Development of Dynamometer for Cutting Force Measurement in Turning Operation

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Abstract. This paper presents the development of dynamometer to measure cutting force in turning operation in particular the tangential force ($F_t$). The dynamometer utilises a straight bar load cell that connected to holder tool to measure at least one axis of force. The designed dynamometer is capable of computing the forces acting on the workpiece in turning operation using any data acquisition system. Two materials of low elastic modulus, Polyoxymethylene (POM) and Polytetrafluoroethylene (PTFE), were employed as workpieces to test the performance of dynamometer. The performance of the dynamometer to measure one axis of cutting forces is considered satisfactory mainly because of the simplicity and low cost are the main requirements in design and construction.

1. Introduction

Machining is one of the most important manufacturing processes. The industrial revolution and the growth of the manufacturing-based economies of the world can be traced largely to the development of the various machining operations [1]. Industrial products that produce components from the machinery process always emphasize quality to win the competition. For many years the innovation process was needed to produce better quality industrial products to meet the requirements and specifications arising from the demands of the times. The common machinery processes are turning, grinding, milling and drilling in which a sharp cutting tool is used to remove metal from the work piece to produce the desired shape and features. In the turning operation, understanding the cutting force mechanism is very influential on the final result. The cutting forces generated during turning operation have a direct effect on the stability of the system, tool wear, quality of machined surface and accuracy of the workpiece. These forces can be measured theoretically, numerically or experimentally. In the experimental work, the cutting forces can be measured by using a dynamometer that attach to the toolpost. Although it is commercially available, dynamometer is still attractive to be designed to suit their individual needs. The most obvious background is certain price and quality [2-6]. This study was conducted to enrich the design of the current dynamometer to measure low modulus of elasticity materials. Design requirements are dynamometer that can be used to measure at least one directional force simultaneously for low elasticity materials at affordable prices.
2. Design and Testing of Dynamometer

The design of dynamometer must be simple and can be mounted on a conventional lathe machine. For this objective, the final design of frame that mounted the load cell is shown in Fig. 1(a) and (b), while Fig. 1(c) showed the dynamometer apparatus. Inside the frame, a straight bar load cell is used that connected to tool holder. The choice of straight bar load cell, limits only 2 axes can be evaluated simultaneously. For current study, conventional lathe machine and one axis of load cell are employed to measure the cutting force ($F_t$) as shown in Fig. 2. If three axis are used, three forces can be recorded simultaneously, e.g. $F_t =$ tangential force (cutting), $F_r =$ radial force (thrust) $F_f =$ feed force (axial), however in this case only two forces are sufficient. The load cell is connected to Arduino micro controller board, displayed in LCD board and analysed in MS Excel (Fig. 3). Static calibration for cutting force was performed in a cantilever beam condition with loads ranging from 0.05 to 0.5 N with linear regression models [6].

2.1. Materials

Two materials with low elastic modulus, Polyoxymethylene (POM) and Polytetrafluoroethylene (PTFE), were employed as workpieces to test the performance of dynamometer. The photograph of both materials can be seen in Fig. 4. The workpiece have dimension of 25 mm diameter and 200 mm long which will be evaluated with a carbide insert tool of DCMT. Mechanical properties of both materials are shown in Table 1 [7].

2.2. Testing method

The tangential force ($F_t$) is evaluated using one axis of load cell. The first test was performed by changing the spindle speeds of 100, 110, 155 and 190 rpm while the depth of cut was maintained at 0.2 mm. For second test, the depth of cut varies from 0.1, 0.2, 0.3, 0.4 and 0.5 mm while the spindle speed is maintained at 155 rpm. Both tests were carried out in dry conditions. The outer surfaces of the workpiece were machined to minimize the roll forming effects such as the outer surface hardness.

| Work piece                  | Density (kg/m$^3$) | Yield Strength (MPa) | Modulus of Elasticity (MPa) |
|-----------------------------|--------------------|----------------------|----------------------------|
| Polyoxymethylene (POM)      | 1410               | 65                   | 2760                       |
| Polytetrafluoroethylene (PTFE) | 2200              | 23                   | 500                        |

(a) Assembly of dynamometer  (b) Top view of dynamometer apparatus  (c) Dynamometer apparatus

Figure 1. Design of dynamometer.
3. Results and Discussion

Performance current dynamometer to measure the force in one direction that is tangential force can be considered satisfactory especially when simplicity and low cost are key requirements in the design and construction. It can be seen in Fig. 5 that the tangential force ($F_t$) is not drastically affected by spindle speed, despite a slight increasing when the spindle speed is elevated. For this test, the depth of cut is maintained at 0.2 mm. The response of tangential force for POM material is slightly high compared to PTFE. Both responses also observed when the depth of cut increase gradually as in Fig. 6. POM, which has higher elastic modulus compared to PTFE, shows higher response. It can be noticed that for a depth of cut of 0.5 mm, the response of the cutting force showed a significant different between POM and PTFE materials. This behaviour can be explained by the fact that with the increase in the depth of cut, the tool indents more into the workpiece and the width of cut becomes reasonably high. This effect increases the chip section and material response in stiffness when it contacts with the tool. The correlation between the increases of cutting force responds to material properties, by the current design, considered well explained.
Figure 4. Materials and forces in turning operation.

Figure 5. Spindle speed versus tangential force

4. Conclusion

In this paper, lathe tool dynamometer for turning operation has been developed. The dynamometer can only be used in two axes of force elements at the same time during turning. The performance of the dynamometer developed was considered satisfactory, especially when simplicity and low cost are taken into account as requirements for the design and construction of the device. The dynamometer was built at the total cost of USD 120 which can be concluded that it was a cost effective manufacture.
Figure 6. Effect of cut depth to tangential force.

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