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# Design, Fabrication and Analysis of Torque Transducer

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***Abstract*** *- The present work is aimed at designing, fabricating and analyzing a 50kg-cm capacity Torque Transducer. A torque transducer is basically a specially designed structure which performs in predictable and repeatable manner when an input force (or torque) is applied. This force is translated into a signal voltage by the resistance change of strain gauges which are applied to transducer structure. The change in resistance indicates a degree of deformation and in turn the torque on the structure. The transducer will be capable of measuring the strain force for the static loading of a shaft. The results will be validated theoretically, practically and by using suitable CAE software.*

***Index Terms*** **– Cruciform shaft, Torque Transducer, Strain Gauge, Wheatstone bridge.**

## I. INTRODUCTION

Torque is defined as the tendency of a force to rotate an object about an axis. Just as a force is a push or a pull, a torque can be thought of as a twist. Due to the fact that torque is readily available in any rotating shaft, the development of sensors to measure torque has been of growing interest, especially in automotive and aerospace applications. Torque Measurement in essence is a very simple mechanical process, in its most basic meaning it is a measure of the force being used in turning (or attempting to turn) something. When a torque is applied to a shaft, the shaft twists (by a very small amount). This twisting produces a stretch in the material of the shaft, in a direction at 45 degrees to the axis of the shaft, between points on the shaft that are moved apart by the twisting motion. The material of the shaft also sees a compression in the opposite $45^0$ direction [1]. This produces a change in the strain on the shaft that is measured in order to calculate the torque. The strain measurement is performed with the help of strain gauges that produce an output voltage that is proportional to the applied torque. The output voltage is produced by a change in the resistance of the strain gauges that are bonded to the torque sensor structure. The magnitude of the resistance change is proportional to the deformation of the transducer shaft and therefore the applied torque. The transducer shaft is made of cruciform cross-section as shown in Fig. 1. The cruciform shape produces high stress or strain values at low values of torque and has good bending strength [2]. Thus the torque transducer will display accurate results for small values of input torque.

## II. EXPERIMENTAL SET-UP

The experimental setup shown in Fig. 2 which consists of a cruciform shaft made of stainless steel. The cruciform shaft consists of two separate plates of 85mm x 30mm x 3.94mm which are press-fitted to form an interlocking shaft structure. The shaft has flanges on each ends. One flange is bolted to a supporting column and is fixed and while the other flange is attached to the lever which can be moved.

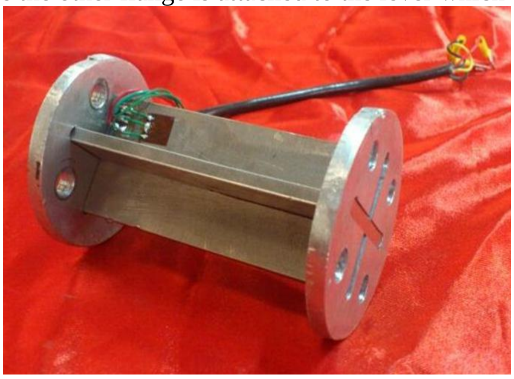


**Fig 1: Cruciform Shaft**

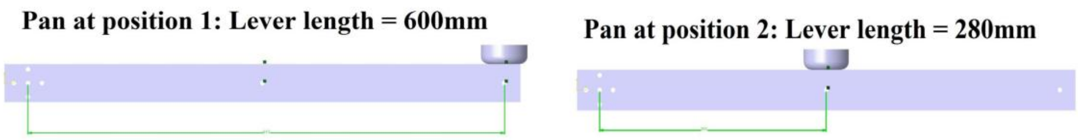
**Fig 2: Experimental Set-up**

The fixed end supporting column is rigidly attached to a stand which forms the base of test rig setup. The base provides support to the entire structure and acts as a counter weight. The lever is made of mild steel of size 62mm x50mm x 6mm and carries a pan at its other end. Two strain gauges are mounted at $45^0$ to each other on the cruciform shaft. The change in the strain on the shaft is measured in order to calculate the torque. Electrical connections are made from the two strain gauges and a bridge (Wheatstone) is formed. This bridge is connected to an external digital panel indicator which displays the value of the given input torque directly on its screen in 'kg-cm' units.

## III. EXPERIMENTAL PROCEDURE

Experimentation on the torque transducer is carried out for the following two conditions:

a. When pan is located at position 1 on the lever
b. When pan is located at position 2 on the lever




**(a)** **(b)**

**Fig 3: Position of Pan**

- To obtain the results, the weights in the pan are gradually increased by 200gm steps up to 1 kg and the corresponding output given by digital panel indicator is recorded.
- Similarly the same procedure is repeated by reducing the weights in the pan gradually by 200gm steps from 1kg up to 0kg and the corresponding output is recorded.
- The position of the pan on the lever is then changed from position 1 to position 2 as shown in Fig. 3 and the above two steps are repeated again.
- In the experimental set up, the distance of strain gauge from load (l) is 600mm, Width of lever (b) = 50mm,Thickness of lever (h) = 6mm,Gauge factor (k) considered is 2 and excitation voltage (Vex) =12V

## IV. RESULT & ANALYSIS

1 . When the pan is located at position 1 on the lever:

**Table I: Increasing weights gradually**

| Sr. No | Load [Kg] | Digital Panel Indicator (Voltmeter) Reading | |
|---|---|---|---|
| | | (while adding weights) [mV] | (while removing weights) [mV] |
| 1. | 0 | 0 | 1.5 |
| 2. | 0.2 | 4 | 7 |
| 3. | 0.4 | 8 | 13 |
| 4. | 0.6 | 13 | 16 |
| 5. | 0.8 | 16 | 16.5 |
| 6. | 1.0 | 17 | 17 |
| 7. | 1.2 | 18 | 17.5 |
| 8. | 1.4 | 18 | 18 |
| 9. | 1.6 | 18.5 | 18.5 |
| 10. | 1.8 | 19 | 19 |
| 11. | 2.0 | 19.5 | 19.5 |

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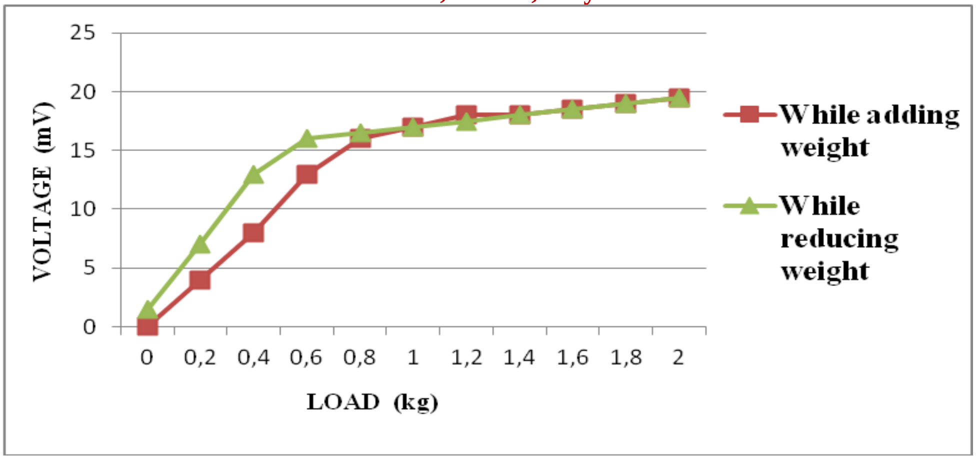
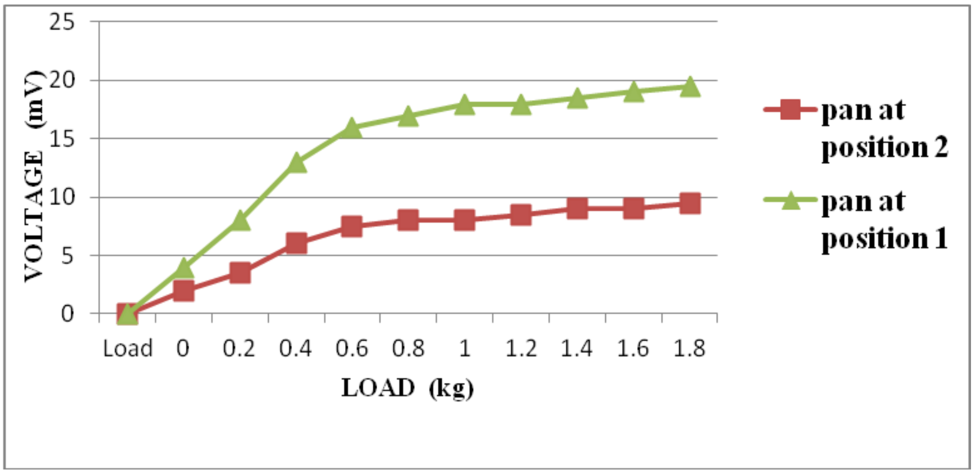



**Graph 1: Load v/s Voltage**

2. When the pan is located at position 2 on the lever

**Table II: Decreasing weights gradually**

| Sr. No | Load [Kg] | Digital Panel Indicator (Voltmeter) Reading | |
|---|---|---|---|
| | | (pan at position 2) [mV] | (pan at position 1) [mV] |
| 1. | 0 | 0 | 0 |
| 2. | 0.2 | 2 | 4 |
| 3. | 0.4 | 3.5 | 8 |
| 4. | 0.6 | 6 | 13 |
| 5. | 0.8 | 7.5 | 16 |
| 6. | 1.0 | 8 | 17 |
| 7. | 1.2 | 8 | 18 |
| 8. | 1.4 | 8.5 | 18 |
| 9. | 1.6 | 9 | 18.5 |
| 10. | 1.8 | 9 | 19 |
| 11. | 2.0 | 9.5 | 19.5 |




**Graph 2: Load v/s Voltage**

### 1. Calibration Factor (CF):

The digital panel indicator gives an output display on its screen in mill volts (mV). By calculating value of the calibration factor (CF), the digital panel indicator can be suitably calibrated to give an output display on its screen

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in torque (kg-cm). Thus it will be possible to read the value of the torque measured by the transducer directly from the screen of the digital panel indicator.
Slope of Graph 2 is calculated by MS excel.
Slope of curve when pan is at position 1 = 3.869047619 (for load range 0.6 – 2 kg)
Slope of curve when pan is at position 2 = 3.041666667 (for load range 0.4 – 2 kg)
Average (Avg.) Slope of both curves = 3.455357143. This value is considered as the calibration factor (CF)

**2. Multiplication Factor (MF):**

The multiplication factor is used to equate the calculated theoretical output voltage with the practical output voltage sensed by the strain gauges. The theoretical output voltage is calculated below [3,4].

1. Strain due to suspended load is given by (taking load = 1kg):

$$\varepsilon = \frac{6WL}{Ebh^2} \qquad \varepsilon = \frac{6\times1\times9.81\times0.60}{200\times10^3\times0.05\times6^2} \qquad \therefore \varepsilon = 9.81\times10^{-5}$$

2. Relative change in the resistance of the strain gauge from equation:

$$\frac{\Delta R}{R} = K.\varepsilon \qquad \frac{\Delta R}{R} = 2\times9.81\times10^{-5} \qquad \frac{\Delta R}{R} = 1.962\times10^{-4}$$

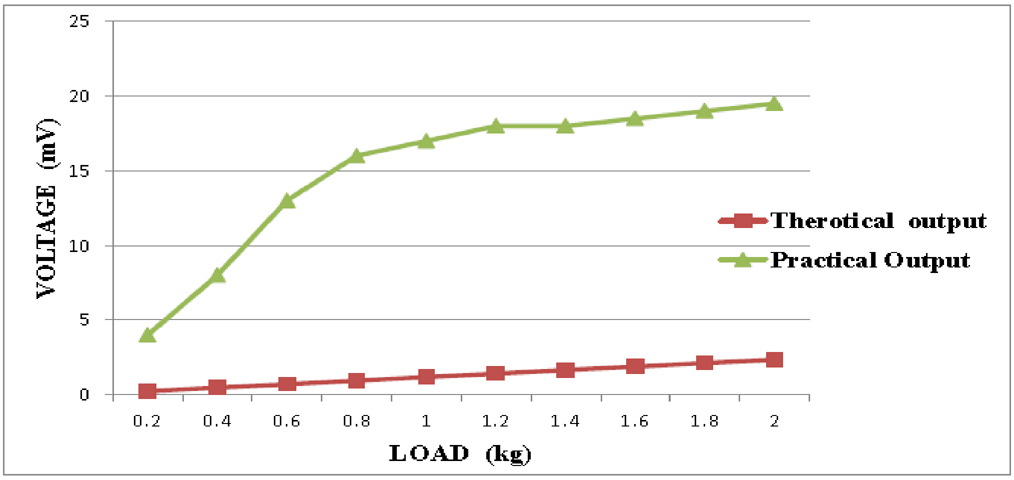
3. Output voltage from equation:

$$V_o = \frac{\Delta R}{R}.\frac{Vex}{2} \qquad V_o = 1.962\times10^{-4}\times\frac{12}{2} \qquad \therefore V_o = 1.772mV$$

The calculated values of theoretical output voltage for load range 0.2kg - 1kg are shown in Table III. The corresponding values of the practical output voltage for the same load range are also shown in Table III.

**Table III: Calculation of Multiplication Factor (MF)**

| Sr. No. | Load [Kg] | Output voltage | |
|---|---|---|---|
| | | Theoretically [mV] | Practically [mV] |
| 1. | 0.2 | 0.23544 | 4 |
| 2. | 0.4 | 0.47088 | 8 |
| 3. | 0.6 | 0.70632 | 13 |
| 4. | 0.8 | 0.94176 | 16 |
| 5. | 1.0 | 1.1772 | 17 |
| 6. | 1.2 | 1.412664 | 18 |
| 7. | 1.4 | 1.648 | 18 |
| 8. | 1.6 | 1.8832 | 18.5 |
| 9. | 1.8 | 2.1189 | 19 |
| 10. | 2.0 | 2.3544 | 19.5 |




**Graph 3: Theoretical v/s practical output voltage**

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From Graph 3, Multiplication factor (MF) as calculated by MS Excel = 9.498725

## V. COMPUTER AIDED ENGINEERING (CAE) ANALYSIS

Modeling of torque transducer is done using CATIA V5R20 and exported to ANSYS workbench14 software. Suitable boundary condition, constraints has been applied and procedure for FEA of Torque for TT has been adopted [5]. The figure 5 shows the mesh density of the torque transducer structure. Total number of element are 693 and number of node are 5846.

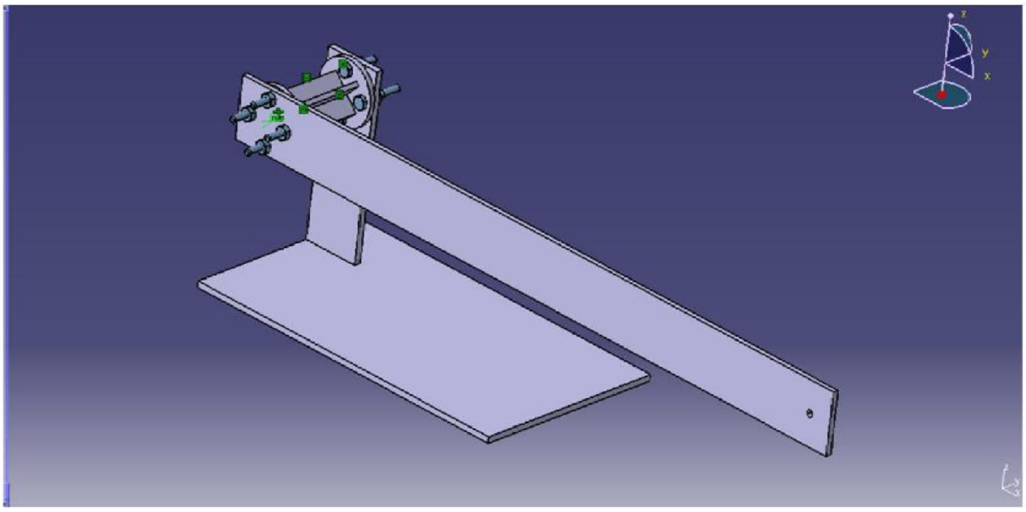

**Fig 4: Three dimensional model**

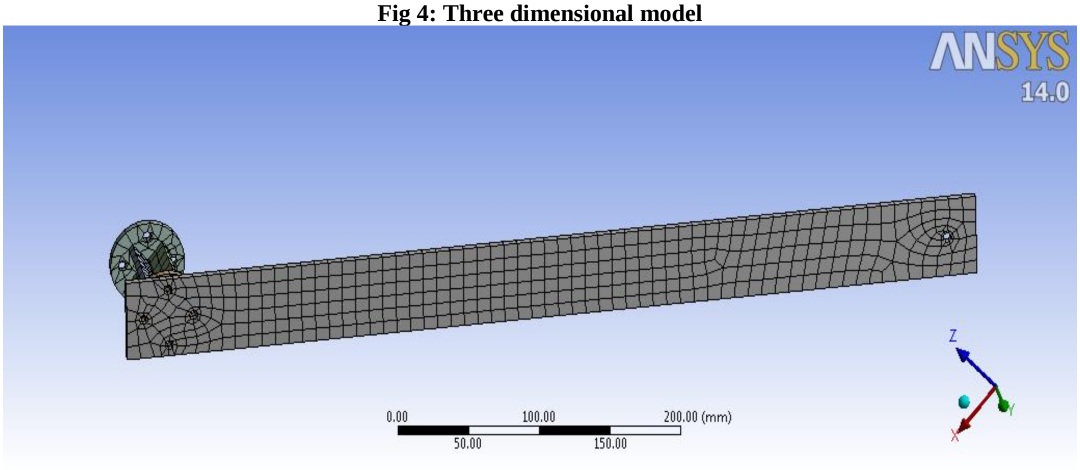


**Fig 5: Mesh density**

The equivalent elastic strain in the torque transducer structure is shown in figure 6.

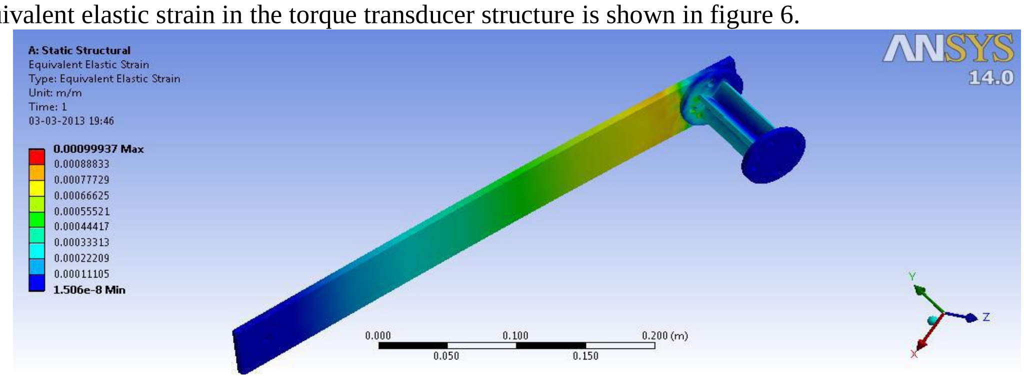


**Fig 6: Equivalent strain in the structure**

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## VI. CONCLUSION

1. The multiplication factor (MF) of the torque transducer is required to be calculated because the formula for calculating theoretical output voltage takes into consideration only the load (i.e. force) applied on the transducer shaft instead of torque which is actually being applied. Since torque is the product of load and distance, the distance at which the load is applied can be accounted for by using a suitable multiplication factor.
2. The calibration factor (CF) of the torque transducer is required to be calculated in order to enable the digital panel indicator to display the output value of the measured torque in kg-cm. The strain gauges sense strain caused by a change in their resistance in milli volts (mV) and therefore the default display on the digital panel indicator is mV. With the help of a suitable calibration factor, digital panel indicator will convert the measured mV value into its corresponding kg-cm value and display it on the screen.
3. Under ideal circumstances the display on the digital panel indicator should show the exact same reading for a particular input load while adding and while removing weights from the pan. However, from Graph 1, it can be seen that there is some difference (i.e. error is present) between the lines drawn while adding and removing weights and they are not purely coincidental. The reason for this error is due to the structural hysteresis of the transducer shaft material. Since the magnitude of the deformation only takes into consideration the maximum stress applied and is independent of frequency or time, a hysteresis error is generated. This error can be either systematic or random in nature.
4. The slopes of the Graph 2 are measured only from the 0.6kg load point onwards since slope of the graph from this load point onwards is relatively constant. On the contrary, there is a large difference in the slopes of the points between the load ranges 0 – 0.6kg. This reason for this difference is that at any given point a certain amount of residual stresses are always present in the transducer shaft material. When the input load to the transducer is small (i.e. in the range of 0 – 0.6kg) the residual stresses have a considerable influence on the strain (in mV) sensed by the strain gauges due to which the accuracy and resolution of the strain measured is poor. Thus for accurate results, readings are considered only from the 0.6kg load point onwards.
5. FEA is used to calculate induced strain due to applied load and it has been found that the results are in good agreement with theoretical values.

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