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Experimental Analysis of Cutting Forces During Turning

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ABSTRACT

Cutting force is an important parameter in turning because it reflects the interaction between the cutting tool and the workpiece. However, commercial cutting-force measurement systems can be expensive and may not be readily available in student laboratories. This study presents a low-cost cutting-force monitoring system developed using an Arduino Uno and a dynamometer, and evaluates its use during the turning of a mild-steel bar on a centre lathe. The cutting forces produced by grooved and un-grooved high-speed steel (HSS) tools were compared. The recorded mean force components for the un-grooved tool were Fx = 1.00 N, Fy = 40.25 N and Fz = 11.12 N; for the grooved tool, they were Fx = 1.00 N, Fy = 46.09 N and Fz = 10.74 N. Compared with the un-grooved tool, the grooved tool showed a 14.5% increase in Fy and a 3.4% decrease in Fz, while Fx remained unchanged. Since only overall values were available and trial-wise readings were not recorded in the results workbook, these findings are descriptive and should be interpreted with caution. The identical Fx values also require verification.

Keywords: *low-cost monitoring, Arduino, cutting force, turning.*

1. Introduction

Turning is widely used to produce cylindrical components. During machining, cutting forces develop at the interface between the tool and the workpiece. Their magnitude depends on parameters such as cutting speed, feed rate, depth of cut, tool geometry and workpiece material. These forces influence machining power, tool loading and the possibility of tool deflection or chatter [1]. Therefore, measuring cutting force is useful for evaluating the turning process. However, commercial force-sensing and data-acquisition systems can be costly, which can limit their availability in college laboratories[2].

Grooves introduced on the rake face can influence chip flow and the contact between the chip and the cutting tool. Their effect on cutting force may vary with groove geometry and workpiece material. For example, a study of a micro-grooved tool used for turning AISI 304 reported a reduction in the main and feed force components [3]. Other work has examined force components under different cutting conditions and tool geometries [4]. In this study, a low-cost system was developed to monitor cutting force during turning, and the recorded forces for grooved and un-grooved HSS tools were compared under the stated experimental plan.

2. Experimental data and method

Experiments were carried out on a centre lathe using a mild-steel (MS) bar measuring 40 mm in diameter and 120 mm in length. Two HSS tools were tested: one with grooves and one without grooves. An Arduino Uno was used to acquire the force signals and transmit the data to a laptop through a USB connection. A dynamometer installed between the tool post and the cross-slide, beneath the tool holder, measured the cutting-force components. The Arduino was placed on a stable table away from the lathe. Previous work has also reported the measurement of cutting forces during single-point turning of MS bars [5]. Each tool was subjected to twelve trials using the cutting parameters listed in Table 1.

Table 1. Cutting parameters used for the twelve trials (same for both tools)

Speed (rpm)	Feed (mm/rev) in the four trials	Depth of cut (mm) in the four trials
112	0.045, 0.045, 0.090, 0.090	0.5, 1.0, 1.5, 2.0
180	0.063, 0.063, 0.125, 0.125	0.5, 1.0, 1.5, 2.0
280	0.137, 0.137, 0.160, 0.160	0.5, 1.0, 1.5, 2.0

The results workbook contains overall force values for each tool condition rather than individual readings for each trial. Therefore, the available data allow a comparison only between the overall results for the two tool conditions. They do not support an assessment of the separate effects of cutting speed, feed rate or depth of cut. For comparison, the resultant force was calculated as $R = \sqrt{(Fx^2 + Fy^2 + Fz^2)}$, along with the ratio Fy/Fz.

3. Results and discussion

Table 2. Mean cutting-force components for the two tools

Tool condition	Fx (N)	Fy (N)	Fz (N)
Without grooves	1.00	40.25	11.12
With grooves	1.00	46.09	10.74

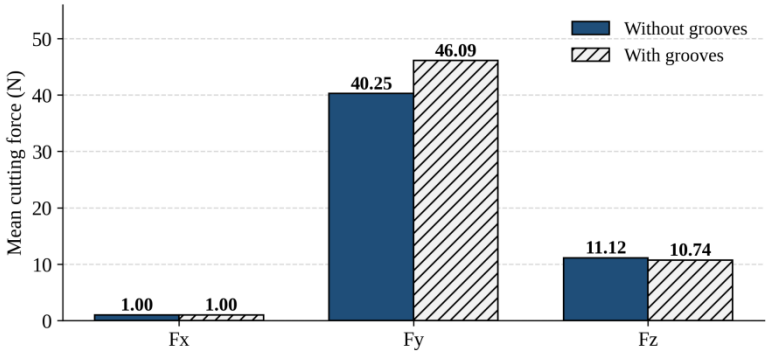


Fig. 1. Mean cutting-force components for the un-grooved and grooved tools.

The Fy component was the largest recorded force component for both tools. The grooved tool recorded 46.09 N, compared with 40.25 N for the un-grooved tool, representing an increase of 5.84 N (approximately 14.5%). In contrast, Fz decreased from 11.12 N to 10.74 N, a reduction of approximately 3.4%. The calculated resultant force increased from 41.77 N for the un-grooved tool to 47.34 N for the grooved tool (approximately 13.3%). The Fy/Fz ratio increased from 3.62 to 4.29. These comparisons describe the overall recorded values and should not be interpreted as trial-wise or statistically validated differences.

The increase in Fy observed in this experiment differs from the reduction in force reported for the micro-grooved tool in [3]. This difference may be related to variations in groove geometry, workpiece material or other experimental conditions. Changes in chip flow or in the contact between the chip and the tool may also have contributed; however, chip behaviour was not measured in the present study, so this explanation cannot be confirmed. Differences in tool-edge condition or clamping may also have influenced the results.

The recorded Fx value was exactly 1.00 N for both tool conditions. Because the same value was obtained in both cases, this component should be verified before drawing a conclusion about the effect of the grooves on Fx. Possible causes include a measurement-channel issue, an incorrect zero or scaling setting, or an error during data export. The raw sensor output and measurement system should therefore be checked. In addition, each trial was performed once, and only overall values were available. Consequently, the statistical significance of the observed change in Fy cannot be established from the present data.

4. Conclusion

A low-cost Arduino-based system was used to monitor cutting force during the turning of a mild-steel bar with grooved and un-grooved HSS tools. Based on the available overall values, the grooved tool recorded a higher Fy (46.09 N compared with 40.25 N) and a slightly lower Fz (10.74 N compared with 11.12 N). Fx was recorded as 1.00 N for both tools and requires verification. The calculated resultant force was approximately 47.34 N for the grooved tool and 41.77 N for the un-grooved tool. Since trial-wise data and repeated measurements were not available, the comparison is preliminary and descriptive. Future work should record and retain the force readings for every trial, repeat each cutting condition, and report the dynamometer calibration and data-acquisition sampling rate. Further examination of chip form and tool wear may help explain the observed differences in cutting force.

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