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Finite Element Analysis of Ring Force Transducer

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Abstract. Ring shaped force transducer have been used for different industrial and metrological applications for about one century since inception at National Institute of Standards and Technology (formerly, National Bureau of Standards), USA. Though, earlier they have been equipped with deflection measuring device say, micrometre, dial gauge or vibrating reed as the case may be. With growing advancement, to limit the inherent shortcomings of analogue instruments, digitization has been done over the past decades. In this regard, few research reports have been published, but up to best of knowledge of the authors, realistic computational investigations are still missing. In past findings, there have been limitations either with coherence with experimental findings or limits of the software used for the investigations. In this regard, commercial software ANSYS has been used for complete ring shaped force transducer and a realistic procedure adopted in line with analytical method. The present study attempts to discuss the procedure and outcome of finite element analysis for a ring shaped force transducer for the material EN 24 with a nominal capacity of 50 kN. The paper discusses details of the approach adopted and salient outcomes. The paper further discusses the implications of the finite element analysis in design and development of the ring shaped force transducer.

Keywords: *Force transducer, finite element analysis, stress, strain, deflection, ANSYS*

1. Introduction

Planning and designing of engineering structures requires a lot of brainstorming and iterative arrangements for achieving desired results with precision. In the field of metrology, accuracy and precision are the most important parameters taken care of while designing instruments. Another parameter which affects the usage of an instrument is time lag. It is always desired that an instrument should give accurate and precise output in less time. For accommodating these requirements in the instrument, designing should be taken care of. Now-a-days, computational and statistical analysis is giving better ways in making different iterations in design parameters. It is easier now to create a simulated environment virtually and check the outputs using software. This study discusses for the application of the engineering analysis tool – finite element analysis using software for determining the output of ring shaped force transducer [1].

2. Ring Shaped Force Transducer

A ring shape force transducer is the simplest form of the mechanical type force transducer. Force transducers are basically used as transfer standards in industries. It has an elastic ring for sensing the applied force and a measuring device for measuring the force in terms of ring deformation [2]. Deflection type dial gauge and digital dial gauge have been used for measuring the force in this study. Figure 1 shows a brief layout of the ring shape force transducer. The compressive force is applied at the end bosses and the measuring device measures the deformation of the elastic ring.

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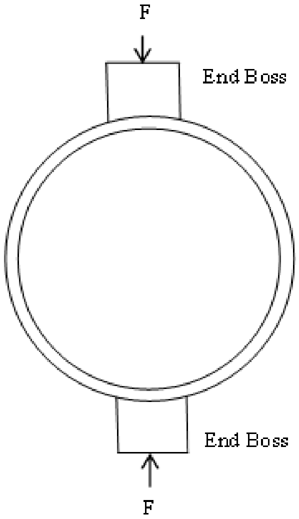

Figure 1. Ring Shape Force sensor

2.1 Design parameters

Table 1. Design parameters of force transducer

S. No.	Symbol and Unit	Parameter	Nominal Value
1	R_o (mm)	Outer Radius	95 mm
2	R_i (mm)	Inner Radius	80 mm
3	R (mm)	Mean Radius	87.5 mm
4	t (mm)	Thickness	15 mm
5	b (mm)	Width	50 mm
6	F (kN)	Force	50 kN
7	E (GPa)	Young's Modulus of Elasticity	210 GPa

2.2 Experiment

The experiment is performed on a dead weight force machine by applying specific forces to the circular ring shape force transducer. The measurement is recorded in terms of deflection of the ring using digital dial gauge. Pre – load test in compression is conducted first, to detect the output pattern at no load, full load and no load. Gradually, the force in compression is applied on the transducer and the deflection is recorded by the measuring instrument. The present paper discusses the behavior of EN 24 elastic ring transducer for 50kN load with following parameters: Ro= 95mm, Ri= 80mm, t= 15mm and b= 50mm. The results obtained so, have been summarized as given in table 2.

Table 2. Experimental Observations

Applied Force (kN)	Digital dial gauge readings (mm)
10	0.173
20	0.345
30	0.517
40	0.690
50	0.863

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3. Computational Analysis

3.1 Need of computational analysis

- Verification of experimental outputs can be matched by theoretical analysis for simple shaped structures. But in case of complex geometries, theoretical analysis is complicated and the output is greatly influenced by assumptions taken. Finite element is a numerical tool which gives the solution for studying complex geometries with required precision and repeatability [3, 4].
- Finite element study can be conducted for different iterations comprising of different designing parameters in virtual environment. It would help in arriving at a better position of desired and accurate output.
- Force transducers are considered as transfer standards in industries. The applied force is realized in terms of elastic ring deformation and locations of maximum stress/strain. Maximum the number of nodes on geometry, the better would be the analysis of the ring deformation and positions of maximum/minimum stress and strain.
- The effect of change of position of load application can easily be observed using software analysis.

3.2 FEM of 50kN ring transducer

The computational analysis of the ring force transducer is done using finite element analysis. The force has been primarily applied to the circular surface of the ring transducer. So, a three dimensional model of the circular ring has been designed using software ANSYS. The entire circular surface of the ring has been selected for finite element analysis. The suitable boundary conditions have been defined according to the analytical method. Number of nodes is selected as 39304 with 7943 meshing elements using mesh generation. Figure 2 shows a 3- dimensional CAD model of the elastic ring sensor with meshing.

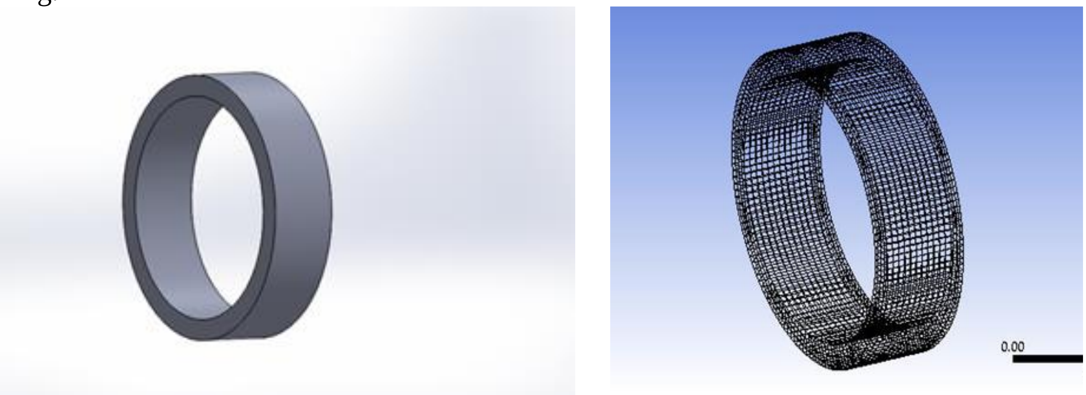

Figure 2.CAD modeling of elastic ring sensor with meshing

It is assumed that the material EN 24 is isotropic in nature. The force is applied in axial direction in compression mode. Suitable procedure for finite element analysis has been adopted and stress/strain and axial deflection has been assessed. Further, the outcomes of the finite element analysis have been summarized in the form of stress/ strain and axial deflection.

3.2.1 Stress

The axial compressive force is applied at the top and bottom portions of the ring shaped transducer. The applied force is considered as a point load for making finite element analysis. Figure 3 shows the stress and strain variation across the circular surface of the ring section. At the point of application of force, the stress is found to be of maximum value and it decreases upto a certain angle. Maximum stress point of 809.71 MPa is the point of application of axial force at an angle of 0° and the stress decreases upto 7.72 MPa at 45°. Further studying the stress pattern along the periphery of the transducer, it is found that the stress increases from 45° to 90° upto the magnitude of 480 MPa and again decreases from 90° to 135° with 7.72 MPa of magnitude. Hence, the change in stress along the full section of the transducer is cyclic in nature. Maximum stress points are at the angles of 0°, 180° and 360°. Similarly, minimum stress points are at the angles of 45°, 135°, 225°, and 315°.

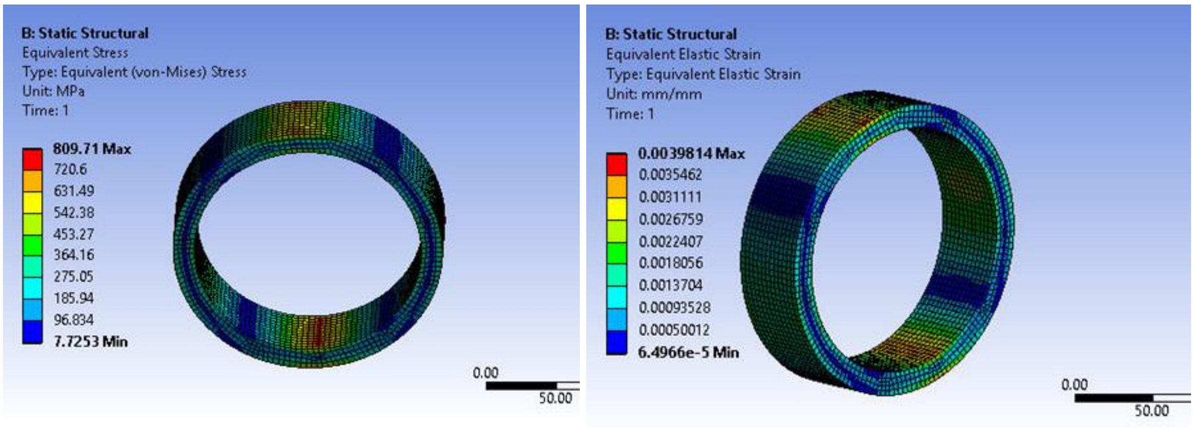

Figure 3. Stress and Strain variation in ring transducer (50kN)

3.2.2 Strain
Strain also varies in a similar fashion as of stress. Maximum strain of magnitude 0.00398 occurs at the point of application of axial force i.e., at 0°. The strain pattern repeats from maximum to minimum (4×10^{-3} to 6.5×10^{-5}) and minimum to maximum along the full section of the ring as shown in figure 3. Maximum stress & strain locations will help in finding suitable locations of sticking the strain gauges for measuring force by Wheatstone bridge while calibration [5].

3.2.3 Deflection
Figure 4 shows the axial deflection of the full ring section for the applied load of 50kN. The maximum deformation of the ring occurs at topmost point at 0°. The magnitude value of maximum and minimum deflection is 0.8952 mm and 0.30438 mm respectively.

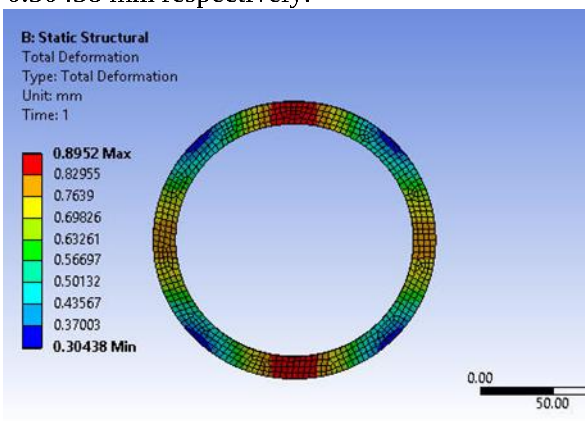

Figure 4. Ring Deflection

4. Conclusion
- Finite element analysis gives opportunity to access the output patterns using various possibilities. It is a beneficial tool for verifying the results obtained from experimental observations.

- Coherent results can be obtained from computational analysis as discussed in section 3.2.
- Optimum number of nodes generated in meshing element, greater would be the chances of getting precise and accurate results.
- The same force transducer can be judged for compressive as well as tensile load using FEM. It provides the opportunity to detect the behavior of the transducer under the altered load without actually performing the experiments.
- ANSYS is software that enables us to perform finite element analysis by generating mesh in ring structure. FEM can also be performed using ABACUS software but ABACUS does not provide generation of mesh elements in the structure.
- Measurement of force using strain gauges can be done by making Wheatstone bridge on the outer periphery of the elastic ring structure. FEM helps in finding the best suitable positions for sticking strain gauges thereby enhancing the sensitivity of the force transducer.
- The present work emphasizes on the development of simple shaped force transducers, as they are easy to operate in comparison with other recent technologies [6]. Strain gauge measurement using Wheatstone bridge is an accurate and low cost method for force measurement.
- Piezoelectric sensors is another technology used by many researchers in past [7, 8] for force measurement. But due to their high cost and susceptibility towards electrical signals (noise), they are not very suitable for applications like force transfer standards or calibration.

References

1. Libii, J N (2006), Design, analysis and testing of a force sensor for use in teaching and research, *World Transactions of Engineering and Technology Education*, vol 5, pp 175-178.
2. Kumar H., Sharma C and Kumar A (2012), Axial deflection analysis of a force transducer, *Sensor Letters*, vol 10, pp 742-747.
3. Cheng B, Wu X and Peng X (2007), Finite element analysis of ring strain sensor, *Sensors and Actuators A*, vol 139, pp 66-69.
4. Kumar H., Sharma C. and Kumar A. (2013), The development and characterization of a square ring shaped force transducer, *Measurement Science and Technology*, 24(9), p. 095007. doi: 10.1088/0957-0233/24/9/095007.
5. Karabay S. (2007), Design creiteia for electro-mechanical transducers and arrangement of strains due to metal cutting forces acting on dynamometers, *Materials and Design,* vol 28, pp 496-506.
6. Kumar, R., Rab, S., Pant, B., D. and Maji, S. (2018). Design, development and characterization of MEMS silicon diaphragm force sensor, Vaccum, 153, pp. 211- 216.
7. Safour, S. And Bernard, Y. (2017). Static force transducer based on resonant piezoelectric structure: root cause investigation, IOP Publishing - Smart Materials and Structures, 26(5), 10.1088/1361-665X/aa63da.
8. Liu, X., Mwangj, M., Li, X., J., Brien, M., O. and Whitesides, G., M. (2011). Paper-based piezoresistive MEMS sensors, Lab on a Chip, 11, 2189-96. 10.1039/c1lc20161a.