Alexandria Engineering Journal (2015) 54, 155–162

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Performance analysis of octal rings as mechanical force transducers

Essam Soliman [1]

Department of Mechanical Engineering, Salman AbdulAziz University, Saudi Arabia

Received 23 August 2014; revised 15 January 2015; accepted 18 January 2015
Available online 12 February 2015

KEYWORDS

Octal rings;
Strain gauge;
Average strain;
Sensitivity;
Stiffness;
Force transducer

Abstract The present work analyzes the characteristics of octal rings as mechanical force transducers. It uses a finite element model of the ring to determine its state of strain upon the application of load. It also correlates ring design parameters and performance measures, using an L_9 orthogonal array of finite element simulations. Design parameters include height, thickness, width, and edge curvature. Performance measures include sensitivity and stiffness. Model simulation results showed a considerable variation in strain along ring face with a considerable difference in the maximum values of the tensile and compressive strains. They, also, revealed a region of a large tensile strain within the ring not addressed in the literature. Moreover, simulation results showed that increasing ring height and decreasing its thickness increases its sensitivity and decreases its stiffness. The width of the ring does not have clear effect of stiffness. However, increasing width decreases sensitivity. Ring edge radius has no significant effect on sensitivity while increasing the edge radius decreases stiffness. A developed relation between strain gauge length and average strain revealed an optimal gauge length that improves ring performance.

1. Introduction

Mechanical force measurement has a wide range of applications. They include weighing systems, material testing, and performance evaluation of equipment. In addition, mechanical force measurement is essential for performance improvement and optimization of machining processes, tool breakage detection and chatter control. Moreover, prediction of chip loading and accuracy of machined surface rely on mechanical force measurement.

Mechanical forces are measured indirectly using two main techniques; in the first one, the force acts on a piezoelectric crystal that accumulates charge proportional to the magnitude of the force. A charge amplifier, then, converts charge to volt. In general, piezoelectric sensors are very sensitive to mechanical forces and have wide bandwidth, over 50 kHz. They are available in different configurations and sensitivities. In addition, charge amplifiers are available in wide range of configuration and characteristics. However, they are expensive, delicate and require a considerable attention when used within the harsh machining environment. They are susceptible to

[1] On leave, from Department of Production Engineering, Faculty of Engineering, Alexandria University.

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.01.004
1110-0168 © 2015 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V.

noise from nearby electrical drives. Therefore, the present work will not consider piezoelectric sensors.

In the second technique, the force acts on an elastic mechanical member. The strain and deflection of the member are proportional to force. A common mechanical member for force measurement is octal ring. A strain gauge converts strain in the strain ring into equivalent volt using a bridge. Octal rings are easy to manufacture to the required size. Strain gauges are relatively inexpensive and are available in a wide range of configurations and characteristics. In addition, bridges, in particular Wheatstone bridge, are easy to operate and maintain. Therefore, octal rings with strain gauges are the candidate for sensing mechanical forces in the present work.

2. Previous research

A considerable amount of research work focused on analyzing performance characteristics of octal rings. The purpose was to use them as force transducers for constructing force dynamometers. Korencke and Hull [1] developed empirical formulae to describe strain, stress and deflection in octal rings. They used ANSYS finite element model and a nonlinear regression model to develop the equations. The developed equations provided close results to experimental data compared to equations available from thin ring theory. However, validity of equations was limited to range of ring thickness and width.

Kim and Kim [2] developed a combined type tool dynamometer for an ultra-precise lathe. They used strain gauges to measure the static force and a piezo-electric film accelerometer to measure the dynamic force. They pointed out that signal conditioning and processing are essential for improving accuracy of force measurement.

Seker et al. [3] used a bending beam type dynamometer to measure machining force for the shaping process. Even though the authors designed the dynamometer, they did not give enough details of its construction. They gave the general characteristics of the load cell used. They focused on the measured force data rather than on the design of the dynamometer. They used cutting force data to correlate cutting parameters, including depth of cut and feedrate, to process performance measures including surface roughness of work part and tool life.

Korkot and Karabay [4,5] used octal strain rings to design milling and drilling dynamometers. They used approximate equations to estimate strain and stiffness in octal rings. They claimed that the dynamometers could measure cutting force with ± 5 N sensitivity and 0.05% or less cross-sensitivity. They presented no information regarding strain gauge type or dimensions. In addition, they did not show clearly the procedure for recording and processing signals from the dynamometers.

Yaldiz and Unsacar [6,7] designed a three-component force dynamometer for the measurement of cutting force in turning. They, also, used octal rings as sensing element and used approximate equations from the thin ring theory to design the rings. The range of the measured force was 3500 N. Sensitivity was ± 5 N and cross-sensitivity was 0.17–0.92%. Length of strain gauge was 6 mm, about 30% of the length of the octal ring face, which was 16.6 mm.

Chen et al. [8] used extended octal rings and strain gauges to design a dynamometer for a tractor drawbar. They used finite element analysis to determine points of maximum strain and fixed strain gauges at these points to get maximum possible sensitively of the dynamometer. However, they did not consider strain distribution around points of maximum strain.

Karabay [9–11] used strain gauges with different forms of octal strain rings to design force dynamometers for the drilling and milling processes. They used equations from the thin ring theory for the design of the rings. No attention was given to strain distribution along the area where strain gauges were fixed. They used calibration to correlate signal from a strain gauge bridge and cutting forces.

Yalidz et al. [12] used octal rings and strain gauges to design a force dynamometer for the milling process. They determined the dynamic characteristics of the dynamometer using the impact test. They showed that the natural frequencies of the dynamometer were low. The only extra feature in their design was using large number of strain gauges to increase dynamometer sensitively.

This work considers octal rings as sensing element for measuring mechanical force. The aim of the work was to investigate strain distribution along the different faces and regions of the ring, with the purpose of deciding on the best area on the ring to adhere strain gauges to end up with maximum possible sensitivity to mechanical force. In addition, this work, considers the correlation between design parameters of the ring and its performance measures.

3. Geometric model

In order to study the state of strain of octal rings, a 3D geometrical model of a ring was constructed using the Solid Edge Software package. Fig. 1 shows the model. The basic design parameters are height, H, width, W, thickness, T, and edge radius R. Other parameters such as face length, L_s and inner hole diameter, D, are derived from the basic design parameters. Then, the finite element method was applied to the model using the same software package. Tetrahedral finite elements were used for the finite element model as shown in Fig. 1. The material of the ring was selected to be Aluminum 1060 with 68.947 GPa modulus of elasticity, 0.33 Poisson ratio, 27.579 MPa yield stress and 68.948 MPa ultimate tensile strength. Fig. 1, also, shows faces and regions of interest where maximum strains or maximum deformations are expected to take place.

A concentrated force, F_z, is applied normal to the face Cu_{out}, in the negative z-direction. The concentrated force represents the worst loading condition of the ring considering deflection and ring stiffness. The magnitude of the force is selected to be $F_z = 100$ N. Such selection ensures no plastic deformation takes place within the ring for the range of design parameters used for the present work and given in the next section. The model considers a ring rigidly fixed at its bottom surface. This simulates a ring welded to its base. The method of fixation of the ring affects mainly state of strain around the fixation region. However, interest is in strains at faces and regions away from ring bottom. In addition, the applied force tends to fix the bottom face of the ring to its base. Therefore, this work does not give the method of fixation a considerable attention.

Upon application of the load and simulating the model, strains of all surface finite elements of the ring were available. Strains at the elements within the aforementioned faces and regions of interest were recorded manually using a strain pick