**The University of Alabama at Birmingham**

**School of Engineering**

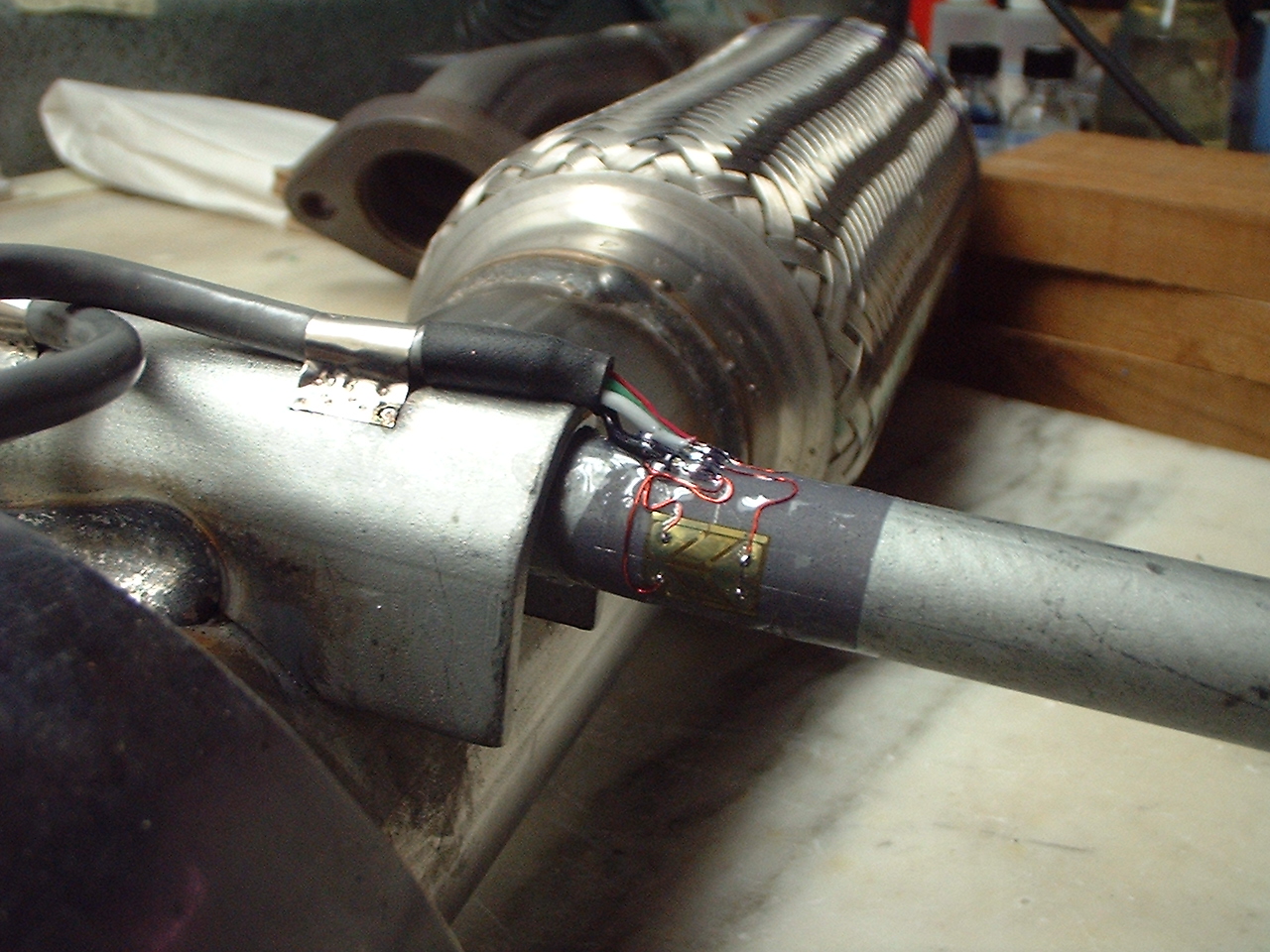
**Department of Mechanical Engineering**

**in collaboration with**

**Center for Advanced Automotive Technology**

**Strain Gauges for Measuring Forces and Torques**

**in Vehicle Applications**



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## Objective

1. To study strain gauge designs and successfully mount a strain gauge on a specimen.
2. To learn relationships between loads and stresses in vehicle parts that strain gauges are designed to measure
3. To conduct an experimental study on measuring a torque applied to a shaft and analyze test results

## Safety

* Do not touch the tip of the solder; doing so will result in burns
* Be careful to not spill the bonding agent on to skin; it may cause skin irritation
* Do not touch any wires connected to a power source; doing so will result in an electric shock and possible injuries

## List of Equipment and Materials Used in Lab

* Strain Gauge
* 0-45-90 Strain Gauge Rosette
* Solder kit
* Wire
* Model P3 Strain Indicator
* Rig for testing torsional shaft
* Aluminum Specimen
* Weights
* Sandpaper
* Adhesive
* Prep Conditioner
* M-200 catalyst
* Gauze sponge or cloth
* Neutralizer
* Q-tip (cotton tipped applicator)
* Tweezer
* Cellophane Tape

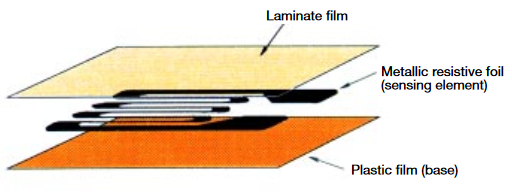
## Strain Gauge Design

### Introduction to Strain Gauge Design

A strain gauge is a type of transducer that is used to measure the strain, the change in length over the initial length, on a specimen to which it has been physically bonded. There are many types of strain gauges. Among them is the universal strain gauge, also known as an electric strain gauge. A universal strain gauge has a structure such that a grid-shaped sensing element of thin metallic resistive foil, usually 3 to 6μm (micro meter) thick, is put on a base of thin plastic film, 15 to 16μm thick, and is laminated with a thin film; this is shown in Figure 1.1 [1]. The strain gauge is tightly bonded to a measuring object so that the sensing element (metallic resistive foil) may elongate (tension) or contract (compression) according to the strain developed by the measuring object. When undergoing mechanical elongation or contraction, most metals undergo a change in electrical resistance. The electrical resistance is the resistance of the strain gauge in ohms. When the specimen is loaded with a mechanical load (a force or a moment), the strain on its surface is transmitted to the grid material by the adhesive and carrier system. The strain in the specimen can be determined due to a change in the electrical resistance of the grid material. The measurement is characterized by the Gauge Factor. The Gauge Factor is the ratio of the change in resistance over the initial resistance of the strain gauge to the change in length (strain) .When the geometry of a wire is changed, so does its electrical resistance change. As the wire elongates and becomes thinner, the resistance of the wire increases and vice versa. This change in resistance can be measured while using a Wheatstone bridge (this is an electrical circuit described later in the lab manual). Due to the change in resistance, the whole electrical circuit becomes unbalanced (the voltage is non-zero). The measure of the imbalance in the circuit is the signal that is used to determine strain. Stress and strain are related to each other by a constant, Young’s Modulus, also called the Modulus of Elasticity, . Eqs. (1) present relationships between the listed parameters, the tension force applied to a rod, , and geometrical parameters of the rod, including the cross-section , original length (before force was applied), and change in the length :

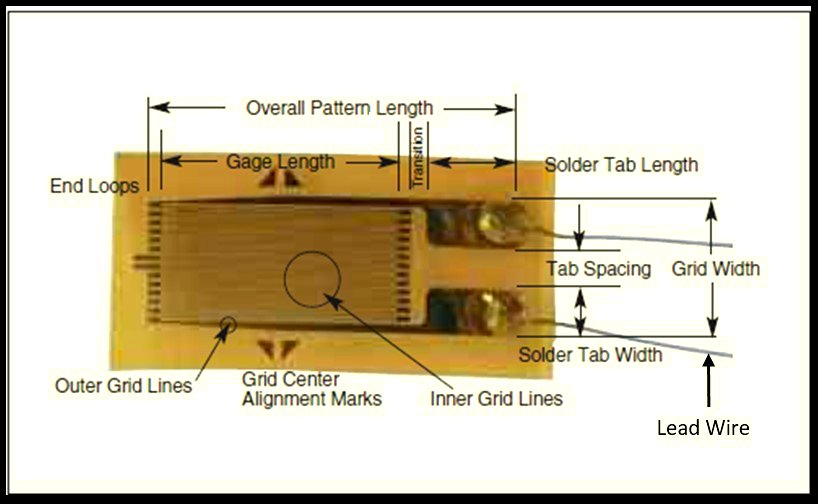
(1)

To reiterate, when the specimen is loaded, the strain on its surface is transmitted to the grid material by the adhesive and carrier system. The strain in the specimen is determined by measuring the change in the electrical resistance of the grid material.



**Figure 1.1: Diagram of the Strain Gauge Parts [1]**

Below is Figure 1.2 showing a detailed layout of the parts of a strain gauge [1]. The distance over which the strain measurement is averaged is called the Gauge Length. This is also the length of the metallic resistive foil. The end loops are a small group of strain sensitive materials that lie transversal to the gauge. The purpose of the end loops is to give the strain gauge a non-zero sensitivity to strain in the transverse direction. The solder tab is the area where the lead wires are attached.



**Figure 1.2: Layout of the Strain Gauge [2]**

Refer to this video for more information on the basics of a strain gauge (watch the first 1 minute). <https://youtu.be/ZPSB37RSO7s>

## Preparing the Specimen

This section will show how to prepare a specimen for a strain gauge and to bond the strain gauge to the surface of the specimen through the use of a bonding agent. The specimen that will be bonded will be similar to a rectangular piece of metal. Also, a regular strain gauge (Figure 1.2), not a strain gauge rosette (Figure 5.1) will be used to bond to the rectangle metal specimen. The bonding agent is M-Bound 200, which is a modified methyl-2 cyanoacrylate compound. This bonding agent has a shelf life of 12 months if stored at 40° F or 9 months if stored at 75 °F **[2]**.

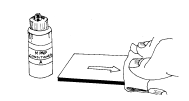
### 2.1 Cleaning the Surface

1. Thoroughly degrease the surface where the gauge will be applied with the degreaser and solvent that is provided. Be careful to not use any contaminated solvents and to also degrease in a uniform matter in the same direction. Switching directions can lead to contamination of the gauging area. See Figure 2.1 [3] as an example.

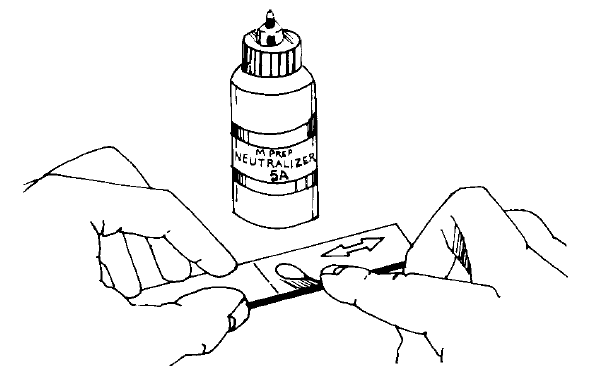


**Figure 2.1: Picture of degreaser [3]**

1. Begin dry-abrading the surface with the finer sandpaper provided (Figure 2.2) [3]. After dry-abrading, apply the Prep Conditioner and begin to wet-abrade the surface with the rougher sandpaper. When done abrading, wipe the dry area with a gauze sponge or gauze cloth (Figure 2.3) [3]. Be careful to not touch the gauging area with your fingers or with any type of oily surface. If this happens the gauging area is contaminated and the process of degreasing must start over in order to achieve a strong bond.

  
 **Figure 2.2 and 2.3: Picture of drying the specimen [3]**

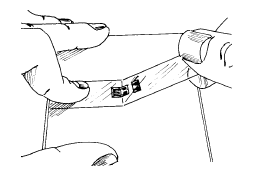
1. Burnish, but do not write any alignment marks on the specimen (it would be helpful to make the marks so that the strain gauge is in the center of the specimen). Now repeatedly apply a small amount of the Prep Conditioner to the gaging area and gently wipe with a gauze sponge or cloth until no residue is left on the cloth or sponge. **Never allow any of the solutions to dry on the surface of the gaging area.** This will cause a thin film to develop over the area resulting in contamination that in turn will reduce the chances of achieving a strong bond. Apply a small amount of the Neutralizer and gently scrub with a Q-tip (cotton tipped applicator). Last, carefully and slowly wipe the area dry with a gauze cloth or sponge; do not wipe back and forth, this may allow some containments to be redeposited on the area. See Figure 2.4 for an example [3].

   
**Figure 2.4: Picture of Burnishing [3]**

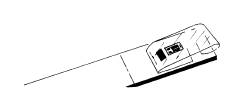
### Applying the Strain Gauge

The next step is applying the strain gauge.

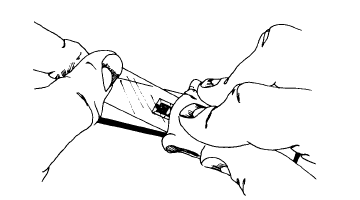
1. Use a tweezer to remove the gauge from its package by grabbing either the corners or the wires. **Do not touch the stain gauge with your hands nor touch the gauge sensors with the tweezer.**  Doing so will damage the strain gauge. Carefully place the strain gauge on the gauging area. Once it is placed grab a piece of cellophane tape, a clear everyday transparent tape, and place it over the strain gauge. Be careful to not touch the center of the tape with your fingers. Carefully remove the tape halfway from the specimen (Figure 2.5), leaving the strain gauge attached to the tape [3].

  
 **Figure 2.5: Picture of removing the tape with gauge applied [3]**

1. Now continue to carefully lift the tape with the strain gauge still attached until it looks similar to Figure 2.6 [3]. Next apply a thin layer of the M-200 catalyst to the back of the strain gauge and the gauging area. **The next few steps have to be completed in a short amount of time due to the quick bonding nature of the adhesive.** **It is advised to read ahead before continuing.**

   
**Figure 2.6: Picture of Strain Gauge with tape before bonding is applied [3]**

1. While holding the tape, apply the adhesive (1 to 2 drops should suffice), and immediately slowly press down on the tape keeping the tape slightly taut. Immediately use a gauze cloth or sponge to press down and smooth out the adhesive like shown in Figure 2.7 [3].



**Figure 2.7: Picture of applying the strain gauge with bonding agent [3]**

1. Next apply pressure firmly with a thumb, either by direct contact to the tape over the strain gauge or by using a gauze cloth. Hold this position for about 2 minutes before attempting to lift the finger. After 2 minutes have past, the strain gauge is securely bonded to the specimen. To remove the tape, slowly pull back the tape over itself to avoid lifting any of the foil on top of the strain gauge.

### 2.3 Soldering the Connections

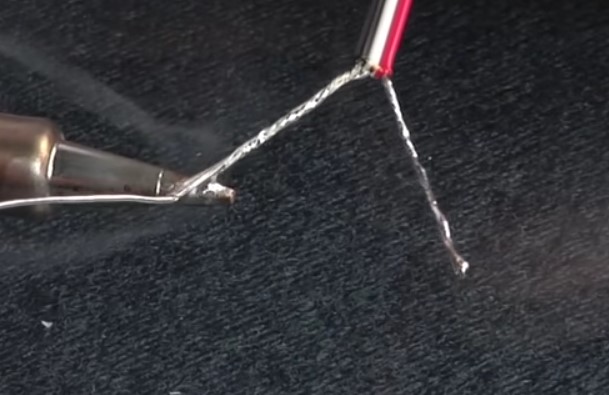
To be able to integrate the strain gauge to a circuit, wires must be connected from the strain gauge to the circuit. The wires that are connected to the strain gauge are also referred to as lead wires and are connected to the solder tab shown before in Figure 1.2 [2].

When soldering the lead wire, be careful not to overheat the strain gauge. Doing so will damage the strain gauge and render it useless. For this experiment a regular strain gauge will be used instead of the rosette strain gauge in order to develop a basic understanding of connecting a strain gauge to a circuit.

Clean the tip of the solder on a wet sponge pad. After that tin (coat a surface in rosin solder) the solder gun tip. The tinning process is shown in Figures 2.8 to 2.10 [4]. Lay the end of the solder rosin across the solder pad and apply the iron tip onto the solder. Apply firm pressure for **no more than a second,** thenremove both the solder and the iron simultaneously. There should now be a bright layer of solder on the pad of the strain gauge. Repeat this until each solder pad is similarly coated. Strip and tin the wires that will be used to connect the strain gauge, these wires are known as the lead wires. Hold the lead wires on the solder pad with little pressure and carefully apply the solder gun to the lead wire until the wire is bonded to the solder pad.



**Figure 2.8: Solder tip before tin [4]**



**Figure 2.9: Solder tip during tin [4]**



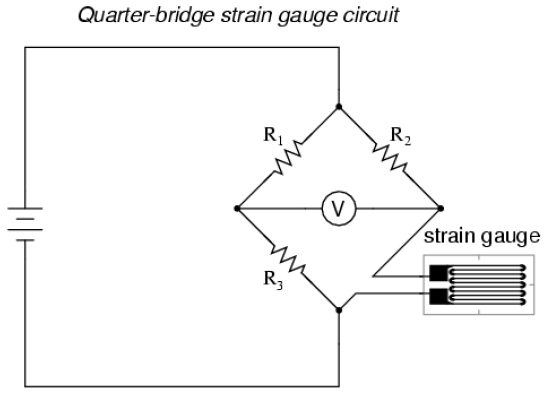
**Figure 2.10: Solder tip when tin is complete [4]**

## Wheatstone Bridge

### 3.1 Introduction

In order to use the strain gauge as a practical instrument, we must measure extremely small changes in resistance with high accuracy. Such demanding precision calls for a bridge measurement circuit. A strain gauge bridge circuit indicates measured strain by the degree of *imbalance*, and uses a precision voltmeter in the center of the bridge to provide an accurate measurement of that imbalance. For this example a regular strain gauge will be used.

There are various circuits’ orientation of a Wheatstone bridge, the first to discuss is a quarter bridge circuit, Figure 3.1 [5]. Typically, the resistance of the rheostat arm of the bridge, labeled R2 in Figure 3.1 [5], is set equal to the strain gauge resistance when no force is applied. The two ratio arms of the bridge (R1 and R3) are set equal to each other. Thus, with no force applied to the strain gauge, the bridge will be symmetrically balanced and the voltmeter will indicate zero volts, representing zero force on the strain gauge. As the strain gauge is either compressed or elongated, its electrical resistance will change thus unbalancing the bridge and producing a signal at the voltmeter.



**Figure 3.1: Diagram of a Quarter Bridge Circuit [5]**

If the upper strain gauge was positioned so that it is exposed to the opposite force as the lower gauge (when the upper gauge is compressed, the lower gauge will be stretched, and vice versa), we will have *both* gauges responding to strain, Figure 3.2. This will allow the bridge to be more responsive to applied force. This utilization is known as a *half-bridge*. The two ratio arms, R1 and R3, are kept at equal resistance to each other.



**Figure 3.2: Diagram of a Half Bridge circuit [5]**

When possible, the full-bridge configuration is the best to use. This is true not only because it is more sensitive than the others, but because it is *linear* while the others are not. Quarter-bridge and half-bridge circuits provide an output (imbalance) signal that is only *approximately* proportional to applied strain gauge force. Linearity, or proportionality, of these bridge circuits is best when the amount of resistance changes due to applied force is very small compared to the nominal resistance of the gauge(s). With a full-bridge, however, the output voltage is directly proportional to applied force, with no approximation (provided that the change in resistance caused by the applied force is equal for all four strain gauges).



**Figure 3.3: Diagram of a Full Bridge circuit [5]**

Both half-bridge and full-bridge configurations grant greater sensitivity over the quarter-bridge circuit, but often it is not possible to bond complementary pairs of strain gauges to the test specimen. Thus, the quarter bridge circuit is frequently used in strain measurement systems.

An example of how a pair of strain gauges works when bonded to a specimen is shown below. Figure 3.4 from reference [5] shows the setup of the strain gauges on a specimen with no applied forces that will undergo a bending stress. Since no forces are applied to the specimen, both strain gauges have equal resistances. However, when a downward force is applied to the specimen at the end, the specimen will deflect downward, elongating strain gauge 1 and compressing strain gauge 2 (Figure 3.5 [5]).



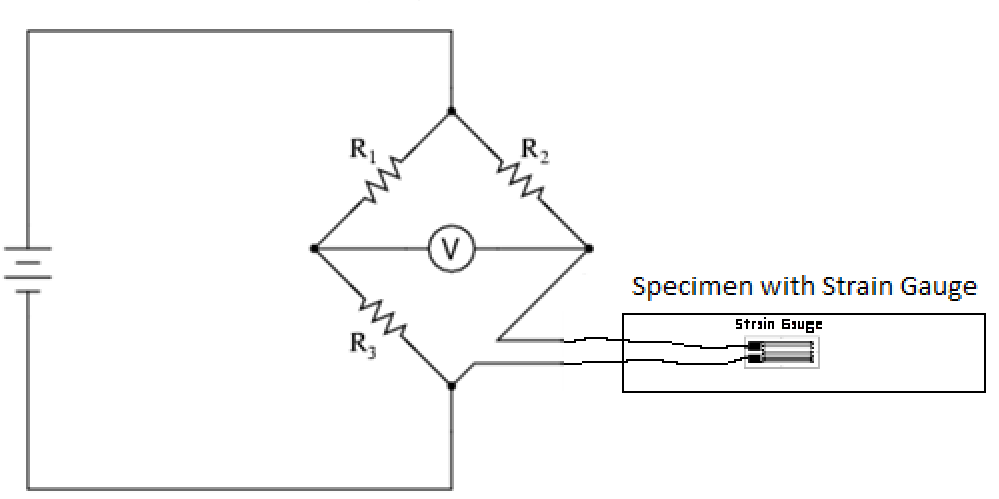
**Figure 3.4: A Specimen with Strain Gauge [5]**



**Figure 3.5: A Specimen with Strain Gauge undergoing Bending [5]**

### **3.2 Setting up the Quarter Bridge Circuit**

For this explanation the Quarter Bridge circuit will be applied as stated earlier. Under load, three strain values are recorded at each load increment. These raw strain readings are designated as the normal strains. Referring to Figure 3.6, the resistance of R2 has to be the same as the resistance of the strain gauge [5]. R1 and R3 must be set equal to each other in order for the circuit to work; the values of the ratio arms are arbitrary.



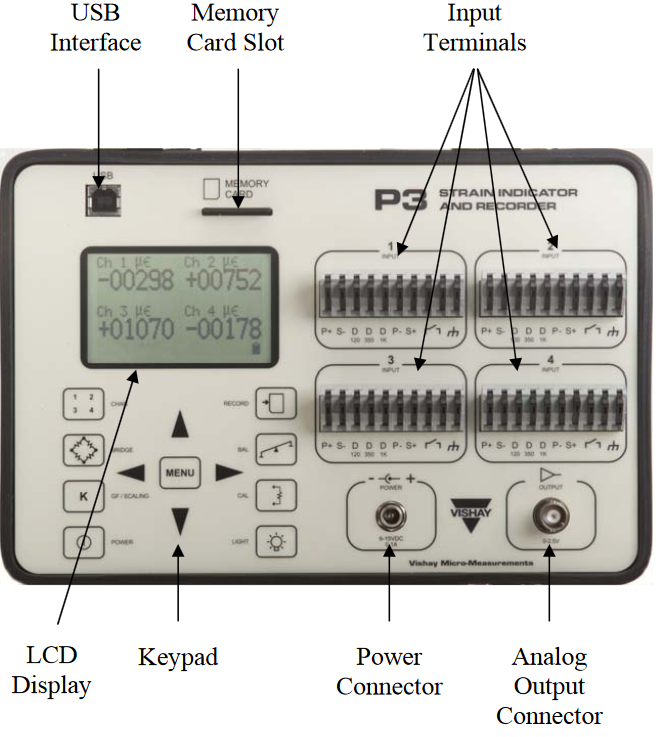
**Figure 3.6: Specimen with Strain Gauge Merge to a Quarter Circuit [5]**

The simplest way to simulate a whetstone circuit is to use a Model P3 Strain Indicator and Recorder. The Model P3 is a portable, battery powered precision instrument for use with resistive strain gauges and strain-gauge-based transducers. The Model P3 accepts full, half and quarter bridge circuits emulating 120, 350, or 1000 ohms resistance. It is possible to operate the Model P3 using menu-driven commands, which can be controlled by either the front panel keypad or remotely via a USB connection. Figure 3.7 [6] shows the Model P3.



**Figure 3.7: Picture of a Model P3 Strain Indicator [6]**

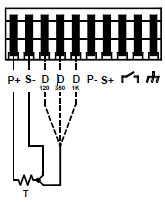
The Model P3 has three sources of power: Battery, USB or an AC adapter. When powering on the Model P3, with more than one power supply present, the power source is determined in the following order: First USB, second AC Adaptor, and third battery. **Note If the Model P3 is using USB or the AC adaptor, the system will remain on as long as power is supplied**. If the Model P3 is using the USB or AC adapter as the power source, an "x" is displayed on the lower right corner of the LCD display, indicating the unit is running on external power. If the system is running on battery power, the ‘x’ is replaced by a battery strength indicator. If no external supply is detected, the system must be turned on by pressing the Power key. When the unit is powered up, a beep should be heard that indicates it is powering up. Figure 3.8 shows the front panel of the Model P3 [6].



**Figure 3.8: Model P3 Front Panel [6]**

The LCD will display values with a channel labeled for each number. The channel numbers correspond to the Input terminals number, meaning that the value from channel one is the value from the Input Terminal 1. The value displayed under each channel is the strain value in micro units.

To make the quarter bridge connection, connect the lead wires to Input Terminals 1. The setup should look similar to Figure 3.9 [6].



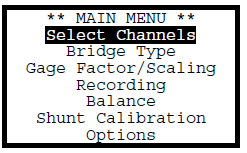
**Figure 3.9: Picture of Connecting Strain Gauge to Terminals [6]**

In Fig. 3, T is the strain gauge and D are the different resistances with the D being dummy terminals (D120, D350, and D1000). Choose the dummy terminal that is the same as the strain gauge.

### 3.3. Model P3 Zeroing

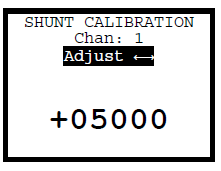
Calibration of the Model P3 means zeroing the output data before the experiment is underway. This is due to the torque arm and the weight of the specimen itself having an effect on the strain value given off by the Model P3. This leads to calibration being required to assure the accuracy and/or linearity of the instrument itself. The Model P3’s sensitivity is how well the system responds to a change in resistance being converted to strain. An example of the latter situation occurs when a strain gauge installation is removed from the Model P3, with measurable signal attenuation due to lead wire resistance. In this case, calibration is used to adjust the sensitivity of the instrument so that it properly registers the strain signal produced by the gauge. Zeroing is also used to set the output of any auxiliary indicating or recording device (oscillography, computer display, etc.) to a convenient scale factor in terms of the applied strain.

If the reading of the strain when the specimen is at rest is not zeroed, than do the following step is performed to calibrate. In mode, press the menu key and select shunt calibration form the menu by pressing the menu key again, Figure 3.10 [6]



**Figure 3.10: Main Menu Interface of Model P3 [6]**

The Shunt Calibration menu should appear; this menu will allow the adjustment of the sensitivity of the selected channel (gauge factor or full scale value). Use the and buttons to select the desired channel for the shunt calibration. To adjust the calibration use the and buttons to highlight *Adjust* and select it. Once that is done use and  to increase and or decrease the sensitivity, Figure 3.11 [6].



**Figure 3.11: Shunt Calibration Menu of Model P3 [6]**

### 3.4 Microstrain Scaling

If the selected units are με (microstrain), scaling is determined by the gage factor of the sensor. To change the gage factor, highlight the "Gage Factor" menu item, and use the  and  keys to select the desired digit to modify. The digit is changed by using the and keys.

The default gage factor is 2.000.

### 3.5 Calibration of the Strain Gauge

This form of calibration is a process of testing a specimen with strain gauges to obtain a mathematical regression line between two parameters. This regression line allows determining of a parameter such that knowing the other term will allow the calculation of the other.

The parameters are: *S* is the signal from the experiment and *F* is the force applied to the specimen. During the experiment, a specimen is loaded with specified values of the force and a signal is measured. To calculate the regression equation, a plot of Signal vs Force needs to be created. The equation of the regression line is

(2)

Where is the slope of the regression line and m is the number of pairs [7]:

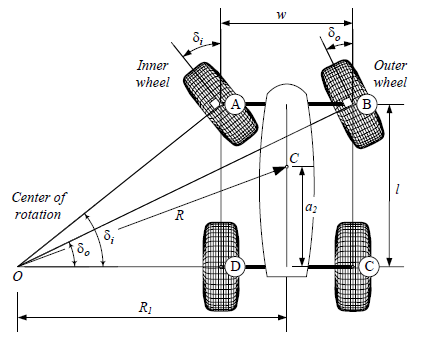
(3)

Refer to this video for more information on the basics of how a strain gauge operates and how it interacts with a Wheatstone bridge: <https://youtu.be/ZPSB37RSO7s>

## Automotive application for Measuring Forces and Torques

### 4.1 Steering systems and Strain Gauges

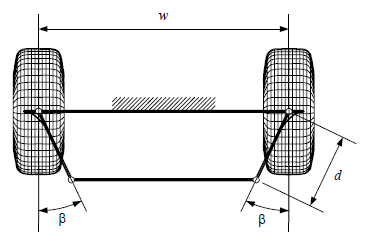
One of the common methods of steering principles used in today’s automotive vehicles is the Ackerman steering principle. To achieve stable turning for a four wheeled vehicle moving through a turn, the lines drawn through each of the four wheel axes make a 90 degree angle with the wheel planes and intersect at the instantaneous center of the turn (Figure 4.1) [8]. The actual position of the instantaneous center constantly changes due to the alteration of the front wheels’ angular position by a driver who attempts to correct the vehicle’s path.   
 The Ackermann principle is based on the two front steered wheels being pivoted at the ends of an axle-beam. The original Ackermann linkage had parallel set track-rod-arms, so that both steered wheels swivel at equal angles. Consequently, the intersecting projection lines do not meet at one point. If both front wheels are free to follow their own natural paths, they would converge and eventually cross each other. Since the vehicle moves along a single mean path, both wheel tracks conflict with each other continuously causing tire slip and tread scrub. A subsequent modified linkage uses inclined track-rod arms so that the inner wheel swivels about its king-pin slightly more than the outer wheel. Hence the lines drawn through the stub-axles converge at a single point somewhere along the rear-axle projection (Figure. 4.1) [8].



**Figure 4.1: Picture of Ackerman Principle [8]**

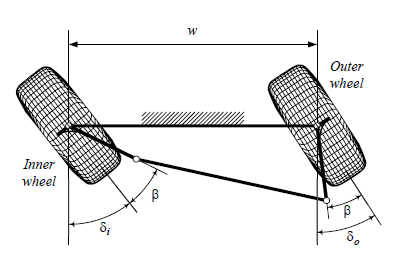
In Figure4.1,*δo*is the steering angle of the outer wheel, while *δi* is the steering angle of the inner wheel [8]. *Rl* is the vehicle radius of turn measured from the longitudinal axis of the vehicle to the center of rotation; *W* is the track width of the vehicle, *l* is the wheel base of the vehicle; *a2* gives the position of the center of gravity.

The geometry of a steering system that applies the Ackerman principle is shown in Figure 4.2 [8]. This geometry is a symmetric 4 bar linkage system that is called a trapezoidal steering mechanism. This steering system’s characteristics values that define the shape are angle *β* and the offset arm length *d* as shown in Figure 4.2 [8].



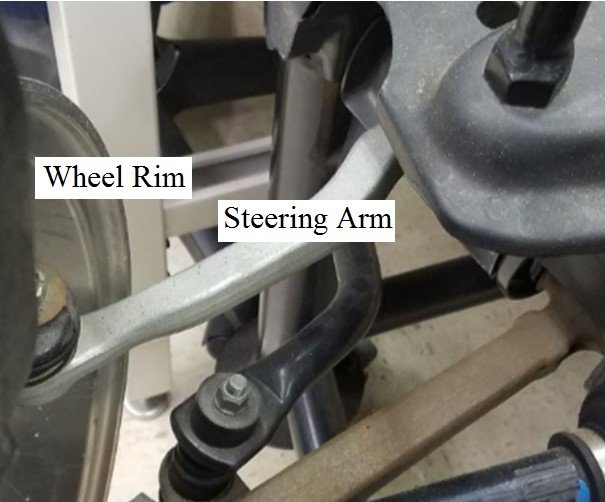
**Figure 4.2: Trapezoidal steering mechanism [8]**

Figure 4.3 shows how the links of the trapezoidal mechanism move when the vehicle is making a turn to left.



**Figure 4.3: Trapezoidal steering mechanism turned to the left [8]**

To measure a force that acts on a link of a steering mechanism, a strain gauge is applied on the steering arm (white or silver looking arm) shown in Figure 4.4 [8]. The technique that is used to apply the strain gauge is the same as stated above, bonding of the gauge to the link.



**Figure 4.4: Picture of the steering mechanism, UAB Vehicle and Robotics Engineering Lab**

### 4.2 Measuring Torques on Shafts

A shaft is a rotating member that usually has a circular cross section and is used to transmit rotational moments, i.e., torques. Shafts provide the necessary axis of rotation for elements such as gears, pulleys, flywheels, cranks, and sprockets while also controlling the gears, pulleys, flywheels, cranks, and sprockets’ geometry of motion. Figure 4.4 illustrates shafts with constant velocity (CV) joints on both ends. The shafts are used to transmit torques from a drive axle differential to the drive wheels of the axle. Strain gauges are usually applied to shafts to measure torques. Figure 4.5 shows a picture of a shaft installed on a vehicle.



**Figure 4.5: CV shaft for a vehicle [9]**



**Figure 4.6: Picture of a CV shaft on a Vehicle, UAB Vehicle and Robotics Engineering Lab**

The shaft can accommodate a wide range of torques from small to high, which occur during sharp maneuvers. As such, strains occurring in the shaft from normal driving conditions tend to be small and difficult to measure. This sensitivity requirement prevents many torque sensors used in other locations from being readily adapted to shaft sensing. For example, at a given torque, the strain sensed on a shaft will be approximately 15 times lower than a steering wheel shaft (10–15 mm in diameter). Furthermore, the shaft itself rotates when the vehicle is in motion, and changes in torque will need to be made in the presence of a baseline signal.

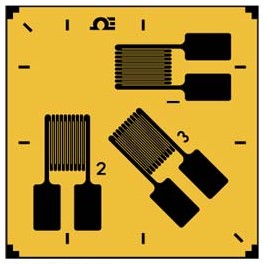
In general, torques may be monitored by measuring strain, angle of twist, or stress, and by sensors based on surface acoustic waves, piezo resistors, Hall-effect sensors, capacitance, and many others that have been used in automotive settings. The next section presents strain gauges and a lab manual to measure torque on a shaft.

## Torsion Test of Shaft

### 5.1 Equipment

* 0-45-90 Strain Gauge Rosette with a resistance of 120 ohms
* Model P3 Strain Indicator
* Rig for testing torsional shaft
* Wires
* Weights

The type of strain gauge that is used in this lab will be a “Rectangular Rosette” strain gauge with a resistance of 120 ohms; Figure 5.1 [10] shows an example of such sensor.



**Figure 5.1: Image of a 0-45-90 degree Strain Gauge Rosette [10]**

Where strain gauge 1 is the 0 degree gauge from the Rosette, strain gauge 2 is the 90 degree gauge from the Rosette and strain gauge 3 is the 45 degree gauge from the Rosette. The 3 strain gauges are used to measure the main strains.

### 5.2 Setup

Figure 5.2 shows the test rig and Figures 5.3 and 5.4 show the diagram of the specimen. The specimen for the experiment is a hollow shaft with dimensions and properties given below. The aluminum shaft is fixed at one end to hold it in place. A bearing is attached to the shaft connected to a vertical support. The torque arm is connected to the free end of the shaft.

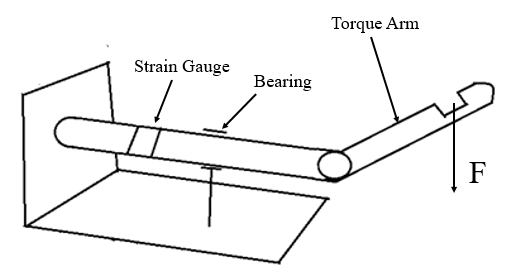
Aluminum hollow shaft:

Aluminum 6061-T6

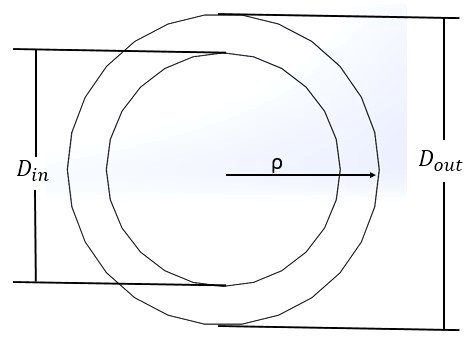
Inner Diameter (): 0.038m

Outer Diameter (): 0.050m

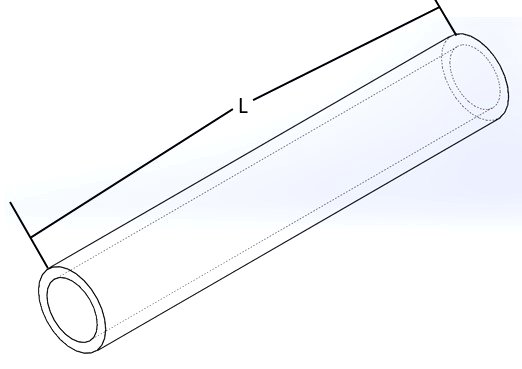
Length (*L*): 0.305m



**Figure 5.2: Test rig layout**



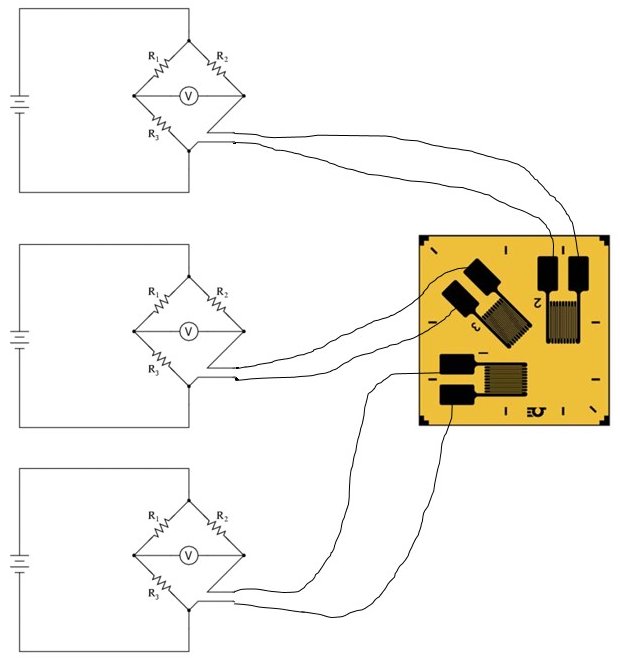
**Figure 5.3: Cross section of the aluminum specimen created in Solidworks [11]**



**Figure 5.4: Isometric view of the Aluminum Shaft created in Solidworks [11]**

For the experiment, three Quarter Bridge circuits will each be connected to the strain gauge rosette, an example as to what the circuit will look like is shown in Figure 5.5. Note that the resistance of *R2* has to be the same resistance of the strain gauge. *R1* and *R3* must be set equal to each other in order for the circuit to work. This will be carried out using the Model P3 strain Indicator.

To make the circuits, connect the lead wire of each strain gauge to separate Input Terminals, by connecting one lead wire to port p and the other to port s- and another wire to first D port (due to the strain gauge rosette having a resistance of 120 ohms), refer to Figure 3.9 [6] to make note of which terminal is connected to which strain gauge.

****

**Figure 5.5 Picture of 3 Quarter Bridge Circuits Connected to a Rectangular Rosette**

### 5.3 Equations

This section contains the equations that are needed for this lab

Equation (4) shows the calculation of the external torque, Figure 5.5:

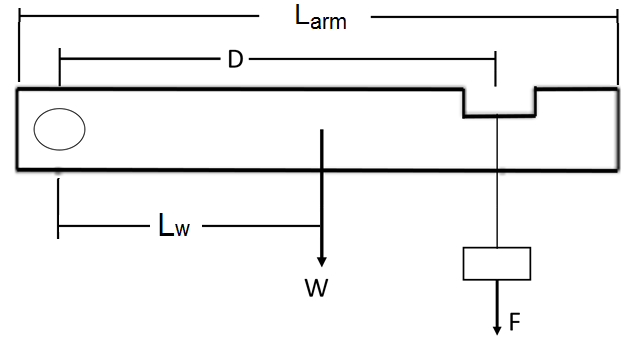
(4)

*T* = an external torque, [N-m]

*D* and *Larm* = the arm of force *F* and the arm length, [m]

*W* = the arm weight, [N]

*Larm* = the arm of weight W, [m]



**Figure 5.6: Drawing of the torque arm**

Eq. (5) shows the calculation for the polar second moment area

(5)

*J* = polar second moment area, [],

= outer diameter of the cross section of the shaft, [m] (see Figure 5.3),

= inner diameter of the cross section of the shaft, [m] (see Figure 5.3).

Eq. (6) shows the shear stress that is developed in the specimen

(6)

*ρ* = the radius of the cross section [m], (see Figure 5.3).

Eq. (7) shows the calculation for the shear strain:

(7)

= shear strain of the specimen,

= strain from the gauge at zero degrees,

= strain from the strain gauge at 45 degrees,

= strain from the strain gauge at 90 degrees.

### 5.4 Test Procedure

Read the manual of the Model P3 Strain Indicator and Recorder and implement all procedures that are required to use this device before you do experiments. Refer to the setup and equations above to complete the following steps.

1. Apply a 2 kg-weight to the hook that is connected to the torque arm.
2. Calculate the external torque that is caused by the applied weight and the weight of the torque arm.
3. Tabulate the force, external torque, stress, and strain received from the Model P3 display for each channel, make note of which channel was set to which strain gauge on the rosette. Tables 1 to 3 are provided below for each channel.
4. Repeat the above steps 8 times; for each time, a 2 kg-weight is added.
5. Use the measured data to generate a graph of shear stress vs. shear strain by applying the regression line from Eqs. (2) and (3). Determine a value of the torsional modulus of elasticity as the regression gain . Compare this value with a torsional modulus of elasticity for Aluminum 6061-T6 found in a materials science and engineering handbook.
6. Determine equation of the regression line and state gain of the graph.

**Table 1**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Channel 1 Strain Gauge\_\_\_\_\_\_** | | | | |
| **Run** | **Force(N)** | **Torque(N-m)** | **Strain** | **Stress(Pa)** |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |
| 7 |  |  |  |  |
| 8 |  |  |  |  |
| 9 |  |  |  |  |
| 10 |  |  |  |  |

**Table 2**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Channel 2 Strain Gauge\_\_\_\_\_\_** | | | | |
| **Run** | **Force(N)** | **Torque(N-m)** | **Strain** | **Stress(Pa)** |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |
| 7 |  |  |  |  |
| 8 |  |  |  |  |
| 9 |  |  |  |  |
| 10 |  |  |  |  |

**Table 3**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Channel 3 Strain Gauge\_\_\_\_\_\_** | | | | |
| **Run** | **Force(N)** | **Torque(N-m)** | **Strain** | **Stress(Pa)** |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |
| 7 |  |  |  |  |
| 8 |  |  |  |  |
| 9 |  |  |  |  |
| 10 |  |  |  |  |

### 5.5 Report

**Use the outline of this lab manual and write a lab report**.

There should be two parts of the report:

Part 1. Describe the concept and design of a strain gauge, the process of applying a strain gauge to a specimen, different types of Wheatstone bridges (quarter, half and full), the examples of automotive application of measuring forces and torques, and the torsional experiment. You should find another 2-3 vehicle applications of strain gauges in technical literature and describe them in the report (remember include references in the lab report).

Part 2. Describe the Test Rig used in the lab, math apparatus for the experiments, test procedure and tables with experimental data. Have a section with graphs and result discussion, and a conclusion.

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