Washington University in St. Louis

James McKelvey School of Engineering

Fall 2030 MEMS 505 Engineering and Science Laboratory

Pre-Lab 2: Basic Vibration Measurements

Lab Instructor: Dr. Bayly

Group T (Friday 11 AM)

We hereby certify that the lab report herein is our original academic work, completed in accordance to the McKelvey School of Engineering and Undergraduate Student academic integrity policies, and submitted to fulfill the requirements of this assignment:

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1 Question 1

(*2pts*) Briefly describe the physics behind the following apparatus. Give a practical application of the device.

a. Accelerometer:

An accelerometer consists of a mass surrounded by piezoelectric material. When the mass accelerates, it will exert a force on the piezoelectric material, which will produce an electric charge. The force and charge are proportional, and the mass is constant, so the charge is proportional to the acceleration experienced by the device as a whole. [1]

A practical application for an accelerometer is to sense when you shake your cellphone. The phone has a tiny accelerometer inside it, and when you shake your phone, the accelerometer registers the shaking and can trigger a software action from it.

b. Force transducer:

The force transducer combines a spring with a known Young's Modulus and Poisson's ratio, and one or more strain gauges in order to measure the force applied to the spring. A strain gauge is essentially a piece of wire stuck fast to a film. When the film stretches, the wire gets longer and the resistance increases. This change in resistance can be measured and related to the change in length of the strain gauge. When a strain gauge is connected to a spring (the simplest case would just be a solid metal cylinder), the strain on that spring can be related to the stress with Hooke's Law, and then the area can be divided out to get the force that was applied. If necking occurred, then the material's Poisson ratio can be used to find what the new area is. [2]

One application for force transducers is in industrial processes where a certain force must be applied to every action (stamping, press brake, etc).

c. Signal conditioner/voltage amplifiers:

A signal conditioner is a general purpose device that takes a signal from a sensor and conditions it so that the measurement device can better read the signal. This may include amplifying the signal with a voltage amplifier, as some sensors output very low voltages or voltages within a very tight range such that in order to accurately measure differences in voltage, the voltage must first be amplified. A voltage amplifier uses operational amplifiers and other complex integrated circuits to change the output voltage of a signal by some constant factor called the gain. A signal conditioner may also filter out noise, linearize a reading that has a non-linear relationship, or even convert analog to digital. [3]

A signal conditioner can be used in a variety of laboratory and industrial applications, such as in a large scale automation and machine control operations, or in data acquisition. Any process that involves interfacing with various sensors would benefit from a signal conditioner.

2 Question 2

(*4pts*) Measurements from an accelerometer (with a known calibration constant) and a force transducer (with an unknown calibration constant) are given data in Table 1 below. Both sensors are mounted on the same plane of an electromagnetic shaker. Recall that an oscillatory displacement can be written as

$$x(t) = x_0 Sin(\omega t + \phi) \tag{1}$$

Table 1: Raw Data Measurements

Mass (g)	Measured Frequency (HZ)	Measured Acceleration Amplitude (m/s2)	Force Transducer Signal Amplitude (mV)	Force Amplitude (N)	Displacement Amplitude, x0 (m)	angular velocity
245	11.34	4.53	2.95	1.11	1.39	1.805
245	23.97	10.99	8.73	2.69	0.76	3.815
245	30.02	12.73	12.53	3.12	0.56	4.778
245	36.42	21.32	16.28	5.22	0.63	5.796
245	45.55	26.92	21.76	6.60	0.51	7.250

a.) Write expressions to estimate the force and displacements amplitudes based on Table 1. Fill in the values.

Force amplitude:

$$\mathrm{f}_n = m\ddot{x}_n \tag{2}$$

where t_n is the force amplitude of the nth instance and $\ddot{x}_n$ is the acceleration amplitude of the corresponding instance.

Displacement amplitude

$$x_0 = \frac{\ddot{x}}{\omega^2 sin(\omega t)} \tag{3}$$

where x_0 is the displacement amplitude, w is the angular velocity which is the frequency over 2π, and ωt is equal to $\frac{\pi}{2}$.

b.) Determine the calibration constant of the force transducer (i) assuming a DC offset and (ii) without a DC offset. Include a MATLAB scatter plot (along with your code) with properly labelled axes, equation of your curve fit and coefficient of determination.

(i) Calibration constant with DC offset:

Calibration constant = 3.257 mV/N

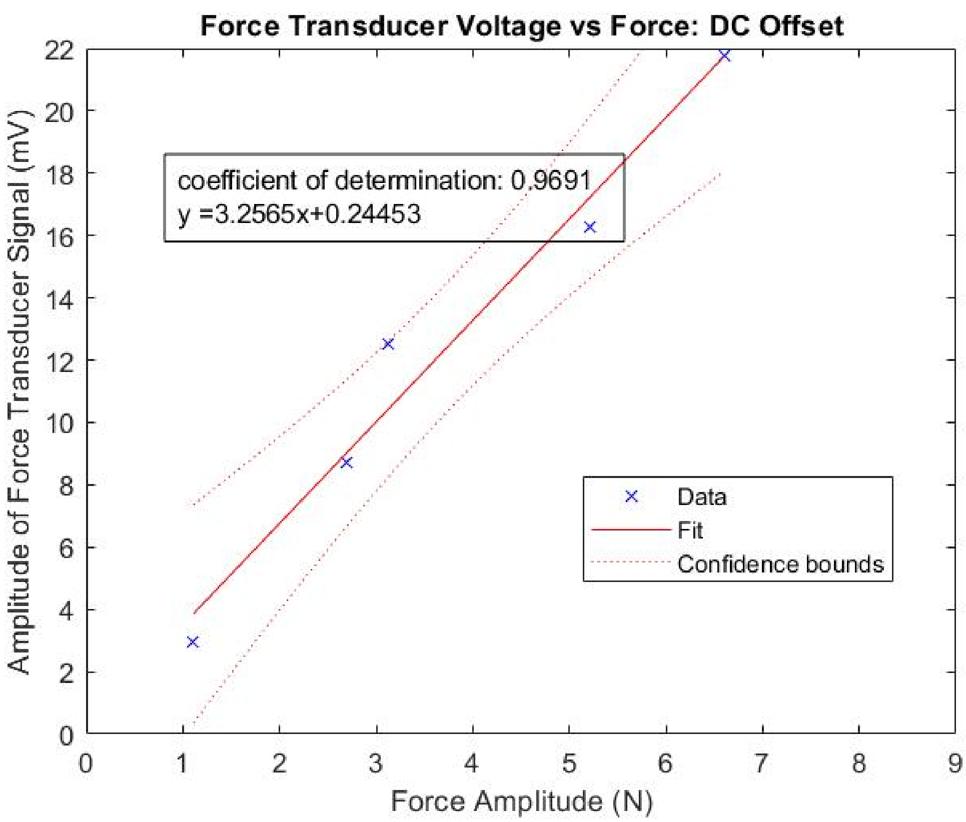

Figure 1 The force transducer voltae vs force with a DC offset. The linear regression line is shown in orange. The equation of the regression line is shown on the figure, as well as dotted lines for the confidence interval.

(ii) Calibration constant without DC offset:

Calibration constant = 3.308 mV/N

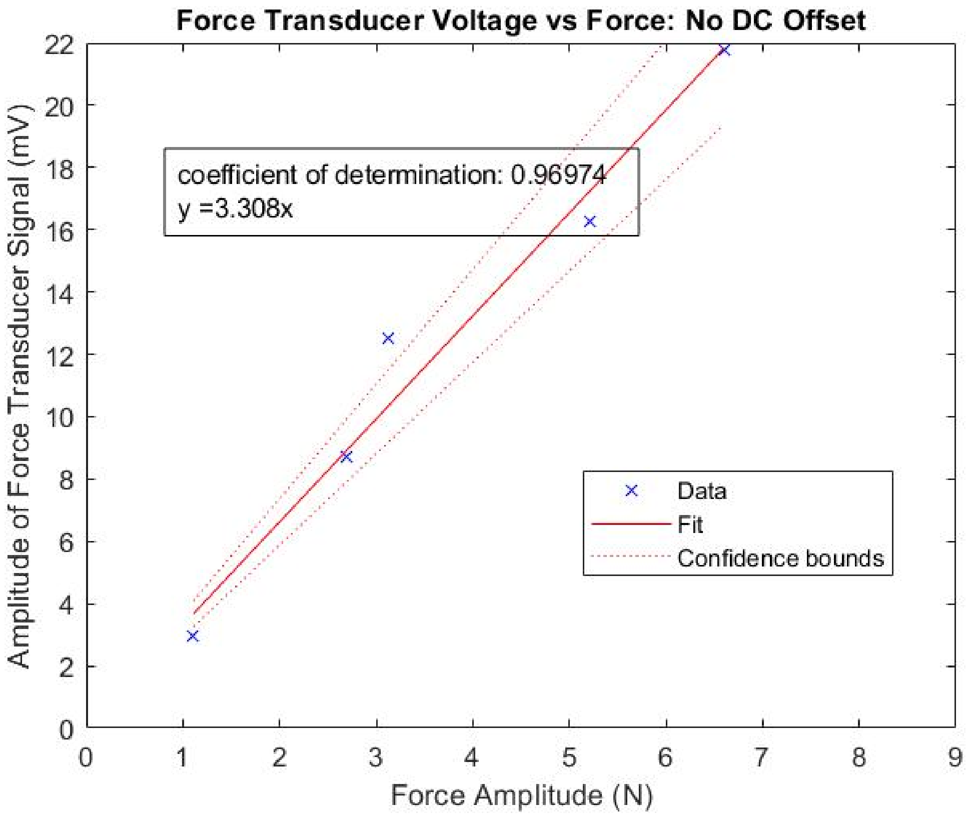

Figure 2 **Force transducer voltage vs. force with no DC offset. Linear regression line is plotted and passes through (0,0), hence the y-intercept of the line is 0.**

matlab code:

```
clear all;
close all;
clc;

%%Data Input

ForceTransducerSignalAmplitudemV = [2.95 8.73 12.53 16.28 21.76]';
ForceTransducerSignalAmplitudemVCopy = [2.95 8.73 12.53 16.28 21.76]';

ForceAmplitudeN = [1.11 2.69 3.12 5.22 6.6]';
ForceAmplitudeNCopy = [1.11 2.69 3.12 5.22 6.6]';

%%2b part i
figure(1);
```

```
scatter(ForceAmplitudeN,ForceTransducerSignalAmplitudemV, 'x');

dlm = fitlm(ForceAmplitudeN,ForceTransducerSignalAmplitudemV, ...
    'Intercept',true);

figure(2)

plot(dlm)

ylim([0 22]);
xlim([0 9]);

r2 = dlm.Rsquared.Ordinary;
slopeandintercept = dlm.Coefficients.Estimate;
m = slopeandintercept(2);
b = slopeandintercept(1);
str = {['coefficient of determination: ',num2str(r2)] ['y =', ...
    num2str(m),'x', '+', num2str(b)]};
dim = [0.2 0.5 0.3 0.3];
annotation('textbox',dim,'String',str,'FitBoxToText','on');

hold on;

title('Force Transducer Voltage vs Force: DC Offset');
ylabel('Amplitude of Force Transducer Signal (mV)');
xlabel('Force Amplitude (N)');

%% 2b part ii

figure(3);

Scatter = scatter(ForceAmplitudeNCopy, ...
    ForceTransducerSignalAmplitudemVCopy);

dlm0 = fitlm(ForceAmplitudeNCopy, ForceTransducerSignalAmplitudemVCopy, ...
    'Intercept',false);

```

```
figure(4)
plot(dlm0)
ylim([0 22]);
xlim([0 9]);
r20 = dlm0.Rsquared.Ordinary;
m0 = dlm0.Coefficients.Estimate;
str0 = {['coefficient of determination: ',num2str(r20)] ['y =', ...
    num2str(m0),'x']};
dim = [0.2 0.5 0.3 0.3];
annotation('textbox',dim,'String',str0,'FitBoxToText','on');
hold on
title('Force Transducer Voltage vs Force: No DC Offset');
ylabel('Amplitude of Force Transducer Signal (mV)');
xlabel('Force Amplitude (N)');
```

3 Question 3

(*2 pts*) In Table 2 below, m is the unknown mass of the shaker armature (the part that moves), and M is the mass of the added weight to the shaker armature. A known uni axial force on the armature is applied.

Table 2: Estimation of armature mass

	Mass (g)	Acceleration amplitude (m/s^2)	Force applied to armature (N)
Case 1	m	a_1	F
Case 2	m + M	a_2	F

a) Assuming a point mass for both cases, draw a free body diagram of the system and determine the equation for the armature mass, m in terms of the unknown variables.

b) Given M = 690g, a1 = 7.65 m/s2 and a2 = 4.22 m/s2, calculate the mass of the shaker armature.

The solution to both problems and both cases is shown in the figure [Fig. 3] below.

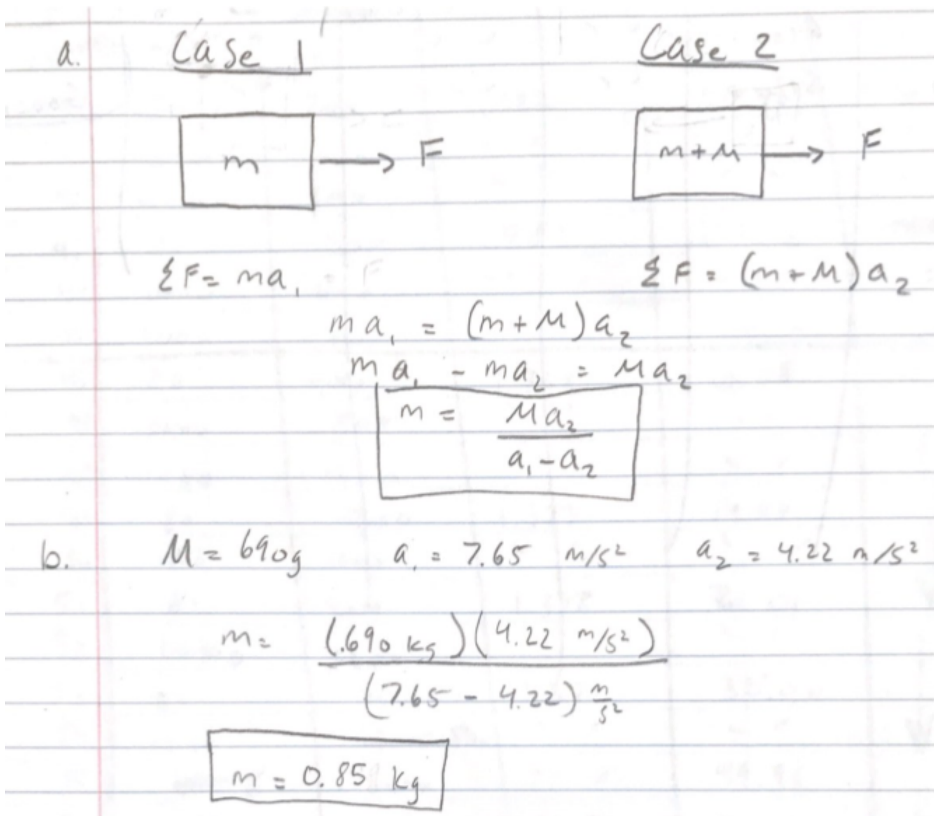

Figure 3 Solution to problem 3 for both case 1 and case 2.

4 Question 4

(*2pts*) 4) Briefly define the following terms below. Include proper ASME citations for each term in a reference list.

- **Signal gain:** The signal gain is the gain that is applied to an input signal with a feedback loop connected. Signal gain can be inverting or non-inverting. Signal gain is simply an overall general term for the voltage gain of an amplifier (for electronics) but relates to the resistances the signal feels through the amplifier [4]. The signal gain in a non-electronic sense would be the amplification of a vibration or any oscillatory motion.

- **DC offset:** "[It] is the mean amplitude displacement from zero". You can see the DC offset on a graph because there will be a y-intercept for the function. [5]

- **Calibration:** It is having equipment standardized to a specified result. It allows for a precise measurement and accurate data. [6]

- **Uncertainty analysis:** It its a method used to tells you how good the results are. This helps show you if the data agrees with the theory. Error can come from the equipment, human error etc... [7]

- **Coefficient of determination(R^2):** It is used to determine how one variable is affected by a second variable. The usefulness is that it will tell you the probability of how likely one variable is to happen given another event. [8]

References

[1] 2020, "Introduction to Accelerometers," Omega, Manchester United Kingdom, https://www.omega.co.uk/prodinfo/accelerometers.html#:~:text=An%20accelerometer%20is%20a%20device,the%20force%20exerted%20upon%20it.

[2] Kleckers, T., 2020, "How does a Force Transducer Actually Work?" HBK, https://www.hbm.com/en/6697/how-does-a-force-transducer-actually-work/

[3] 2020, "What is a signal conditioner?" HBK, https://www.hbm.com/en/7339/what-is-a-signal-conditioner/

[4] Zumbahlen, H., 2008, *Linear Circuit Design Handbook*, Newnes/Elsevier, doi: 10.1055/acprof.oso/97890.0394.000.

[5] "DC Offset," Audacity, https://manual.audacityteam.org/man/dc_offset.html

[6] *Calibrate*.

[7] "Error Analysis (Uncertainty Analysis)," https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-621-experimental-projects-i-spring-2003/lecture-notes/10_errors03.pdf

[8] "Coefficient of Determination (R Squared): Definition, Calculation," Statics How To, https://www.statisticshowto.com/probability-and-statistics/coefficient-of-determination-r-squared/