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　　大学物理实验（I）

开课实验室（学院）Laboratory (School)　　JCI

学院 School　　CQU-UC　　年级专业班 Student Group　18ME01

学生姓名 Student Name　　易弘睿　　学号 Student Number　　20186103

学年 Academic Year　　2019　　学期 Semester　　Spring

成绩 Grade	
教师签名 Signature of Instructor	

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.

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开课学院、实验室 Academic School/ Laboratory　CQU-UC

实验时间 Date of Experiment　2019　年 Year　03　月 Month　19　日 Day

报告时间 Date of Report　2019　年 Year　03　月 Month　20　日 Day

课程名称 Course Name		实验项目 名称 Experiment Project		实验项目类型 Type of experiment project				
				验　证 Verification	演　示 Presentation	综　合 Comprehensive	设计 Design	其他 Others
指导老师 Supervisor		成绩 Grade						

实验目的 Description/Instruction:

Strain sensor is a kind of sensor based on measuring the strain produced by the force and deformation of the object. Resistance strain gauge is the most commonly used sensor. It is a kind of sensor which can transform the strain change on mechanical components into resistance change. It has the advantages of high accuracy, wide measurement range, simple structure and small size. It is widely used in the measurement of strain, load, pressure, acceleration and displacement. This experiment requires us to master the working principle and use method of strain gauge, the working principle of unbalanced bridge and the method of using strain gauge to design electronic scale.

原理和设计 Principle and Design:

1. The working principle of strain gauge

The working principle of resistance strain gauge is based on strain effect (also known as resistance strain effect), that is, when a conductor or semiconductor material is mechanically deformed by external force (tension or pressure), the resistance value of the material changes accordingly. As shown in Fig.1, the original resistance value of the root metal resistance under the force of meter is as follows:

$$\mathrm{R} = \rho \frac{L}{A} \tag{1.1}$$

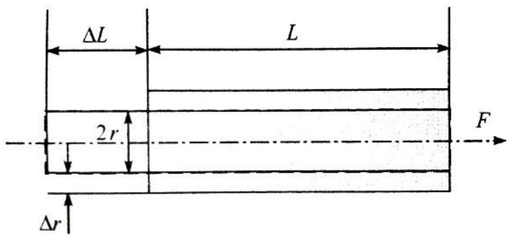


Figure1: Schematic Diagram of Stress and Deformation of Metal Wire

In the formula, L is the length of the resistor wire, ρ is the resistivity of the resistor wire, and A is the cross-sectional area of the resistor wire. Under the action of external (pulling) force F, will be elongated ΔL, the radius of cross section will decrease Δr, and the resistivity will change Δρ because of the lattice deformation and other factors. The relative variation of resistance value is as follows:

$$\frac{\Delta R}{R} = \frac{\Delta R}{L} - 2\frac{\Delta r}{r} + \frac{\Delta \rho}{\rho} \tag{1.2}$$

Generally speaking, $\frac{\Delta L}{L}$ is the axial strain and $\frac{\Delta r}{r}$ is the transverse strain. Within the elastic range, the relationship between the axial strain and the transverse strain is as follows:

$$\frac{\Delta r}{r} = -\mu \frac{\Delta L}{L} \tag{1.3}$$

In the formula, μ is the Poisson's ratio of material, and the negative sign indicates that the direction of transverse strain is opposite to that of axial strain.

In addition, $\frac{\Delta \rho}{\rho} = \lambda E \frac{\Delta L}{L}$, λ are piezoresistive coefficients related to materials and E is Young's modulus. The proxy formula can be obtained as follows:

$$\frac{\Delta R}{R} = (1 + 2\mu + \lambda E)\frac{\Delta L}{L} = k_m \frac{\Delta L}{L} \tag{1.4}$$

The strain gauge is firmly attached to the tested piece (or elastic element), so that the strain gauge and the tested piece (or elastic element) have the same mechanical deformation. By measuring the resistance change of the strain gauge ΔR, the axial strain $\frac{\Delta L}{L}$ of the tested object can be obtained, and then the external force F of the object can be measured according to Hooke's law.

2. Measurement circuit of unbalanced bridge

In general, unbalanced bridge is used as the measuring circuit of strain gauge. Its basic structure is shown in Fig.2. The open circuit output voltage of the bridge is:

$$U_0 = E\left(\frac{R_1}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right) = \frac{R_1 R_4 - R_2 R_3}{(R_1 + R_2)(R_3 + R_4)} \tag{1.5}$$

When the bridge is balanced, $U_0 = 0$, $R_1 R_4 = R_2 R_3$, which is called bridge equilibrium's necessary and sufficient conditions.

In general, $R_1 = R_2 = R_3 = R_4$, so the bridge is in equilibrium at the initial state, and the unbalanced output voltage is 0.

If R_1 is connected to strain gauge, R_2, R_3 and R_4 are fixed resistors, this circuit is called 1/4 bridge circuit.

If R_1 and R_2 are connected to two strain gauges with opposite strain directions, R_3 and R_4 are fixed resistors, this circuit is called differential half-bridge circuit.

If R_1, R_2, R_3 and R_4 are connected as strain gauges according to the principle that the strain direction of adjacent arms is opposite and the strain direction of opposite arms is the same, the circuit is called full bridge differential circuit.

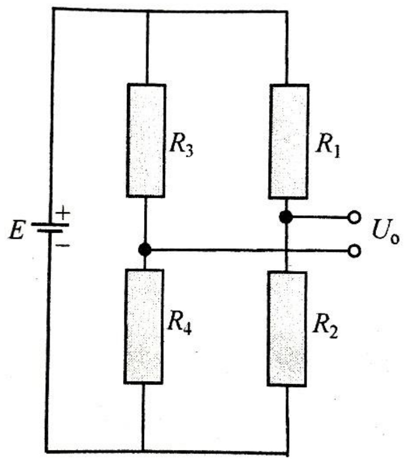


Figure 2: Unbalanced measuring bridge

The unbalanced output voltage of the point bridge is assumed to be:

For the 1/4 bridge circuit:

$$U_0 = \frac{E}{4}\frac{\Delta R}{R} \tag{1.6}$$

For differential half-bridge circuit:

$$U_0 = \frac{E}{2}\frac{\Delta R}{R} \tag{1.7}$$

For differential full bridge circuits:

$$U_0 = E\frac{\Delta R}{R} \tag{1.8}$$

In practical use, due to errors, it is impossible for the four resistors to achieve exactly the same resistance value. Therefore, it is necessary to consider the bridge balancing repair circuit. If Fig.3 is shown, the R_w in the adjustment chart can make the bridge balanced.

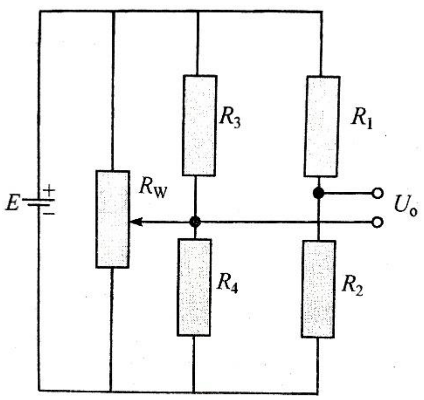


Figure 3: Bridge Balance Compensation Circuit

实验器材 List of instruments and materials:

There are four foil strain gauge cantilever beams, ten 20g weights, one universal table, DC regulated power supply (with ±15V, ±5V power supply), one 22kΩ/2W potentiometer, one adjustable zero differential amplifier, three 50Ω/0.25W resistors, and several conductors.

实验步骤 Implementation:

1. Observe the sticking position of strain gauges on cantilever beams, judge their strain direction, and measure the initial resistance of strain gauges at room temperature.
2. When the cantilever beam is bent under external force F, the output voltage U_0 of the bridge is measured unbalanced. It will change accordingly. The experimental scheme will be designed to map the U_0- F curves of 1/4 bridge, differential half bridge and differential full bridge, and compare their sensitivity $\frac{\Delta U_0}{\Delta F}$.

Requirement:
(1) U. It should be mV order of magnitude.
(2) Give the system circuit diagram and main experimental steps.
(3) The three curves should be depicted in the same coordinate system.

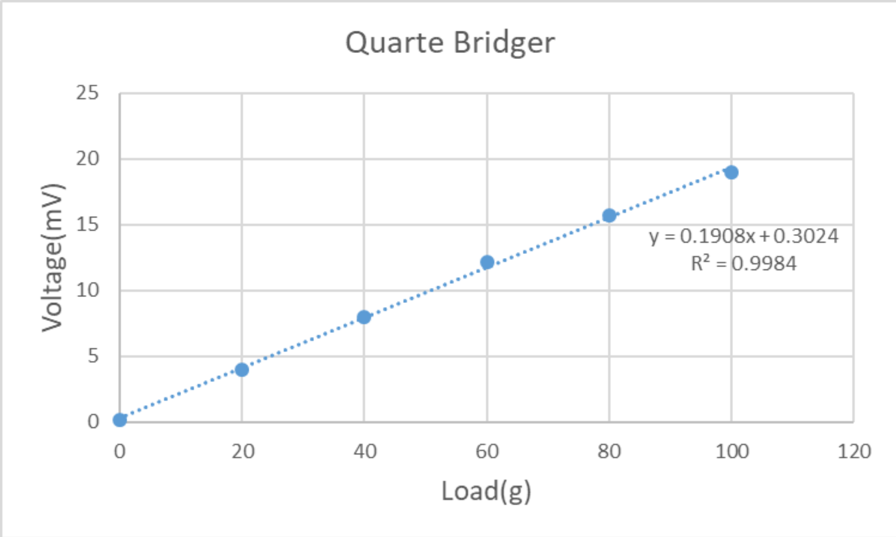
3. Using digital multimeter as display device, design and manufacture an electronic scale with a range of 0-200, describe its output characteristic curve of 0-200 mV and calculate its accuracy grade. It is required that when the load on the pallet is 0-200, the corresponding indication of the multimeter is 0-200 mV.

实验结果和数据处理 Results and Data processing:

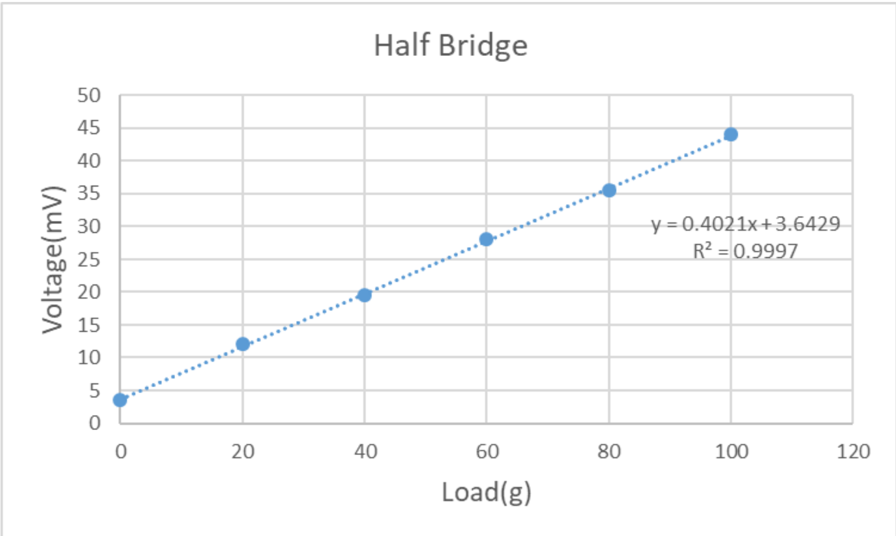
Results:

<table>
<tr><td colspan="8">Designation of Electronic Weighing Scale using Strain Gauges Data Recording Form</td></tr>
<tr><td rowspan="5">Quarte Bridger</td><td>Load(g)</td><td>0</td><td>20</td><td>40</td><td>60</td><td>80</td><td>100</td></tr>
<tr><td>Voltage V_G^1(mV) Loading</td><td>0.2</td><td>4</td><td>8</td><td>12</td><td>15.8</td><td>19</td></tr>
<tr><td>Voltage V_G^2 (mV) Loading</td><td>0.1</td><td>4</td><td>8</td><td>12.4</td><td>15.6</td><td>19</td></tr>
<tr><td>Mean Value VG(mV) $(V_G^1+V_G^2)/2$</td><td>0.15</td><td>4</td><td>8</td><td>12.2</td><td>15.7</td><td>19</td></tr>
<tr><td>Weight of your phone(g)</td><td colspan="6">174g (33.50mV)</td></tr>
<tr><td rowspan="5">Half Bridge</td><td>Load(g)</td><td>0</td><td>20</td><td>40</td><td>60</td><td>80</td><td>100</td></tr>
<tr><td>Voltage V_G^1(mV) Loading</td><td>4</td><td>12</td><td>20</td><td>28</td><td>35</td><td>44</td></tr>
<tr><td>Voltage V_G^2 (mV) Loading</td><td>3</td><td>12</td><td>18</td><td>28</td><td>36</td><td>44</td></tr>
<tr><td>Mean Value VG(mV) $(V_G^1+V_G^2)/2$</td><td>3.5</td><td>12</td><td>19.5</td><td>28</td><td>35.5</td><td>44</td></tr>
<tr><td>Weight of your phone(g)</td><td colspan="6">174g (73.61mV)</td></tr>
<tr><td rowspan="5">Full Bridge</td><td>Load(g)</td><td>0</td><td>20</td><td>40</td><td>60</td><td>80</td><td>100</td></tr>
<tr><td>Voltage V_G^1(mV) Loading</td><td>30</td><td>-32</td><td>-67</td><td>-97</td><td>-133</td><td>-168</td></tr>
<tr><td>Voltage V_G^2 (mV) Loading</td><td>1</td><td>-28</td><td>-64</td><td>-99</td><td>-134</td><td>-168</td></tr>
<tr><td>Mean Value VG(mV) $(V_G^1+V_G^2)/2$</td><td>2</td><td>-30</td><td>-65.5</td><td>-98</td><td>-133.5</td><td>-168</td></tr>
<tr><td>Weight of your phone(g)</td><td colspan="6">174g (-293.50mV)</td></tr>
</table>

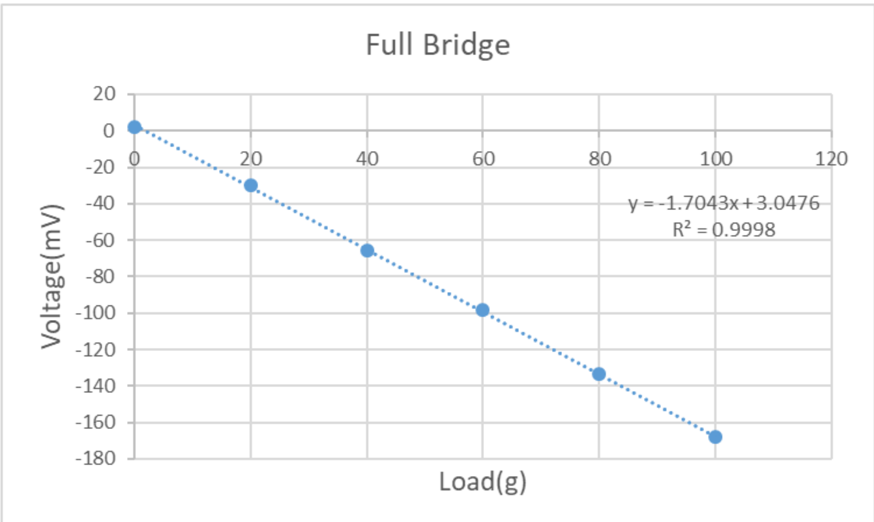
Form 1: Experiment Data



Graph 1: Quarte Bridger



Graph 2: Half Bridger



Graph 3: Full Bridger

Calculation of the phone's quality:

For the Quarter Bridge: For the Half Bridge: For the Full Bridge:

M=$\frac{33.5-0.3024}{0.1908}$ =174(g) M=$\frac{73.61-3.6429}{0.4021}$ =174(g) M=$\frac{-293.5-3.0476}{-1.7043}$ =174(g)

Calculation of Uncertainties:

1. u_A

For the Quarter Bridge:

$$u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(V_i-\overline{V_1})^2}{k(k-1)}}=2.57\times\sqrt{\frac{(0.15-11.84)^2+(4-11.84)^2+(8-11.84)^2+(24.2-11.84)^2+(15.7-11.84)^2+(19.0-11.84)^2}{6\times5}} = 9.750230$$

For the Half Bridge:

$$u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(V_i-\overline{V_1})^2}{k(k-1)}}=2.57\times\sqrt{\frac{(3.5-23.75)^2+(12-23.75)^2+(19.5-23.75)^2+(28-23.75)^2+(35.5-23.75)^2+(44.0-23.75)^2}{6\times5}} = 15.789473$$

For the Full Bridge:

$$u_A = t_p\sqrt{\frac{\sum_{i=1}^{k}(V_i-\overline{V_1})^2}{k(k-1)}} = 2.57\times\sqrt{\frac{(2.0+82.17)^2+(-30.0+82.76)^2+(-65.5+82.76)^2+(-98.0+82.76)^2+(-133.5+82.76)^2+(-168+82.76)^2}{6\times5}} = 66.912741$$

2. u_B

Uncertainties	$\boldsymbol{U_B}$	
	$\boldsymbol{U_I}$	$\boldsymbol{U_E}$
电压表(mV)	0.0.1	0.01

<u>实验讨论 Discussions:</u>

1. What is the principle of resistance strain gauge weighing sensor?

Principle of Resistance Strain Weighing Sensor: Elastomer (elastic element, sensitive beam) produces elastic deformation under external action, so that the resistance strain gauge (conversion element) pasted on his surface also produces deformation. After the resistance strain gauge is deformed, its resistance value will change (increase or decrease), and then the resistance change will be converted into electrical signal (voltage) by corresponding measuring circuit. In this way, the process of converting external force into electrical signal is completed.

2. What is the equilibrium bridge? What is unbalanced bridge? What are the similarities and differences?

Balanced bridge is to compare the resistance to be measured with the standard resistance. By adjusting the balance of the bridge, the resistance to be measured can be measured, such as single-arm DC bridge (Whiston bridge) and double-arm DC bridge (Kelvin bridge). They can only be used to measure the physical quantities with relatively stable state. In practical engineering and scientific experiments, many physical quantities are continuously changing, and unbalanced electricity can only be used. The basic principle of unbalanced bridge is to measure resistance by bridge circuit. According to unbalanced voltage output from bridge, the calculation is carried out to obtain other physical quantities that cause resistance changes, such as temperature, pressure, deformation, etc.