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A Study on the Effect of Rake Angle and Feed Rate on Cutting Forces during Orthogonal Cutting

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ABSTRACT

The effects of rake angle and feed rate on the cutting forces in an orthogonal turning process have been studied. A cylindrical mild carbon steel, CS1030 work piece was turned using tools of grades TP20 carbide flat-top inserts and 8 µm TiN coating on a CNC lathe for 3 different rake angles (-5^0, 0^0, 5^0). A total of 12 experiments were carried out with 4 different feed rates (0.1, 0.17, 0.24, 0.31 mm/rev) for each rake angle, keeping the cutting speed (200 m/min.) and depth of cut (2.5 mm) constant. During the experimentation, the forces were measured using a 3-component piezoelectric dynamometer. The experimental results show that the feed force (F_x) is greater than the tangential force (F_y) and the longitudinal force (F_z) is least in magnitude irrespective of the tool rake angle. The cutting forces were found to increase with the increase in feed rate and decrease with the increase in rake angle.

Keywords: Cutting forces, Feed rate, Orthogonal cutting, Rake angle

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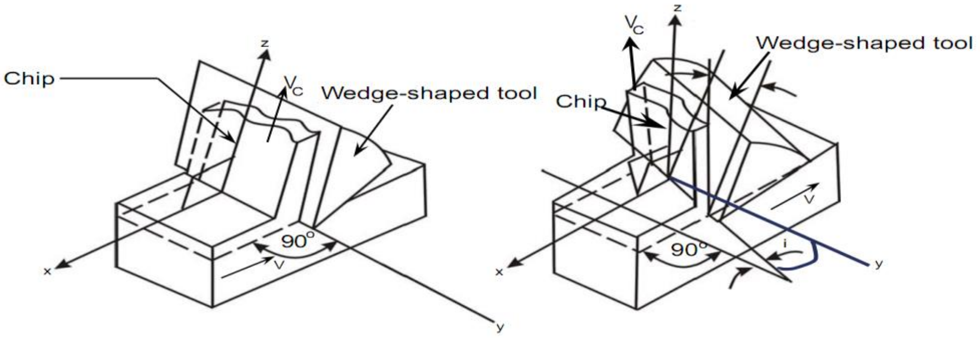
INTRODUCTION

In metal cutting operation, the position of the cutting tool is important based on which the cutting operation is classified as orthogonal cutting and oblique cutting shown in Figure 1. Orthogonal cutting is also known as two dimensional metal cutting in which the cutting edge is normal to the work piece. In turning process which is classified as oblique, the workpiece material is rotated and the cutting tool will travel and remove a surface layer (chip) of the workpiece material, producing three cutting forces components, i.e. the tangential force (F_y), which acts on the cutting speed direction, the feed force (F_x), which acts on the feed direction and the radial force (F_z), which acts on the direction normal to the cutting speed. In orthogonal cutting no force exists in direction perpendicular to relative motion between tool and work piece. It was observed that the cutting forces directly depended on the cutting parameters i.e. cutting speed, feed rate, depth of cut, tool material, geometry and workpiece material type [1-5].

LITERATURE REVIEW

In metal removal operations, many researches were carried out in the past and many are continuing for the purpose of decreasing production cost and manufacturing parameters without reducing product quality.



(a) **(b)**
Fig. 1 Turning process (a) Orthogonal turning (b) Oblique turning

Table -1 Chemical Compositions and Mechanical Properties of Carbon Steel, CS1030 Source [12]

C	Mn	P	S	Density, ρ (Kg/m^3)	Tensile strength (MPA)	Hardness (BHN)
0.3%	0.6%	0.04%	0.05%	$8.03x10^3$	463.7	126

Baldoukas *et al* [6] experimentally investigated the effect of feed rate and tool rake angle by conducting 24 experiments on AISI 1020 steel and found that main cutting force has an increasing trend with the increasing in feed and a decreasing trend as the rake angle increases. Gunay *et al* [7] investigated the effect of rake angle on the main cutting force by conducting experiments on AISI 1040 workpiece material. Experimental results were compared with the Empirical results according to Kienzle approach and found that main cutting force has a decreasing trend as the rake angle increased from negative to positive values. The deviation between empirical approach and experiments was in the order of 10–15%. Saglam, *et al* [8] have made a comparison of measured and calculated results of cutting force components and temperature variation generated on the tool tip in turning for different cutting parameters and different tools having various tool geometries while machining AISI 1040 steel hardened at Rockwel Hardness of 40. For making a comparison, the main cutting and tangential force components for different cutting parameters and tool geometries were calculated by Kienzle approach and the temperature values were calculated based on orthogonal cutting mechanism. Finally, the effects of cutting parameters and tool geometry on cutting forces and tool tip temperature were analysed and found that the average deviation between measured and calculated force results were found as 0.37%. Baldoukas *et al* [6] investigated experimentally the influence of cutting depth, tool rake angle and workpiece material type on the main cutting force and chip morphology during a turning process. During the experimental procedure they removed chips and were collected and evaluated together with the main measured cutting forces, in order to estimate the optimum rake angle for each type material. The experimental results show that the main cutting force has an increasing trend with the increase of the cutting depth. Lalwani *et al* [9] investigated the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel (equivalent to 18Ni (250) maraging steel) using coated ceramic tool. The results show that cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55–93 m/min. Fang and Jawahir [10] investigated the effects of workpiece hardness, cutting edge geometry, feed rate, cutting speed and surface roughness on hardened AISI H13 steel bars with CBN tools. The effects of two-factor interactions of the edge geometry and the workpiece hardness, the edge geometry and the feed rate, and the cutting speed and feed rate also appeared to be important. Especially for honed edge geometry and lower workpiece surface hardness resulted in better surface roughness.

In this study, the influence of tool rakes angles on cutting force was determined during machining of mild carbon steel, *CS1030* material, which has well known physical, chemical and machinability properties as shown in Table 1. During the experimental procedure the forces were measured using a Kistler type 3-component piezoelectric dynamometer.

MATERIALS AND METHODS

Mild carbon steel, *CS1030* steel has been used as the workpiece material to conduct all the experiments. For conducting experiments, hollow cylindrical bar with inner diameter of 25 mm and outer diameter of 30 mm were used. Prior to the experiments the specimens were turned with 1 mm cutting depth in order to remove the outer layer, which could appear discontinuous or unexpected hardening distribution due to their extrusion production process. The chemical composition and mechanical properties of the selected workpiece material are listed in Table 1.

Single point cutting tools of grades *TP20* carbide flat-top inserts and 8 μm TiN coating were used in all the experiments to ensure that tool wear is same in all cases. Different rake angles of -5^0, 0^0 and 5^0 and a constant clearance angle of 5^0 were produced on each tool with the help of a tool cutter and abrasive grinder. While turning a ductile material using a sharp tool, the continuous chip would flow over the tool's rake surface and in the direction apparently perpendicular to the principal cutting edge, i.e., along orthogonal plane which is normal to the cutting plane containing the principal cutting edge. This is referred to as 'orthogonal turning.' Practically, the chip may not flow along the orthogonal plane but this assumption is made for an ideal case.

In pure orthogonal cutting, the chip flow along orthogonal plane (η_0) and principle cutting edge angle ($\phi = 90^0$) as typically shown in Figure 2 where a pipe like job of uniform thickness is turned in a center lathe by a turning tool of geometry orthogonal rake (λ=0) and $\phi = 90^0$ resulting chip flow along (η_0) which is also machined in longitudinal plane (η_x) in this case.

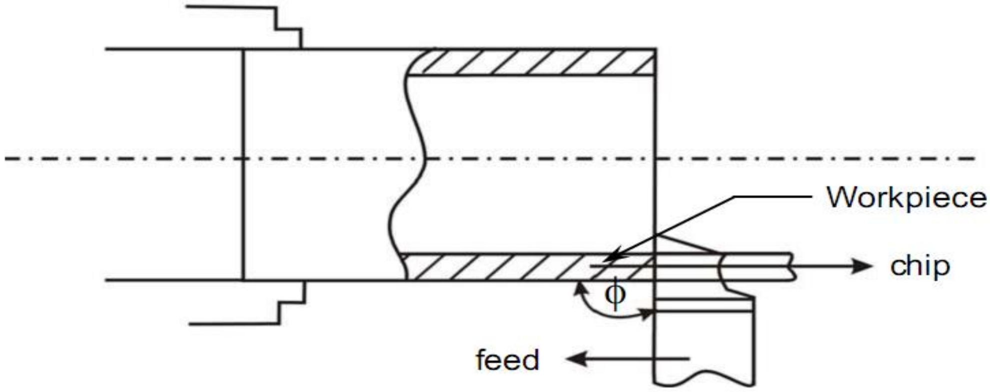


Fig. 2 Pure orthogonal turning (Pipe turning)

EXPERIMENTAL SETUP

Turning tests were conducted using cutting tools of grades *TP20* carbide flat-top inserts and 8 μm TiN coating on a PRODIS CORP CNC lathe. A hollow cylindrical workpiece made of mild carbon steel, *CS1030* with outer diameter of 30 mm and inner diameter 25 mm, was used whose major chemical compositions and mechanical properties are given in Table 1 [12]. A total of 12 experiments were performed with 3 different rake angles $-5^0, 0^0$ *and* 5^0 at a constant speed of 200 rpm and depth of cut of 2.5 mm at 4 different feed rates of 0.1, 0.17, 0.24, 0.31 mm/rev respectively.

RESULTS AND DISCUSSION

The results of the experiments carried out to measure the effects of the change in rake angle and feed rate on cutting force in all three directions are presented in Table -2. The cutting forces were measured by using Kistler 3-component piezoelectric dynamometer and variations were plotted as shown in Figs. 3-7.

The turning process has been assumed to be a pure orthogonal process. For such an assumption only 2 components of force must exist in the orthogonal plane. From the experimental results shown in figures 3 to 5 it is clear that for all cases of rake angle and feed force, the feed force (F_x) > tangential force (F_y) > radial force (F_z). It is also clear that the values of F_z are very small compare to the other two forces therefore, this force is almost negligible. Hence the experiments carried out can be assumed to be orthogonal turning process.

From Figures 6 and 7, it is clear that the cutting forces decreases with increase in rake angle and the cutting forces were found to increase continuously with an increase in feed for all rake angles. This is due to the fact that the volume of work material coming in contact with the tool or the volume of material being removed also increases with the increase in feed rate. It can also be observed from Figures 6 and 7 that, the cutting forces continuously increase with feed, the increase is more prominent at lower rake angles while less at higher rake angles. This is because the plunging effect of the tool into the workpiece material at a greater rake angle overshadows the effect of increase in cutting force with increase in feed at higher rake angles.

Table - 2 Machining Parameters and Experimental Results

Group No.	Expt. No.	Feed (f) (mm/rev)	Rake angle (γ^0)	$F_x(N)$	$F_y(N)$	$F_z(N)$
1	1	0.1	-5	126.14	54.78	5.69
	2	0.17		216.36	97.32	10.14
	3	0.24		619.83	213.37	17.84
	4	0.31		815.48	258.82	22.36
2	1	0.1	0	147.4	58.97	2.62
	2	0.17		328.4	121.99	1.33
	3	0.24		496.9	187.43	0.47
	4	0.31		600	218.93	2.66
3	1	0.1	5	83.75	50.48	2.41
	2	0.17		183.38	107.2	3.99
	3	0.24		325.37	187.25	6.03
	4	0.31		410.29	224.97	8.7

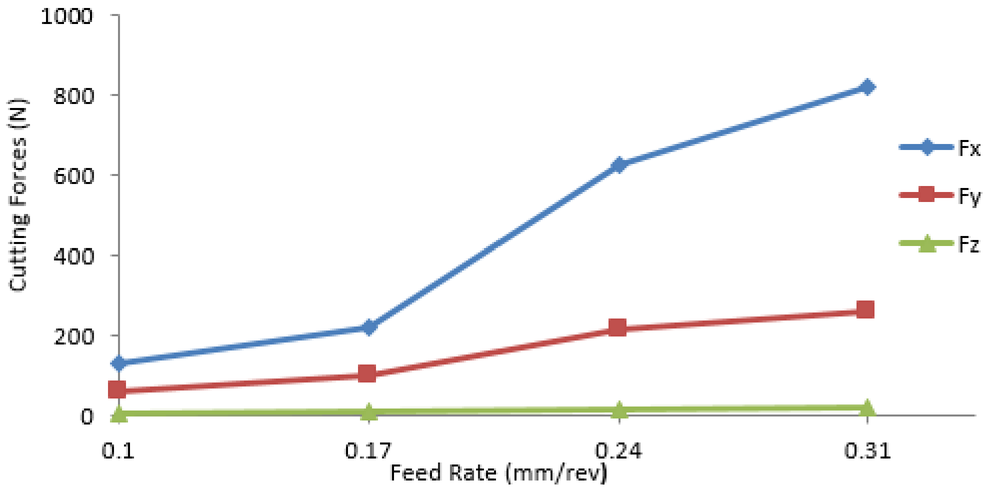


Fig. 3 Effect of feed rate on cutting forces at -5^0 rake angle

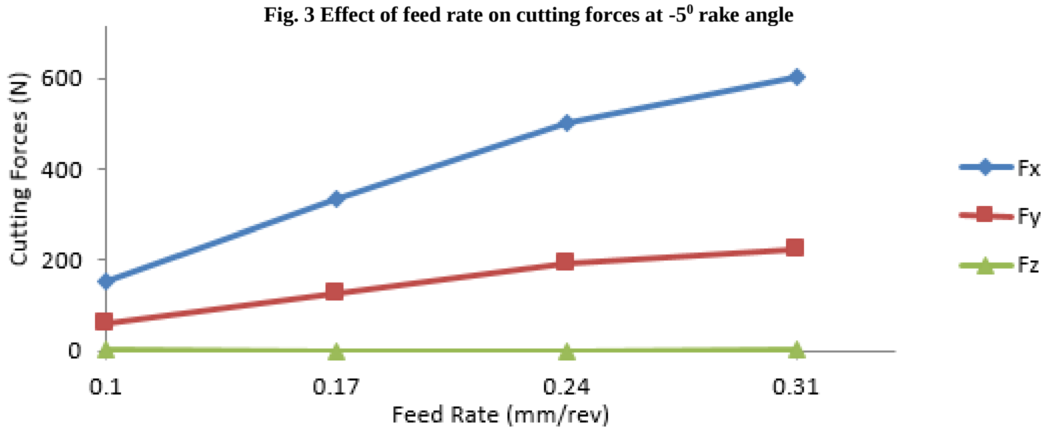


Fig. 4 Effect of feed rate on cutting forces at 0^0 rake angle

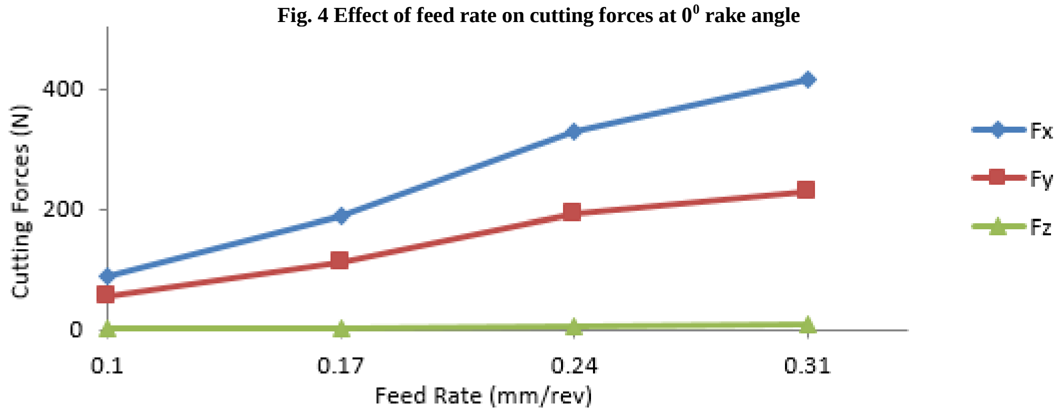


Fig. 5 Effect of feed rate on cutting forces at 5^0 rake angle

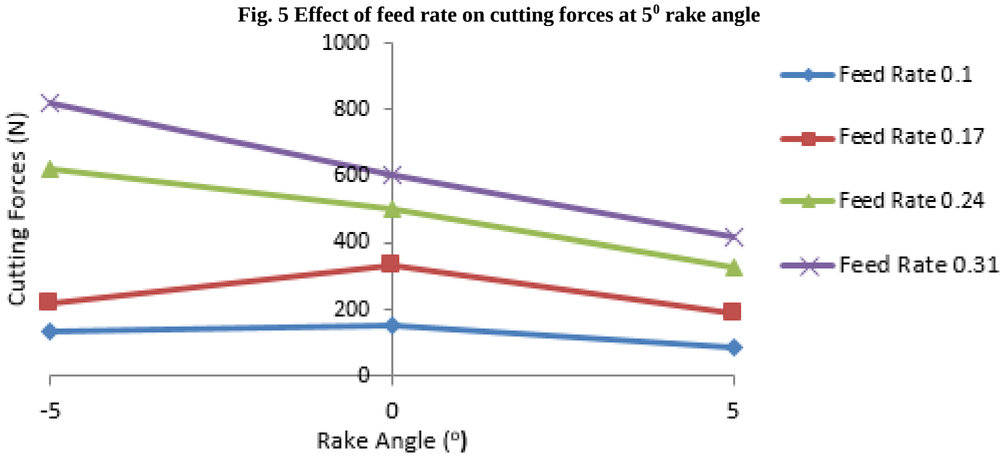


Fig. 6 Change in feed and cutting forces with increase in rake angle for different feeds for F_x

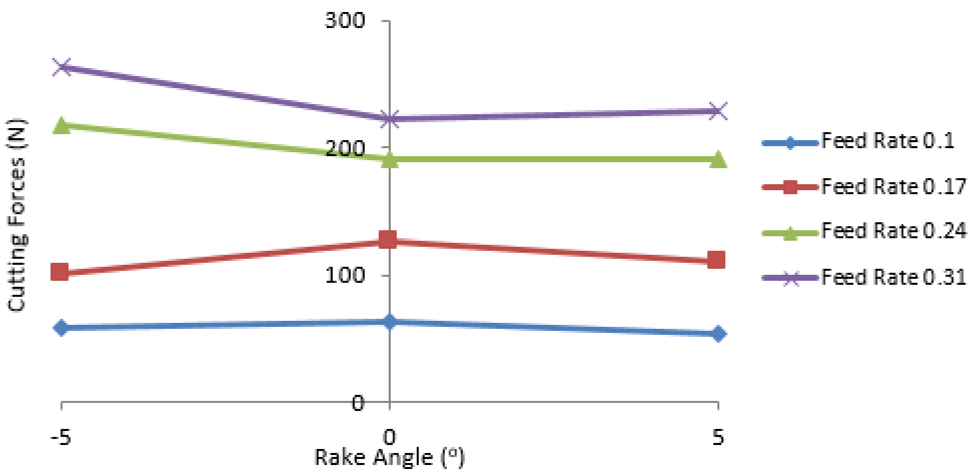


Fig. 7 Change in feed and cutting forces with increase in rake angle for different feeds for F_x

CONCLUSION

In this paper, the effect of feed rate and rake angles on the cutting forces during orthogonal turning of *CS1030* work piece using tools of grades *TP20* carbide flat-top inserts and 8 μm TiN coating have been investigated. The results of this work indicates that, the feed force (F_x) is greater than tangential force (F_y). It is also observed that the radial force (F_z) in the present experimental set-up is very small and negligible when compared to the other two force components. As the radial force is negligible, the turning of a hollow cylindrical workpiece makes it more near to the orthogonal machining process. It was also observed that the cutting forces increase with the increase in feed rate and the cutting forces decrease with the increase in rake angle from -5^0 to 5^0.

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