RESEARCH ARTICLE OPEN ACCESS

Effects of Machining Parameters on Cutting Forces during Turning of Hardened AISI 52100 Steel using PCBN Tooling

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ABSTRACT
The motivation of this investigate is to study the effects of machining parameters on the cutting performance of hard turned parts with PCBN (polycrystalline cubic boron nitride) tools , in wholly dry cutting. The data obtained gives a wide scope to understand the influence of cutting conditions such as the cutting speed, feed rate and depth of cut on the axial force, radial force, tangential force and cutting power. The ANOVA technique and MINITAB16 software were used for analysis of results. The results presented will be useful for application of AISI 52100 steel for the development of turning processes.
Keywords - Hard Turning, Cutting forces

I. INTRODUCTION

Hard turning is a cost-effective, high productivity and flexible machining process for ferrous metal work pieces that are often hardened above 45 HRc to 68 HRc. Hard machining is performed by using ceramics and polycrystalline cubic boron nitride (PCBN, commonly CBN) cutting tools due to the required tool material hardness. Hard turning is a lathe machining process where most of the cutting is done with the nose of the inserts.. Most hard turning applications involve turning of hardened steels [1]. The hard turning research discussed in the literature, can be generally separated into five main areas: a) mechanics of chip formation in turning of hardened steels b) effects of tool edge preparation and tool wear c) effects of machining parameters d) dynamic requirements of machine tool and e) surface quality and integrity of the hard turned functional surface. The hard turning process differs from conventional turning due to the work piece hardness, the cutting tool required, and the chip formation mechanism involved. Hardened steel has been used particularly in the automotive industry for components such as bearings,gears,shafts,cams, forgings, dies and molds etc.Hard turning offers a number of potential benefits over traditional grinding, including lower equipment costs, shorter setup time, fewer process steps, greater part geometry flexibility, and elimination of the use of cutting fluid [1, 2 and 3].Hard turning is, therefore, of great importance to both the manufacturing industry and research community.

II. EXPERIMENTAL SETUP

Hardened 52100 bearing steel with hardness of 48~50 HRc was chosen for experimental studies because of its wide use in both automobile industry and research fields. The chemical composition as tested is shown in Table 1.

Table 1: Chemical composition of the steel material

C	Cr	Mn	Si	S	P
0.92	1.06	0.51	0.22	0.039	0.040

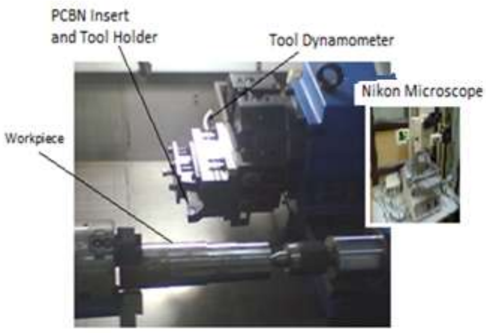

Figure 1 - Experimental set-up

The experimental set-up is shown in Fig. 1.

The uncoated CBN cutting inserts (Mitsubishi, Japan) with a negative land and a 0.8 mm nose radius were used for turning experiments. Inserts are recommended for machining hardened steel and cast iron in finish operations.The geometry and grade of insert is NP-CNMA120408G.The tool holder used for clamping the insert is PCLNR 2525 M (Make- WIDIA). It has 95º approach angle and -6º back rake angle.The force plate with cutting tool was mounted on a lathe machine.

2.1 EXPERIMENTAL DESIGN

The experiments were conducted according to Taguchi L_9 orthogonal array [4,5 and 6]. Based on the experimental work, the results are existing in this paper. Statistical analysis of variance (ANOVA) is performed to analyses the statistically significant process parameters. The statistical analysis was performed in order to determine the significant factors that have more effect on the cutting force components and cutting power using MINITAB16 software. Table 2 presents experimental layout according to L_9 design.

Table 2 : Design layout according to L_9 design

Expt. No.	Cutting Speed, *v* (m/min)	Feed, *f* (mm/rev)	Depth of cut ,a_p (mm)
1	250	0.03	0.1
2	250	0.04	0.2
3	250	0.05	0.3
4	300	0.03	0.2
5	300	0.04	0.3
6	300	0.05	0.1
7	350	0.03	0.3
8	350	0.04	0.1
9	350	0.05	0.2

All three levels of every factor are equally represented in 9 experiments. Since the experimental design is orthogonal, it is possible to separate out the effect of each factor at each level.The results predicated by ANOVA at the 95% confidence interval. Hard turning operation involves various input variables that include cutting speed, feed rate and depth of cut. These variables have direct as well as indirect effect on the performance of hard turning process.

2.2 EXPERIMENTAL PROCEDURE

The cutting experiments are conducted in continuous dry conditions using the CNC lathe. This machine is high rigidity and is also suitable for running hard turning tests. The cylindrical work piece having dia.80 mm and length 250 mm was mounted on Jobber CNC lathe machine with tail stock support. The force plate with cutting tool was mounted on a lathe machine. The tests were conducted without cutting fluid utilization and the used cutting parameters were: cutting speed: 250,300 and 350 m/mim; feed rate: 0.03,0.04 and 0.05 mm/rev; cutting depth: 0.1,0.2 and 0.3 mm and tool nose radius: 0.8 mm.For every new experiment, the same workpiece was used hence its diameter decreases. But according to cutting speed and diameter of workpiece the rpm of spindle was adjusted. In this manner total nine experiments were performed one by one in random order. While performing experiments the forces (F_x, F_y and F_z) were measured online and recorded on computer with DYNOWARE software. For cutting force sensing three components Kistler piezoelectric dynamometer were used with charge amplifier.

III. RESULTS AND DISCUSSION

3.1 CUTTING FORCES

Cutting forces are caused by plastic deformation of materials. Forces varied based on the hardness of work materials, working parameters, structure of chips, temperature developed, tool wear etc. Table 3 presents experimental results of cutting force components (Fx, Fy, Fz & Fr) for various combinations of cutting regime parameters according to L_9 design.

These are the axial or feed component (Fx), radial or passive component (Fy), tangential or cutting force component (Fz) and resultant force or mean machining force(Fr).The investigations show that the radial force component is the highest in machining of external cylindrical surface. While the other two force components shows less values. It is different from the force relation which is valid in the that the chip formation mainly occurs on the tool nose radius in hard turning and the machining is done with having negative rake angle. The large negative rake angle is also the main cause for the high radial force. traditional cutting where the main cutting (tangential) force is the highest.

Table 3: Experimental results for cutting force by Kistler Dynamometer

Exp. No.	Axial Force Fx (N)	Radial Force Fy (N)	Tangential (Cutting) Force Fz (N)	Resultan t Force, Fr (N)
1	6.5613	11.352	4.9133	14.00
2	11.9324	17.822	8.5144	23.07
3	26.2451	51.269	24.0479	62.65
4	23.4070	39.184	20.4468	50.013
5	42.3889	69.107	35.9802	85.83
6	58.0444	97.351	88.1653	143.59
7	91.9495	97.320	52.2766	143.72
8	36.2244	49.865	45.5017	76.61
9	10.4370	24.414	11.2610	28.84

From Table 3 it shows that the radial force arises 98 N. values. As a result chip, the chip sectional area was very small, which contributes to lower cutting forces.

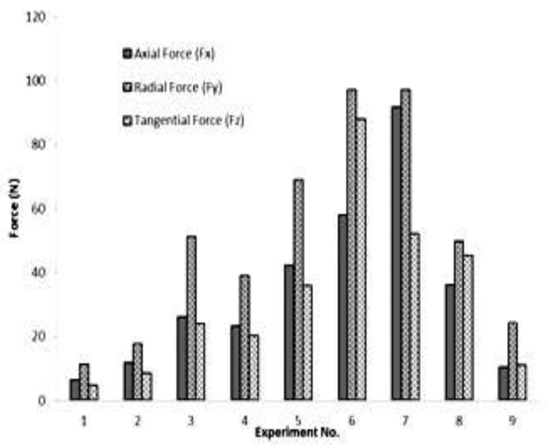

Figure 2 - Results of three forces components for all cutting conditions tested

The explanation is Figure 2 and Appendix I&II (Fig.4&5) shows, radial force showed to be the highest and becomes the largest of the three force components due to the very small depth of cut (0.1, 0.2 and0.3mm) and the feed rates (0.03,0.04 and 0.05mm/rev.) selected were significantly smaller than the insert nose radius (0.8mm).

3.2 CUTTING POWER

The main cutting force component is the tangential force Fz, in hard turning process . The cutting power P_c is calculated as [7,8].

$P_c = F_Z.V$ (1)

Table 4 illustrates the experimental results of Cutting Power (Kw).

Table 4: Experimental results for cutting power

Expt. No.	Cutting Speed, *v* (m/min)	Feed, *f* (mm/rev)	Depth of cut ,a_p (mm)	Cutting power (Kw)
1	250	0.03	0.1	0.04
2	250	0.04	0.2	0.07
3	250	0.05	0.3	0.21
4	300	0.03	0.2	0.19
5	300	0.04	0.3	0.34
6	300	0.05	0.1	0.48
7	350	0.03	0.3	0.56
8	350	0.04	0.1	0.29
9	350	0.05	0.2	0.14

Table 5 shows that the major effect on the response is due to cutting speed and very little effect due to feed rate during power consumption.

Table 5: Analysis of Variance for cutting power (P_c)

Source	Sum of Squares (SS)	DOF	Mean Squares (SS/ DOF)	F-ratio (MS/ Error)	P-valu	Cont (%)
Cutting speed	0.102	2	2	0.05	1.67	40.8
Feed	0.002	2	2	0.00	0.05	1.17
Depth Of cut	0.084	2	2	0.04	1.38	33.6
Error	0.061	2	2	0.03	--	24.4
Total	0.251	8	8	--	--	100
R-Sq = 75.60%						

The effect of depth of cut and cutting speed is more as compared to variation in feed rate. The Figure 3 illustrates that the evolution of the cutting power according to the cutting speed, feed rate and depth of cut.

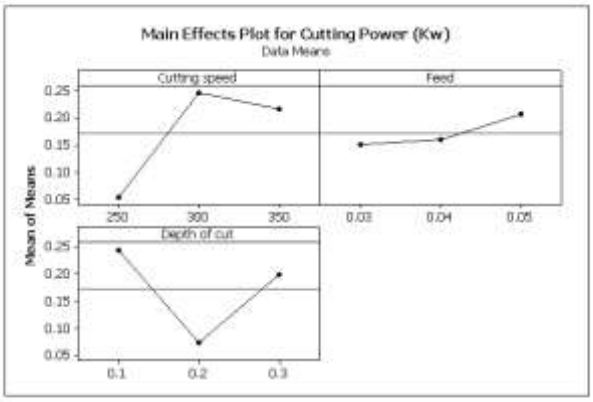

Figure 3 - Main effect plot for cutting power

A relatively large error in the prediction of cutting power due to vibration of the machine tooling and tool wear. Figure 3 shows, the variation of individual response with the three parameters, i.e., cutting speed, feed rate and depth of cut separately.

IV. CONCLUSIONS

The present work reports a systematic experimental investigation on, the influence of turning parameters on cutting forces and cutting power in hard turning of AISI 52100 steel with uncoated PCBN (Mitsubishi) insert.

From the analysis of experimental data the following significant findings were concluded from this research.

The force relations occurring during hard turning significantly difference from the traditional cutting because the radial force component is the highest here. This work proved that the cutting speed influence significantly on the cutting forces generated during cutting. This research confirms that in dry hard turning of this steel and for all cutting conditions tested, the major force is the thrust force. Radial (thrust) force is dominating compared to both others and that for the entire cutting system and measured values of the radial force were always the largest compare to axial and tangential cutting forces. The cutting speed and depth of cut were the most significant factors under the radial force.Lower values of cutting speed are essential to minimize cutting power..The effects of cutting feed and the depth of cut on the cutting power seem to be insignificant.

Analysis of variance shows that the major effect on the responses is due to the cutting speed and very little effect due to feed rate and depth of cut.

Taguchi technique has the advantage of investigating the influence of each machining variable on the values of technological parameters. It is found that the parameter design of Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the turning parameters.

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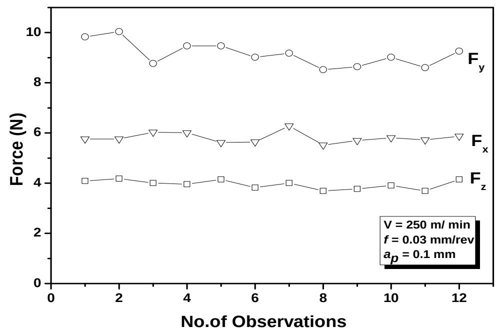
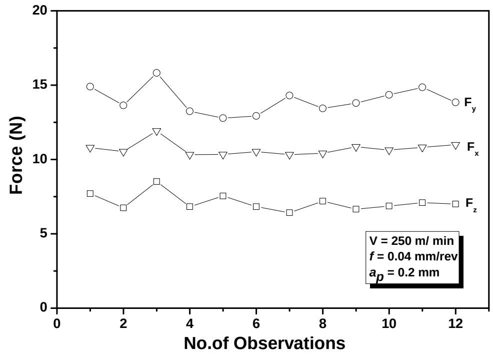
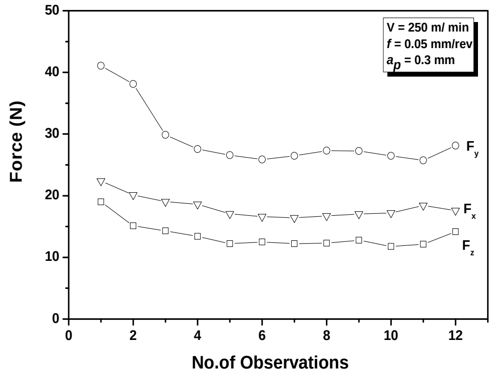
APPENDIX I



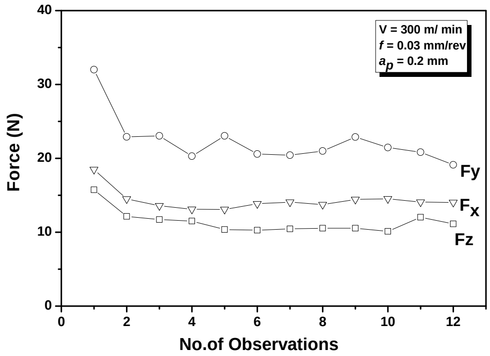
(a) Expt.1



(b)Expt. 2



(c) Expt. 3



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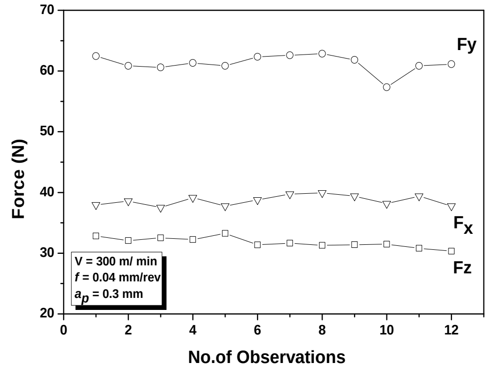

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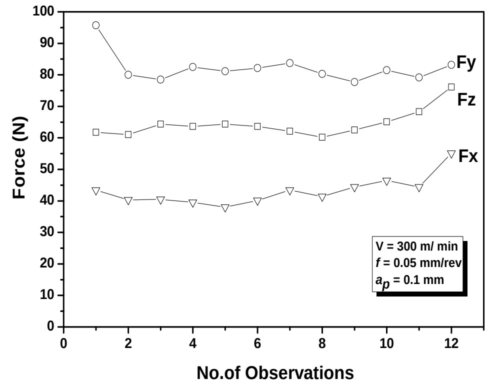

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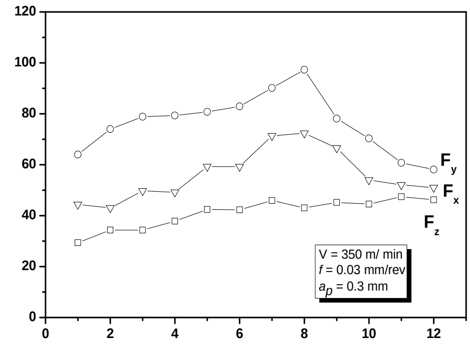
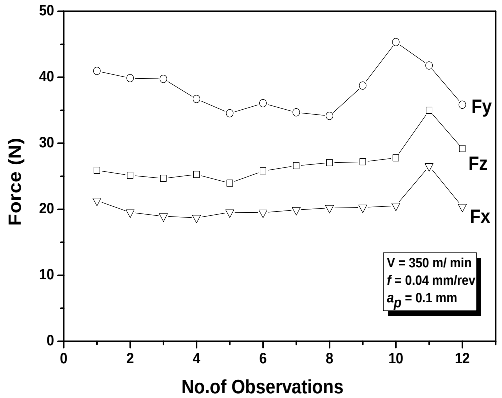


(g) Expt. 7



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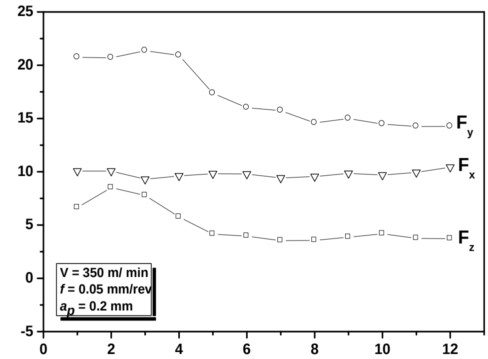
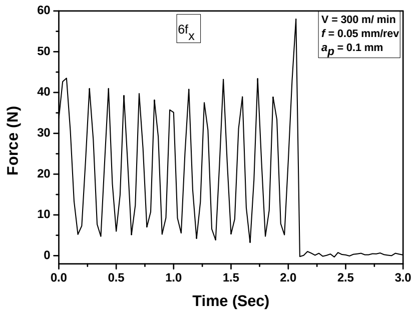


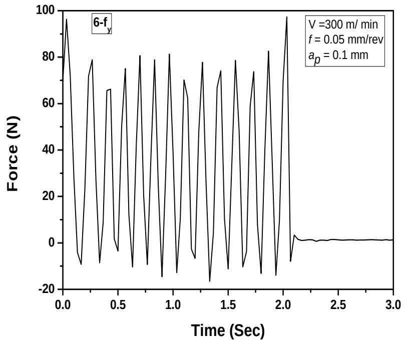
(I) Expt. 9

Figure 4 - Obseravations From Kistler Dynoware For Cutting Forces

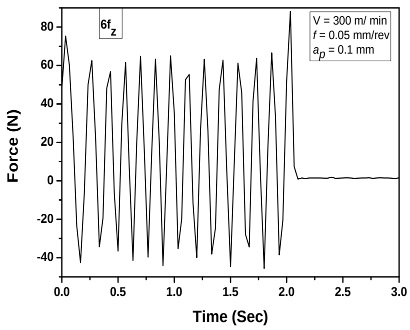
APPENDIX II



(a) Axial force



(b) Radial force



(c) Tangential force

Figure 5 - Output From Dynoware Software Of Exp.