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DESIGN AND DEVELOPMENT OF A DYNAMOMETER FOR MEASURING THRUST AND TORQUE IN DRILLING APPLICATION

SREEJITH C[1],MANU RAJ K R[2]
[1]PG Scholar, M.Tech Machine Design, Nehru College of Engineering and Research Centre (NCERC), Trissur, India
[2]Asst.prof.,Department of Automobile engineering, Nehru College of Engineering and Research Centre (NCERC), Trissur, India

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ABSTRACT

In this work, a strain gauge based dynamometer has been designed and constructed using octagonal ring sensing elements for measuring thrust force and torque during drilling operations. Elastic theory of thin circular ring has been studied in detail to analyze the advantages of octagonal ring transducers over circular rings. The position of strain gauges on the octagonal ring sensing element and the ring dimensions are determined by calculating elastic stresses on various faces of octagonal ring. The designed dynamometer was then analyzed in ANSYS to check whether the maximum applied load and torque within safe limit.Vertical and torsional natural frequencies are determined and analysed considerably in detail to confirm rigidity of dynamometer during drilling operation. After having completed the construction of it, the dynamometer was calibrated for thrust force and torque. The performance testing of the dynamometer was done by conducting linearity and eccentricity test. Complete construction drawings of the dynamometer were also presented in this work

Keywords— Cutting forces; Drilling; Dynamometer; Octagonal ring; Drill force measurement; Strain gage; Wheatstone bridge; Calibration; Natural frequency of dynamometer.

I. INTRODUCTION

Metal cutting plays an important role in manufacturing processes and is used widely in industries like automotive, aerospace and household items etc. The basic geometries of machine tools are similar to some extent but functionality of these machine tools can be improved by incorporating pneumatic, hydraulic, numerical control, computer numerical control and simulation systems. Machine tools should be designed and constructed in such a way that it should be effective for the cutting operation .while designing the machine tool the force analysis should be done to check whether it can work without deformation. Also during metal cutting operation, the cutting forces should not deform the cutting tools and tool holders. The moving parts of the machine tool should be protected against wear for a long machine tool service life. In order to prevent tool breakage due to excess cutting forces, mechanical properties of the cutting tool should be known clearly and care should be taken to prevent the breakage of machine tool and ultimately it should be prevented.

In metal cutting applications Knowledge of stresses is important as they play vital role in the design of machine tools, cutting tools and fixtures.

Therefore, many studies are still happening in the field of metal cutting operation for the detailed investigation of elastic stresses. The various parameters such as generation of heat, and thus tool wear, quality of machined surface and accuracy of the work piece have a direct influence on the cutting forces generated during metal cutting. Theoretical cutting force calculations failed to produce accurate results Due to the complex tool configurations/cutting conditions of metal cutting operations and some unknown factors and stresses. Therefore, cutting forces should be measured experimentally to avoid errors in a large extent. This is the reason why many dynamometers have been designed and developed for various cutting operations. Elastic deformation of the materials is the base for the measurement in these dynamometers.

Various studies concerning dynamometer design and construction can be found in the published Refs.

This project outlines the design and development of an octagonal ring strain gauge-based drilling dynamometer. This dynamometer is capable of measuring thrust force and torque during drilling operation with minimum of errors.

II. DESIGN AND DEVELOPMENT

A.DESIGN OF SENSING ELEMENT OF THE DYNAMOMETER

In this work octagonal rings were used as sensing elements. Strain ring has proven to be very useful device in measurement cutting force or torque during machining operations. Strain rings provide a high ratio of sensitivity to stiffness and it also have adequate stability against buckling. Since the inside faces of octagonal ring are always in an opposite state of strain from the outside faces allows four active arms to be effectively used in Wheatstone bridge circuit. The ring provides heat flow in parallel paths and hence it is to be expected that equivalent points on opposite sides of a ring will be at the same temperature. The formulas for finding strains, deflections and stiffness of octagonal ring, which are derived by Lowen and Cook, are used in this work for the design calculations.

B.SELECTION OF OCTAGONAL RING MATERIAL

Rigidity, High natural frequency, Corrosion resistance, High heat conductivity, and elastic properties conform to that of strain gauges were the factors taken into account when selecting the ring materials. AISI 1040 steel, which meets the above requirements, was so selected as the ring material. The physical properties of this material are given in Table 1.

TABLE 1 Properties of Ring Material AISI 1040 Steel

Tensile strength	550-570 N/mm^2
Yield strength	280 N/mm^2
Permissible stress	186.66 N/mm^2
Modulus of elasticity	210000 N/mm^2
Poisson ratio	0.3
Carbon content	0.35-0.44%
Brinell hardness	172 HB

C.DETERMINATION OF OCTAGONAL RING DIMENSIONS

The three basic controllable parameters that affect the rigidity and sensitivity of the octagonal ring are: thickness t, radius r and width b. Since there is no effect width of octagonal ring b and young's modulus of the ring material E on the strain per unit deflection of the octagonal ring, $b_{minimum}$ can be taken as 20mm to set up the rings securely. As per ring theory it is proven that the octagonal ring is substantially stiffer than the circular ring when ratio between ring thickness and ring radius (t/r) equals 0.25 or less. In order to be consistent with this expression, the octagonal ring thickness t and octagonal ring radius r were taken as 4mm and 16mm respectively. Thus the rate of t/r = 4/16 = 0.250 provides corresponding sensitivity to stiffness ratio ε/ (δ/r) for octagonal ring.

D.VERIFICATION OF THE DIMENSIONS OF OCTAGONAL RING

In designing of the octagonal rings, maximum thrust force T_V and drill torque M_d exerted by drill to the dynamometer were assumed as 10,000 N and 100 N-m, respectively. Taking in to account dimensions, Stress on the octagonal ring due to thrust force and torque are calculated to be 109.38 N/mm^2 and 29.17 N/mm^2 respectively. As AISI 1040 steel was used for manufacturing the octagonal ring and its yield strength is 280 N/mm^2, the calculated stress values occurring on the octagonal rings are within the safety limit for this material. The verified dimensions of octagonal rings are summarised in table 2.

TABLE 2 Dimensions of Octagonal Ring

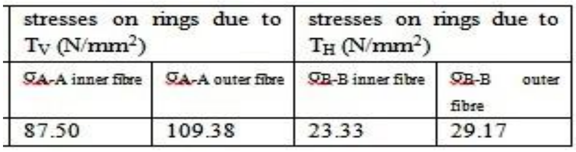
Design thrust T_V (N)	Design torque M_d (Nm)	Ring Thickness t (mm)	Breadth of ring b (mm)	Ring Diameter D (mm)
2500	25	4	20	32

E.ELASTIC PROPERTIES OF OCTAGONAL RING

The elastic properties of octagonal ring should be determined in order to select suitable strain gauge to measure the strains caused by thrust force and torque during drilling operation. The maximum possible elongation of the octagonal should be lower than the allowable elongation limits of the strain gauges in order to sense the signal effectively.

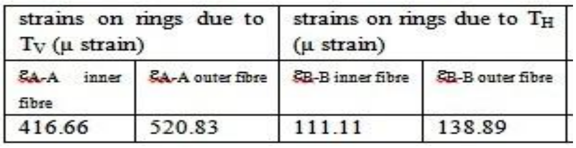
The important elastic properties computed using octagonal ring theory are summarised in table 3.

TABLE 3 Computed Stresses on the Octagonal Ring for Axes A-A and B-B Due to Drill Thrust Force T_H and Drill Torque M_d



stresses on rings due to T_V (N/mm²)		stresses on rings due to T_H (N/mm²)	
σA-A inner fibre	σA-A outer fibre	σB-B inner fibre	σB-B outer fibre
87.50	109.38	23.33	29.17

TABLE 4 Elastic Strains on the Octagonal Ring for Axes A-A and B-B Due to Drill Thrust Force T_H and Drill Torque M_d



strains on rings due to T_V (μ strain)		strains on rings due to T_H (μ strain)	
εA-A inner fibre	εA-A outer fibre	εB-B inner fibre	εB-B outer fibre
416.66	520.83	111.11	138.89

F.DYNAMIC PROPERTIES OF DYNAMOMETER

All machine tools operate with some vibrations. The amplitude of vibrations will be large in certain cutting operations. In order that the recorded force not be influenced by any vibrating motion of the dynamometer, its natural frequency must be large compared to the exciting vibration frequency. The natural frequency of dynamometer should be at least four times the vibration frequency of the machine tool.

(a) Determination of Vertical Natural Frequency

The simplified vibration model of drilling dynamometer system in vertical direction can be taken into consideration as in Fig.1 for determining natural frequency. Equation of the motion of the model is defined in (1)

$$m_s y^n + k_e y = 0 \qquad (1)$$

The various parameters for determining vertical natural frequency such as plate constant, effective stiffness, circular natural frequency etc. are calculated and natural frequency is found to be 688.88 Hz. The values of parameters are given in table 5.

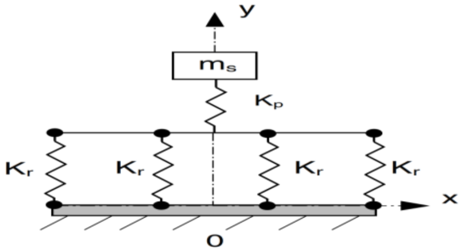


Fig.1.Vertical Vibration Model of the Dynamometer.

TABLE 5 Values of the Parameters Required for Vertical Natural Frequency and Computed Value of f_n

Parameters	Unit	Computed data
K_r	N/m	25605852.77
K_p	N/m	171847810.10
K_e	N/m	64174574.43
Z	Nm	19230.77
m_s	Kg	9.173
m_p	Kg	2.54
m_{cd}	Kg	5
m_{wp}	Kg	4
ω_0	Rad/sec	31587.46
Q	Kg/m²	63.5
λ		0.068
f_n	Hz	688.88

(b) Determination of Rotational Natural Frequency

Torsional vibration behavior of the octagonal ring type dynamometer can be expressed as given in (2)

$$J_{0T}\theta'' + 3K_t e^2 \theta = 0 \qquad (2)$$

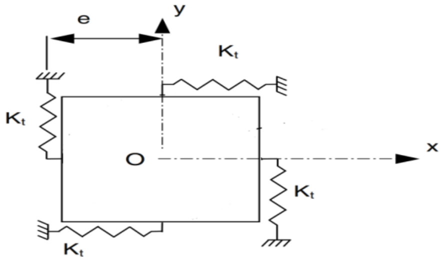
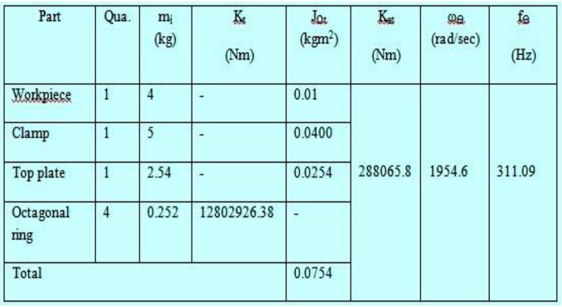


Fig. 2. Torsional Vibration Model of the Dynamometer.

The values of the parameters required for determining torsional natural frequency have been tabulated in Table 6.Under nominal working condition, spindle of the machine is run at 370 and 1150 rpm and excitation frequency of the machine is around 6 and 19 Hz. respectively. Natural frequency of the dynamometer is higher than excitation frequency of the machine tool. so, the dynamometer can be run without facing any resonance vibrations.

TABLE 6 Values of the Parameters Required for Torsional Natural Frequency and Computed Value of f_n



Part	Qua.	m_i (kg)	K_t (Nm)	J_{Ot} (kgm^2)	K_{et} (Nm)	ω_n (rad/sec)	f_n (Hz)
Workpiece	1	4	-	0.01	288065.8	1954.6	311.09
Clamp	1	5	-	0.0400			
Top plate	1	2.54	-	0.0254			
Octagonal ring	4	0.252	12802926.38	-			
Total				0.0754			

G.FINITE ELEMENT ANALYSIS OF THE DYNAMOMETER

Finite element analysis is an important stage in the design of the drilling dynamometer in order to assure the results obtained from theories using an analyzing software package. Here in this project ANSYS is used for the finite element analysis of the dynamometer.

The maximum designed thrust force and torque values are verified by applying these values on the designed dynamometer and analyzing whether the induced stress is within safe limits. The result of analysis is shown in fig.3. The result of this analysis shows that the designed load and torque are within safe limit.

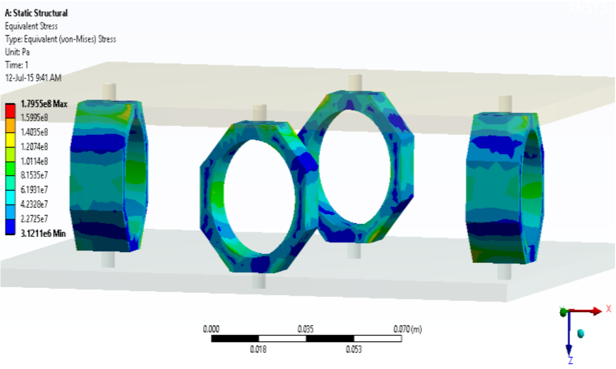


Fig.3. Equivalent Stress Diagram.

H.ORIENTATION OF STRAIN GAUGES AND THE RINGS ON THE DYNAMOMETER

The proper selection of the points where the strain gauges are mounted is essential for achieving high accuracy in the Wheatstone bridge circuits. The octagonal rings are located on the points of the circle at 0^0, 90^0, 180^0 and 270^0 on the base plate. An upper plate is fixed to the rings to carry work piece and to transmit thrust force equally to the main elastic members of the dynamometer. Ring arrangement and wiring diagrams are given in Fig.5 and 6, respectively.

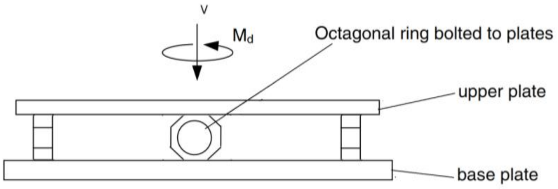


Fig.4. Front View of Drill Press Dynamometer

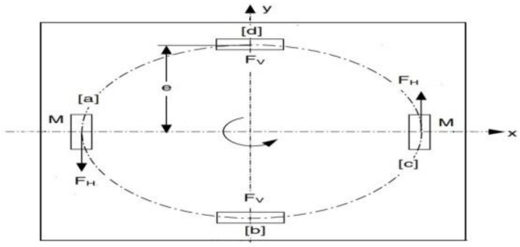


Fig.5. Arrangement of the Octagonal Rings.

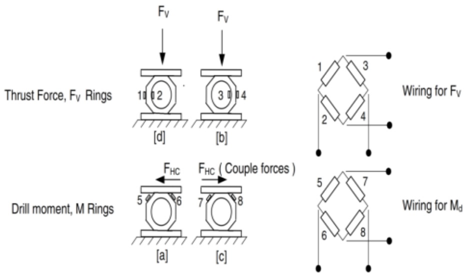


Fig.6. Wheatstone bridge Design of Thrust Force and Torque .

I. ELECTRONIC CIRCUIT DIAGRAM FOR DYNAMOMETER

In this work two Wheatstone bridge circuits are using, one is for thrust force measurement and other is for torque during drilling operation. If four active arms are used in one bridge, the bridge output becomes four times greater than the single arm bridge. Also, full bridge circuit is fully compensated for any change in resistance due to temperature.

The strain gauges used have 5% elongation limit on a 6mm length.so the maximum allowed elongation should be less than 6×5%=0.3mm.Thus the obtained possible elongation value 0.096mm is lower than 0.3mm allowable elongation limit and so the strain gauge used can effectively work with octagonal ring. The electrical circuit of the dynamometer was designed as shown in fig.7.

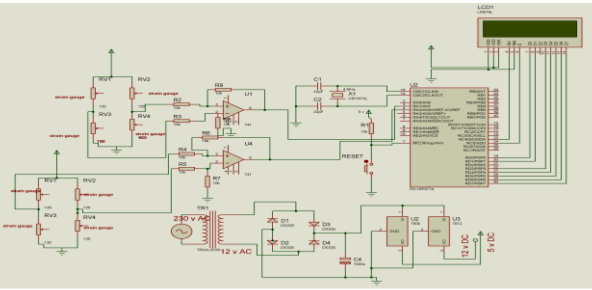


Fig.7. Electrical Circuit of the Dynamometer

J. DYNAMOMETER CALIBRATION

In order to determine the elastic deflection of ring components and consequently the output voltage under static load, the dynamometer was calibrated. The calibration was made both for thrust force and torque. The output voltages of millivolt were averaged for each direction. The calibration curves were obtained to convert the output voltage reading in to cutting force and torque values. For calibration, the calculation used in 'Tool engineering and design by M C Shah' was used. The calibration curves are shown in fig. (15) and (16).

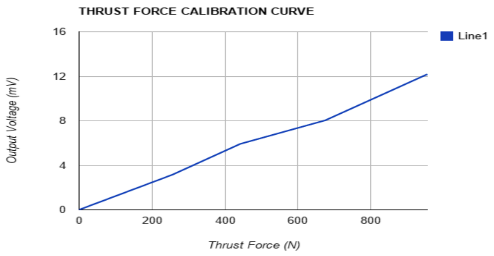


Fig.15. Thrust Force Calibration Curve

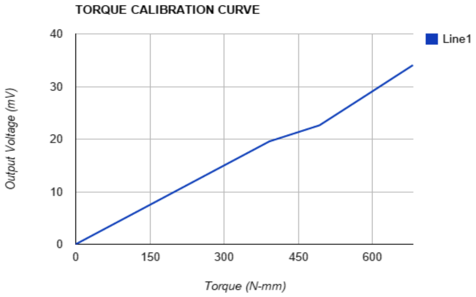


Fig.16. Torque Calibration Curve

III RESULT AND DISCUSSION

The linearity and eccentricity test were conducted for testing the performance of dynamometer. The percentage errors for linearity test were calculated as 1.3% and 1.2% respectively. In order to test the dependence of outputs of gauges affected by application point of drill, the force was applied to the dynamometer at centre and at an eccentricity of 50mm distance from calibration point. The percentage of output errors were found as 0.18 and 0.13. These errors seem to be acceptable for the drilling dynamometer that will be used in intermittent cutting operations.

REFERENCE

[1]. Ihsan Korkut, "a dynamometer design and its construction for milling operation" International journal for machine tool and design, 2003, published by science direct

[2]. Suleyman Yaldız, Faruk Unsacar ,"design development and testing of a four-component drilling dynamometer for the measurement of cutting force and torque" International journal for machine tool and design,2006, published by science direct

[3]. Muhammad Rizal, Jaharah A Ghani," Development and testing of an integrated rotating dynamometer on tool holder for milling process" International journal for machine tool and design,2013, published by science direct

[4]. Rahul Joshi, Pradeep Kumar Patil "Design and Development of Load Cell Base Tool Dynamometer to Measure Twisting Moment and Drill Forces of Twist Drill using Visual Basic" International journal for machine tool and design,2007, published by science direct

[5]. Maury L.Hull, Richard Brewer, and David Hawkins "A New Force Plate Design Incorporating Octagonal Strain Rings" journal of applied biomechanics, 1995.