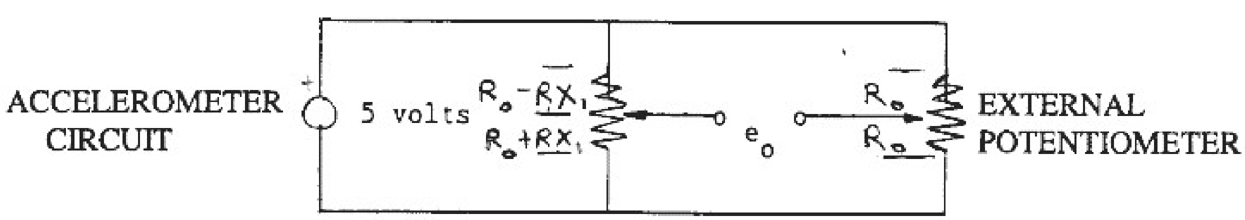
The piezoelectric devices use the stiffness of the crystal, and the unique transformation of the crystal deflection rate (of the crystal) to current, to convert acceleration/force to a voltage. Unique charge amplifiers are required for appropriate signal conditioning. This device can measure dynamic and quasi-static acceleration but not steady-state acceleration.

Vibration resulting from a falling mass will be measured using an accelerometer and force sensor attached to the core shaft of an LVT. The shaft will be dropped into foam which can be represented as a spring-mass-damper system. Vibration from a falling mass will also be measured using a force sensor located under foam.

NOTE: Numbered questions are lab work, lettered questions are for the write-up. You should make sure that you have all necessary data to answer these questions.

1 Potentiometer Accelerometer

The proof mass of the accelerometer is connected to a four arm Wheatstone bridge to get a voltage output proportional to acceleration (figure below).



1. Sketch the setup, noting the bridge arrangement shown above. Input 5V to the bridge circuit and place the accelerometer unit on the table so that the deflection of the copper bar is horizontal. Check the bias output voltage for no deflection of the accelerometer copper bar (mass). It should be around 0.4 V for setups 3 and 4, and 1 V for setups 2 and 8. If far off from these values, ask the instructor to adjust the potentiometer. Adjustment of the potentiometer also affects the range of the accelerometer.

2. Record the maximum output voltage e_o when the moving mass (copper bar) is deflected to its maximum position (do not apply excessive force). Also record the output voltage for no deflection of the mass.

3. Place the accelerometer on its side so the mass is moving in the vertical direction, and record the change in output voltage Δe_o. Add weights to the moving mass (copper bar) using the bucket and hook attached to the mass, and record e_o vs. weight (for both increasing and decreasing weight, to the maximum displacement of the mass).

4. Displace the hook attached to the accelerometer mass and release it, using the oscilloscope to get $e_o(t)$ versus time. Make sure you get a response with some overshoot. Save/export the data.

a) Plot e_o vs. weight and find the sensitivity in volts/oz_f.

b) Plot $e_o(t)$ vs. time for the initial displacement and, along with the plot from a), determine the following parameters for the accelerometer (use % overshoot plot given in Canvas to get ζ): spring constant K (oz_f/in), natural frequency ω_n (rad/sec), effective mass M (oz_m), damping ratio ζ.

c) What is the sensitivity of the accelerometer in volts/(in/sec^2)?

d) What is the maximum acceleration that can be measured with this instrument?

e) Use Matlab to make a Bode plot of the transfer function $E_o(s)/\ddot{X}_i(s)$ and comment on the accuracy of the accelerometer for measuring sinusoidal accelerations. Recall from homework that $E_o(s)/\ddot{X}_i(s)$ = ($MRE_s/2RoK$) / ($Ms^2/K + Bs/K + 1$) where $MRE_s/2RoK = K_s$ the steady state gain.

2 Piezoelectric Force Sensor

2.1 PCB Characteristics

1. Connect the PCB force sensor to the input of the charge amplifier (amp), and the output of the charge amp to the NI scope. Turn on the charge amp and wait a minute for the system to warm up. The charge amp should have a pointer in the green zone indicating a good connection. If the arrow is in the yellow or red zones reconnect the wire to the load cell and to the amplifier.

2. Calibrate the PCB force transducer from 0 to1.6 kg in increments of 0.2 kg by placing the weight on the transducer and capturing the waveform with the scope. Use the "steady state" value immediately after the transient dies out. Do not attempt to get increasing and decreasing weight readings.

3. Next, place a 1 kg mass on the load cell, and use the scope to find the decay time constant of the PCB transducer. Before recording the trace on the scope, click on the scope HORZ button and set the record length to 50k and the time scale to 3.3 seconds. Save/export the data.

4. Change the data points to 5k and gently (but sharply) tap the top of the load cell (plastic handle of screw driver) and record the output with the scope (use an appropriate time scale with triggering). Save/export the data.

a) Plot the calibration curve and give the sensitivity (mV/lb_f) and error in % full scale (FS).

b) Give the decay time constant of the PCB and comment on the sensor's ability to measure steady state forces.

c) Find the natural frequency of the PCB/structure, and discuss what this means in terms of dynamic performance.

2.2 Impulse loading and vibration

1. Place a large rectangular section of foam over the force sensor plate and set a 2 lbf plate on the foam. Push the foam down with the weight to “seat” the foam. Tap on the weight with the plastic end of a screwdriver and capture the force trace making sure the data is smooth and linear with several oscillations. Save/export this data for analysis.

a) For the foam-mass system, find the damping ratio ζ, natural frequency ω_n , and spring constant k (lb_f/in).

b) Find the damping coefficient B, lb_f/(in/sec), of the foam-mass system.

c) Write the “governing” differential equation of the system and simulate the response of the system to the “impulse” force (use Matlab and/or Simulink). You will have to approximate the “impulse” loading from the tapping. Plot the simulated and experimental data on the same plot and compare them.

3 Vibration Analysis

Mechanical vibration can be analyzed using sensors that measure displacement, velocity, acceleration and force. You will use a combination of sensors to analyze the LVT core movement as it freefalls onto foam.

1. Sketch the LVT setup, noting the piezoelectric accelerometer on the top of the core mass, and the piezoelectric force sensor on the bottom of the core. The accelerometer is attached by wax, which is adequate for low amplitude/frequency vibrations.

2. Connect the LVT and the accelerometer outputs to the scope. The accelerometer is a piezoelectric based sensor, like the force sensor, that needs a charge amplifier. Make sure the amplifier is connected to the accelerometer and to the scope. As before, make sure the charge amp pointer is in the green zone, indicating that the system is operating normally.

3. Lift the core shaft, until the accelerometer contacts the LVT housing, and release it, allowing it to oscillate on the foam. Observe the oscillation on the scope, using the trigger position on the scope to obtain the complete output response. Make sure that the output responses are easily seen on the scope, but are not clipped (adjust scope sensitivities). Save/export this data for plotting. Remember that the output curves are velocity and acceleration.

4. Now connect the LVT and force outputs to the scope. Repeat the core shaft freefall drop trying to use the same initial displacement height as before. Save/export this data for plotting. Remember that the output curves are velocity and force.

a) Plot the LVT and accelerometer output vs. time. Find the sensitivity of the accelerometer in volts/(in/sec^2) and the LVT in volts/(in/sec).

b) Integrate the accelerometer signal using Matlab (cumtrapz) and plot that signal (units of in/sec) and the LVT signal (units of in/sec) vs. time. Compare them.

c) Indicate on the plot from a) the time that the following occur: i) beginning of the drop, ii) first contact between the core shaft and foam, iii) the maximum displacement of the core shaft, iv) the separation between the core and foam (bounce), v) permanent contact between the core and foam.

d) Calculate the maximum velocity of the core.

e) Plot the LVT and force sensor output vs. time. Using the sensitivity of the force sensor, 0.491 volts/lb_f, find the force on the foam at maximum velocity of the core, and the steady-state force between the foam and the core. Finally, calculate the total mass of the core with attached sensors.