# FABRICATION, TESTING AND CALIBRATION OF TWO DIRECTIONAL FORCE SENSOR

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## ABSTRACT

*Force and Torque sensors are important in robotic industries for various applications including assembling parts, accepting and rejecting the objects etc. Force and Torque measurement has become popular area of research has demanded by the respective applications. Considerable work has been done on the Force and Torque measurement using different techniques like strain gauges and piezoelectric sensors mounted on flexible members. For specific applications physical models have been proposed with characterization for the Forces and the Torque. This thesis describes development of Two Directional Force Sensor for force measuring along X and Y axis simultaneously using strain gauges. Mechanical structure for the Force sensor has been developed which contains sensing element mounted near optimize strain region. The identified parameters are characterized against the loading forces in X and Y direction. Generalized equations are developed for this parameters subsequently valuated using soft computing tool i.e., ANSYS software. Results shows that the sensitivity of device can be increased by changing physical parameters of sensing element, and so as to apply this device for assembling platform or robotic are configurations.*

**Keyword: -** *Force sensor1 , Force-sensing element2, Foil strain gauge3, and Wheatstone bridge4.etc….*

## 1. INTRODUCTION

In many manufacturing applications involving industrial robots, it is extremely important to be able to adjust and /or monitor the Force and Torque being applied to the part. Work has been done on the Force and Torque measurement using different techniques like strain gauges and piezoelectric sensors mounted on flexible members. From many years strain gauges have been used as the basic sensing element for vast applications like pressure sensors, load cells, force sensors, torque sensor and position sensors etc. from literature review, forces are measured for particular dimensions of the beam sensing element. Wrist force sensors are developed for grasping an object with different degrees of freedom. Piezoelectric sensors are used for dynamic measurement. It is cannot perform static measurements accurately. Work is consider on static so strain gauge sensor is better for measuring Force. This paper describes Two Directional Force sensors with low cost and minimum numbers strain gauge? Forces are measured using strain gauge as a sensing element along X and Y axis. It is avoiding the difficulties in the calibration. Here groove making is needed for increasing the sensitivity. Forces are measured in terms of milli volt by using Digital volt meter. In chapter 2 of this paper, the design requirements of two directional Force sensor, selection of materials and the use of strain gauges and methodology are described. Chapter 3 describes the complete hardware design and fabrication, making grooves and analysis beam. Chapter 4 Simulation results of the beam analysis. Chapter 5 describes the experimental results of Simple cantilever beam and force sensor. Chapter 6 brings out the Results and conclusion.

## 2. TWO DIRECTIONAL FORCE SENSOR DESIGN REQUIREMENTS

A force sensor measures two components of the force along X and Y axis.A force sensor design depends on the task it is intended for. In this case, the objective of the design is to develop a Two Directional Force Sensor, which is capable of sensing force. The design also uses bending elastic elements to measure small forces and strain gauges to convert mechanical strain to electrical signals.

A complete design of a force sensor for two directional force sensor structure requires many stages, which begins with the selection of material that is best suited in terms of characteristics, feedback, noise and friction. Then, it is followed by a proposed design of two directional force sensor to obtain maximum information from the object without much compromising on other characteristics in order to suit many applications. The construction of the force sensor will be completed by keeping in mind the application that it would be involved and also the way of apply this device for assembling platform or robotic are configurations.

Prior to the design and development of the electronic and instrumentation circuits to measure 2D forces, the simulations of the beams contribute significantly in identifying the placement of the strain gauges.

### 2.1 Fabrication Materials

Two materials, namely aluminum, steel were tested. The analysis for the selection of materials are based on these criteria, which are high stiffness, low friction, noise, immunity and less hysteresis It was found that aluminum is malleable and can have permanent-set if subjected to accidental force. Steel obviously offers a high stiffness and can attenuate force-signal if applied in shape determination. Aluminum is used for fabricating two directional force sensor structures. It is easily available and cheap.

### 2.2 Strain Gauge

Strain gauge force sensors have high sensitivity and measurement accuracy requiring relatively simple amplifier circuitries. The specifications of the strain gauge are in Table I. Here, one micro strain is equal to an extension of 0.000 I %.

**Table-1:** Strain gauge specifications

| | |
|---|---|
| Gauge length | 2mm |
| Measurable strain | 2 to 4% |
| Temperature range | -30 to 180°C |
| Gauge resistance | 350 ohms |
| Gauge factor | 2.00 |
| Temperature Coefficient | 0.015%/°C |
| Fatigue life | 10^6 reversals at 1000 micro strain |
| Foil material | Copper Nickel alloy |
| Base material | Polyamide |

### . 2.3. Wheatstone Bridge:

1) Output Voltage of 4-gage System
   The 4-gage system has four gages connected one each to all four sides of the bridge.

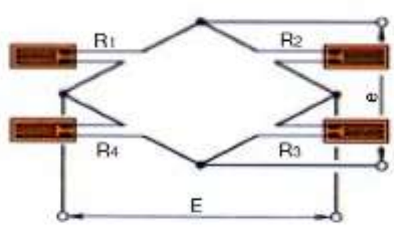


**Fig-1:** 4-Gauges System

When the gages at the four sides have their resistance changed to R1 + ΔR1, R2 + ΔR2, R3 + ΔR3 and R4 + ΔR4, respectively, the bridge output voltage, e, is:

$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) E \quad (1)$$

If the gages at the four sides are equal in specifications including the gage factor, K, and receive strains, ϵ1, ϵ2, ϵ3 and ϵ4, respectively, the equation above will be:

$$e = \frac{1}{4}.K\,(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)\,E \quad (2)$$

2) Output Voltage of 1-gage System:

In the cited equation for the 4-gage system, the 1- gage system undergoes resistance change, R1, at one side only. Thus, the output voltage is:

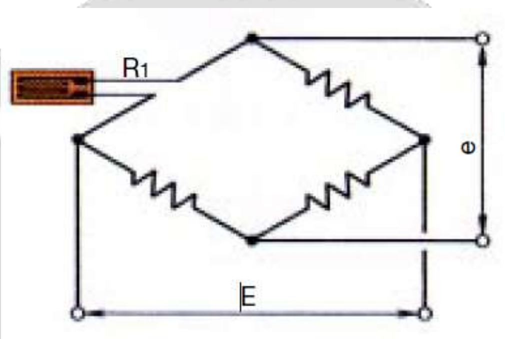


**Fig-2:** 1-Gauges System

$$e = \frac{1}{4}.\frac{\Delta R_1}{R_1}.E \quad (3)$$

(or)

$$e = \frac{1}{4}.K.\varepsilon_1.E \quad (4)$$

3) Output Voltage of 2-gage System:

Two sides among the four initiate resistance change. Thus, the 2-gage system in the case of Fig.3 provides the following output voltage:

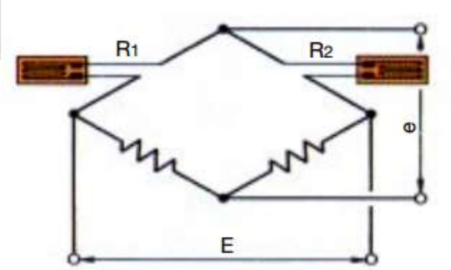


**Fig-3:** 2 Gauge System of Adjacent Connection

$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2}\right).E \quad (5)$$

(or)

$$e = \frac{1}{4}.K\,(\varepsilon_1 - \varepsilon_2).E \quad (6)$$

## 3. FABRICATION OF FORCE SENSOR STRUCTURE:

In this section, the details of the proposed hardware of the two directional force sensor will he discussed

### 3.1 A New Mechanical Structure for Force Sensor:

A new mechanical structure with two DOF force sensor has been developed. The elastic body of the sensor comprises of 4 I-section beams, 8 side plates and 3 blocks. The side plates are connected to the 3 blocks and I-section beams are composed of 4 Horizontal beams that are connected from side plates. Aluminum material is used for Fabricating Two directional force sensor. As shown in figure 4.

**Fig-4:** Mechanical Structure of Force Sensor

1). Block:

Dimensions of block are 126×126×20 as showed in fig 5.

2). Side Plate:

Dimensions of side plate are 56×26×12 as shown in fig 6.

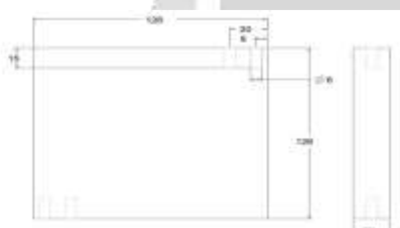

**Fig-5:** Dimensions of Block

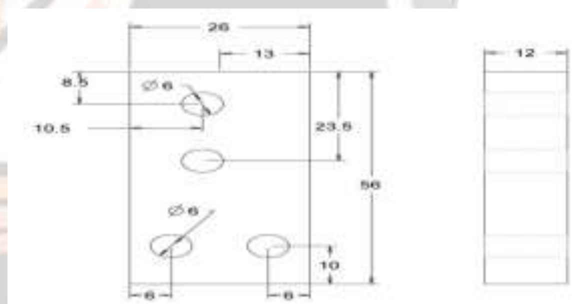


**Fig-6:** Dimensions of Side Plate



3) I-Section Beam:

Dimensions of I-Section Beam are 130×32×6 as showed in fig 7.

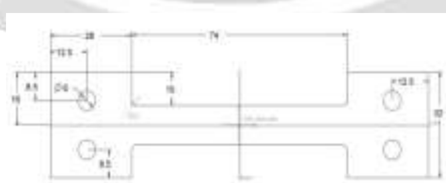

**Fig-7:** Dimensions of I-Section Beam

### 3.2. Analysis of I-section Beam.

Analysis of simple cantilever beam is required for pasting the Strain gauge where the maximum strain is occurred. Strain is maximum at the place of 38mm distance from fixed end. Strain gauges are pasted at the place of 38mm distance from both the ends of beam.

### 3.3. Making Groove Thickness:

Groove is made at the place of 38mm distance from both the ends of I-section beam. It will increase the sensitivity of the device. Strain gages are pasted on one side of the beam and grooves are made on other side of the beam. Here groove thickness is taken in incremental order with difference of 0.3mm i.e. 0.3mm,0.6mm,0.9mm,1.2mm,1.5mm,1.8mm,2.1mm,2.4mm,2.7mm and 3mm and then fixing two grooved beams to the setup only in X-axis direction. Grooved beam is shown below.

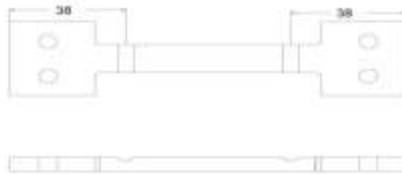


**Fig-8** Grooved Beam

### 3.4. Calibration Kit:

The calibration kit is specifically designed and fabricated for the purpose of testing and calibration of two directional force sensor. This module consists of pulley holder, base plate, hook and weight holder. The fully assembled calibration kit is shown in Figure 9.

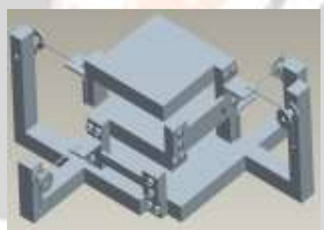

**Fig-9:** Fully Assembled Calibration Kit

## 4. FINITE ELEMENT MODEL OF THE ELASTIC BODY:

The discretization of the domain into sub-regions is the first of a series of steps that must be performed for FEM. The subdivision is usually called mesh generation, and a finite number of sub-domains are called elements. The discretization of the body involves the decision as to the element number, size and shape of sub-regions used to model the real body.

**Fig-10:** Finite Element Model of Force Sensor

Figure 10 shows a FEM model of the elastic body of the 2 DOF force sensor with 19527 element nodes and 7151 elements after mesh generation and Figure 11 shows a FEM model of the Simple cantilever beam with 4891 element nodes and 1048 elements after mesh generation. The material of the elastic body is aluminum.

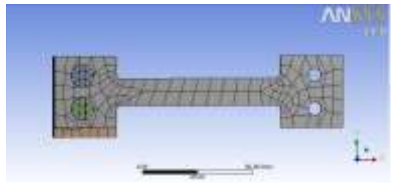

**Fig-11:** Finite Element Model of Simple Cantilever beam

**4.1 Strain analysis under two axis forces.**

(1) Boundary conditions

The elastic body is fixed on the shell of the force sensor through bolts on the base, so the connection between them can be regarded as rigid connection. Therefore the total degree-of-freedom of the base of the elastic body can be set as zero.

(2) Applied force/torques

Each single one of the two axis force is applied to the elastic body on the corner of the beam, respectively. When a single force is applied to the elastic body, the overall deformation of the elastic body is easy to calculate by using the ANSYS software.

Strain outputs at the 4 points on the I-section beam, to which the 4 strain gauges are stuck. The strain of the tensile surface of the beam is defined as positive strain, and the strain of the compressed surface is defined as negative strain. The measurement range of the analyzed 2 DOF force sensor is designed as Fx = 10.2 N.For the convenience of FEM analysis, the applied force to elastic body is chosen as the maximum 10.2 N. Results are shown in table 2.

**Table 2:** 3mm root thickness

| **3mm root thickness** | | |
|---|---|---|
| **safe load (kg)** | **Strain** | **Voltage (V)** |
| 1.02 | 0.00021304 | 0.0021304 |
| 2.04 | 0.00042608 | 0.0042608 |
| 3.06 | 0.00063912 | 0.0063912 |
| 4.08 | 0.00085216 | 0.0085216 |
| 5.1 | 0.0010652 | 0.010652 |
| 6.12 | 0.00127824 | 0.0127824 |
| 7.14 | 0.00149128 | 0.0149128 |
| 8.16 | 0.00170432 | 0.0170432 |
| 9.18 | 0.00191736 | 0.0191736 |
| 10.2 | 0.0021304 | 0.021304 |

## 5. Experimental results:

### 5.1 Measuring Resistance

Connected the terminals of the strain gauge to the digital volt meter and then applied load on the pan by increasing 1kg up to Fx=10.2kg load and note down the variable resistance for each 1kg load from 0kg to 10.2kg and also for Unloading from 10.2kg to 0kg. Then calculated the equivalent elastic strain from Resistance by using formulae

$$(\Delta R/R)=K.\varepsilon \qquad (5.1)$$

### 5.2 Measuring output voltage

Output voltages are measured by connecting Quarter Bridge, Half bridge and Full bridge .In Quarter bridge circuit one strain gauge is active and three strain gauges are dummy(variable resistors are used),in Half bridge circuit two strain gauges are active and two strain gauges are dummy(two variable resistors).In Full bridge circuit four strain gauges are active.

After connecting Wheatstone bridge circuit, input terminals are connected to constant input voltage circuit board and output terminals are connected to digital volt meter as showed below. Note down the output voltage for each 1kg load from 0kg to 10.2kg load and also for unloading from 10k.2g to 0kg. Then calculated the equivalent elastic strain from voltage by using formulae

For Quarter Bridge $V_{out}$ = (K.V.ε)/4 (5.2)

For Half Bridge $V_{out}$ = (K.V.ε)/2 (5.3)

For Full Bridge $V_{out}$ = K.V.ε (5.4)

Where

K= Gauge factor ε= Equivalent Elastic Strain

V= Constant Input voltage $V_{out}$ = output Voltage

**Table-3:** 3mm grooved beam is fixed to the force sensor device and measuring the voltage.

| Load | `Voltage | | Strain | |
|---|---|---|---|---|
| **kg** | **Loading** | **Unloading** | **Loading** | **Unloading** |
| 1 | 0.001 | 0.002 | 1E-4 | 2.E-04 |
| 2 | 0.002 | 0.004 | 2.E-04 | 4E-04 |
| 3 | 0.003 | 0.006 | 3E-04 | 6.E-04 |
| 4 | 0.005 | 0.007 | 5.E-04 | 7E-04 |
| 5 | 0.006 | 0.008 | 6E-04 | 8E-04 |
| 6 | 0.007 | 0.01 | 7.E-04 | 1E-03 |
| 7 | 0.009 | 0.011 | 9.E-04 | 1.1E-3 |
| 8 | 0.01 | 0.012 | 1.E-03 | 1.2E-3 |
| 9 | 0.012 | 0.013 | 1.2E-03 | 1.3E-3 |
| 10 | 0.014 | 0.014 | 1.4E-03 | 1.4E-3 |

Below the graph is drawn for Load Vs voltage and strain.

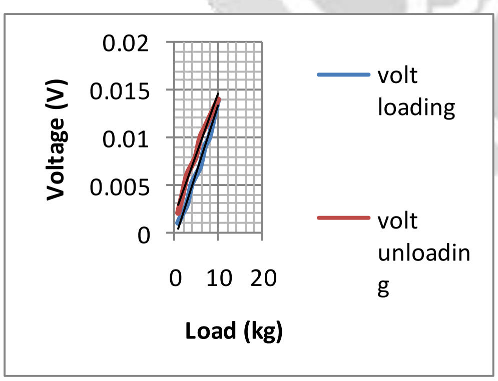


**Fig-12:** Load Vs Voltage

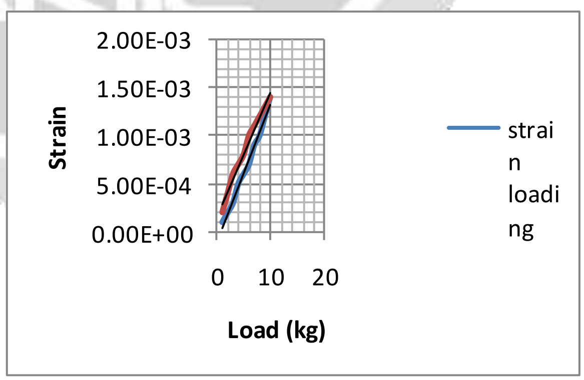


**Fig-13:** Load Vs Strain

Comparison of analysis and practical voltage values graph plotted in figure 14.

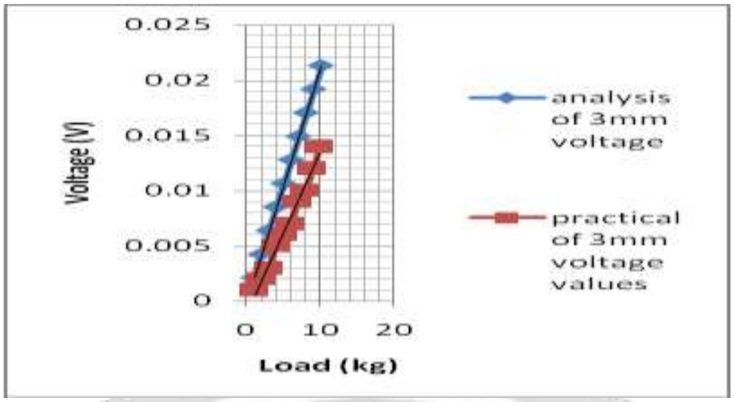


**Fig-14:** calibration of voltage for 3mm root thickness

## 6. CONCLUSION

Two directional Force sensors were developed for calculating sensitivity of the mechanical Force sensor device. Forces are measured in terms of milli volts by using strain gauges. Sensitivity of the device has been found for different grooved thickness. Resistances and Voltages are measured by using Digital volt meter.

Resistance and voltages are measured by applied load from 0kg to 10kg with a difference of 1kg load.

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