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Finite element analysis of a force transducer

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Abstract
Force transducer have been designed on the basis of theories of thin rings and design plays an important role in various applications like verification of material testing machines, monitoring force components in different cutting tools, agriculture related applications, hardness testing machines etc. Generally, some assumptions and approximations have been made for deriving analytical expressions for stress / strain analysis / deflection of force transducers. For more rigorous validation of analytical derived expressions, numerical methods need to be used. In the present study, a ring shaped force transducer, commonly used for force measurement, has been studied using finite element analysis. The study provides scope for the effect of nominal quantities over the design of ring shaped force transducers.

Keywords: Force transducer, finite element analysis, stress, strain, deflection.

Introduction

Force measurement has been playing a critical role in various applications by means of different types of force transducers like ring shaped force transducers, elliptical dynamometer, standardizing boxes, strain gauged load cells and sometimes tuning fork type force sensors. These force transducers have varying degree of accuracy and capacities depending upon design and applications intended for. Ring shaped force transducers are generally used due to ease of machining and simple in design considerations. It mainly consists of an elastic ring of steel alloy with a deflection measuring device (like dial gauge / micrometer/ vibrating reed), to measure the change in diameter of the ring. As the force is applied through the end bosses or shackles, the elastic ring gets deformed and the deflection is measured by the measuring device.

A force transducer is designed on the basis of certain assumptions to derive the analytical expressions for stress / strain / deflection for the ring shaped force transducer. A number of researchers have worked for the design studies and development of ring shaped force transducer and a number of analytical expressions have been developed for measurement of the stress / strain / deflection in past (O'Dogherty,1996; DuQuesnay, 2002; Josue Njock Libii,2004; Rehman & Rehman, 2007; Sedat Karabay, 2007a,b; Harish Kumar *et al.*, 2011; Sudhir Kumar *et al*., 2011). Some efforts have been made to develop analytical expression for stress / strain and deflection based on elastic theory and numerical methods to analyze the ring shaped force transducer, but their results have not been found in coherence with the experimental measurements (Bray, 1981). Recently, attempts have been made to design square ring shaped force transducers based on the finite element analysis (Madhuban Prasad *et al*., 2011).

The present study involves the studies of a ring shaped force transducer using finite element analysis to evaluate the stress / strain and deflection. The ring shaped force transducer has been idealized as a ring with rectangular cross section. The study leads to realize the role of finite element analysis in a systematic design procedure for the ring shaped force transducers. Suitable locations for fixing strain gauges have been suggested using finite element analysis. It may be used to study any other nominal quantity over the force transducer.

Finite element model and analysis

A three dimensional model of the force transducer, idealized as ring has been designed using software ABAQUS standard student edition 6.7. A quarter of the ring has been selected for finite element analysis due to symmetry. The suitable boundary conditions have been defined using the software. The material is assumed to be isotropic in nature and the analysis is of linear type. The dimensions of the force transducer includes inner radii 86 mm, outer radii 96 mm, thickness 10 mm and width 45 mm. The modulus of elasticity is 210 GPa and poission ratio 0.3 for EN 24 steel. Standard types of elements from the library have been selected and reduced integration approach has been used. The force is applied in compression mode. Suitable procedure for finite element analysis has been used and the stress / strain and deflections have been computed and plotted (Chen *et al*., 2007; Harish Kumar & Jain, 2009).

Table 1 Deflection of force transducer at different forces

F (kN)	Deflection (mm) Finite element analysis
4	0.354
8	0.708
12	1.062
16	1.416
20	1.770

Fig.1-3 illustrates the findings of finite element analysis of the ring shaped force transducer under the specific external force applied 20 kN. The finite element analysis has revealed the following results:

- Maximum stress occurs at the upper top point where the force is applied (force applied is concentrated force). From the point of axial force application along the periphery, the stress tends to decrease upto an angle of about 40^o (more precisely 39.6^o), where the stress is least and it starts to increase along the periphery for the rest of the quarter of the force transducer (Fig.1).

- The strain distribution for the quarter of the force transducer follows the similar trend like the stress distribution as in Fig.2.
- The deflection for the quarter of the force transducer when it is subjected to the axial compression forces is shown in Fig.3. The deflection is highest at the point of application of axial force, but tends to decrease along the periphery of the quarter and is almost negligible at the other end of the quarter (this end is considered fixed according to analytically derived expressions). The deflections for forces 4 kN, 8kN, 12kN, 16kN and 20 kN have been computed and summarized in Table 1.
- The finite element analysis has been done for only one quadrant, but as the ring has been symmetric to either axis, the rest of the three quarters may be considered for similar response.

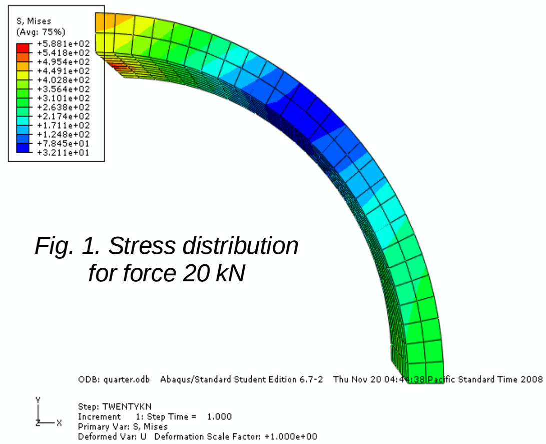

Fig. 1. Stress distribution for force 20 kN

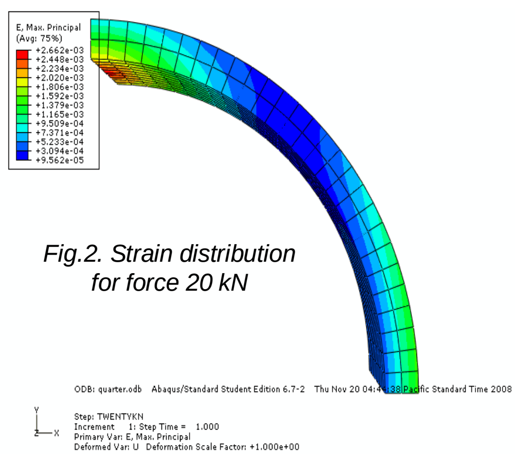

Fig.2. Strain distribution for force 20 kN

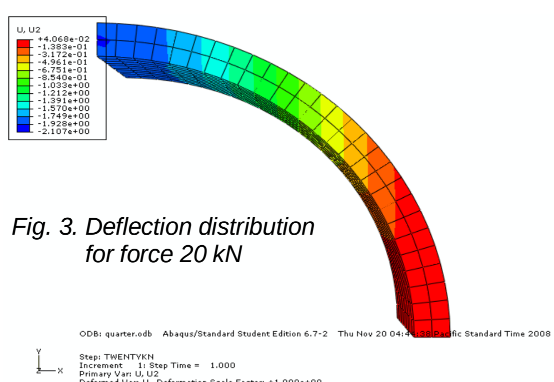

Fig. 3. Deflection distribution for force 20 kN

Conclusions

We report finite element analysis of the ring shaped force transducer. The findings have been focused on stress, strain and deflection plots / patterns. The stress -strain pattern guides the way for effective locations of strain gauges for developing the force transducer. It is found that at 90^o to the either axis, the stress - strain has moderate values and suitable places for locating the strain gauges. This study may now be used for determining the various dimensions of force transducer and studying the effect of various factors considered while designing the force transducers. The study can find use in improving the force transducers.

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