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Research Article

DESIGN, DEVELOPMENT AND TESTING OF A FOUR COMPONENT MILLING TOOL DYNAMOMETER

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ABSTRACT
Knowledge of cutting forces is essential in metal cutting applications as they are used in the design of machine tools, cutting tools and fixtures. The cutting forces generated during metal cutting have a direct influence on the generation of heat and thus tool wear, quality of machined surface and accuracy of the work piece. Due to the complex tool geometry and cutting conditions of metal cutting and some unknown factors and stresses, analytical cutting force calculations may not give the accurate results and hence the experimental measurement of cutting forces is essential. For this purpose the 4 component milling dynamometer is designed, developed and tested to measure the three cutting forces and torque during milling operation as a part of M.E. dissertation work.

Key Words*- Cutting Forces, Torque, Milling, Dynamometer*

INTRODUCTION
Metal removal occupies the first and most important section of production of mechanical items. The process of metal removal has been a subject of research of many scientist and engineers. For over 100 years, metal cutting researchers have investigated the forces in metal cutting. As progress has been made in the machine tool field, parallel progress has characterized the development of cutting force-measuring systems. The cutting forces developed in machining operations may be estimated indirectly by obtaining the power consumed or directly from metal cutting dynamometers; mechanical, hydraulic, and pneumatic or several types of electro-mechanical dynamometers. Owing to the complexity of the metal cutting process, theoretical calculation of the forces activated when removing of the chip from a work piece should match with the results recorded by means of very sensitive electro-mechanic force measuring devices. Therefore the accuracy of the empirical equations used to estimate cutting forces should be confirmed by the experiments. Knowledge of cutting forces is essential to machine tool builders in calculating power requirements and frame rigidity. At the design of tool that have sufficient strength capable to remove chip at the desired quantity from the work piece and to calculate power of tool driver system, quantity from the work piece and to calculate power of tool driver system, cutting forces acting on the tool must be measured. In a very competitive market, it is also necessary that tool condition should be monitored continuously to increase cutting efficiency and total quality and decrease machine maintenance time.

Design of the dynamometer

The criterions for dynamometer design
While designing a dynamometer, due considerations need to be given to following requirement, for its satisfactory working, accuracy & consistency of force measurements.

1. Sensitivity of transducing device
2. Rigidity of component of dynamometer
3. Accuracy of force measurement
4. Linearity of calculation
5. Minimum cross sensitivity
6. Frequency of the dynamometer to be much higher a operating frequency

7. Sliding component to be minimum
8. Minimum environmental effect
9. Compacting unit of a dynamometer unit
10. Simplified instrument design

The rigidity and sensitivity are two opposing but basic requirements in dynamometer design. In addition, the structure of the dynamometer has to meet more strict requirements concerning the natural frequency and wide frequency response and small cross-sensitivity. The ring elements must be machined identical and symmetrical to prevent cross-sensitivity and they should have certain surface quality and high measurement tolerance. The mechanical properties of strain rings must be determined experimentally.
A dynamometer essentially consists of an important ring element. The rigidity, high natural frequency, corrosion resistance and high heat conductivity factors were taken into consideration while selecting the ring materials. Also, deformation under the load should conform to that of strain gauges.
In this project, AISI 4140 steel, which meets the above requirements, was selected as the ring material. The dimensions for the ring element are width (b) = 30 mm; radius (r) = 32 mm; thickness (t) = 8 mm.

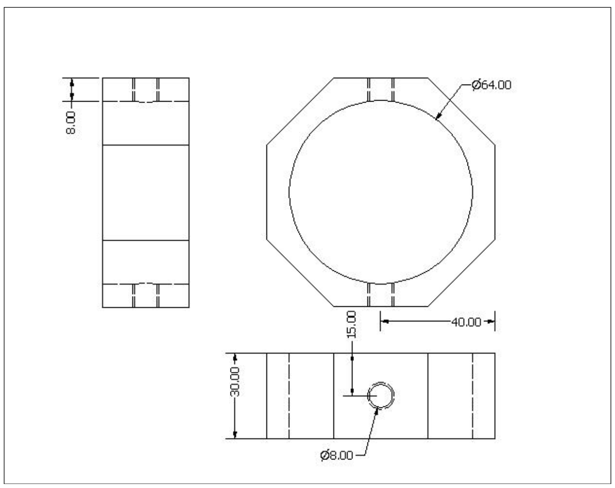

Figure 1: Octagonal ring

Experimental set up-
1) Machine Tool- Vertical Milling Machine at Rajendra Mane college of Engineering & Technology workshop.
2) Dynamometer- The dynamometer designed is a three force components and one torque component analogue type capable of measuring cutting forces during milling operations. A computer interface is made for data acquisition. The schematic representation of the cutting force measurement system, capable of measuring feed force (F_f), Thrust force (F_t), and the main cutting force (F_c) that occurs during milling operations is shown in the figure. The dynamometer consists of four elastic octagonal rings on which strain gauges have been mounted and necessary connections provided to form measuring the Wheatstone bridges.
3) Data Logger- On-line and real-time information of the cutting force data are automatically read and stored by a system during metal cutting. Since the output from the Wheatstone bridge circuit is very low due to the high stiffness requirement of the dynamometer, the analogue signals coming from dynamometer amplified by the strain gauge input modules are then converted into digital signals and captured by the data logger system. The stored data can be retrieved and used for analysis when required.

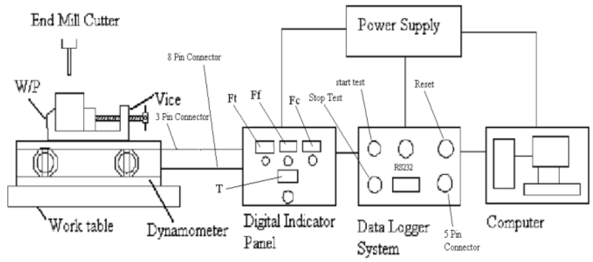

Fig.2 Schematic Diagram of experimental set up

Orientation of the strain gauges on the ring elements

The thrust force F_t are supported by A–D rings of the dynamometer as shown in Fig. 5.2. The strain gauges 3, 4, 7, 8, 11, 12, 15 and 16 are affected by the thrust force F_t. Among these strain gauges, 3, 7, 11 and 15 are subject to tensile stress while 4, 8, 12 and 16 are subject to compressive stress.

The feed force F_f is supported by A and C rings of the dynamometer as shown in Fig. 5.2. The strain gauges to measure the feed force F_f should be mounted on the outer surfaces of A and C rings with 45° inclination angle. As shown in Fig. 5.2, the strain gauges 1, 2, 5 and 6 are affected by the feed force F_f. Among these strain gauges, 1 and 5 are subject to tensile stress while 2 and 6 are subject to compressive stress.

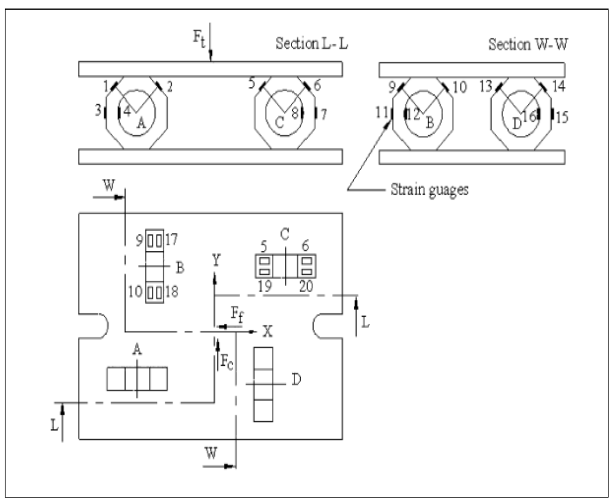

Fig.3 Schematic diagram showing location of strain gauges and orientation of octagonal rings

The main cutting force F_c is supported by B and D rings as seen in Fig. 5.2. The strain gauges for measuring the main cutting force F_c are mounted on rings B and D with 45° inclination angle with respect to the vertical plane. As shown in Fig. 5.2, the strain gauges 9, 10, 13 and 14 are affected by the main cutting force F_c.

The strain gauges 17 and 18 mounted on to ring B, 19 and 20 mounted on to ring C, as seen in Fig. 5.2, are for the torque. These strain gauges are mounted onto the outer surfaces of rings with 45° inclination angle. The reason for using the separate strain gauges on the same location for the torque is to prevent any interference of Wheatstone bridge signals in real-time operation dedicated for force and torque. So, the signals of strain gauges 17–20 are used to form the Wheatstone bridge to be used for torque in operations like drilling, tapping, etc.

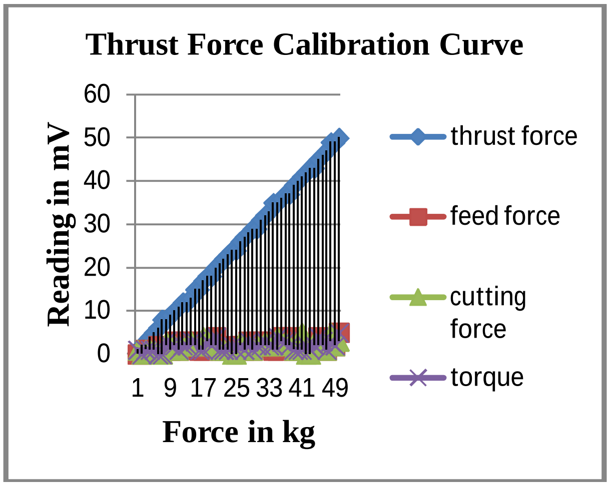

Fig.4 Calibration of thrust force

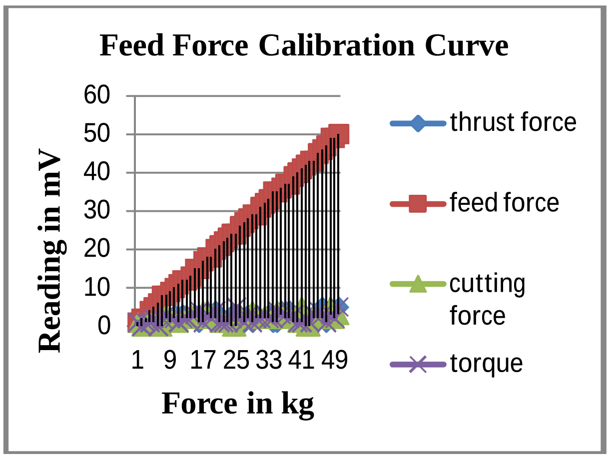

Fig.5 Calibration of Feed force

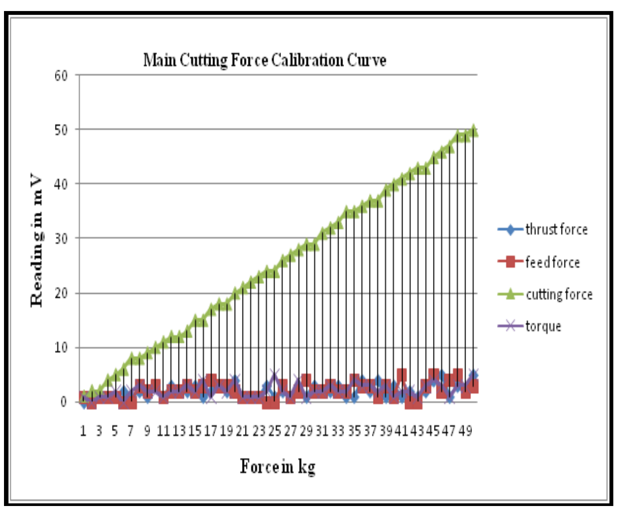

Fig.6 Calibration of Cross Feed (Main Cutting) force

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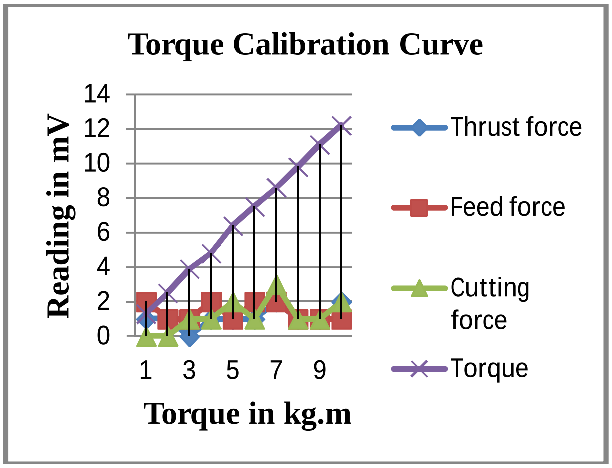

Fig.7 Calibration of Torque

PROJECT REPORT - R. V. DANDAGE

Machine Model : 4C-MTD Machine Sr No. : Ni

File Name : 06012010_7.txt

Sr.No.	Time (sec)	Thrust	Feed	Cross Feed	Torque
1	0.3	32	50	2	2
2	0.6	25	42	5	1
3	0.9	21	45	7	-2
4	1.2	24	62	-1	7
5	1.5	21	53	6	2
6	1.8	23	45	4	1
7	2.1	14	48	2	2
8	2.4	33	48	5	-3
9	2.6	23	62	1	4
10	2.9	32	45	7	2
11	3.2	18	48	6	1
12	3.5	38	53	5	1
13	3.8	20	56	3	0
14	4.1	20	78	4	-2
15	4.4	34	56	-4	7
16	4.7	29	50	6	5
17	5	18	62	5	0
18	5.3	35	50	5	3
19	5.6	18	53	8	-4
20	5.9	22	64	1	3
21	6.2	32	53	3	3
22	6.5	18	48	5	-1
23	6.8	30	50	8	1
24	7.1	26	45	1	0
25	7.4	33	62	2	-2
26	7.6	24	25	3	4
27	7.9	31	48	5	2
28	8.2	9	36	0	2
29	8.5	27	45	5	3
30	8.8	21	62	5	2
31	9.1	23	42	1	6
32	9.4	26	34	3	2
33	9.7	5	64	4	5
34	10	23	45	5	1
35	10.3	13	53	4	4
36	10.6	18	50	3	-2
37	10.9	34	42	5	8
38	11.2	24	39	8	-3
39	11.5	17	31	4	2
40	11.8	37	39	6	2

Fig.8 Sample testing report generated

Testing of the Dynamometer-

The developed milling tool dynamometer was tested for the following tests.

Linearity Test- During calibration, the loads were applied in each direction gradually one at a time and observed that the dynamometer shows linear variation in the strain developed. The calibration curve for each component shows the linear behavior of the dynamometer.

Cross sensitivity Test- During calibration, it was observed that the effect of other components on the loaded component is minimal. The calibration curve for each component shows the effect of cross sensitivity on each component. It has been observed that the cross sensitivity is around 10 to 15 %.

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