重庆大学-辛辛那提大学联合学院

学生实验报告

CQU-UC Joint Co-op Institute (JCI)

Student Experiment Report

实验课程名称 Experiment Course Name Circuit and Sensor Experiment

开课实验室（学院）Laboratory (School) College of Mechanical Engineering

学院 School Joint Co-op Institut 年级 2018 专业 ME01 班 Student Group 02

学生姓名 Student Name Yi, Hongrui 学号 Student Number 20186103

学生姓名 Student Name Zhuang, Yan 学号 Student Number 20186105

学生姓名 Student Name Han, Xiangyu 学号 Student Number 20186102

学年 Academic Year 2021 学期 Semester Summer

成绩 Grade		
教师签名 Signature of Instructor		

批改说明 Marking instructions:

批改说明 Marking instructions:

指导老师请用红色水笔批改，在扣分处标明所扣分数并给出相应理由，在封面的平时成绩处注明成绩。

Supervisors should mark the report with a **red ink pen**. Please write down **the points deducted** for each section when errors arise and specify the corresponding reasons. Please write down **the total grade** in the table on the cover page.

重庆大学-辛辛那提大学联合学院 2016 年制订

University of Cincinnati
College of Engineering & Applied Science
School of Dynamic Systems

Course Code	: **20-MECH-3070C**
Course Title	: **Circuits and Sensing Lab**
Experiment Number	: **4**
Experiment Title	: **Transducer Medley**
Date(s) Performed	: **June 23, 2021**
Date Submitted	: **August 06, 2021**
Group Code	: **02**
Group Members	: **Yi, Hongrui**
	: **Zhuang, Yan**
	: **Han, Xiangyu**
Instructor	: **Wang, Xian**

Experiment Results	= ______/40
Analysis	= ______/30
Answers to Questions	= ______/20
Writing	= ______/10
TOTAL SCORE	**= ______/100**

ABSTRACT

By using the sensors, their functions can be known. The sensors that were measured are force transducer, accelerometer, displacement transducer, thermocouple and thermistor. The task of the laboratory is to familiarize us with the functions and operations of the sensors and their application.

In the part 1, force transducers and four weights are used to measure the output voltage. And we will use these values to compute the sensitivity at each step. Finally, we will take an average value for the overall sensitivity. Compute the relative error in the final step. Then, we can use it to measure the weight of a mobile phone , and use this result to calculate the nominal sensitivity value for the force transducer.

In the part 2 of the experiment is as follows: measure the sensitivity of the accelerometer, and then measure the resonance frequency of the cantilever beam. Using a known accelerometer, the sensitivity of the unknown accelerometer was obtained by adjusting the parameters. The resonant frequency of the resonant cantilever beam is obtained by adjusting the experimental conditions. The first peak in the simulated display screen is the resonant frequency of scan and knock. Finally, the resonant frequency read by the experiment is compared with the value obtained by the experiment.

In the part 3, we will use the LVDT as a displacement sensor to construct the structure and measure the displacement of the rod. The corresponding output voltage for each position is measured using the DMM. The sensitivity of each displacement change is then calculated and averaged. Finally, use the data from the mobile as the nominal value and compare the calculated value with this value.

In the part 4, we will use a multimeter to measure the resistance of the thermometer at different temperatures. Draw the thermistor calibration curve. An experimental platform was developed to collect data to monitor the relationship between output voltage and temperature of thermocouples, to draw up a diagram, to compare the ratio between the measured flow value and the theoretically predicted value, and to analyze the results.

Table of Contents

1. Objectives

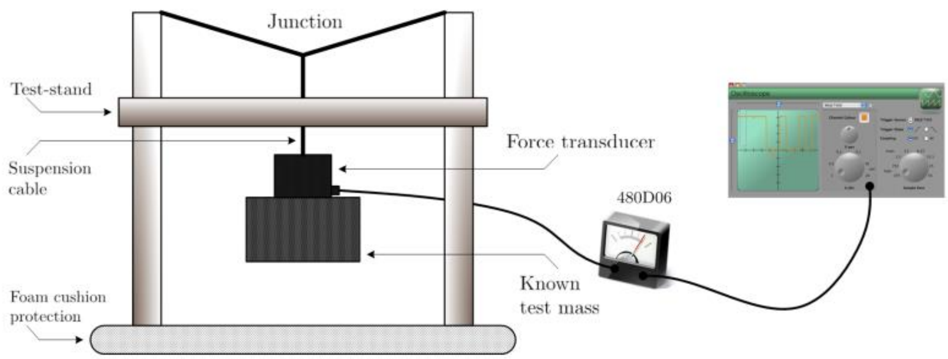
At the end of this experiment, the students are expected to:

- Learn how to use a variety of transducers.
- Investigate the operation of the following: displacement sensor, accelerometer, force transducer, thermocouple, thermistor and pressure transducer.
- Develop calibration curves, perform linearization and curve fitting.

2. Theoretical Background

For part 1:

A load cell is a transducer used to measure force. It contains an internal deflection element, usually with multiple strain gages on its surface. The bending element is shaped so that the output of the strain gauge can be easily related to the applied force. The load cell is usually connected to a bridge circuit to produce a voltage proportional to the load. The structure is shown below:



Test setup for calibration of a force transducer

The change in resistance of the device is reasonably linear function of its deformation.

Since L and A both change as a wire is stretched it is reasonable to think that we can rewrite the equation R= r×L/A to relate strain to changes in resistance.

Start with the differential: dR = dρ× (L/A) + ρ×d(L/A)

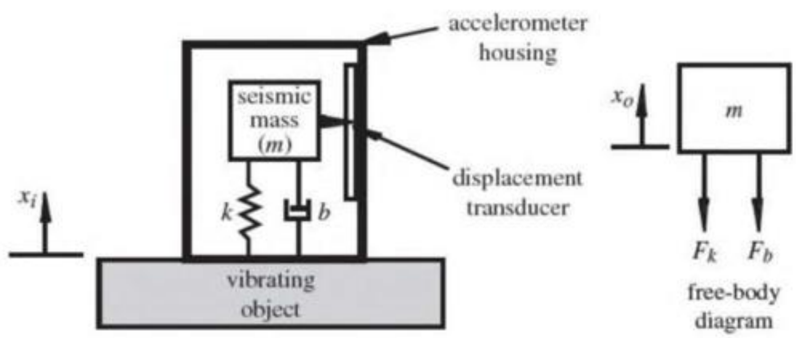
using chain rule and plug A = wh into it, we can get

$$\frac{dR}{R} = \varepsilon_{axial}(1 + 2\mu) + \frac{d\rho}{\rho}$$

$$F = \frac{\frac{dR}{R}}{\varepsilon_{axial}} = 1 + 2\mu + \frac{1}{\varepsilon_{axial}}\frac{d\rho}{\rho}$$

For part 2:

The design of the accelerometer is based on the inertia effect associated with the mass connected to the moving object via springs, dampers and displacement transducers. The figure is shown below:



In the free-body diagram, we define the relative displacement xr between the seismic mass and the object as:

$$x_r = x_o - x_i$$

The spring force can be expressed as

$$F_k = k(x_o - x_i) = kx_r$$

The damper force can be expressed as

$$F_k = b(\dot{x}_o - \dot{x}_i) = b\dot{x}_r$$

Applying Newton's second law, the equation of motion for the seismic mass is

$$\sum F_{ext} = m\ddot{x} \text{ or} - F_k - F_b = m\ddot{x}_o$$

We can rearrange those equations as

$$m\ddot{x}_r + b\dot{x}_r + kx_r = -m\ddot{x}_i$$

Rewrite this equation as

$$\ddot{x}_r + 2\,\zeta\,\omega_n\dot{x}_r + \omega_n{}^2x_r = -\ddot{x}_i$$

where the natural frequency is $\omega_n = \sqrt{\frac{k}{m}}$, the damping ratio is $\zeta = \frac{b}{2\sqrt{km}}$.

For sinusoidal input:

$$x_i(t) = X_i \sin(\omega t)$$

Because the system is linear, the output is:

$$x_r(t) = X_r \sin(\omega t + \emptyset)$$

The frequency response analysis results in the amplitude ratio is

$$\frac{X_r}{X_i} = \frac{\left(\omega/\omega_n\right)^2}{\left(\left[1-\left(\omega/\omega_n\right)^2\right]^2 + 4\zeta^2\left(\omega/\omega_n\right)^2\right)^{1/2}}$$

And the phase angle is

$$\emptyset = -\tan^{-1}\left(\frac{2\zeta\left(\omega/\omega_n\right)}{1-\left(\omega/\omega_n\right)^2}\right)$$

Because we concentrate on acceleration, so

$$\ddot{x}_i(t) = -X_i i\omega^2 \sin(\omega t)$$

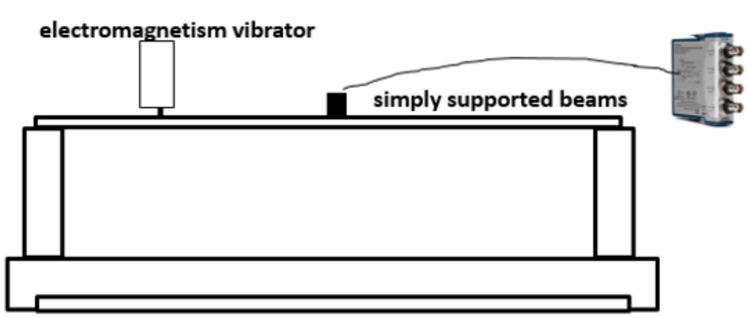
Rearranging Equation of amplitude ratio

$$H_a(\omega) = \frac{X_r {\omega_n}^2}{X_i \omega^2} = \frac{1}{\left(\left[1-\left(\omega/\omega_n\right)^2\right]^2 + 4\zeta^2\left(\omega/\omega_n\right)^2\right)^{1/2}}$$

$$X_r = \frac{1}{{\omega_n}^2} H_a(\omega)(X_i\omega^2)$$

$$X_i\omega^2 = \frac{X_r {\omega_n}^2}{H_a(\omega)}$$

If we design the accelerometer so that is nearly 1 over a large frequency range. The largest frequency range resulting in a unity amplitude ratio occurs when the damping ratio is 0.707 and the natural frequency is as large as possible.



Simply supported beams are supported on the ends which are free to rotate and have no moment resistance. There is not a unique resonance frequency.

Calculate the resonance frequency of the beam

$$f_0 = \frac{1}{2\pi}(\frac{\pi}{l})^2\sqrt{\frac{EI}{\rho s}}$$

$$\mathrm{E} = 210\mathrm{Gpa} \quad \mathrm{I} = \frac{bh^3}{12} \quad \rho = 7850\, {}^{kg}/_{m^3}$$

l: the length of the simply supported beam

E: the modulus of elasticity

A: the cross-section area

ρ: the density of material

I: the bending moment of inertia at the cross section

b: the width at the cross section

h: the height at the cross section

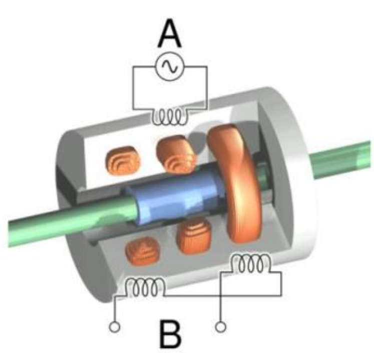
the first order resonance frequency is f_0

the second order $f_2 = 4f_0$

the third order $f_3 = 9f_0$

For part 3:

The linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement. The transformer has three solenoidal coils placed end-to-end around a tube. The center coil is the primary, and the two outer coils are the secondary. A cylindrical ferromagnetic core, attached to the object whose position is to be measured, slides along the axis of the tube.

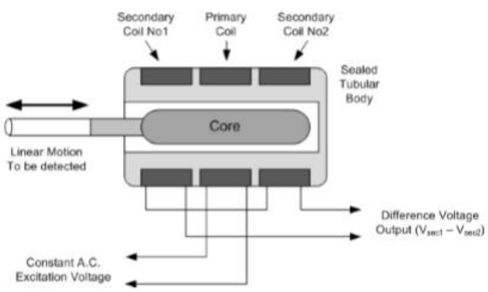


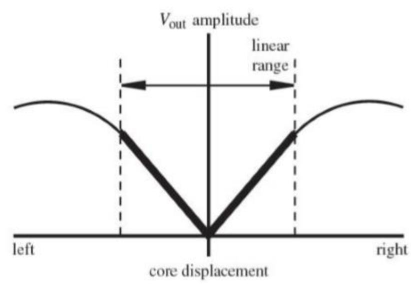
The LVDT operation hinges on the fundamental transformer principle wherein the voltage potential that develops on a transformer side is proportional to the number of windings. This equation is given as

$$\frac{\mathrm{Vs}}{Vp} = \frac{ns}{np}$$

where V_s and V_p are the secondary and primary voltage readings respectively while ns and np indicate the number of turns or coil windings in the secondary and primary side, respectively.

The LVDT operates in such a way that when the iron core (also known as an armature) is "displaced" or moved along its axis, a certain number of transformer turns or coil windings are affected by the position of the core. Since the two sets of coil windings are connected in a "series-opposing" mode, the output voltage, V_s (shown as V_{out} in figure) is the difference between the voltage across each coil. Consequently, a displacement of the core generates a unique output voltage V_s.



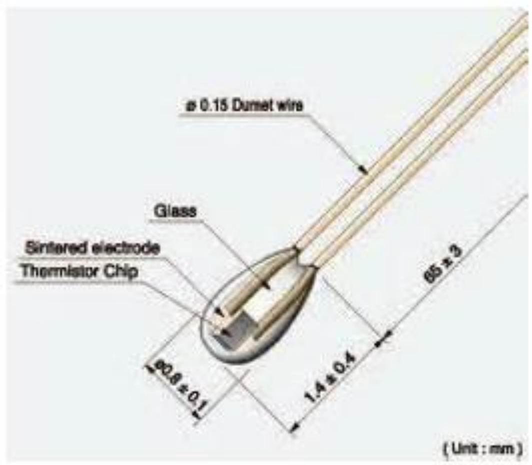


The LVDT is a position-to-electrical sensor whose output is proportional to the position of a movable magnetic core. The core moves linearly inside a transformer consisting of a center primary coil and two outer secondary coils wound on a cylindrical form. The primary winding is excited with an ac voltage source (typically several kHz), inducing secondary voltages that vary with the position of the magnetic core within the assembly. The core is usually threaded in order to facilitate attachment to a non-ferromagnetic rod which, in turn, is attached to the object whose movement or displacement is being measured. The secondary windings are wound out of phase with each other. When the core is centered, the voltages in the two secondary windings oppose each other, and the net output voltage is zero. When the core is moved off center, the voltage in the secondary toward which the core is moved increases, while the opposite voltage decreases. The result is a differential voltage output that varies linearly with the core's position. Linearity is excellent over the design range of movement, typically 0.5% or better. The LVDT offers good accuracy, linearity, sensitivity, infinite resolution, frictionless operation, and mechanical ruggedness.

A wide variety of measurement ranges are available in different LVDTs, typically from ±100 μm to ±25 cm. Typical excitation voltages range from 1 V to 24 V rms, with frequencies from 50 Hz to 20 kHz. Note that a true null does not occur when the core is centered because of mismatches between the two secondary windings and leakage inductance. Also, a simple measurement of the output voltage, V_{OUT}, will not tell the side of the null position on which the core resides.

For part 4:

1) Thermistor:

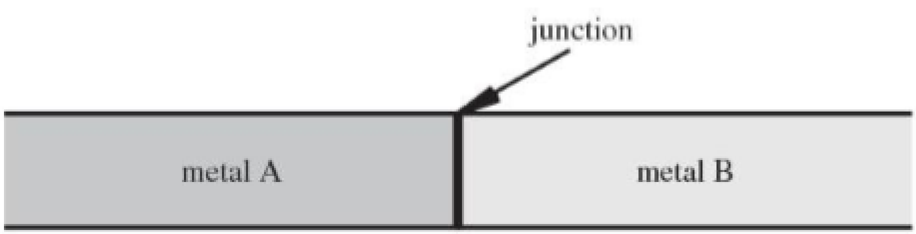


The structure of thermistor

A thermistor is a semiconductor device, available in probes of different shapes and sizes, whose resistance changes exponentially with temperature. The equation is below:

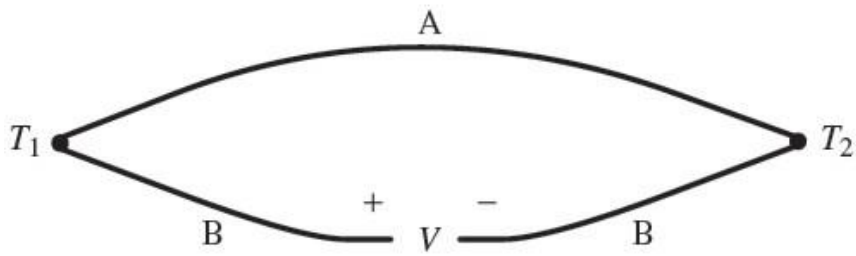
$$R = R_0 \, e^{\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]}$$

Where T_0 is a reference temperature, R0 is the resistance at the reference temperature, β is a calibration constant called the characteristic temperature of the materials



2) Thermocouple:

Wires of metals A and B forming junctions at different temperatures T_1 and T_2, resulting in a potential V that can be measured.



The equation is below (α is called the Seeback coefficient):

$$V = \alpha(T_1 - T_2)$$

3. Experimentation

3.1 Force Transducer

3.1.1 Summary of Procedure

a) Make sure that the test apparatus is set up as figure 1

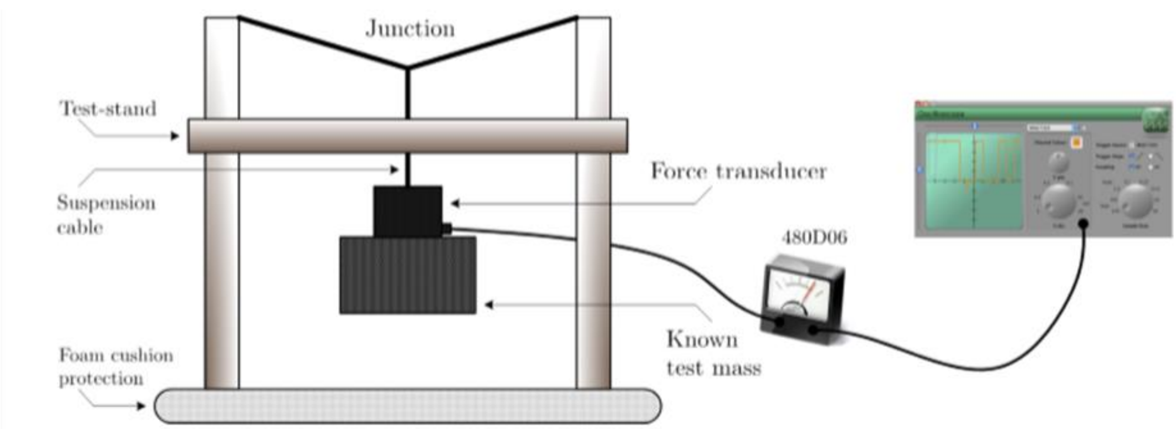


Figure 1. Test setup for calibration of a force transducer

b) Set up an oscilloscope to measure the output V_f of the force transducer.

- Set channel 1 of the oscilloscope to measure V_f with DC coupling;
- Use the rising trigger slope option to capture the signal;
- Using the previously utilized settings capture the signal in the oscilloscope screen. This step might take a few iterations.

c) perform four trials of the experiment of the force transducer. For each test, record ΔV_f and the sensitivity S_f in mV/kg (weight of the test mass is engraved) in Table 1.

d) Compare the measured sensitivity to the nominal sensitivity of the force transducer. Use the following equation to determine the percentage error.

$$\%\mathbf{ERROR} = \frac{\mathbf{Predicted - Measured}}{\mathbf{Predicted}} \times \mathbf{100}$$

3.1.2 Results

Table 1. Force transducer Output Voltage & Sensitivity

Trial	ΔV_f (mV)	Mass (kg)	S_f (mV/kg)	Nominal S_f (mV/kg)	% Error
1	494	1	494.0		
2	991	2	495.5		
3	1486	3	495.3		
			AVE 494.93	495	0.014

Using the force transducer to measure the mobile phone:

Nominal Mass(g): 200

Measured Mass(g): 200.03

Relative Error: 0.015%

Computations:

$$S_1 = \frac{\Delta V_1}{\Delta m_1} = \frac{494\text{mV}}{1\text{kg}} = 494.0\text{mV/kg}$$

$$S_2 = \frac{\Delta V_2}{\Delta m_2} = \frac{991\text{mV}}{2\text{kg}} = 495.5\text{mV/kg}$$

$$S_3 = \frac{\Delta V_3}{\Delta m_3} = \frac{1486\text{mV}}{3\text{kg}} = 495.3\text{mV/kg}$$

$$S_{f-avg} = \frac{494.0 + 495.5 + 495.3}{3}\text{mV/kg} = 494.93\text{mV/kg}$$

$$m_{\text{mobile}} = \frac{\Delta V}{S_{f-avg}} = \frac{99\text{mV}}{494.93\text{mV/kg}} = 200.03\text{ g}$$

For the mobile phone's measurement:

$$\%\text{ERROR} = \frac{200.03-200}{200} \times 100\% = 0.015\%$$

For the nominal sensitivity value of the force transducer:

$$S_{\text{Nominal}} = \frac{\Delta V}{m} = \frac{99\text{mV}}{0.2kg} = 495\text{mV/kg}$$

$$\%\mathbf{ERROR} = \frac{\mathbf{495mV/kg - 494.93mV/kg}}{\mathbf{495mV/kg}} \times \mathbf{100}\% = \mathbf{0.014}\%$$

Using MATLAB to get the sensitivity: S_f =495.2857mV/kg

$$\%\mathbf{ERROR} = \frac{\mathbf{495.2857mV/kg - 495mV/kg}}{\mathbf{495mV/kg}} \times \mathbf{100\%} = \mathbf{0.057\%}$$

3.1.3 Analysis & Discussion

The experimenter can measure the force applied according to the sensitivity obtained during the experiment. By measuring the variation of voltage, the experimenter can find that the variation of output voltage is linearly related to the force exerted on the sensor, and the calculation also proves this point. By varying the number of known mass increases, the experimenter found that the calculated value of the sensitivity was similar, so the experimenter could calculate the average of four similar sensitivities to obtain the true value of the sensor's sensitivity.

On the other hand, according to the data, we can see that the actual mass of an phone is 200g, but the data we calculated through the sensor is 200.03g, with an error of 0.015%. The results show that using force sensor is an effective method to obtain the numerical value of force.

However, some procedures can still cause errors in this experiment. Due to the fluctuation of the DMM, we cannot record a very precise voltage reading. Besides, although we used a precise scale to obtain the weight of the phone, the wind people will influence the weight data.

The main reason for the error during the experiment may be the fluctuation of the value on DMM. The experimenter was unable to record very accurate voltage readings. In addition, electronic scales such as mobile phones may have certain errors.

3.2 Accelerometer

3.2.1 Summary of Procedure

a) Make sure that the test apparatus is set up as shown in the figure

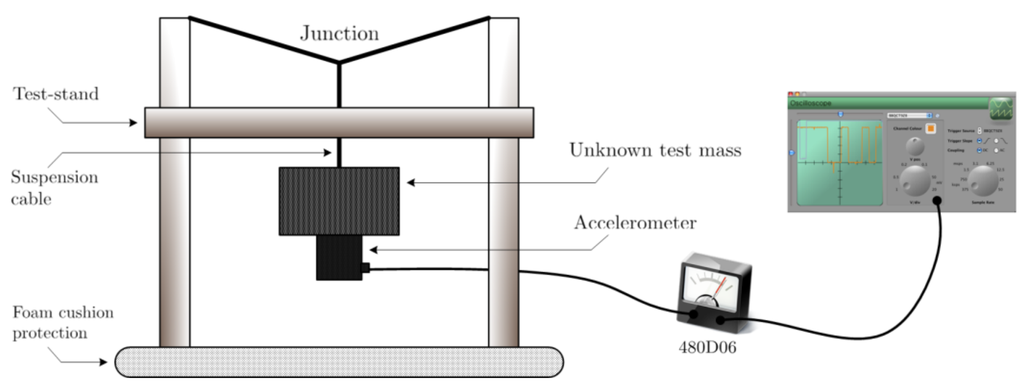


Figure 2. Test setup for calibration of an accelerometer

b) Set up channel 1 with a known accelerometer and channel 2 with an unknown accelerometer. Use computer to simulate the actual condition and find the curve of two channels. Change the estimate value of unknown sensitivity until the two curves become overlap. Record the sensitivity of unknown accelerometer in Table 2 and compare the measured sensitivity to the nominal sensitivity of the accelerometer (ask your lab instructors for this value).

c) Use gain method to measure the resonance frequency.

- Change the frequency of vibrator from 45 to 60, the step is 1Hz. simply supported beams electromagnetism vibrator.
- To find a more accurate value, change the frequency of vibrator in the range which the vibrator has the max value of magnitude, the step is 1 Hz.
- Record the amplitude of accelerometer in Table 3, mark each point in coordinate.
- Connect the points and find result.

d) Use a hammer to knock the beam

- Use a hammer to knock the beam
- Record the output of accelerometer using analyzer in computer. Find the value of first peak and record result in Table 5
- Observe the result

e) Measure the length and section area of simple supported beam. Calculate the theoretical resonance frequency of the beam.

3.2.2 Results

Table 2. Accelerometer Sensitivity

S_a (mV/g) of reference Accelerometer	Calibrated S_a (mV/g)	Nominal S_a (mV/g)	% Error
502	96	99	3.03

$$\text{Error} = \frac{|calibrated - nominal|}{nominal} = \frac{|99-96|}{99} = 3.03\%$$

Table *. Frequency & Magnitude by Gain Method

f/Hz	Magnitude
39	0.18097
40	0.199526
41	0.232162
42	0.275859

43	0.333703
44	0.408187
45	0.512714
46	0.63064
47	0.827595
48	1.35213
48.5	1.79439
48.7	2.25217
48.8	2.525
49	4.60781
49.1	5.26654
49.3	4.96885
49.4	4.64316
49.5	4.54668
49.6	4.28737
50	3.09135
51	2.07664
52	1.27882
53	0.925359
54	0.73482
55	0.615068
56	0.532642
57	0.475942
58	0.432606
59	0.392277
60	0.364315

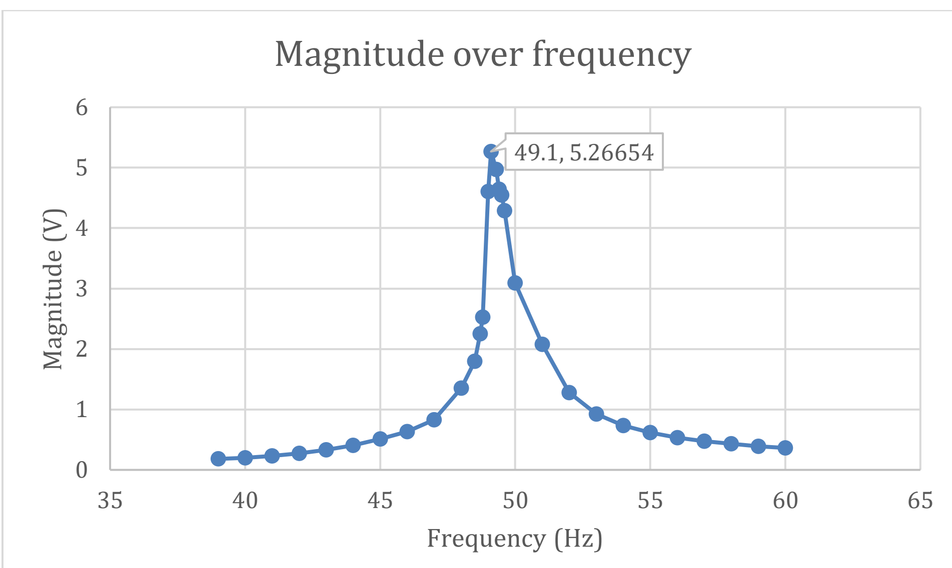


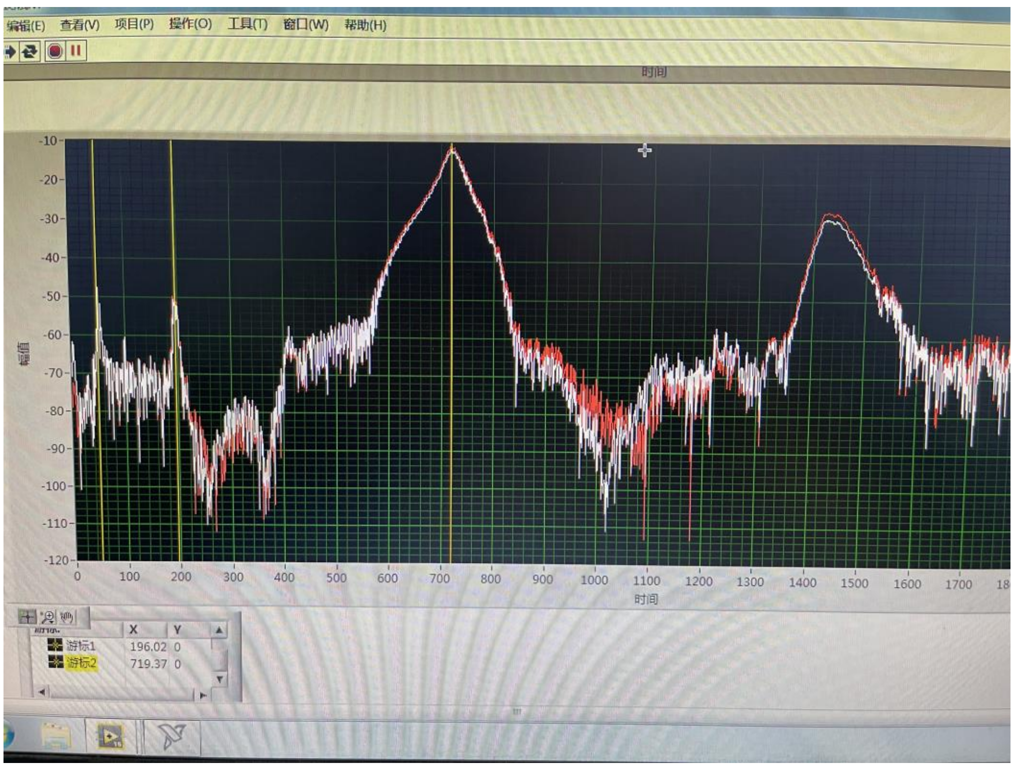
Figure 2-1. Frequency & Magnitude

By observe Figure 2-1, the experimenter got that the maximum magnitude appears when frequency is around 49.1 Hz, which represents that the resonance frequency for the beam is 49.1 Hz.

Table 3. Simply supported beam Dimensions

Parameter	Measurement (cm)
b	5.00
h	0.8
x	14.50
L	58.00

Young's Modulus for Steel (E, GPa)	200



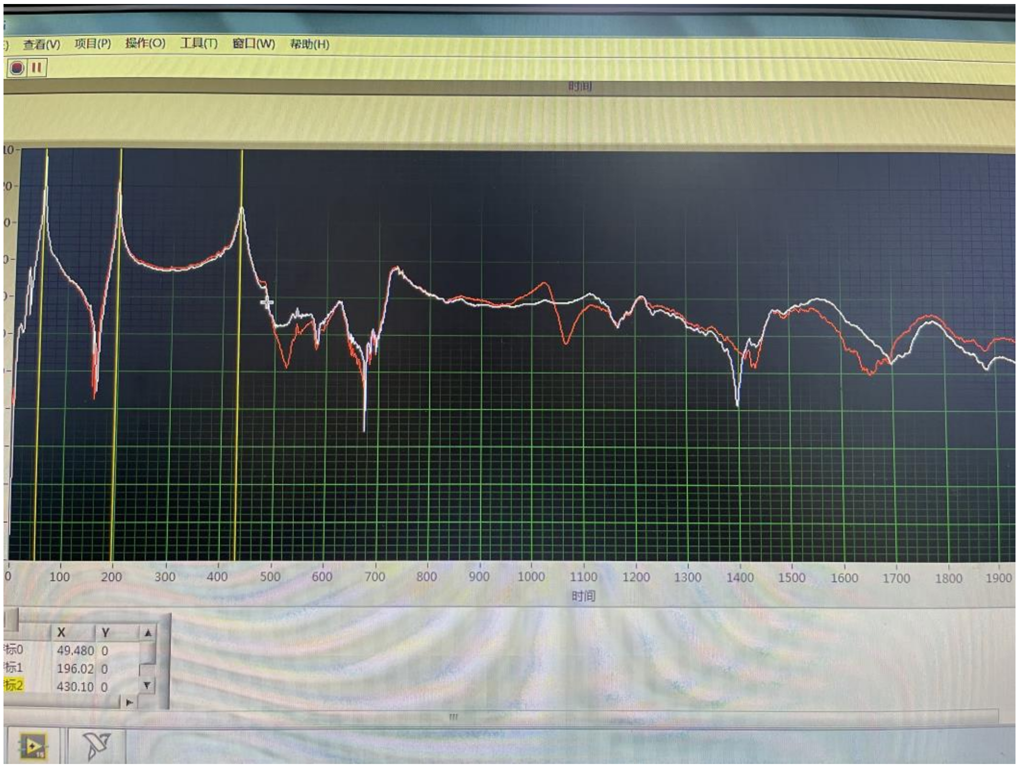


Table 3. Natural frequency of simply supported beam

Method	1st order	2nd order	3rd order	4rd order
Theoretical	48.6	194.73	438.15	778.95
Step	49.1			
Sweep	49.48	188.4	426.29	719.37
Impact	49.48	196.02	430.10	726.39

By observing the experiment figures and the Table 3, the resonance frequency got from seep and impact methods are both 49.48 Hz.

Calculate the nominal resonance frequency:

$$f_0 = \frac{1}{2\pi}\left(\frac{\pi}{l}\right)^2\sqrt{\frac{EI}{\rho s}}$$

L = 58cm; b = 5cm; h = 0.8cm.

E = $2\text{x}10^{11}$kg/m^2; ρ=7830kg/m^3

$$\mathrm{I} = \frac{bh^3}{12} = \frac{0.05m \times (0.008m)^3}{12} = 2.133 \times 10^{-9} m^4$$

$$f_0 = \frac{1}{2\pi}\left(\frac{\pi}{l}\right)^2\sqrt{\frac{EI}{\rho s}} = \frac{1}{2\pi} \times \left(\frac{\pi}{0.58m}\right)^2\sqrt{\frac{2 \times \frac{10^{11}\mathrm{kg}}{\mathrm{m}^2} \times 2.133 \times 10^{-9}m^4}{\frac{7830\mathrm{kg}}{\mathrm{m}^3} \times 0.05m \times 0.008m}} = 54.5\mathrm{Hz}$$

For the knock method, the relative error is:

$$\%\mathrm{ERROR} = \left|\frac{f_{theoretical} - f_{knock}}{f_{theoretical}}\right| = \left|\frac{54.5 - 48.6}{48.6}\right| = 12.14\%$$

3.2.3 Analysis & Discussion

In this part of experiment, the experimenters use the analyze software on computer to match the sensitivity of accelerometer. By observing Table*, the experimenters find that the unknown value and known value is quite different, which caused by the experiment equipment itself, such as mechanic aging, bad connection and manufacturing errors. By observing these, the result value is reasonable. By measuring the frequency response of simply supported beams, which use frequency variance from 30Hz to 60Hz. By plotting by Excel, the experimenter get the estimated value of resonance frequency which is about 49.1 Hz.

Then the experimenters use following equations to calculated the resonance frequency of the beam, which has a huge difference between the measured one. After discussion, the experimenters dawn a conclusion that the error may introduced by the measured length of the beam. The calculated value may not.

$$\mathrm{I} = \frac{bh^3}{12}$$

$$f_0 = \frac{1}{2\pi}\left(\frac{\pi}{l}\right)^2\sqrt{\frac{EI}{\rho\ s}}$$

3.3 Displacement Transducer

3.3.1 Summary of Procedure

The test setup for the calibration of the LVDT sensor is shown in the following figure.

a) The structure is constructed, and the power supply is used to provide 24V DC power supply voltage for the LVDT. (Only use the voltage of 24 V, which is different from the procedure.)

b) Use the DMM to measure the displacement transducer output. Record the data necessary to construct a calibration curve for the displacement transducer in Table 5.

c) Use MATLAB to calculate the sensitivity of the LVDT.

d) Calculate the thickness of the phone.

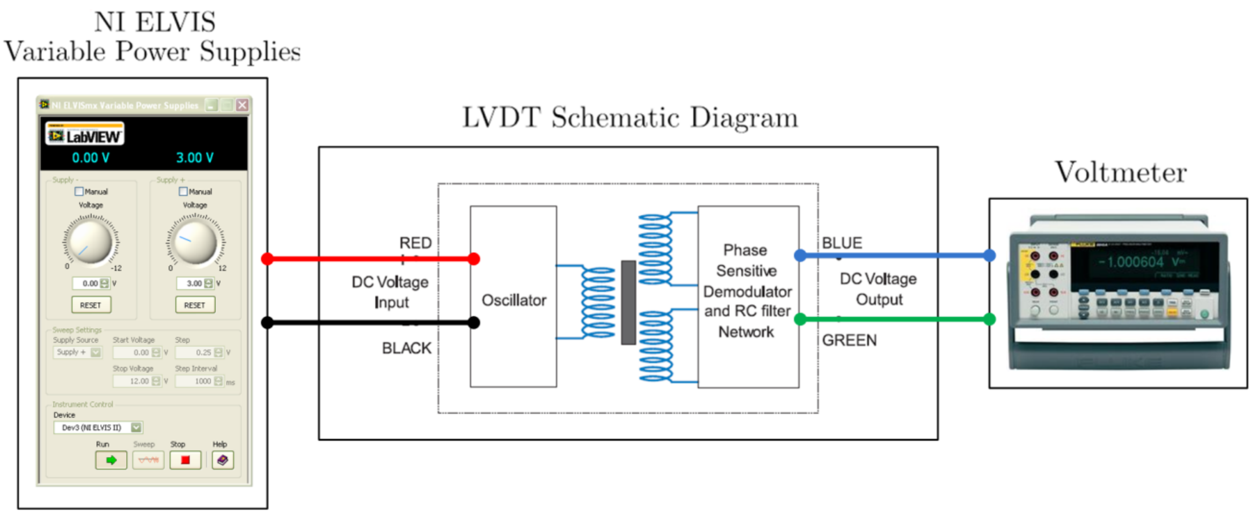


Figure 3. Schematic Diagram of the LVDT Circuit

3.3.2 Results

Table 5. Displacement Transducer Output Voltage

Input Voltage		Displacement (mm)										
Nom	**Actual**	**0.5**	**1**	**1.5**	**2.0**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**
24 V	24.0V	0.32	0.51	0.795	0.97	1.24	1.449	1.7185	2.07	2.3598	2.6	2.7775
S_f (V/mm)		0.64	0.51	0.53	0.485	0.496	0.483	0.491	0.5175	0.5244	0.52	0.505

$(S_f)_{mean}$=0.5156 V/mm

Measure the mobile phone:

Changing voltage ΔV	Nominal thickness(mm)	Measured thickness(mm)	Error
4.5	8.8	8.73	0.795%

Calculation:

$$S_1 = \frac{\Delta V_1}{\Delta d} = \frac{0.32\text{V}}{0.5\text{mm}} = 0.64\text{V}/mm$$

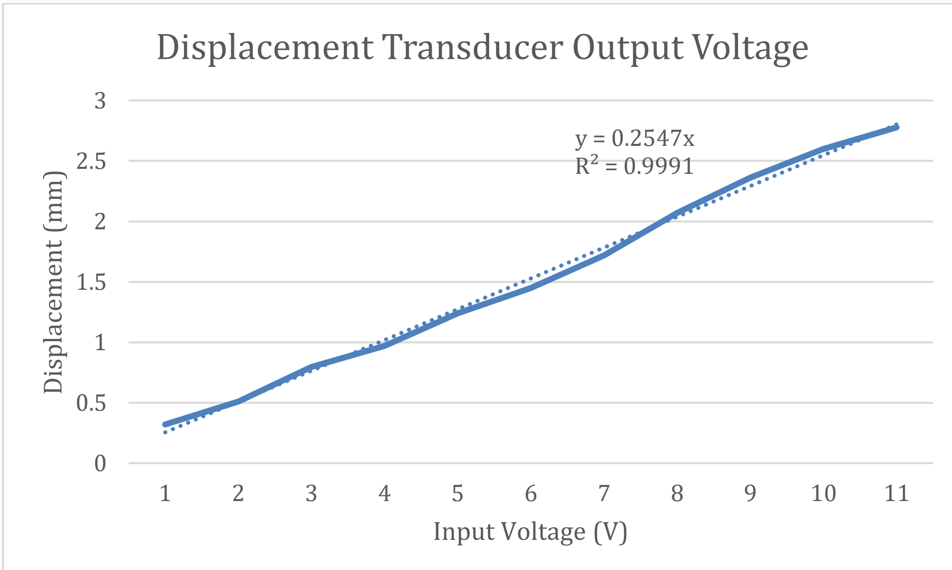
$$S_{f-avg} = \frac{0.64 + 0.51 + 0.53 + \cdots + 0.505}{11}\text{V/mm} = 0.5156\text{V/mm}$$

$$m_{\text{mobile}} = \frac{\Delta V}{S_{f-avg}} = \frac{|1.51V - 6.01V|}{0.5156V/mm} = 8.73\text{mm}$$

For the mobile phone's measurement:

$$\%\text{ERROR} = \frac{8.8-8.73}{8.8} \times 100\% = 0.795\%$$

Through the fitting of Excel, the sensitivity was calculated as 0.47. The following figure was obtained:



3.3.3 Analysis & Discussion

When the core of LVDT is far away from its initial position, the output voltage value should be increased. Because during the experiment, the positive and negative poles of the multimeter are reversed, resulting in a negative voltage output value. Although the value is getting smaller and smaller, the increasing absolute value also meets the principle of LVDT.

Through the calculation and fitting of the experimental data, the experimenter found that the experimental data were relatively accurate. The sensitivity of the calculated results is the same as that of the actual fitted curves. And the same sensitivity was obtained when measuring the thickness of the phone, so it can be said that this experiment has little effect on the error.

3.4 Thermocouple and Thermistor

3.4.1 Summary of Procedure

a) Set up the thermocouple circuit as shown in Figure 4.

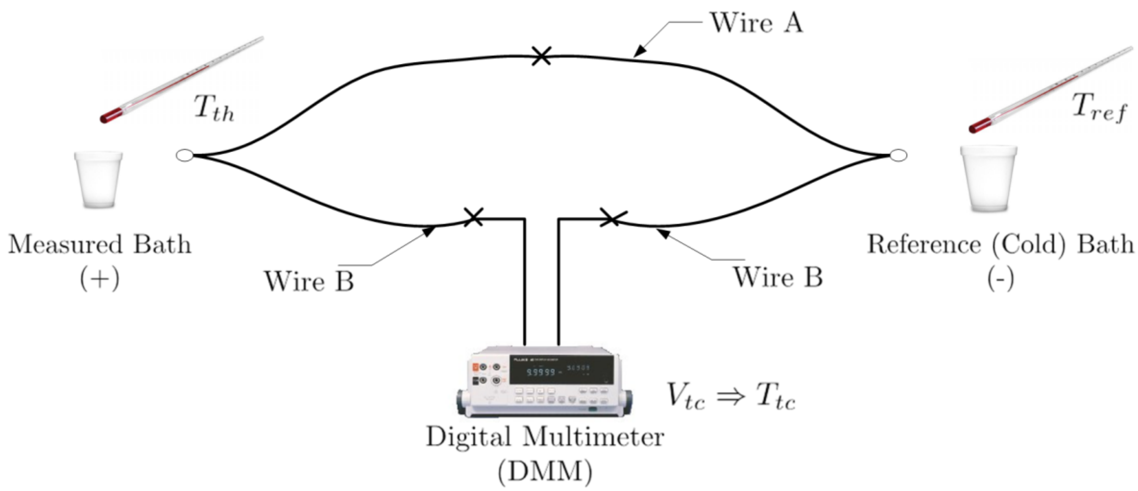


Figure 4. Test setup for calibration of a thermocouple.

b) Set up the thermocouple circuit as shown in Figure 4 with the T_{ref} junction in an ice bath. (TIP: T_{ref} is supposed to be constant throughout the test. Make sure that the ice in the ice bath does not completely melt.) Place the other junction in the variable temperature water bath. Use the DMM to measure the voltage V_{tc} for a sequence of progressively colder water bath temperatures (10 readings). For each reading, measure the actual water bath temperature T_{th} using a thermometer. Use the thermocouple tables to determine the water bath temperature V_{tc} as indicated by the thermocouple. Also, calculate the difference between the thermometer and thermocouple readings. Record the data in Table 6. In the report, describe what happens to the output voltage reading (V_{tc}) as the temperature (in the measured bath) decreases.

c) Immerse the thermistor in the hot water bath and measure the thermistor resistance R_{therm} for a sequence of progressively colder water bath temperatures. For each reading, measure the actual water bath temperature T_{th} using a thermometer. Record both R_{therm} and the actual water bath temperature T_{th} in Table 7. Use a multimeter to record the data required to draw the calibration curve.

3.4.2 Results

Table 6. Thermocouple Temperature & Voltage Readings

Reading	Temperature (℃)			V_{tc}(mV)	%DIFF (T_{th} vs T_{tc})
	T_{ref}(℃)	T_{th}(℃)	T_{tc}(℃) - table		
1	2.5	80	69	2.79	10.97
2	2.5	78	66	2.68	12.58
3	2.5	76	63.5	2.58	13.61
4	2.5	74	62	2.50	13.29
5	2.5	72	60	2.43	13.67
6	2.5	70	58	2.34	14.07
7	2.5	68	56	2.28	14.50
8	2.5	66	54	2.21	14.96
9	2.5	64	52.5	2.12	14.63
10	2.5	62	50	2.02	15.97

Table 7. Thermistor Resistance & Temperature Readings

Reading	Rtherm (kΩ)	Tth (0℃)
1	1.24	80
2	1.35	78
3	1.44	76
4	1.55	74
5	1.64	72
6	1.77	70
7	1.90	68
8	2.02	66
9	2.18	64
10	2.35	62

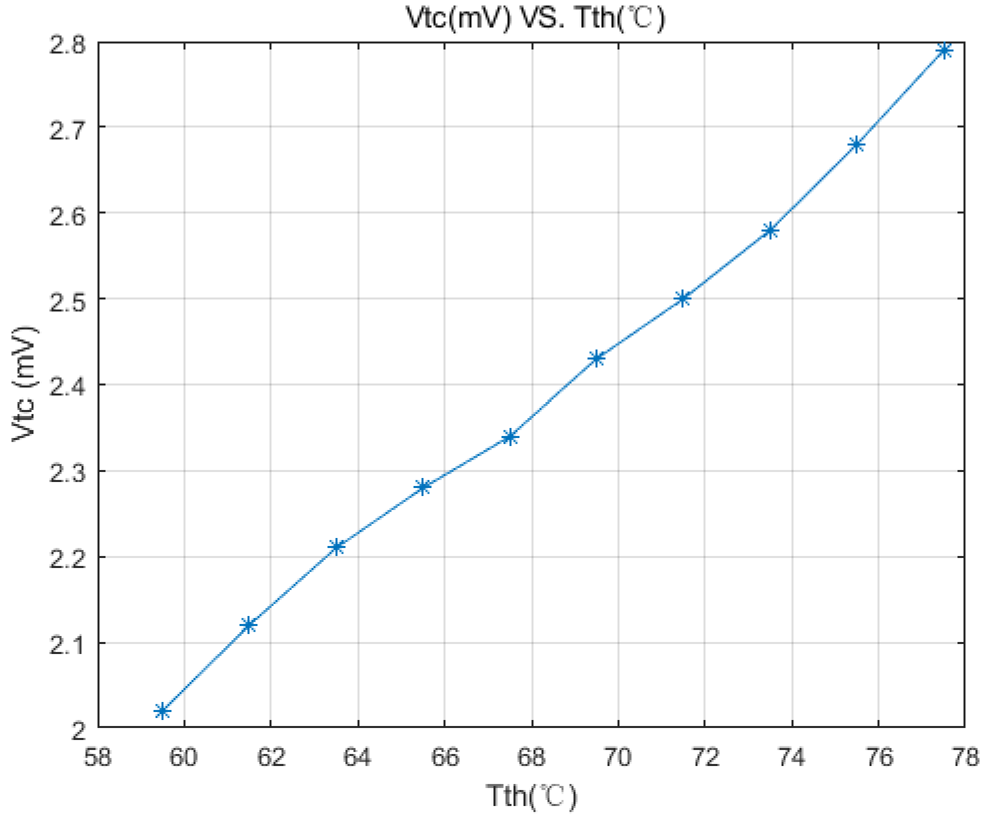


Figure 4_1. V_{th}(mV) & T_{th}(degree)

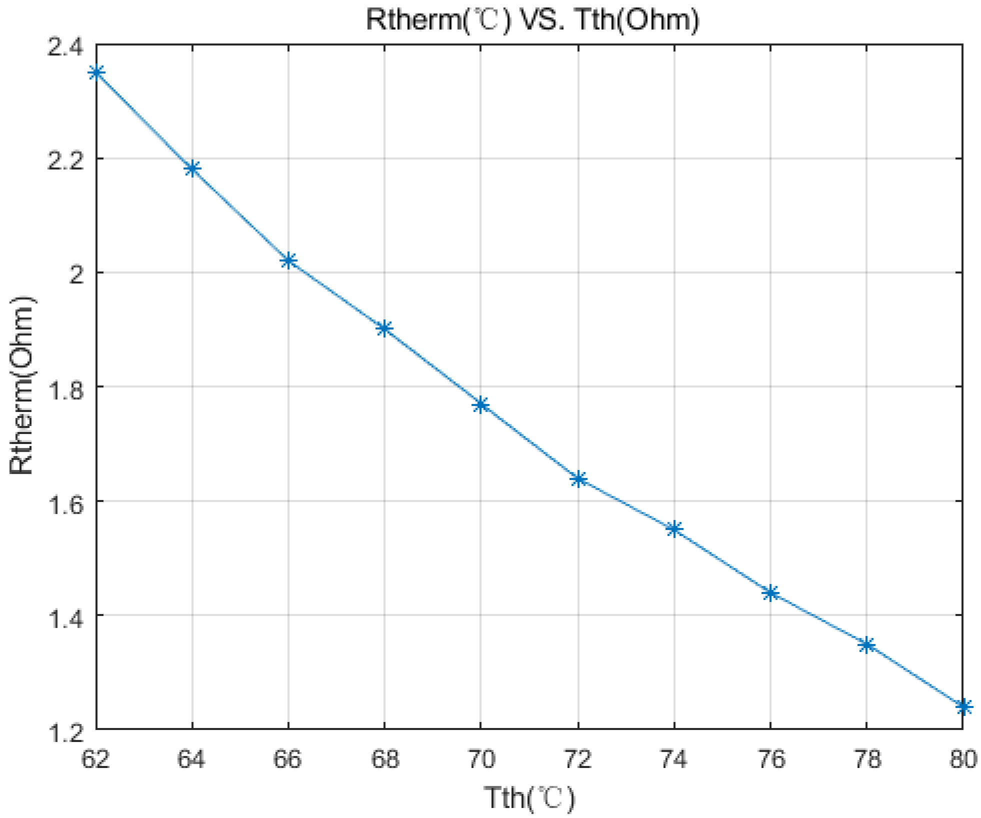


Figure 4_2. $R_{therm}(\Omega)$ & T_{th}(degree)

3.4.3 Analysis & Discussion

By plotting the data in Figure 4_1, the experimenters observed that when temperature goes down, the voltage linearly decreases correspondingly.

By plotting the data in Figure 4_2, the experimenters observed that when temperature goes down, the voltage linearly increases correspondingly.

Also, by observing Table 4, the error is relatively large and increasing as time pass by, which may because the temperature of the ice water cup was not kept constant. After the experiment, the experimenters observed that the ice in the lower part of the cup had all melted, but the ice in the upper part did not disappear. After measuring with a thermometer, the experimenters found that the temperature in the lower part was higher than that in the upper part.

Considering that the thermocouple was placed at the bottom of the cup during the experiment, this temperature instability phenomenon might be the main reason for the gradual increase of the error of the experimental data as the experiment progressed.

4. Answers/Solutions to Questions

i) Describe the following with your own words:
• Accuracy • Linear operating range • Hysteresis • Infinite resolution

Answer:

- **Accuracy**: Accuracy refers to how close the obtained value is to the true value. The higher the accuracy, the closer the obtained value is to the true value; the lower the accuracy, the greater the difference between the obtained value and the true value.
- **Linear operating range:** At any level range and specified frequency, the level linearity error is within the sound level range specified in this section. The linear operating range is expressed in decibels (dB).
- **Hysteresis:** The relative lag between one phenomenon and another closely related phenomenon. Especially if a physical result is not present in time, or an indicator is slow to respond to a recorded change.
- **Infinite resolution:** Can be decomposed an infinite number of times. That means some indicators are perfect.

ii) Can the accelerometer of part 2.2 accurately measure a constant acceleration of 0.5 g for a period of 6 seconds? Explain your answer.

Answer:

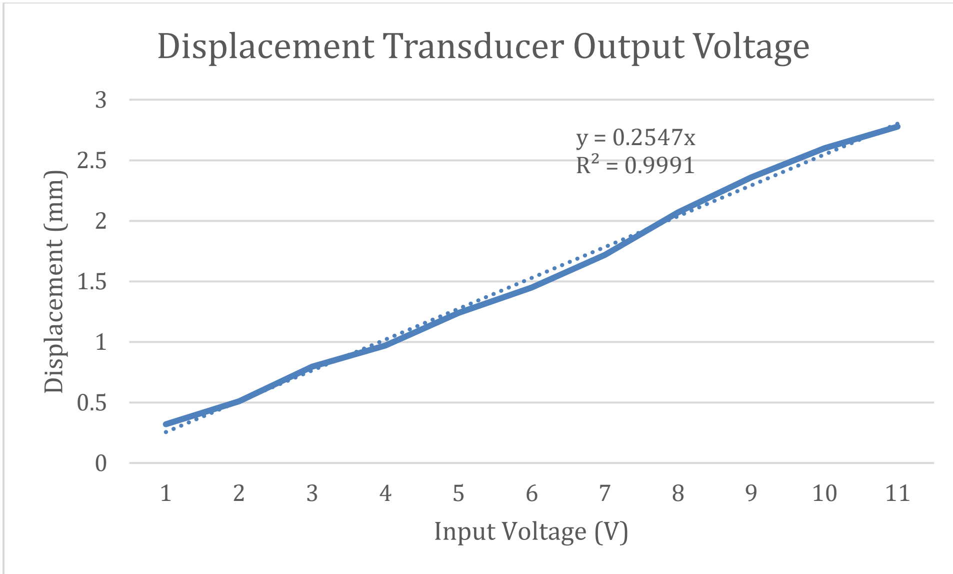
Yes. Because if the period equals to 6 seconds, then the frequency will be:

$$f = \frac{2\pi}{6} = 1.05Hz < 54.5\mathrm{H}z$$

Which is much smaller than ether 54.5 Hz(calculated value), or 49.1Hz(measured value).

iii) Use the data in part 2.3 to construct calibration curves for the LVDT displacement transducer with a supply voltage of 24 VDC and 16 VDC, respectively. Use the least squares method to estimate the sensitivity of the displacement transducer in each case. What happens with the sensitivity with a change in the supply voltage?

Answer:



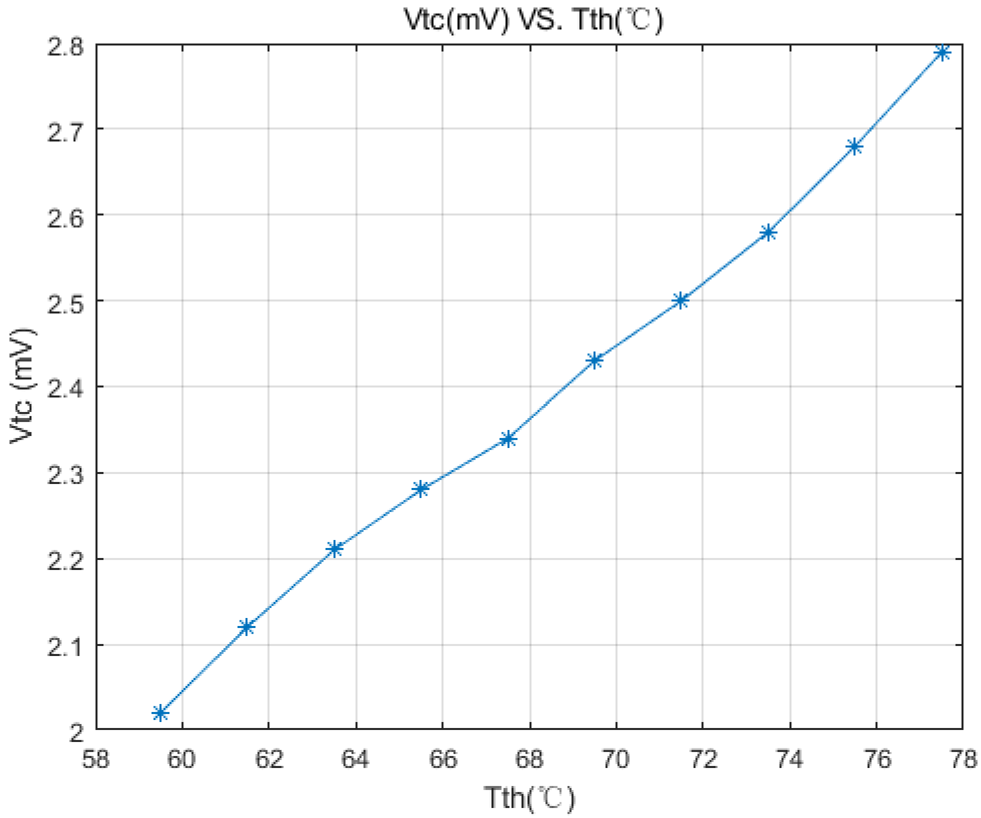
Through MATLAB fitting function, the linear equation of data can be obtained.

The sensitivity is 0.5156v/mm.

iv) Use the data from step 2.4.b and the polynomial relating temperature to voltage for the thermocouple to calculate the indicated temperature Ttc for each data point. (Note: use the polynomial given in the PPT.)

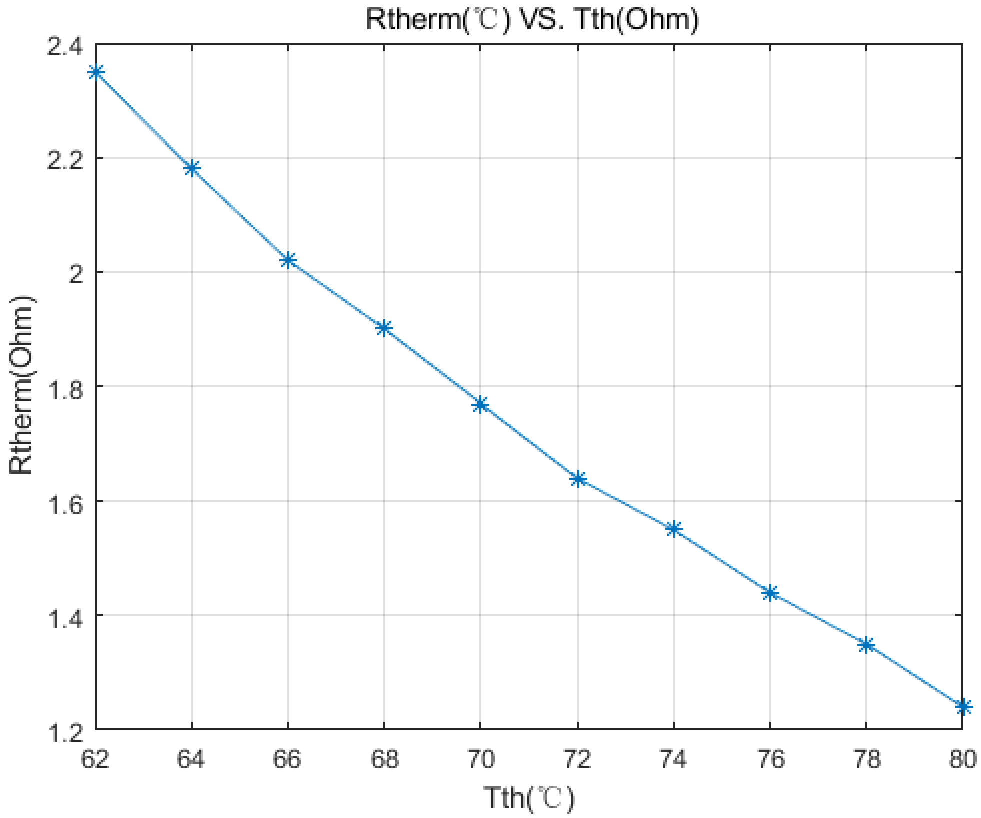
Answer:

the polynomial relating temperatures to voltage for the thermocouple are calculated in the table of 2.4.b.



v) Use the data from step 2.4.c to construct a calibration curve (RTherm versus Tth) for the thermistor. Is RTherm a linear function of the temperature? Is RTherm directly or inversely related to the temperature?

Answer:



When temperature goes down, the voltage linearly increases correspondingly, so ***R**Therm* is a linear function of the temperature. And ***R**Therm* is inversely related to the temperature.

vi) The Five Basic Laws of Thermocouples are in your textbook (p. 410-410 text). Explain which laws are critical (and why) to the experiment we performed in lab. Hint: three are relevant for, (1) the voltage measurement, (2) the connection in the ELVIS bread board, and (3) the solder material at the tip.

Answer:

The Five Basic Laws of Thermocouples are in your textbook (p.410 text). Explain which laws are critical (and why) to the experiment we performed in lab. Hint: three are relevant for, (1) the voltage measurement, (2) the connection in the bread board, and (3) the solder material at the tip. We believe that in this experiment the temperature law of the wire lines is crucial. Given that in this experiment there are only two metals, and the thermoelectric voltage depends only on the junction temperatures T1 and T2. The conditions of our experiment are the same as the law of temperatures of wires.

5. Conclusions

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

- For the part 1, the experimenter built a load cell using force sensors and four weights to measure the output voltage and the weights. From the measured data, the experimenters came to the conclusion that the output voltage is linearly proportional to the increased mass. In addition, the sensitivity of the force sensor is calculated as 494.93 mV/kg. In order to obtain the nominal sensitivity, the experimenter used two methods. First, by measuring the changes in the output voltage and actual weight of the phone, we can calculate a nominal sensitivity value of 495 mV/kg. The other method is to achieve curve fitting in MATLAB. Combined with the experimental data, a straight line whose slope represents the nominal sensitivity of the force sensor is 495.2857 mV/kg is obtained. In general, the measurements in the experiment were very close to these two nominal values. The margin of error is also acceptable.
- For the part 2, the experimenter learned how the measure the sensitivity of accelerometer, and how to measure and calculate the resonance frequency of the single support beam. In this part of experiment, the experimenters use the analyze software on computer to match the sensitivity of accelerometer. By observing Table2, the experimenters find that the unknown value and known value is quite different, which caused by the experiment equipment itself, such as mechanic aging, bad connection and manufacturing errors. By observing these, the result value is reasonable. By measuring the frequency response of simply supported beams, which use frequency variance from 30Hz to 60Hz. By plotting by MATLAB, the experimenter get the estimated value of resonance frequency which is about 49.1 Hz. Then the experimenters use following equations to calculate the resonance frequency of the beam, which has a huge difference between the measured one. After discussion, the experimenters dawn a conclusion that the error may introduced by the measured length of the beam. The calculated value may not.

$$\mathrm{I} = \frac{bh^3}{12}$$

$$f_0 = \frac{1}{2\pi}\left(\frac{\pi}{l}\right)^2 \sqrt{\frac{EI}{\rho\ s}}$$

- For part 3, the experimenter used LVDT as a displacement sensor to measure the displacement of the rod. It can be seen from the data that as the LVDT core moves from the center to both sides, the absolute value of the output voltage will increase. It can be seen from the data that as the LVDT core moves from the center to both sides, the absolute value of the output voltage will increase. It can be seen from the data that as the LVDT core moves from the center to both sides, the absolute value of the output voltage will increase. In addition, the absolute change in the output voltage is proportional to each displacement. Meanwhile, the average sensitivity was 0.5156 V /mm. there was almost no error in the whole experiment. The measurement of experimental data is more accurate. This reflects the advantage of HIGH accuracy of LVDT in a certain range. However, LVDT also has the disadvantages of low sensitivity and limited motion range.
- For part 4, the experimenters learned the basic process of using thermocouple and observed two plotted curves: By plotting the data in Figure 4_1, the experimenters observed that when temperature goes down, the voltage linearly decreases correspondingly. By plotting the data in Figure 4_2, the experimenters observed that

when temperature goes down, the voltage linearly increases correspondingly. Also, by observing Table 4, the error is relatively large and increasing as time pass by, which may because the temperature of the ice water cup was not kept constant. After the experiment, the experimenters observed that the ice in the lower part of the cup had all melted, but the ice in the upper part did not disappear. After measuring with a thermometer, the experimenters found that the temperature in the lower part was higher than that in the upper part. Considering that the thermocouple was placed at the bottom of the cup during the experiment, this temperature instability phenomenon might be the main reason for the gradual increase of the error of the experimental data as the experiment progressed.

APPENDICES

A – EQUIPMENT LIST

Table 4. Part 1 Equipment List

Equipment Description	Model Number	Serial Number
Tektronix Dual Oscilloscope	ZK-4ZCJ	
PCB Force Transducer	MIK-LCS1	

Table 5. Part 2 Equipment List

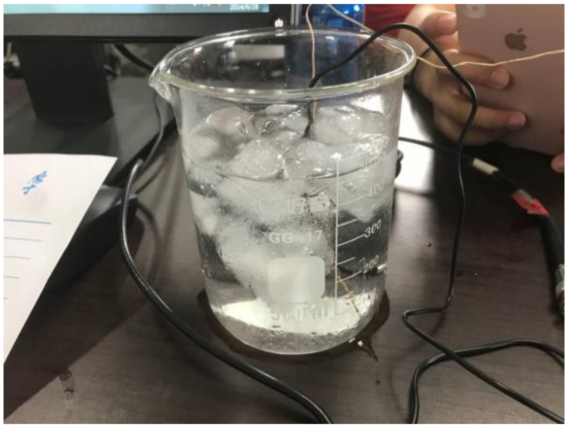
Equipment Description	Model Number	Serial Number
Tektronix Dual Oscilloscope		
PCB Accelerometer		

Table 6. Part 3 Equipment List

Equipment Description	Model Number	Serial Number
Power Supply	APS3005D	
VICTOR Digital Multimeter	VC890D	
Transtek LVDT	Transtek Series 240	
ELVIS bread board		

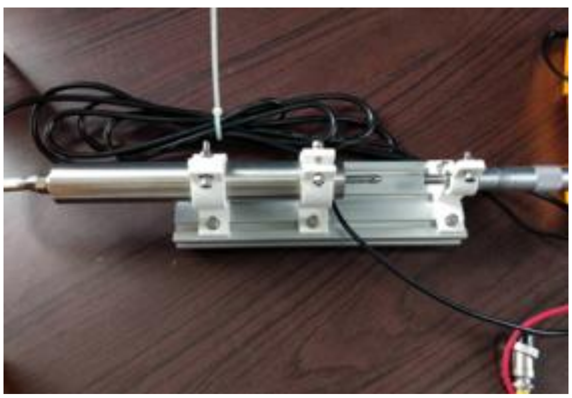
Table 7. Part 4 Equipment List

Equipment Description	Model Number	Serial Number
Thermometer		
ELVIS bread board		
VICTOR Digital Multimeter	VC890D	



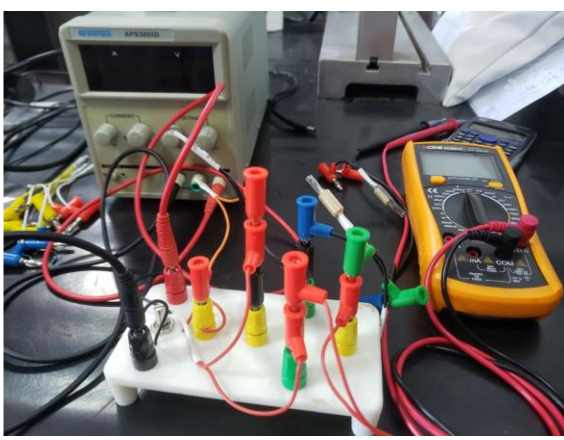
Ice

The test apparatus



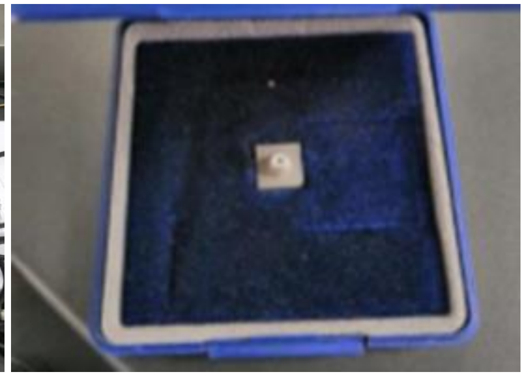
LVDT

The wave generator



Power supply

Force transducer



Intermediary instrument Sensor

VICTOR Digital Multimeter

B – Lab Notes

Group Number		Names		Date	
Expt. Number	4	Expt. Title	Transducer Medley		

Part 1: Force Transducer

Table 1. Force Transducer Output Voltage & Sensitivity

Trial	ΔV_f(mV)	Mass (kg)	S_f(mV/kg)
1	494	1	494.0
2	991	2	495.5
3	1486	3	495.3
		AVE	494.93

The weight of cellphone: **Nominal W(g)** 200g

Measured W(g) $\frac{99}{494.93} = 200.03$

% Error 0.015%

524
1018
− 524
494
1515
524

623
− 524

Part 2: Accelerometer

Table 2. Accelerometer Sensitivity

S_a (mv/g) of reference Accelerometer	Calibrated S_a (mv/g)	Nominal S_a (mv/g)	% Error
502	96	99	3.03

Table 3. Simply supported beam Dimensions

Parameter	Measurement (cm)
b	3.00
h	0.8
x	14.50
L	58.00

Young's Modulus for Steel (E, 10⁶ psi)	200 GPa

Table 4. Natural frequency of simply supported beam

Method	1st order	2nd order	3rd order	4th order
Theoretical	48.6	194.73	438.15	778.9477
Step	49.1			
Sweep	49.48	198.4	436.29	719.37
Impact	49.48	196.02	432.10	726.39

Lab Notes for Experiment 4 - Transducer Medley (revised by) Page 1

7.08V

1.31 - 6.21 = 4.5

Part 3: Displacement Transducer

Table 5. Displacement Transducer Output Voltage

Input Voltage		Displacement (mm)												
Nom	Actual		0.5mm	1mm	1.5mm	2mm	2.5mm	3mm	3.5mm	4mm	4.5mm	5mm	5.5mm	
24 V			0.32V	0.51V	0.75V	0.97V	1.19V	1.42V	1.71V	2.07V	2.14V	2.6V	2.78V	
			0.19V	0.21	0.23	0.485	[illegible]	[illegible]	0.491	0.515	0.544	0.52	0.53	

Sample Computation(s): Nominal T (mm)
Measured T (mm) 88
% Error 87.6

0.5156 V/mm

0.785 %

Part 4: Thermocouple and Thermistor

8.55 kΩ

Table 6. Thermocouple Temperature & Voltage Readings

Reading	Temperature (°C)			V_{tc} (mV)	%DIFF (T_{th} vs T_{tc})
	T_{ref} (°C)	T_{th} (°C)	T_{tc} (°C) - *table*		
1	2.5	80	68	2.78	10.87
2	2.5	78	66	2.68	11.58
3	2.5	76	63.5	2.58	13.61
4	2.5	74	61	2.50	13.28
5	2.5	72	60	2.43	13.67
6	2.5	70	58	2.34	14.07
7	2.5	68	56	2.28	14.50
8	2.5	66	54	2.21	14.86
9	2.5	64	52.5	2.12	14.63
10	2.5	62	50	2.02	15.89

Table 7. Thermistor Resistance & Temperature Readings

Reading	R_{therm} (Ω)	T_{th} (°C)
1	1.24	80
2	1.35	78
3	1.44	76
4	1.53	74
5	1.64	72
6	1.77	70
7	1.90	68
8	2.02	66
9	2.18	64
10	2.35	62

C – Matlab Code

Part1

```
clear;close all;clc
V = [1000;900;1000;1000];
M = [1000;1000;1000;1000];
p = regress(M,V);
fprintf('The slope is %.2f mV/g.', p)
```

Part4

```
% exp4_part4
clear;close all; clc
Tth = [80 78 76 74 72 70 68 66 64 62]
Ttc_table = [69 66 63.5 62 60 58 56 54 52.5 50]
Tth_real = Tth -2.5
% error
error = (Tth_real - Ttc_table)./Tth_real
% plot Vth(mV) vs. Tth(degree)
Vth = [2.79 2.68 2.58 2.50 2.43 2.34 2.28 2.21 2.12 2.02]
figure(1)
plot(Tth_real,Vth,'*-')
xlabel('Tth(¡æ)');
ylabel('Vtc (mV)');
title(' Vtc(mV) VS. Tth(¡æ)');
grid on
% plot Tth vs Rtherm
Tth = [80 78 76 74 72 70 68 66 64 62]
Rtherm = [1.24 1.35 1.44 1.55 1.64 1.77 1.90 2.02 2.18
2.35]
figure(2)
plot(Tth,Rtherm,'*-');
xlabel('Tth(¡æ)');
```

```
ylabel('Rtherm(¦¸)');
title(' Rtherm(¦¸) VS. Tth(¡æ)');
grid on
```