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Development and metrological characterization of a precision force transducer for static force measurement related applications

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ABSTRACT

The present paper discusses design and development of a force transducer of octagonal ring shape, which is a modified version of ring shaped force transducer. Nominal capacity of the force transducer designed and developed is 25 kN. This force transducer has been investigated for its utilization as force transfer standard for static force measurement and related applications. This force transducer is studied using dial gauge and strain gauges for its metrological characterization according to the calibration procedure based on standard ISO 376:2011/IS 4169:1988 (reaffirmed 2003) and is found to have good metrological results as compared to the existing ring shaped force transducers.

1. Introduction

Force transducers are used for force measurement since many decades and serve as force transfer standards. Force transducers may be of different types such as ring or elliptical shaped, strain gauged type and tuning fork type [1,2]. Ring shaped force transducers are commonly used due to ease of manufacturing and a variety of experiments have also demonstrated the utility of ring shaped force transducers in various fields. In addition, ring shaped force transducers have ability to separate the normal and tangential components of force [3].

A number of researchers carried out computational studies on ring shaped force transducers and introduced some substantial modifications for specified applications [4]. Efforts have been made to develop extended octagonal ring shaped force transducers as well as octagonal ring shaped force transducers, but those were limited to particular studies like tillage studies and measurement of cutting forces in different machining processes such as milling, turning, and drilling [5,6]. Up to best of the knowledge of authors, no documented record was found about the employment of octagonal ring shaped force transducers for precision static force measurement related applications. Tuning fork type force transducers have been developed recently and reported to have better uncertainty, but they have been developed for very low force capacity i.e. 50 N [7]. Their suitability for force measurement in higher capacity (say kN, MN), is yet to be investigated.

The strain gauged force transducers employ strain gauges arranged in from of Wheatstone bridge and their output is recorded through suitable digital indicators. Some commercial force transducers (manufactured by different manufacturers like GTM – Germany, Interface Inc. – USA, HBM – Germany, Sushma Industries – India, etc.) for force measurement are also available with improved

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Nomenclature

b	width of the cross section of ring (mm)
t	thickness of cross section of ring (mm)
D_o	outer diameter (mm)
D_i	inner diameter (mm)
R_o	outer radius (mm)
R_i	inner radius (mm)
R	mean radius (mm)
F	applied force (N)
E	Young's modulus of elasticity (N/m^2)
δ	axial deflection of the ring (mm)
e	strain
σ	stress (N/mm^2)
ε	strain (mm/mm)
I	moment of inertia (mm^4)
k	coverage factor
w^2	variance
rep	relative deviation due to repeatability (%)
rpr	relative deviation due to reproducibility (%)
res	relative deviation due to resolution (%)
zer	relative deviation due to zero offset (%)
rev	relative deviation due to reversibility (%)
w_{rep}	relative uncertainty contribution due to repeatability (%)
w_{int}	relative uncertainty contribution due to interpolation (%)
w_{zer}	relative uncertainty contribution due to zero offset (%)
w_{rev}	relative uncertainty contribution due to reversibility (%)
w_{rpr}	relative uncertainty contribution due to reproducibility (%)
w_{res}	relative uncertainty contribution due to resolution (%)
$w_{c(\mathrm{tra})}$	relative uncertainty of measurement (%)
W_{tra}	expanded uncertainty of measurement (%) at coverage factor, $k = 2$
bmc	best measurement capability (BMC) of force standard/calibration machine (%)
W	overall uncertainty of measurement of the force transducer (%) at coverage factor, $k = 2$

uncertainty of measurement (as low as 0.025%). These force transducers are of very complex shape. Machining of complex elements and their strain gauging is very difficult task. These force transducers are very difficult to analyze on the basis of conventional theories, which is a critical barrier to the development of such force transducers at laboratory level. Hence for development of force transducers at laboratory level, there is need to emphasis over force transducers which has simple shape and can be analyzed by conventional theories. The present investigation aims to demonstrate the force transducers with simple design and manufacturing considerations to serve as force transfer standards. The force transducers, which may be used through a wide range of force measurement with uncertainty of measurement better than 0.05% ($k = 2$) and serve as force transfer standards is the major concern here.

The present paper discusses development of octagonal ring shaped force transducer as a modified ring shaped force transducer. Its metrological performance is analyzed as per ISO 376:2011 and IS 4169:1988 (reaffirmed 2003). Extended octagonal ring shaped force transducers have been demonstrated earlier also, but they were not used for static force measurement and related applications. Here, an octagonal ring shaped force transducer is designed and developed for a nominal capacity of 25 kN and is computationally studied using finite element analysis. The uncertainty of force measurement for this force transducer is better than 0.10% ($k = 2$) using dial gauge and 0.05% ($k = 2$) using strain gauge for 40–100% of the nominal capacity.

2. Analytical and computational investigations

Ring shaped force transducers have been suitably modified and converted into extended octagonal ring shaped force transducers by researchers and suitable analytical expressions have been developed and validated by experimental observations (Fig. 1). The advanced expressions were obtained by modifying the expressions available previously for stress–strain and axial deflection, while using ring shaped force transducer [5,6].

$$\delta = \frac{FR^3}{Ebt^3} \tag{1}$$

$$\sigma = \frac{1.09\,FR}{bt^2} \tag{2}$$

$$\varepsilon = \frac{1.09\,FR}{Ebt^2} \tag{3}$$

where

$$R = \frac{R_i + R_o}{2}$$

The expressions discussed above hold good for extended octagonal ring shaped force transducers (bending effect is neglected) and a number of researchers have used them for development of force transducers for various applications. These force transducers could not be used for static force measurement and thus they could also not serve as force transfer standard to establish traceability of force measurement from force standard machines to

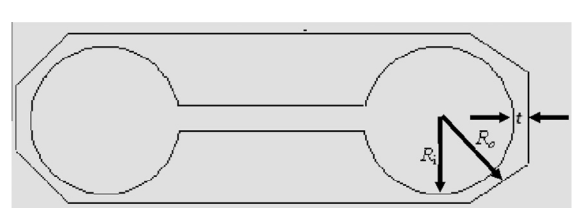

Fig. 1. A typical extended octagonal ring shaped force transducer [6].