Design, Development and Testing of a Three Component Lathe Tool Dynamometer Using Resistance Strain Gauges

Rahul Jain, J.K. Rathore and V.K. Gorana

Abstract In this paper, a lathe tool dynamometer that can evaluate fixed cutting forces by using level of resistance stress gauges has been designed and developed. These stress gauges insured to the cylindrical bar. The alignment of the cylindrical bar and stress gauge places has been identified to increase sensitivity and reduce cross-sensitivity. The designed dynamometer is capable of computing the forces acting on the workpiece in turning operation using any data acquisition system. The sensing system measures the deflection in stress gauges, and these signals are modified into other quantity and computed in the form of forces on the display system as well as on PC also. Tests finished at different machining factors revealed that the dynamometer could be utilized continually to evaluate cutting forces.

Keywords Cutting forces · Dynamometer · Resistance strain gauge · Turning

1 Introduction

The metal cutting process (Jain and Chitale 2010) defined as removing a layer of metal from the blank to get a product of quantified shape and size with identified precision and surface finish. The cutting process was carried out on metal cutting machine tools with the help of metal cutting tools.

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The rise in responsiveness vis-à-vis the requirement to optimize manufacturing process (Milfelner et al. 2005) efficacy has directed to an excessive deal of investigation directed at machine tool condition monitoring. One of the primary difficulties that live in testing metal-forming force reductions was a great spread in the measures (Astakhov and Shvets 2001) of the physical pressure force(s). One of the unique purposes in manufacturing is the smart machining arrangement (Kuljanic and Sortino 2005), so for designing of such intelligent system for lathe tool dynamometer for turning process this literature have studied in which these process of machining included like turning (Panzera et al. 2012; Totis and Sortino 2011; Yaldiz et al. 2007), orthogonal cutting (Kim and Kim 1997), drilling (Korkut 2003), grinding (Korkut 2003), milling (Korkut 2003; Seker et al. 2002) and shaping (Seker et al. 2004; Yaldiz and Unsacar 2006) was the major investigation area of the researcher. Various type of assemblies like octagonal rings assembly with strain gauge (Korkut 2003; Yaldiz and Unsacar 2006; Yaldiz et al. 2007), Kistler dynamometer (Kim and Kim 1997), load cells on the tool post (Seker et al. 2002; 2004), piezoelectric force ring integrated into a commercial tool shank6 and square cross-section bar with strain gauge (Panzera et al. 2012) has used by several researchers for their research work but there is no such literature found for design and develop a cylindrical bar assembly for mounting using resistance strain gauge.

2 Literature Review

Machining of metal comprises driving of cutting tool from end to end the excess material of the workpiece and the process factors in tool cutting (Astakhov and Shvets 2001). This information provides the chance for a fast determination of the cutting speed resultant to the highest possible produced area of workpiece before the selected wear restrict obtained, reducing with straight line movement (Seker et al. 2002) allows us to assess the impact of tool life and surface area roughness of the workpiece.

2.1 Cutting Force Measurement

Research on the contrivance of flaw development was first carried away by French scientist Tresca, as far back as 1873. However, fundamental theories have been developed only during the past three or four decades. The compression of the chip, however, was recognized correctly by Tresca. Tresca wrote that the material of workpiece started to flow over the tool face in an upward direction, shearing along an oblique plane as the planner tool advances. Many other earlier scientists were interested in the problem of the shearing of metals undercut; among them were Thime in 1877, Hauser in 1892 and others. However, they did not arrive at any significant conclusion. After so many years, Merchant (1945) and others had developed the fundamentals in the field of metal cutting. Merchant (1945) castoff an intellectual thought of chip formation, for which an exact geometry might be reserved as the base for various readings of the mechanism of metal cutting. That was for the cutting forces created in the development of steel cutting have a continuous effect on the heat creation, and therefore tool wear, worth formed area and precision of the workpiece. Outstanding and innovative device arrangements/cutting configurations of metal cutting procedures and roughly unidentified issues and pressures, risk in cutting force computations failed in producing accurate results. Subsequently, the investigational statistic of the reducing causes changes out to be inevitable. On behalf of this objective, various dynamometers have been designed. In these dynamometers, cutting force measurement is mostly depending on flexible deformation (Korkut 2003; Panzera et al. 2012; Yaldiz and Unsacar 2006; Yaldiz et al. 2007) of the components. Determination of cutting force(s) depending on three key philosophies:

(1) Measurement of flexible deflection of a body exposed to the cutting force.
(2) Measurement of flexible deformation, i.e. stress caused by the force.
(3) Measurement of stress designed in a method by the force.

The kind of the transducer relies on how that deflection, stress or strain recognized and quantified. Literature shows that there was no research work found on cutting force measurement by using under category measurement of the flexible deformation of the cylindrical bar using resistance strain gauge. So in this paper we will discuss the design and fabrication of this type of dynamometer assembly for turning process. Each functional module discussed in detail, materials and method used, strain gauge classification, and testing discussed in more information.

3 Design and Building of a Resistance Strain Gauge Based Dynamometer for Lathe

3.1 Fundamental Design Requirement for Dynamometer

For reliably exact and consistent measurement, the resulting rations which were considered in previous literatures (Korkut 2003; Panzera et al. 2012; Yaldiz and Unsacar 2006; Yaldiz et al. 2007) in design and creation of tool dynamometers are as:

- Sensitivity: The dynamometer should be reasonably delicate for flawlessness measurement.
- Hardness: The dynamometer need to be quite firm to hold up against the causes without resulting in much deflection which may impact the machining situation.
- Cross understanding the dynamometer should be totally exempt from combination understanding such that one force (say P_z) does not impact statistic of the other forces (say P_y and P_x).

- Steadiness in contradiction moisture and heat range.
- Rapid time reaction.

A high-frequency reaction such that the observations were not suffering from vibrations within a rationally great variety of regularity consistency, i.e. the dynamometer should perform desirably over an longer timeframe.

3.2 Design Standards and Material of Dynamometer

Sensitivity, hardness, flexibility, precision, relaxed correction, budget and stability in the cutting environment carried in the account for developing the dynamometer. Dimensions, shape and subject material of dynamometer were deliberated to be useful aspects on powerful qualities of the dynamometer. A dynamometer mainly involves of a major cylindrical section. The hardness, high natural regularity, deterioration level of resistance and great temperature conductivity aspects were reserved into deliberation while choosing the cylindrical materials. Also, deformation within the fill should comply with that of stress gauges (Tlusty and Andrews 1983).

In this study, AISI 4140 metal, which satisfies above requirements, was chosen as the cylindrical content. The qualities of this content are given in Table 1.

3.3 Determination of Measurements of the Cylindrical Bar

Probably the simplest method measuring unidirectional force is to use some bar in tension and compression. For maximum sensitivity strain gauge may be arranged as shown and connected to form a Wheatstone bridge. It is clear that gauges 1 and 4 will measure axial strain while the circumferential strain caused by origins effect will be measured by gauges 2 and 3. The strain in the gauges will be,

$$e_1 = e_4 = \frac{F}{AE}$$

$$e_2 = e_3 = -\frac{vF}{AE}$$

where, F is the axial force, A is the cross-sectional area, E is the Young modulus of elasticity and v is the Poisson's ratio. Subscripts 1, 2, 3, 4 refer to the gauges.

By using the concepts of design for maximum force and strain as used in the previous studies (Korkut 2003; Yaldiz and Unsacar 2006; Yaldiz et al. 2007) the dimension of the cylindrical bar has been determined. So below Fig. 1 shows the

Table 1 Properties of AISI 4140 steel

Strength	Elasticity	Poisson ratio	Hardness
550–900 N/mm^2	210000 N/mm^2	0.3	217 HB

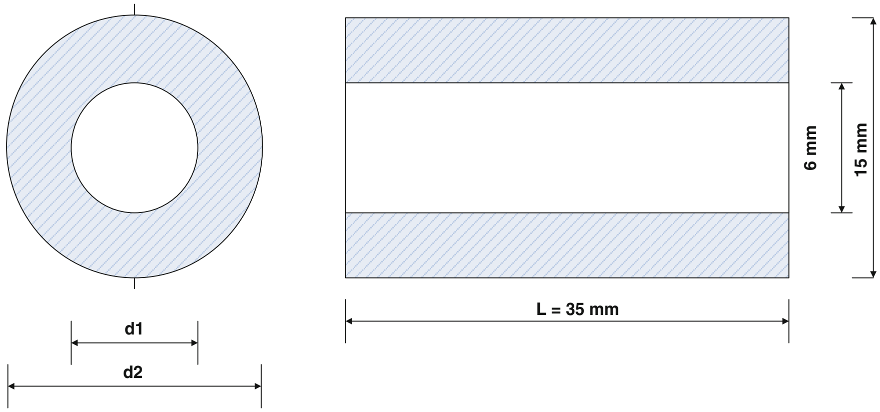

Fig. 1 Cylindrical bar with dimensions

designed specifications for the cylindrical hollow bar with inner and outer diameter of 6 and 15 mm along with length of 35 mm.

4 Materials and Method

A lathe tool dynamometer was a multi-component dynamometer that castoff to evaluate forces in the employment of the machine tool. Trial forecasts of these causes can be cross-checked and verified experimentally using these machine tool dynamometers. With a progression of technology, machine tool dynamometers have progressively used for precise statistic of forces and optimization of the machining process. These multi-component forces are approximated as an individual element force in individually coordinate, based on the organize system used. The forces through machining are reliant on the depth of cut, feed rate, cutting speed, device content and geometry, the content of the workpiece. Other aspects such as the use of lubrication/chilling during machining also impact machining considerably. The graphic interpretation of the cutting force measurement prearrangement presented in Fig. 2.

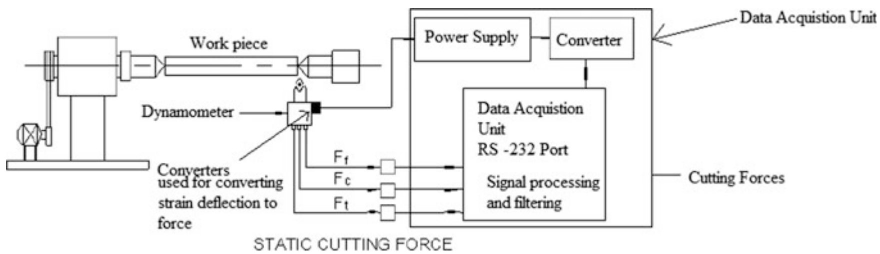

Fig. 2 Schematic diagram of measurement system

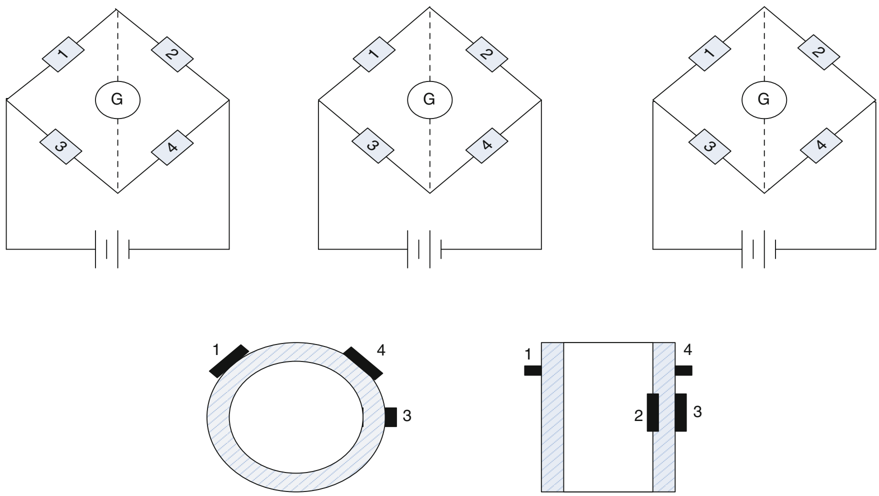

Fig. 3 Manufactured cylindrical dynamometer bar and there placing in Wheatstone bridge

4.1 Dynamometer

The designed and developed dynamometer is accomplished of computing main cutting force (F_c), feed force (F_f) and radial or thrust force (F_t). Figure 3 provides the Wheatstone bridge acquaintances for F_c, F_t, and F_f forces.

4.2 Data Acquisition

Real-time data of the cutting force information is instantly read and deposited in an arrangement in the course of metal cutting. As the yield of Wheatstone bridge circuits is minute due to the high rigidity needs of the dynamometer. The analogue dynamometer elevated by stress gauge feedback segments (Microcontroller AT89C52) are then transformed to digital signals and taken by RS-232 information acquisition card set up in MS-Windows based PC.

4.3 Estimating Various Parameters Related to Strain Gauges

After the considerations of various studies about parameters and application of the different type of strain gauges and principles. Wheatstone bridge for measuring forces that strain gauge to be used (to posted on bar) have following characteristics:

- Input Voltage: For excitation of the strain gauges minimum voltage required usually according to the TML standards 10–20 V is necessary.
- Resistance of Strain Gauges: Resistance of the strain according to the machining required is 350 Ω.
- Gauge Factor: For the resistance type strain gauge of 350 Ω the gauge factor is 2.13 ± 1 %.
- Bridge: The full bridge operation can be used. By using gauges as entirely four supports of the Wheatstone bridge, is a rational addition of the half bridge and can be used to additional rise the sensitivity of a computing scheme.

With this arrangement of gauges, bridge output will be insensitive to any loading other than F. We are of course assuming that gauges symmetrically placed. Suppose a bending load causes additional strain in gauge 1, gauge 4 will then have an equal, and opposite strain. The effect will cancel out in the bridge since gauges 1, and 4 are a different arms. In the actual practice, however, they never cancel out completely, and the degree of accuracy be subject to the characteristics of the strain gauges, and the mounting technique is used.

5 Calibrations

5.1 Stationary Correction of the Dynamometer

In order to choose the flexible deformation of cylindrical bar and subsequently the outcome volts less than fixed load, the dynamometer was adjusted. The correction done in three ways for F_f, F_t, F_c and the outcome of millivolt be an average of volts to each route. The plenty up to 2000 N by 50 N durations were used and the stress principles documented for collectively load. Thus, correction graphs were acquired to turn the outcome numbers into cutting force values. Figure 4a, b and c displays the calibration curves produced by using Minitab 16 for feed force, thrust force, and main cutting force correspondingly.

To be able to confirm the reliability, the dimensions were recurring for three intervals and close values were acquired as seen in Fig. 4a, b, and c. The impact of loading in one path on another force elements also analysed, and minimal variations were noticed. These results were little sufficient to disregard. The dynamometer was run non-productive for 10–20 moments before each calibration assessments as it was prepared for measure the reliability in force.

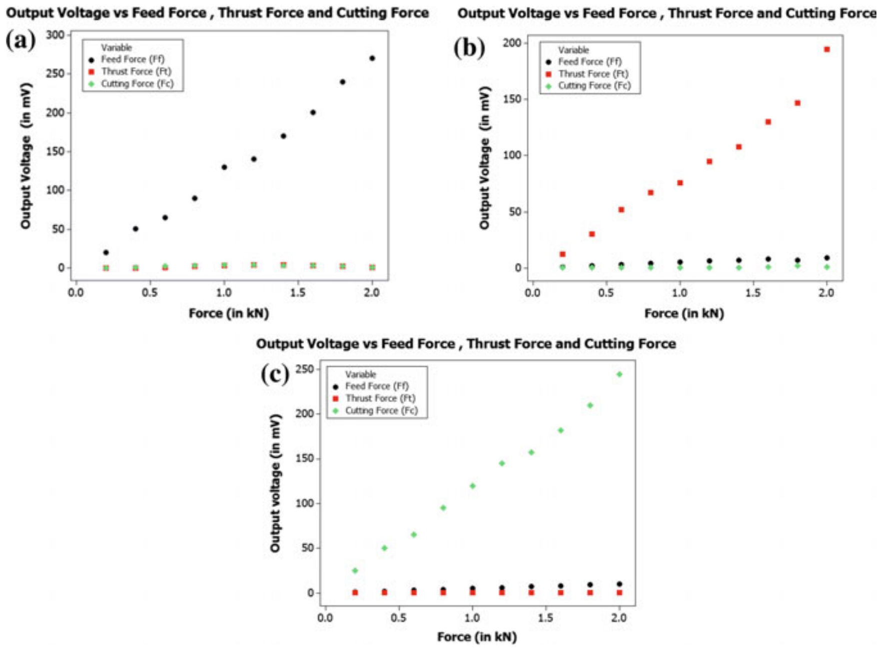

Fig. 4 Correction curve and cross-sensitivity for **a** feed force F_f, **b** thrust force F_t, cutting force F_c

6 Conclusion

In this paper, lathe tool dynamometer setup for turning has been produced and exhibited. It was developed and along with complete information procurement settlement made up. The dynamometer can cover three vertical force elements at the same time during turning, and the calculated mathematical principles can store on the PC by information procurement settlement. This dynamometer was developed to evaluate up to 3500 N extreme force with the comprehending of the application is ±5 N. The setup can assume as consistent as the lesser value can be ignored. In machining processes, satisfactory outcomes were gained for force extents. The acquired results of machining assessments performed at different cutting factors show that the setup can be used effectively to evaluate at a various range of forces. Although this configuration was developed mainly for turning, it can be used for milling, drilling, etc.

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