University of Cincinnati
College of Engineering and Applied Science
Department of Mechanical & Materials Engineering

Course Code : **20-MECH-4071C**
Course Title : **Measurements & Instrumentation Lab**

Experiment Number : **#4**
Experiment Title : **Dynamic Testing of Mechanical Systems Steady-State Measurements**

Date(s) Performed : October 25th & **November 8th, 2022**
Date Submitted : **November 8th, 2022**

Group Code : **M-05**
Group Members : **YI, Hongrui**
: **FENG, Haoting**

Instructor : **Dr. Aimee M. Frame**

Deductions by TA:

Initials	Content	Form/Writ
LB	10.5	2 (lang., form)
SJ	0	1(writ)
DP	1	0

TOTAL SCORE = 185.5 **/200**

ABSTRACT

In the first experiment, it is expected to understand the process of Trial Weight Method of balancing for single-plane balance. The location and the magnitude of the balance weight need to be calculated to balance the rotating system. The coherence of Baseline condition and Trial condition would become the key factor to determine the weight and location needed to balance the system by applying the corresponding frequency. Meanwhile, it is required to grasp the essence of steady-state test and get familiar with the listed experimental equipment. The result shows that the vibration could be reduced, and coherence could be consistent after balance. In conclusion, the fan could be regarded as a single-plane rotating system and be improved by Trial Weight Method.

In the second experiment, it is expected to explore the relationship between power and impedance using constant heat and cold sources to keep the temperature difference constant. The result shows that the resistance value of the thermoelectric system is about 15 Ω. In conclusion, when $R_{ext}= R_{TEC}$, the power reaches the maximum.

-1; procedure description must be more precise and elaborate

In the third experiment, an analogous electrical circuit is built to measure the response of the equivalent mechanical system. The measured response and the calculated theoretical response are compared in the Bode plot, and the two curves are basically consistent. In the process of data processing, it is found that the calculation of frequency domain data is simpler than that of time domain data, and algebraic operation can be carried out directly. The result shows that using some circuit elements including one inductance (L=462 mH RL=611.5 Ω), two capacitances (C1=19.5 mF, C2=0.91 nF), and a resistance (R=46.65 Ω), the FRF plot from the analogous circuit is very similar to the result from the mechanical system. In conclusion, during the experiment, it is found that building an analog electrical circuit is easier to operate than building a mechanical system, and the measurement is less affected by noise.

Table of Contents

1. Objectives

For the first experiment, it is expected to understand the process of how to reach the balance of a rotating unbalanced single-plane system, learn to master the Trial Weight Method of Balancing and learn to calculate the location and magnitude of balance weight of single-plane system. For the second experiment, explore the relationship between power and impedance using constant heat and cold sources to keep the temperature difference constant. For the third experiment, it is expected to combine the learned knowledge to convert the mechanical system into an analogous electrical circuit, and measure the response of the analogous electrical circuit by Bode analysis and compare with the theoretical response of mechanical system. Verify the benefit of using frequency domain analysis in modeling systems -1 writing

2. Theoretical Background

2.1 Balance of Rotating Equipment-Single-Plane

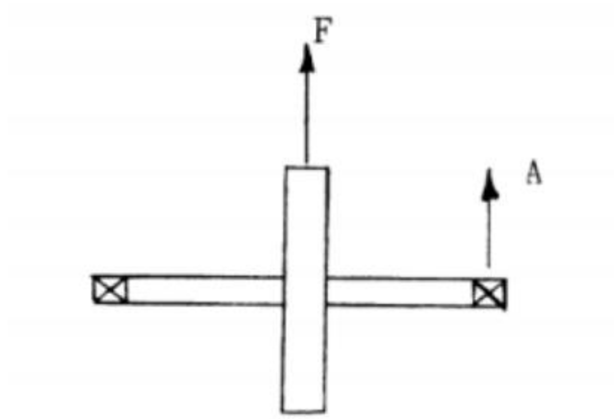


Figure 1 Single plane balancing concept

For single plane balancing, the original condition is:

$$A1\,(\omega) = \; H1a\,(\omega)Fa\,(\omega)$$

Unknown unbalance:

$$Fa(\omega) = mara\omega^2$$

Trial weight conditions:

$$A1a(\omega) = H1a(\omega)F1a(\omega)$$

Where:

$$F1a(\omega) = Fa(\omega) + \Delta Fa(\omega)$$

$$\Delta Fa(\omega) = \Delta mara\omega^2$$

After rearrangement:

$$\frac{Fa(\omega)}{\Delta Fa(\omega)} = \frac{A1(\omega)}{A1a(\omega) - A1(\omega)} = Me^{j\theta}$$

$$m_a r = M\Delta m_a r_a$$

The unbalance $F1$ is of magnitude $R\Delta F$ located at θ degrees relative to the trial weight location.

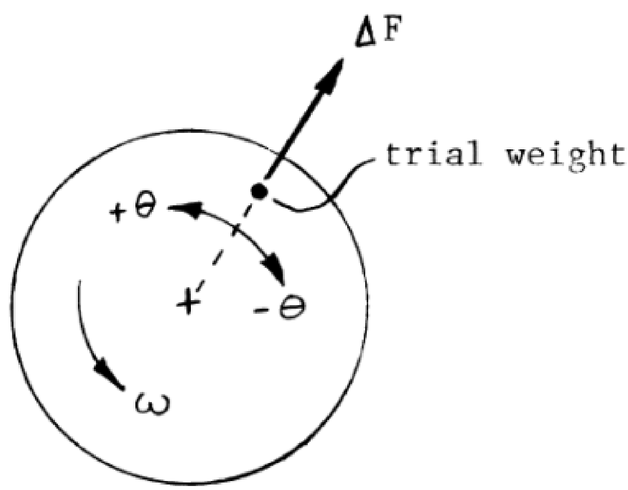


Figure 2 Single plane unbalance location

2.2 Efficiency of a Thermoelectric Device

When using thermoelectric devices as a battery source, it is often desired to determine the optimal design for maximum power output. The power of a resistor can be calculated as:

$$P = \frac{V^2}{R}$$

The power generated by a thermoelectric device can be calculated using the following equation:

$$P = \frac{R_{ext} S^2 (\Delta T)^2}{(R_{ext} + R_{TEC})^2}$$

Where ΔT is the temperature difference, S is the device's Seebeck coefficient.

setting $\boldsymbol{\frac{\partial P}{\partial R_{ext}} = 0}$ to find a local maximum:

$$\frac{\partial P}{\partial R_{ext}} = \frac{S^2(\Delta T)^2 (R_{ext} + R_{TEC})^2 - R_{ext} S^2 (\Delta T)^2 (2R_{ext} + 2R_{TEC})}{(R_{ext} + R_{TEC})^4} = 0$$

Then, it can be calculated that:

$$R_{\text{ext}} = \mathrm{R}_{TEC}$$

The power output of a thermoelectric device depends on several factors including the temperature difference and impedance of the external load connected to the device.

2.3 Simulation of Mechanical System Using Electro-Mechanical Analogies

Analog translation between mechanical and electrical systems could be represented as follows by textbook.

Generic quantity	Mechanical translation	Mechanical rotation	Electrical	Hydraulic
Effort (E)	Force (F)	Torque (T)	Voltage (V)	Pressure (P)
Flow (F)	Speed (v)	Angular speed (ω)	Current (i)	Volumetric flow rate (Q)
Displacement (q)	Displacement (x)	Angular displacement (θ)	Charge (q)	Volume ($\mathcal{V}$)
Momentum (p)	Linear momentum ($p = mv$)	Angular momentum ($h = J\omega$)	Flux linkage ($I = N\Phi = Li$)	Momentum/area ($\Gamma = IQ$)
Resistor (R)	Damper (b)	Rotary damper (B)	Resistor (R)	Resistor (R)
Capacitor (C)	Spring ($1/k$)	Torsion spring ($1/k$)	Capacitor (C)	Tank (C)
Inertia (I)	Mass (m)	Moment of inertia (J)	Inductor (L)	Inertance (I)
Inertia energy storage (special case)	$F = \dot{p}$ ($F = ma$)	$T = \dot{h}$ ($T = J\alpha$)	$V = \dot{\lambda}$ ($V = L\, di/dt$)	$P = \dot{\Gamma}$ ($P = I\, dQ/dt$)
Capacitor energy storage	$F = kx$	($T = k\theta$)	$V = (1/C)q$	$P = (1/C)\mathcal{V}$
Dissipative	$F = bv$	$T = B\omega$	$V = Ri$	$P = RQ$

Figure 3. Second-order System Modeling Analogies

3. Experimentation

3.1 Balance of Rotating Equipment-Single-Plane

3.1.1 Procedure Objectives

In this experiment, it is expected to understand the process of how to reach the balance of a rotating unbalanced single-plane system. Learn to master the Trial Weight Method of Balancing and calculate the location and magnitude of balance weight of single-plane system

3.1.2 Experimental Results

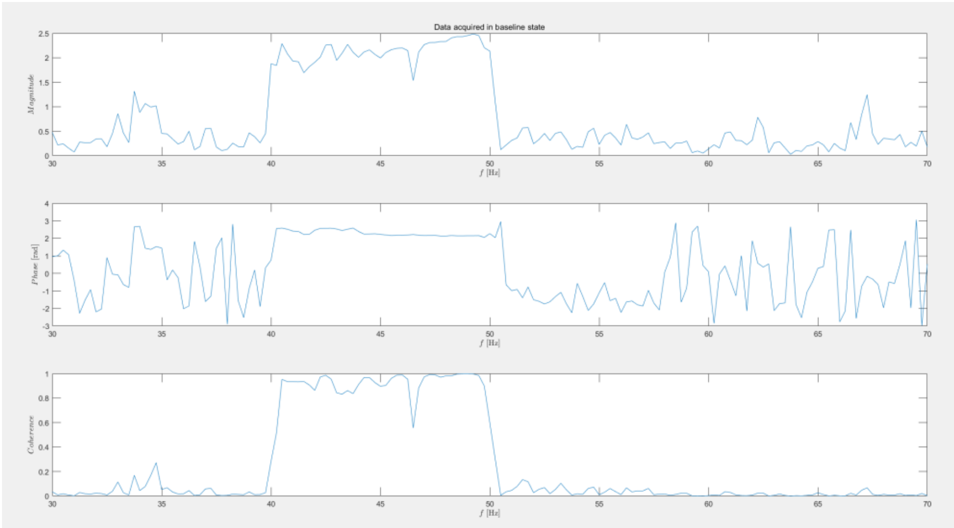


Figure 4 The data acquired in baseline state

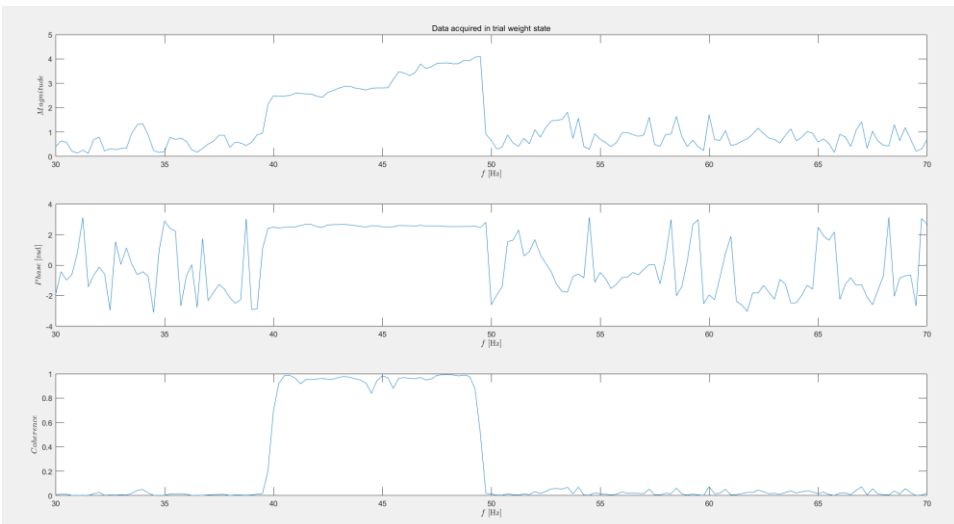


Figure 5 The data acquired in trial weight state

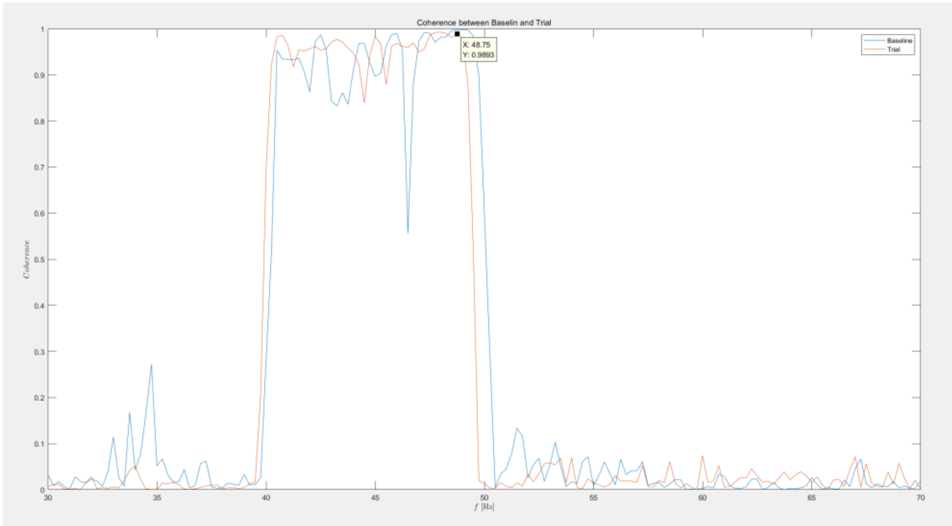


Figure 6 Coherence plot of single-plane (Baseline and trial)

3.1.3 Analysis Questions

Use Matlab to accomplish the figures and the calculations. Based on the figure above, the value of coherence is high from 30 to 50 HZ, its magnitude approximately equals to 1 when f = 48.75 HZ. Use this number to calculate the location of balance weight:

The location of balance weight: 180° – 51.46° = 128.54°

Because the trial weight were 2 silver stickers:

Since the fan has 7 blades, the distance between each blade is 360/7=51.43°. The angle of the decomposed vector must be an integer multiple of 51.43°, and the magnitude of the vector must be an integer. Using the vector calculator, the position and number of weights in equilibrium can be calculated:

-4; did not explain procedure or provided formulas how balance weight values were obtained

-1; did not mention multiplication of trial mass

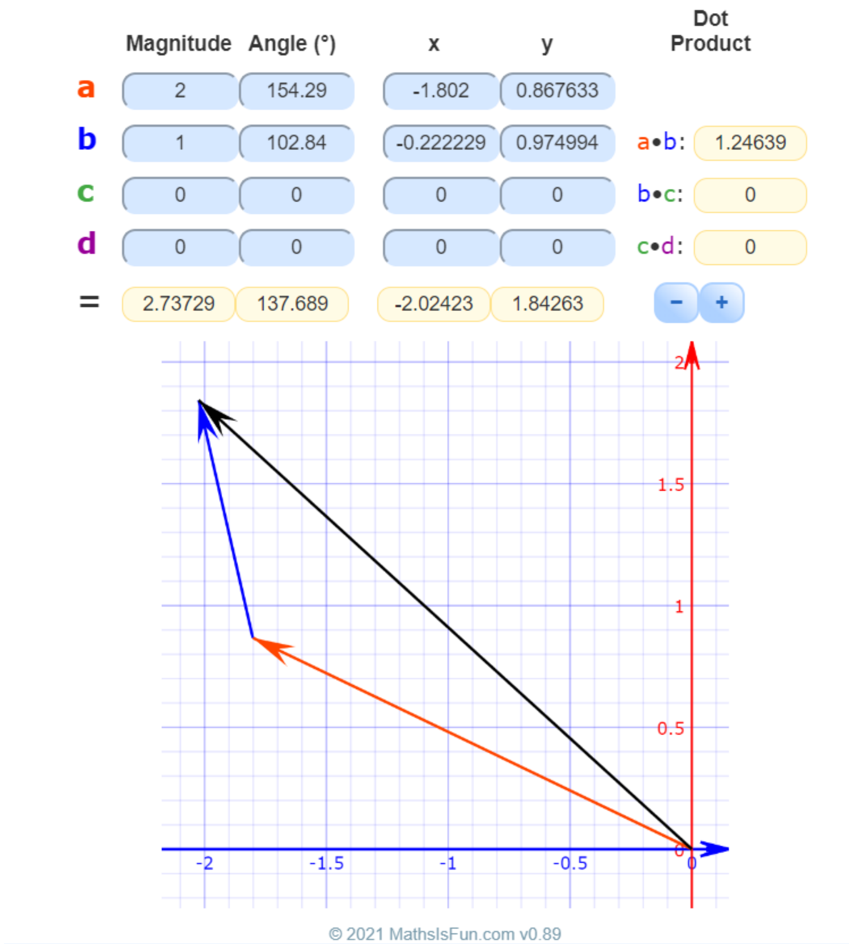
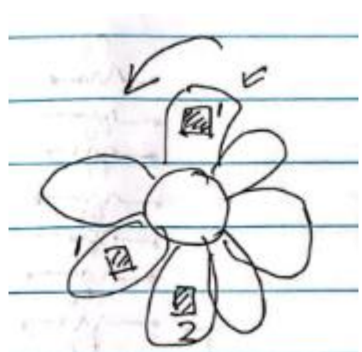


Figure 7 Single-plane vector calculation on Canvas

do not use personal pronouns

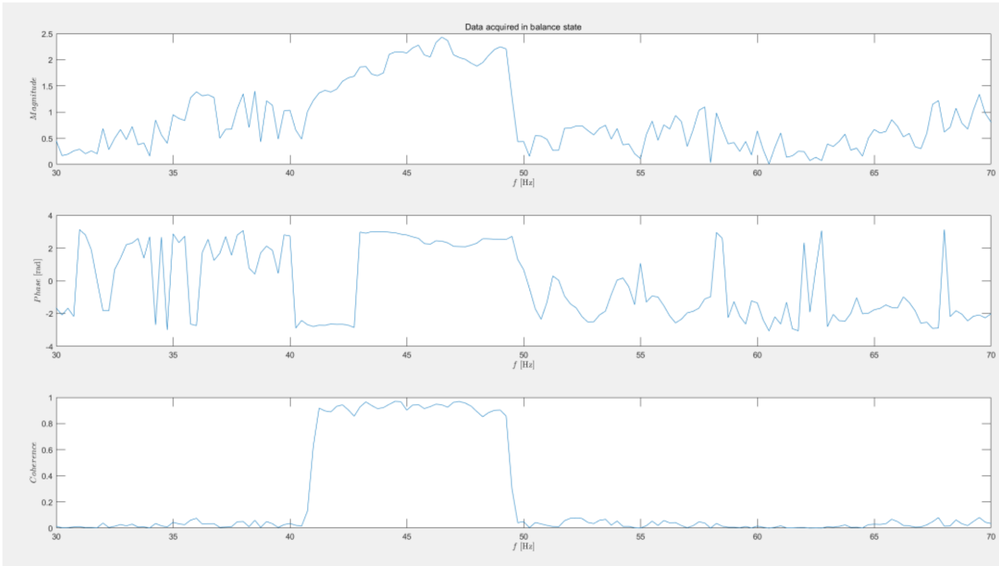
According to the calculation, we get the final placement: place a silver sticker at 102.85° counterclockwise from the original silver sticker, and place two silver stickers at 154.29° counterclockwise, as shown in the figure below：



-1; formatting - no hand drawn figures

Figure 8 Placement of balanced weights

Measure the plot in the balance state:



-0.5; labeling

Figure 9 The data acquired unbalanced state

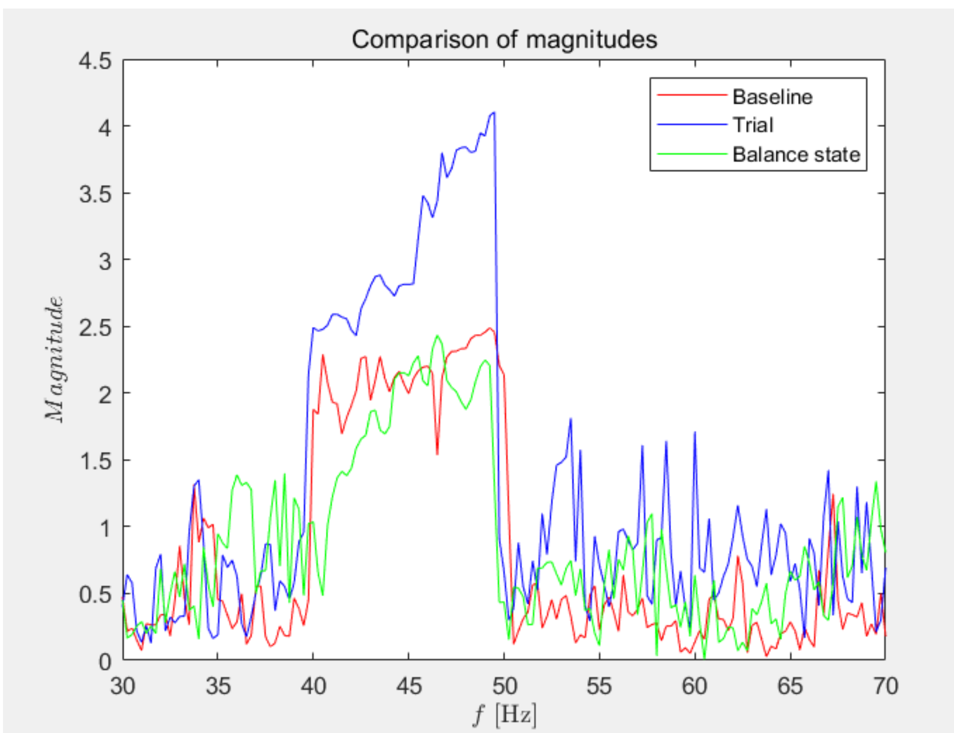


Figure 10 Comparison of magnitudes

A. Present data that compares the data taken in the baseline and balanced configurations. Does this comparison demonstrate an improvement in the balance condition of the fan system? Be sure to comment on any observations, issues, etc. that your group had during this procedure that would support your answer.

-2; did not mention additional observations etc. that support comparison of mag graph

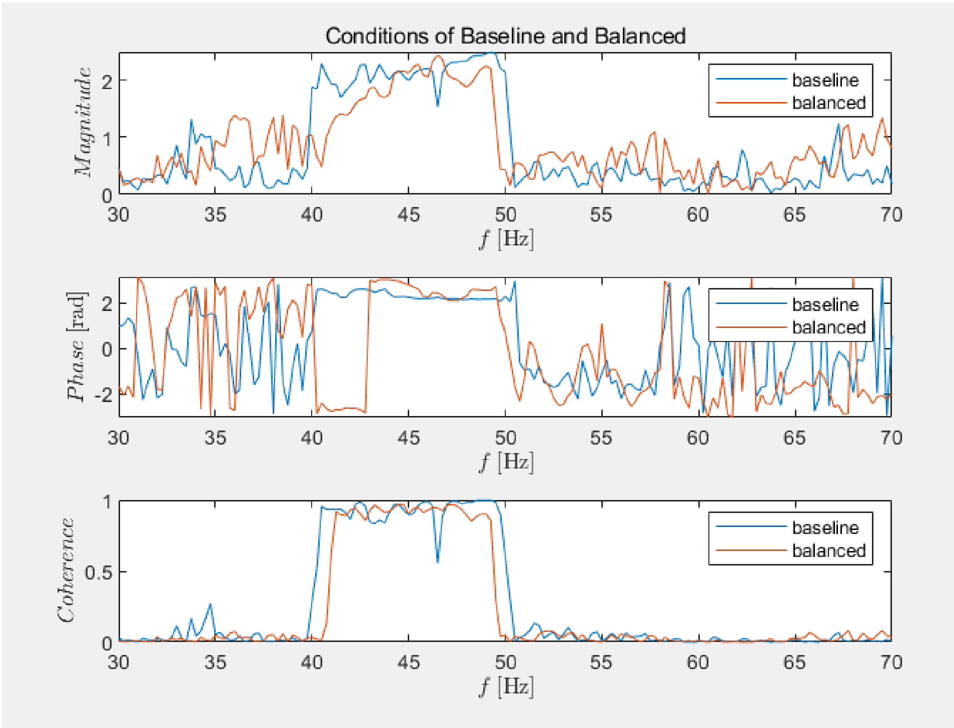


Figure 11 The FRF along with the coherence of the baseline and balanced

Comparing the magnitude of baseline and balanced, it can be found that the vibration of the balanced fan measured by the acceleration sensor is much smaller than that of the trail weight and is lower than the baseline in most frequency bands. So, the added silver stickers effectively balance the fan and reduce the vibration of the fan in the working state. Comparing the coherence data at 40 to 50 Hz, the balanced curve is flatter and closer to 1 than the baseline. Both points indicate that the balance of the fan system has been improved.

-1; coherence does not show system improvement

B. Theoretically, the single plane balancing procedure does not typically yield a significant improvement for 3-dimensional systems. However, for the rig used in lab, near perfect balancing can be achieved. Explain why balancing is possible in this case.

The system used for the experiments has a short axis and is a relatively simple system. All components are on one plane. In this way, it can be viewed as an idealized planar system. Therefore, a better balance can be achieved for the rigs used in this laboratory.

3.1.4 General Discussion

During the experiment, the vibration of the fan will change significantly depending on the weight, but the rotational speed should be similar under the three weight conditions. However, when measuring the vibration of the trial weight, it was observed that the fan speed decreased significantly, and even stopped. After checking the circuit, it is found that there is a contact problem between the fan and the power supply. After adjusting the connection state, we performed the experiment again to avoid the error of the experiment

-1; discuss results more precise

3.2 Efficiency of a Thermoelectric Device

3.2.1 Procedure Objectives

During this experiment, it is expected to explore the relationship between power and impedance using constant heat and cold sources to keep the temperature difference constant.

3.2.2 Experimental Results

Table 1 The Nominal Values of Resistors

Resistor	Nominal
R1	10.094 Ω
R2	10.124 Ω
R3	14.960 Ω
R4	22.156 Ω
R5	32.782 Ω
R6	46.582Ω
R7	67.18Ω

Also, by paralleling R6 and R7, we get Req=5.054Ω.

Table 2 The Voltage Across the External Resistors

Resistance (Ω)	Voltage (V)
5.054	185.56
10.094	347.08
14.96	481.08
22.156	529.4
32.78	617.1
46.582	658.4
67.18	692.7

The plot of these values vs the resistor values is as follows:

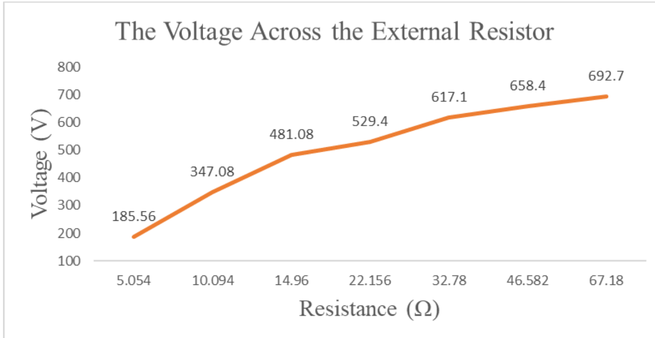


Figure 12 The Plot of Voltage vs the Resistor Values

3.2.3 Analysis Questions

A. Using your measured resistance and voltage values, calculate the power across the external resistor. Plot these values vs the resistor values used.

By using the equation:

$$P = \frac{V^2}{R}$$

The power across the external resistor could be calculated as follows:

Table 3 The Power Across the External Resistors

Resistance (Ω)	Power (W*10^-3)
5.054	6.81
10.094	11.93
14.96	15.47
22.156	12.65
32.78	11.62
46.582	9.31
67.18	7.14

The plot of these values vs the resistor values is as follows:

Figure 13 The Plot of Power vs the Resistor Values

B. The power that can be generated by a thermoelectric device can be calculated using the following equation:

$$\boldsymbol{P} = \frac{\boldsymbol{R_{ext}S^2(\Delta T)^2}}{\boldsymbol{(R_{ext} + R_{TEC})^2}}$$

Where ΔT is the temperature difference, S is the device's Seebeck coefficient

Find the relationship between the external resistor value and the TEC resistance at which maximum power can be achieved. Note that this will involve setting $\frac{\partial P}{\partial R_{ext}} = 0$ to find a local maximum.

When $\frac{\partial P}{\partial R_{ext}} = 0$, the value of power is local maximum.

So, Take the first-order derivative of power, and calculate the relationship between R_{ext} and R_{TEC} when the first-order derivative of power is equal to 0 .

$$\frac{\partial P}{\partial R_{ext}} = \frac{S^2(\Delta T)^2(R_{ext} + R_{TEC})^2 - R_{ext}S^2(\Delta T)^2(2R_{ext} + 2R_{TEC})}{(R_{ext} + R_{TEC})^4} = 0$$

$$S^2(\Delta T)^2R_{TEC}^2 - S^2(\Delta T)^2R_{ext}^2 = 0$$

$$R_{ext}^2 = R_{TEC}^2$$
$$R_{\text{ext}} = \text{R}_{TEC}$$

So, when $R_{\text{ext}} = R_{\text{TEC}}$ the external resistor value can achieve the maximum power.

C. Using the results of the previous analysis questions, determine the resistance value of the thermoelectric system used in this experiment.

From question B, when $R_{ext}= R_{TEC}$, the external resistor value can achieve the maximum power From question A, when the resistance value of the external resistor is 14.96 Ω, the resistance power is the largest. Hence, the resistance value of the thermoelectric system is around 15 Ω.

3.2.4 General Discussion

Knowing the formula for calculating the power that a thermoelectric device can generate, it can take the first-order derivative of the power formula and find the local maximum of the power when the derivative is equal to 0. Through the solution, it is known that when $R_{ext}= R_{TEC}$, the power reaches the maximum. From the working power of the external resistor obtained from the experimental data, it can be known that when the external resistor is 14.96 Ω, the power is the largest. Therefore, it can be obtained that the resistance value of the thermoelectric system is about 15 Ω.

3.3 Simulation of Mechanical System Using Electro-Mechanical Analogies

3.2.1 Procedure Objectives

During this experiment, it is expected to combine the learned knowledge to convert the mechanical system into an analogous electrical circuit and measure the response of the analogous electrical circuit by Bode analysis and compare with the theoretical response of mechanical system. Verify the benefit of using frequency domain analysis in modeling systems.

3.2.2 Experimental Results

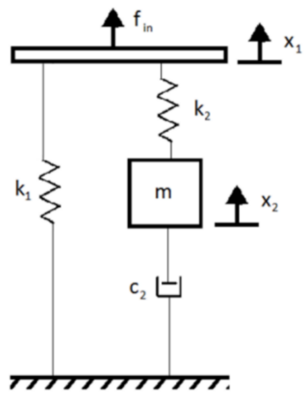
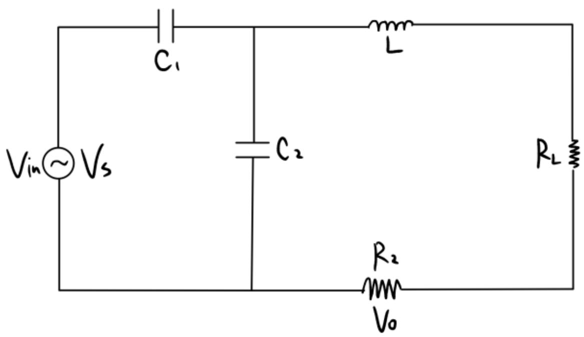


Figure 14 Mechanical system



-1; missing Vin, Vout indicator

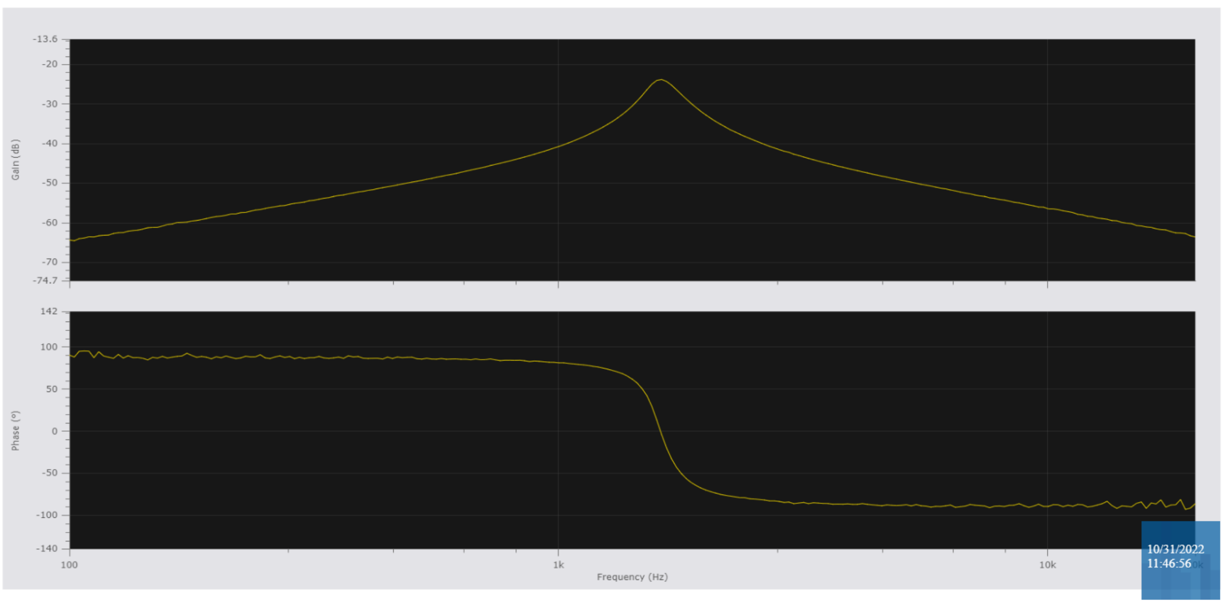
Figure 15 Analogous Electrical Circuit

Table 4 Mechanical System Parameters

Mechanical Parameter	Nominal
m	0.47 kg
k1	50 MN/m
k2	1100 MN/m
c	620 Ns/m

Table 5 Circuit System Parameters

Mechanical Parameter	Theoretical Values	Measured Values
L	470 mH	462 kg
c1	20 mF	19.5 mF
c2	0.909 nF	0.91 nF
R	620 Ω	46.65 Ω
RL		611.5 Ω



Stimulus Channel	
Start Frequency	100 Hz
Stop Frequency	20 kHz
Steps Per Decade	100
Peak Amplitude	1 V

Response Channels

Response Name	State	Channel Label
Response 1	Enabled	Oscilloscope CH2
Response 2	Disabled	
Response 3	Disabled	

Reference Channels

Reference Name	State	Mode	Source File Name	Channel
Reference 1	Disabled			
Reference 2	Disabled			

Figure 16 Bode Plot for Analogous Circuit

3.2.3 Analysis Questions

A. Using the mechanical system model, develop a matrix expression for the frequency response functions of the system. Indicate which term in the resulting matrix relates the motion of the mass (x2) to the input force (f)

FBD for mechanical system:

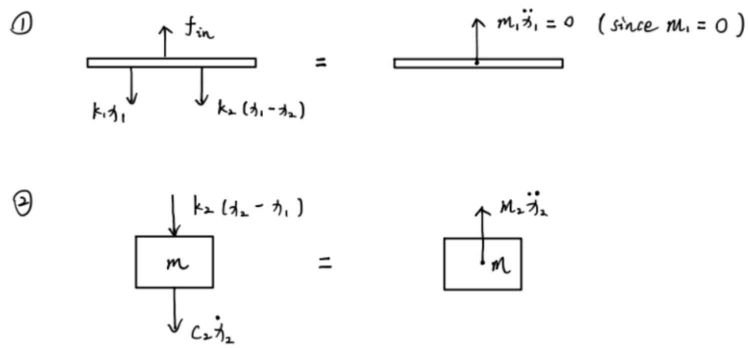


Figure 17 FBD for Mechanical System

Mechanical system equations:

$$k_1 x_1 + k_2(x_1 - x_2) = f_{in}$$
$$m_2 \ddot{x}_2 + k_2(x_2 - x_1) + c\dot{x}_2 = 0$$

Convert to matrix form:

$$\begin{bmatrix} 0 & 0 \\ 0 & m_2 \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & c \end{bmatrix} \begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{Bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{Bmatrix} f_{\text{in}} \\ 0 \end{Bmatrix}$$

$$M \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{Bmatrix} + C \begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{Bmatrix} + K \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{Bmatrix} f_{\text{in}} \\ 0 \end{Bmatrix}$$

$$M = \begin{bmatrix} 0 & 0 \\ 0 & m_2 \end{bmatrix};\ C = \begin{bmatrix} 0 & 0 \\ 0 & c \end{bmatrix};\ K = \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix}$$

After Fourier transform, Define matrix A as:

$$A = M(jw)^2 + C(jw) + K$$

$$A = \begin{bmatrix} 0 & 0 \\ 0 & m_2 \end{bmatrix} (jw)^2 + \begin{bmatrix} 0 & 0 \\ 0 & c \end{bmatrix} (jw) + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & -k_2 \end{bmatrix}$$

Then the equation can be written as:

$$A \begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{Bmatrix} f_{in} \\ 0 \end{Bmatrix}$$

$$\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = A^{-1} \begin{Bmatrix} f_{in} \\ 0 \end{Bmatrix}$$

$$\begin{Bmatrix} x_1 \\ x_2 \end{Bmatrix} = \begin{bmatrix} \frac{x_1}{f_1} & \frac{x_1}{f_2} \\ \frac{x_2}{f_1} & \frac{x_2}{f_2} \end{bmatrix} \begin{Bmatrix} f_1 \\ f_2 \end{Bmatrix}$$

Therefore, the term of 2nd row 1st column in the resulting matrix A^{-1} relates the motion of the mass (x2) to the input force (f)

B. What modifications to the system model obtained in question A are needed to represent the actual measurement taken?

According to the properties of Fourier transform,

$$\frac{v_2}{f_{\text{in}}} = \frac{\dot{x}_2}{f_{\text{in}}} = \frac{x_2}{f_{\text{in}}}(jw)$$

According to second-order system modeling analogies, the speed of a mechanical system is analogous to the current of a circuit, and the force of a mechanical system is analogous to the voltage of a circuit.

$$\frac{v_2}{f_{in}} \overset{\text{Analogy}}{\Leftrightarrow} \frac{i_2}{V_{in}}$$

According to Ohm's law,

$$V_o = i_2 R_2$$

The whole process can be expressed as:

$$\frac{x_2}{f_{in}} \xrightarrow{*jw} \frac{v_2}{f_{in}} \overset{\text{Analogy}}{\Leftrightarrow} \frac{i_2}{V_{in}} \xrightarrow{*R_2} \frac{V_o}{V_{in}}$$

C. Calculate the theoretical response of the mechanical system using the measured values from Procedure 4.2.B and the system model from questions A and B.

a. Plot the result and the collected Bode data on the same graph (use mag/phase subplots)

b. Be sure that the calculated result is converted into the same units as the data taken

According to the above contents, calculate the corresponding theoretical response (see Appendix MATLAB Code for the calculation process). The Bode plot of the calculated theoretical response and the measured response is as follows:

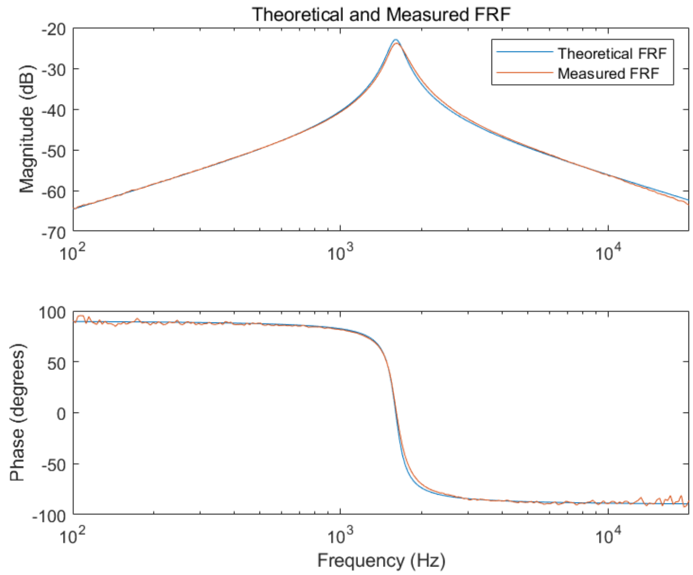


Figure 18 Theoretical and Measured FRF

D. Is the response of the system what you expected? What may account for the discrepancies?

According to the theoretical and measured Bode plot, the two curves are basically coincident, which means it is what we expected. However, some discrepancies do occur, especially in high frequency areas. In the high frequency region, some noise is unavoidable, which considered to be one of the main reasons for the discrepancies. In addition, some experimental equipment is idealized when calculating the theoretical response. The actual parameters of components and the measurement of experimental equipment will cause some errors.

E. How might the use of an electrical circuit be better than using the actual mechanical system for testing purposes?

Compared with the mechanical system to measure displacement, the electric circuit to measure voltage is easier to operate. Compared with building a huge mechanical system, building an analog electrical circuit is more space-saving and easier to operate. Compared with the noise encountered in mechanical system measurement, the noise interference encountered in electrical circuit measurement is less.

F. Based on this procedure, what are some benefits of working with frequency data?

In the analog conversion of mechanical system and electrical circuit, it is necessary to transform the parameters to correlate. When calculating the response function, simple algebraic operations can be carried out directly by using frequency domain data. Using time domain data requires more complex and additional conversion. The frequency domain data is obtained by Fourier transform. The essence of Fourier transform is to decompose the original continuous signal into the superposition of a series of sinusoidal or complex exponential signals. Therefore, when there is noise, the frequency domain data is clearer than the time domain data and receives less interference.

3.2.4 General Discussion

Setting up an analogous circuit is easier and cheaper than the mechanical system does. After using some circuit elements including one inductance (L=462 mH RL=611.5 Ω), two capacitances (C1=19.5 mF, C2=0.91 nF), and a resistance (R=46.65 Ω), the FRF plot from the analogous circuit is very similar to the result from the mechanical system, and the little differences from the measured response and the calculated response may be caused by the differences of measured value of the mechanical parameter.

4. Conclusions

Having performed the experiment, and after a thorough analysis of the data, the following points are therefore concluded.

As for experiment 1, the almost perfect balanced system could be reached in the single plane rotating system as its low complexity. When the coherence of trial and baseline data nearly equals to 1, apply the corresponding frequency to calculate the magnitude as well as the location of the balance weight. Moreover, the comparison of FRF plots of balance condition and baseline condition could indicate the improvement in the balance condition of fan system.

As for experiment 2, it is known through the experiment that when R_{ext}= R_{TEC}, the power reaches the maximum. From the working power of the external resistor obtained from the experimental data, it can be known that when the external resistor is 14.96 Ω, the power is the largest. Therefore, it can be obtained that the resistance value of the thermoelectric system is about 15 Ω.

As for experiment 3, when measuring the response of a mechanical system, an analog electrical circuit can be built to measure its response. Compared with the measurement of mechanical system, the measurement operation of analog electrical circuit is easier and less affected by noise. Moreover, analog electrical circuits are easier to build than mechanical systems. When calculating the response function, simple algebraic operations can be carried out directly by using frequency domain data. Using time domain data requires more complex and additional conversion.

APPENDICES

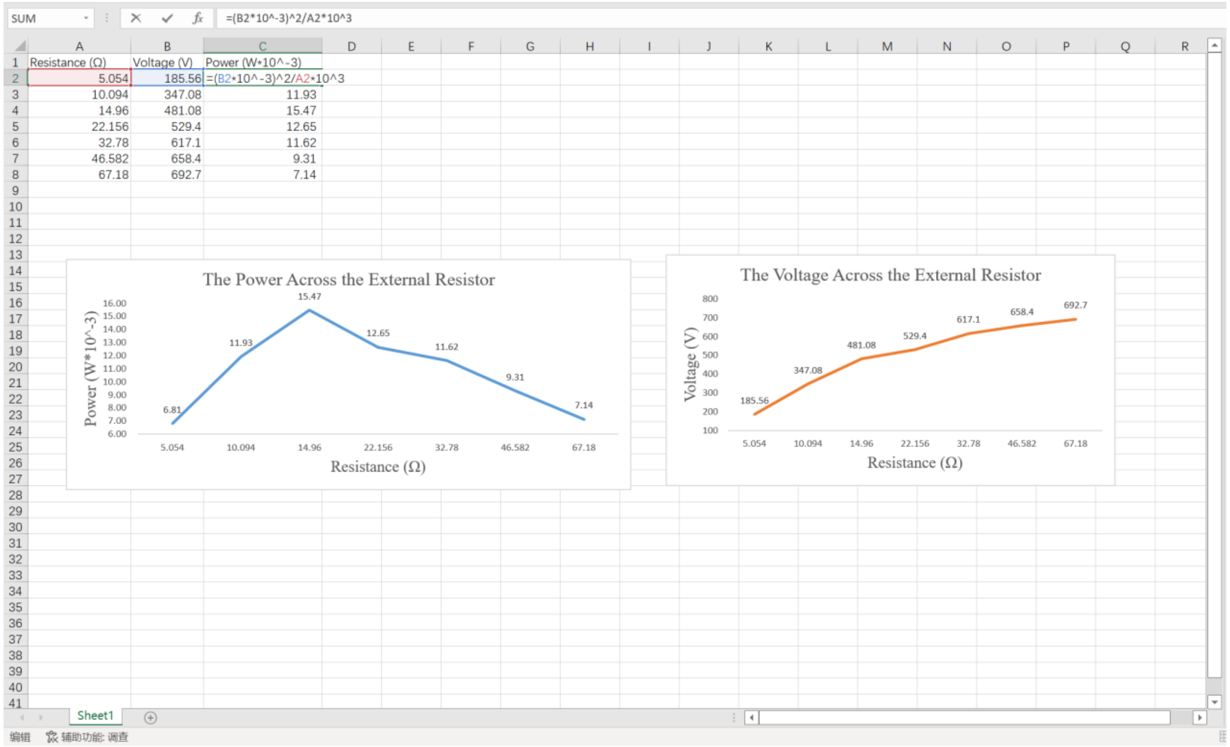
A – EQUIPMENT LIST

Table 6. Equipment List

Experiment	Equipment Description	Model Number	Serial Number
Balance of Rotating Equipment – Single Plane	Prototyping Base	NI ELVIS III	307E834
	Prototyping Board	NI ELVIS III	E01X0448A
	ICP Sensor Signal Conditioner	480E09	2127119
	PCB Piezotronics	333B30	LW56745
	Fin		5
Efficiency of a Thermoelectric Device	Prototyping Board	NI ELVIS III	316A000
	TEC	TECX1	12706
Simulation of Mechanical System Using Electro-Mechanical Analogies	Prototyping Board	NI ELVIS III	316835

B – MATLAB Code (or Excel, other computational software, etc)

Excel Sheet:



=(B2*10^-3)^2/A2*10^3

	A	B	C
1	Resistance (Ω)	Voltage (V)	Power (W*10^-3)
2	5.054	185.56	=(B2*10^-3)^2/A2*10^3
3	10.094	347.08	11.93
4	14.96	481.08	15.47
5	22.156	529.4	12.65
6	32.78	617.1	11.62
7	46.582	658.4	9.31
8	67.18	692.7	7.14

MATLAB Code:

```
clear;clc;close all
load('Lab3_2_2_A.mat') %¼ÓÔØÔ-Ê¼Êý¾Ý
f1 = Measurements.FRF.freq;
H1=squeeze(Measurements.FRF.H);
mag1 = abs(squeeze(Measurements.FRF.H));
COH1 = squeeze(Measurements.COH.gamma2);
phase1 = angle(squeeze(Measurements.FRF.H));
figure (1)
subplot(3,1,1)
plot(f1,mag1);
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Magnitude $'],'interpreter','latex')
title('Data acquired in baseline state')
subplot(3,1,2)
plot(f1,phase1);
```

```
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Phase\;\mathrm{[rad]}
$'],'interpreter','latex')
xlim([30,70]);
subplot(3,1,3)
plot(f1,abs(COH1));
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Coherence $'],'interpreter','latex')
xlim([30,70]);
%% B
load('Lab3_2_2_B.mat')%¼ÓÔØ¸°ÔØÊý¾Ý
f2 = Measurements.FRF.freq;
H2=squeeze(Measurements.FRF.H);
mag2 = abs(squeeze(Measurements.FRF.H));
COH2 = squeeze(Measurements.COH.gamma2);
phase2 = angle(squeeze(Measurements.FRF.H));
figure (2)
subplot(3,1,1)
plot(f1,mag2);
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Magnitude $'],'interpreter','latex')
title('Data acquired in trial weight state')
subplot(3,1,2)
plot(f1,phase2);
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Phase\;\mathrm{[rad]}
$'],'interpreter','latex')
subplot(3,1,3)
plot(f1,abs(COH2));
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
```

```
ylabel(['$ Coherence $'],'interpreter','latex')
%% D
load('Lab3_2_2_D.mat')%¼ÓÔØÆ½°â°óÊý¾Ý
f3 = Measurements.FRF.freq;
H3=squeeze(Measurements.FRF.H);
mag3 = abs(squeeze(Measurements.FRF.H));
COH3 = squeeze(Measurements.COH.gamma2);
phase3 = angle(squeeze(Measurements.FRF.H));
figure (3)
subplot(3,1,1)
plot(f1,mag3);
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Magnitude $'],'interpreter','latex')
title('Data acquired in balance state')
subplot(3,1,2)
plot(f1,phase3);
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Magnitude $'],'interpreter','latex')
title('Data acquired in balance state')
subplot(3,1,2)
plot(f1,phase3);
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Phase\;\mathrm{[rad]}
$'],'interpreter','latex')
subplot(3,1,3)
plot(f1,abs(COH3));
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Coherence $'],'interpreter','latex')
figure (4)
plot(f1,abs(COH1));
```

```
hold on
plot(f1,abs(COH2));
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Coherence $'],'interpreter','latex')
legend('Baseline','Trial')
title('Coherence between Baselin and Trial')
% M=H1./(H2-H1);
% magtotal = abs(M);
% phasetotal = angle(M);
% figure (1)
% plot(Measurements.FRF.freq,real(COH1))
% hold on
% plot(Measurements.FRF.freq,real(COH2))
% plot(Measurements.FRF.freq,real(COH3))
% figure (2)
% plot(Measurements.FRF.freq,phase1)
% hold on
% plot(Measurements.FRF.freq,phase2)
% plot(Measurements.FRF.freq,phase3)
figure (5)
plot(Measurements.FRF.freq,mag1,'-r')
hold on
plot(Measurements.FRF.freq,mag2,'-b')
plot(Measurements.FRF.freq,mag3,'-g')
xlim([30,70])
legend('Baseline','Trial','Balance state')
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Magnitude $'],'interpreter','latex')
title('Comparison of magnitudes')
%% Question A
figure (6)
subplot(3,1,1)
plot(f1,mag1);
hold on
plot(f1,mag3);
```

```
legend('baseline','balanced')
xlim([30,70]);
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Magnitude $'],'interpreter','latex')
title('Conditions of Baseline and Balanced')
subplot(3,1,2)
plot(f1,phase1);
hold on
plot(f1,phase3);
legend('baseline','balanced')
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Phase\;\mathrm{[rad]}
$'],'interpreter','latex')
xlim([30,70]);
subplot(3,1,3)
plot(f1,abs(COH1));
hold on
plot(f1,abs(COH3));
legend('baseline','balanced')
xlabel(['$ f\;\mathrm{[Hz]}
$'],'interpreter','latex')
ylabel(['$ Coherence $'],'interpreter','latex')
xlim([30,70]);

% The code applied in the Question C of section
3.3:
% Question C
clear;close all;clc
% Load measured data
dataF=xlsread('Lab4_2.csv','A2:A232');
dataM=xlsread('Lab4_2.csv','B2:B232');
dataP=xlsread('Lab4_2.csv','C2:C232');
% Input parameter value
m = 0.470; %kg
k1 = 50*10^6; %N/m
k2 = 1.1*10^9; %N/m
```

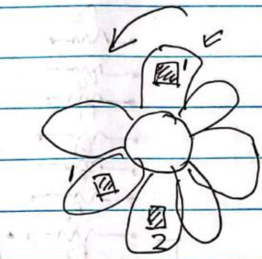
```
c = 620; %Ns/m
R2 = 46.65; %ohms
f = dataF; %Hz
w = 2*pi*f; %rad/s
% Calculated FRF
for kk = 1:length(f)
A = [0 0;0 m]*(1i*w(kk))^2+[0 0;0
c]*(1i*w(kk))+[k1+k2 -k2;-k2 k2];
invA = inv(A);
H(kk) = invA(2,1)*1i*w(kk)*R2;
end
% Plot
figure(1)
subplot(2,1,1)
semilogx(f,20*log10(abs(H)))
hold on
semilogx(dataF,20*log10(dataM))
title('Section 4: Theoretical and Measured FRF')
ylabel('Magnitude (dB)')
legend('Theoretical FRF','Measured FRF')
subplot(2,1,2)
semilogx(f,180/pi*angle(H))
hold on
semilogx(dataF,dataP)
ylabel('Phase (degrees)')
xlabel('Frequency (Hz)')
```

C – Scanned Lab Notes

Lab 4

2.3.3 phase : (48.75 , − 51.46)

mag : (48.75 , 1.252) should be x 2



$2.5\angle 129^\circ = A\angle\theta_A + B\angle\theta_B$

NI ELVIS II #307E834 /Board# E01X0448A

ICP Sensor Signal Condition 480E09 #0427119

PCB 333130 #LW56745

Fan #5

LB 10.24

Lab 4 Day 2

NI ELVIS III 316A000

TEC1-12706

3.2

$R_1 = 32.782$

$R_2 = 14.92$

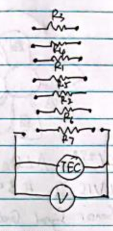
$R_3 = 67.18$

$R_4 = 46.582$

$R_5 = 22.156$

$R_6 = 10.124$

$R_7 = 10.094$



R = 61.18	V = 692.7 mV
R = 46.582	V = 658.4 mV
R = 32.782	V = 617.1 mV
R = 22.156	V = 529.4 mV
R = 14.96	V = 481.608 mV
R = 10.094	V = 347.08 mV
R = 5.054	V = 185.56 mV

LB 10.31

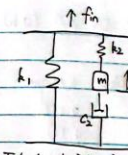
4.2

$m = 0.47\,kg$

$k_1 = 50\times10^6\,N/m$

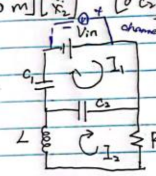
$k_2 = 1.1\times10^9\,N/m$

$C = 620\,Ns/m$



$$\begin{bmatrix}0&0\\0&m\end{bmatrix}\begin{bmatrix}\ddot{x}_1\\\ddot{x}_2\end{bmatrix}+\begin{bmatrix}0&0\\0&C_2\end{bmatrix}\begin{bmatrix}\dot{x}_1\\\dot{x}_2\end{bmatrix}+\begin{bmatrix}k_1+k_2&-k_2\\-k_2&-k_2\end{bmatrix}\begin{bmatrix}x_1\\x_2\end{bmatrix}=\begin{bmatrix}f_{in}\\0\end{bmatrix}$$

$C = \frac{Q}{U}\ \frac{V}{A\cdot S}$



Unit

$\frac{1}{C}\rightarrow k \quad \frac{V}{A\cdot S}=\frac{1}{F}=N/m$

$R\rightarrow C \quad \frac{V}{A}=\Omega=N\cdot S/m$

$L\rightarrow m \quad \frac{VS}{A}=H=kg$

where $L = 0.47\,H$ Board 316831

$C_1 = \frac{1}{50\times10^6} = 2\times10^{-8}\,F$

$C_2 = \frac{1}{1.1\times10^9} = 9.09\times10^{-10}\,F$

$R = 620\,\Omega$