Design and Fabrication of low capacity Torque Transducer

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Abstract

The current work focuses on the development of a Torque Transducer capability of 10 Nm and analysis of it using FEA software ABQUS V.2018, it also focuses on identification of important parameters that impacts the stress values like mesh type and global seed size, values of stresses obtained using both analytically and computational are compared and parameters for which most conforming results are obtained is identified. Effect of mesh size and type has been thoroughly studied and it is analyzed what mesh type and what mesh size gives results most closer to analytical values. Using the same analysis it is found out at what point maximum stress, strain values occur on the surface, this helps in ascertaining the locations where strain gauges could be mounted on the sensing elements. For analysis purpose model is prepared using Autodesk Fusion 360 software and on that FEA is performed. Further the designed model has been fabricated using series of CNC machining operations After the fabrication is complete, strain gauges are mounted on previously identified location to measure the strain / stress values.

Keywords: Torque transducer, Strain gauges, Stress/ Strain, Finite element analysis, ABAQUS

1. Introduction

In recent decades, demand for more reliable torque measurement with low uncertainty has been expanded [1]. Torque is a force that twists a structure. Different from axial loads that produce a uniform, or mean stress on the cross section, torque creates a stress distribution over the cross section. Torque leads to development of angular acceleration. It is a vector quantity. The direction of the torque vector is given by right hand rule; it is given by the expression.

\[ T = F.r \]  

(1)

Shafts transmitting a torsional load that is torques are very common in engineering applications like a motor, generator, automobiles, aircrafts, agricultural machinery etc. Are some of the few examples of torque application, where shafts of different materials, shape and types are being used. Shafts of uniform circular cross section are commonly used in these applications and they most of the times carry pure torsional loads, torques. If a load is applied to an engine shaft which is fixed, it generates reaction torque on the shaft [2]. The two equal and opposite torques at the end of the shaft will deform it. Torque being an important physical quantity its calculation has always an important for various analyses. Torsion theory gives relationship between torque and other
related quantities and constant for cylindrical body and that equation is referred to as torsion equation. Torsion equation is given as,

\[ \frac{T}{I_p} = \frac{\tau}{r} = \frac{G\theta}{l} \]  

(2)

2. Design analysis of transducer

For a circular shaft which is rigidly clamped at one end and twisted from other end, relationship between various involved parameters is well established by torsion theory[3]. Torque transducer are generally made up of steel, which is suitable for most of the applications, other material that could be considered for fabrication of torque transducer is high strength Al alloy like Al7075, which is better suited for low strength transducers. Sensing element is of square cross section, on which strain gauges are mounted to sense the deformation produced [4]. It undergoes deformation under the influence of external torque that is with help of strain gauges mounted on it. Relationship between torque and shear stress for rectangular cross-section (according to St. Venant's theory) is given by following analytical expression based on which dimension cross-section is found out expression is:

\[ T = \frac{x^2 y^2 \tau}{3y + 1.8x} \]  

(3)

\( T \) = Torque applied, \( \tau \) = shear stress induced due to applied torque, \( x \) and \( y \) = length of sides of cross-section, for Square cross-section \( x = y \), so the equation becomes

\[ T = 0.208x^3 \tau \]  

(4)

For design of sensing element, it is required to find out the dimension of square cross-section, for \( T = 10 \) Nm and \( x = 0.009 \), \( \tau = 65.95 \) MPa.

3. Finite Element Analysis

3.1 CAD model
On the basis of calculations and suggested design following drawing of transducer was prepared in Autodesk 360 software using the same software CAD model of the drawing was prepared.

![Front View](image1)

![Top View](image2)

![CAD Model](image3)

After preparation of the CAD model, finite element analysis of the drawing was carried out using ABAQUS CAE and following results were obtained. On applying suitable boundary conditions and constraints and adopting standard procedure for FEM, different mesh types and mesh sizes were analyzed and following results were elaborated using it.

### 3.2 Tetrahedral mesh type

Shear stress distribution on sensing element under external torque of 10 Nm shows that maximum values of stress are obtained on middle region of each side of sensing element.

![Shear Stress for Tetrahedral Mesh](image4)

For tetrahedral mesh type, shear stress values for all the three considered mesh sizes i.e. 0.004, 0.002 and 0.001 are 70.73 MPa, 65.5 MPa, 68.18 MPa respectively which are suitable for safe design factor of safety being 2.

### 3.3 Hexagonal mesh type

Shear stress distribution for this mesh type follows the same pattern as tetrahedral mesh type i.e. it is maximum on middle region and decreases towards side, for same external torque value and global seed size of 0.004 shear stress values obtained were 27.2MPa.
For hexagonal mesh type shear stress values obtained using FEM analysis are not conforming with analytical results and as mesh is being refined, values tend to get closer to analytical results. Closest results were obtained for global seed size of 0.001 which was 55.76 MPa. On studying the FEA results obtained for the two considered mesh type that is tetrahedral and hexagonal, it was concluded that out of the two, tetrahedral mesh gives results closest to analytical result this is because of close packing factor of tetrahedral mesh type. Closest results were obtained for global seed size of 0.002 of tetrahedral mesh. Analytically found value is 65.25 MPa.

4. Strain gauge

A strain-sensitive material is the material whose resistance varies with instantaneous strain developed over its surface. They can be either metallic or can be a semiconductor. When a material such as this is stretched, length of it increases and thereby decreasing its cross-section which leads to an increase in its electrical resistance. Change in its resistance is measure of its strain values. Thus a strain gauge is an electrical unit which uses change in electrical resistance to measure strain. Strain gauge are utilized to measure strain on an object, it consist mechanical inputs like force, pressure, weight etc. into change in electrical resistance that could be measured. It is a sensor whose resistance changes with applied force strain gauge is widely used electrical measurement technique, for mechanical quantities. Strain can be tensile or compressive, thus strain gauge can be used to identify both expansion and contraction. Strain can be generated due to external load or stress in the body. Strain may be caused due to pressure, torque, heat, structural changes of the material. Under certain conditions by measuring the strain we can evaluate the quantity causing the strain. This is widely used for experimental stress analysis. It not only evaluates stress on the part but also predicts its safety and endurance. For shock or vibration instrumentation, resistance strain gauges may be used, it might be the active element in commercial or special purpose transducer.

On application of stress on metal conductor its resistance changes, as resistance is a function of length and cross-section area, resistance of conductor is also changed due to change in resistivity of the conductor, it is called as piezoresistive property so strain gauges are also known as piezoresistive gauges. On application of tensile force on metallic wire of length $l_1$ its length increases, if $l_2$ is the initial length of wire and $l_2$ final length of wire then strain is given by
equation 5,

\[ \varepsilon = \frac{L_2 - L_1}{L_1} \]  

Further its diameter decreases, since resistance of the conductor is inversely proportional to length, change in resistance due to change in length can be measured and calibrated, thus strain gauges is used to measure force and other parameters like displacement, stress etc. Relationship between input and output parameters is expressed by term gauge factor or gauge gradient, Gauge factor (GF) is defined by equation (6)

\[ GF = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{L}} \]  

Figure 4.1 strain gauge constructions  

Figure 4.2 final strain gauged transducer

For the wires of strain gauge to have sufficiently high electrical resistance (60-350 ohm) they need to be very thin, so it is difficult to handle, so in order to facilitate ease of handling it needs to be planted on a carrier medium like paper or plastic. Backing material is used to provide ease of handling, Required amount of lateral resistance is provided so that it could be shortened without buckling, both compressive and tensile stresses could be measured. Connection terminals are provided, a protective coating is applied over strain gauge.

For measuring the value of stress/strain developed on the sensing element strain sensor have been used. Position of fixing the sensors have been ascertained using Finite Element Analysis done earlier, for the purpose of fixing the sensor the surface should be dirt free and it should be fixed at an angle of 45° on the surface taken from horizontal surface. This is the point of maximum stress/strain concentration. It is important to properly do the curing of the model. The connections are made according to wheat-stone Bridge.

5. Results and discussion

Torque transducer of capacity 10 N-in has been designed using torque and shear stress relationship for square cross-section obtained from St. Venant’s investigation, Here dimensions
of the sensing element is $9 \times 9$ mm value of shear stress induced for 10 N·m has been found which is equal to 65.949 MPa. Computational results obtained though FEA have been found conforming with analytical values. Out of two different mesh types and three different global seed sizes used for analysis purpose the results for tetrahedral mesh and global seed size of 0.002 is found to be closest to analytical values. FEA analysis also helped in guiding out regions of maximum stress/strain on the sensing element. After the fabrication being done of the designed part using CNC machining processes, Strain gauges were required to be affixed at predetermined locations on the sides of sensing elements. These should be dirt free for affixing the strain gauges and suitable curing and post curing is carried out. Strain gauges are affixed in order to sense the values of stress or strain generated at points of maximum shear stress as shown by analysis on the ABAQUS.

Conclusion

Presented work dealt with design and development of torque transducer of capacity 10 Nm, finite element analysis was carried on using ABAQUS software and it was found out to be close to analytical results. After the finite element analysis of the model and ascertaining positions of maximum strain or stress, strain gauging was done on that position. Shear stress and strain values were found to be maximum at the centre of sides of the cross-section, where strain gauge needs to be fixed for measurement of strain values. Torque transducer being important for calibration of various torque measurement techniques, there is requirement of development of other torque transducers of nominal capacities. Presented work could be redesigned to prepare torque transducer of increased capacities moreover in the present work sensing element is of square cross-section this can be modified to circular parabolic or any irregular shape and similar analysis could be performed on it. Based upon the analysis new design could be fabricated and calibrated using standard calibration procedures. Metrological Characterization of the designed model needs to be done against standard torque machine.

Reference

[1] Kumar H., Kumar A., Gupta S. (2011), Design studies and testing of a torque transducer, Indian Journal of Pure & Applied Physics, pp. 653-656.
[2] Warnock F.V., Benham P. P. (1965), Mechanics of solids and strength of materials, Sir Isaac Pitmann, London.
[3] Diddens D., Reynaerts D., Brussel H.V. (1995), Design of a ring shaped three axis micro force / torque sensor, *Sen and Actu A*, pp. 225-232.
[4] Madni A. M., Hansen R. K., Vuong J. B. & Wells. R. F. (2005), A differential capacitive torque sensor (DCTS), *Proceedings of IEEE Sensors*, pp. 1286-1289.
[5] Zhang J., Chen G., Wang W., & Sun H. (2016), Design and application of strain brushless torque sensor, *Icamia*. pp. 1-5.
[6] Aghili F., Buehler M. & Hollerbach J. M. (2001), Design of a hollow hexaform torque sensor for robot joints, *International Journal of Robotics Research*, pp. 967-976.
[7] Hoehn. K., Olsson A., & Arkwright J. W. (2017), High Capacity Torque and Compression measurements using fibre optic sensors, *International conference of fibre – optic and photonic sensors for industrial and safety applications*, pp. 39-44.
[8] Kim I. M., Kim. H. S. & Song J. B. (2012), Design of joint torque sensor and joint structure of a robot arm to minimize crosstalk and torque ripple, *International conference*
on ubiquitous robots and ambient intelligence, pp. 404-407.

[9] Nazar M., Islam U., Cheng P., Oelinnann B. (2018), Torque sensor design considering thermal stability for harsh industrial environments, *International conference on sensing technology*, pp. 83-86.

[10] Sorli M., Pastorelli S. (1995), Six axis reticulated structure force / torque sensor with adaptable performances, *Mechatronics*, pp. 585-601.

[11] Hon Y., Zeng D., Yao J., Kang K. & Zhao Y. (2009), Optimal design of a hyperstatic stewart platform based force / torque sensor with genetic algorithms, *Mechatronics*, pp. 199-204.

[12] Zhiwen Y., Zhibin F., Weina H. (2015), Torque measuring device structural design and experimental analysis for drive shaft, *China Measurement &Test*, pp. 120-123.

[13] Jinquan H., Xiaoping W., Hui Y. (2015), Design of high-precision torque measurement system based on STM32, *Transducer and Microsystems Technologies*, pp. 99-101.

[14] Baolin Y., Ying Y., Zeitiing L., Sliiqhig G. (2011), Study on design principle of strain torque sensor, *Machinery Design & Manufacture*, pp. 13-15.

[15] Chunmei Z., Zhaoxia W., Xiaofeng H. (2009), Design and study of torque measurement system.” *Machinery Design & Manufacture*, pp 30-32.