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Experimental Investigations of the Effects of Depth of Cut on Cutting Force in Turning

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ABSTRACT:
In the manufacturing process the net shape components from a work piece can be produced either by metal forming process or metal cutting process. The object is given shape by plastic deformation in metal forming processes, while conserving mass. Whereas, net shape objects can be produced with complex geometry and fine tolerances by metal removal in metal cutting, which is the focus of present paper. Extensive stresses, plastic deformation, high compressive and frictional contact stresses on the tool face results in substantial cutting force. The present paper deals with the study of effects of cutting parameters on cutting forces. The manufacturing industry has been trying to attain a required cutting performance of high precision, fast productivity and less maintenance cost. Cutting forces during machining can be a serious problem influencing manufactured parts quality, precision, tool service life, lathe performance and cutting rates. This paper presents an analysis of cutting mechanics in turning process, effects of cutting parameters (speed, feed and depth of cut) on cutting force. Cutting forces have significant impact on cutting process stability, which affects the quality of manufactured parts and productivity rates. During cutting operation the cutting forces are generated in longitudinal, axial and lateral directions. An experimental setup was prepared in on the conventional lathe and lathe tool dynamometer was used to measure the generated cutting forces in all directions. It is concluded that the effect of feed and depth of cut is more on cutting forces than spindle speed.

KEY WORDS: Cutting Forces, Cutting parameters, Dynamometer, Turning

1. INTRODUCTION:

There are two distinct types of manufacturing processes that rely on the behavior of the material past the yield point to form net shape components from a work piece. The first is a deformation process, which produces the required shape by plastic deformation of the material while conserving mass. The second process and the focus of this paper is the machining process, which forms the net shape work piece by removing material. Metal cutting process is one of the most common production processes for shaping the object. The production of complex geometry and fine tolerances can be made using metal cutting operations. Cutting is a process of extensive stresses and plastic deformations. The high compressive and frictional contact stresses on the tool face result in a substantial cutting force. Lathe machine is commonly used for cutting operations in which work piece is rotated on Lathe chuck and tool moves radially, axially or both ways simultaneously to give required surface. Cutting operations are widely used in workshop practice carried out on conventional machine tools as well as on NC, CNC and machining centers. Simple turning operation is used to generate the cylindrical surfaces on lathe machine. The work piece in turning operation is rotated on spindle and a single point cutting tool move parallel to work piece axis. Turning and Milling are the machining operations used in industrial manufacturing processes to obtain specific characteristics of machined work piece, such as part geometry, surface roughness, etc. During cutting process there is a relative movement between the cutting tool and the work piece, which causes to generate the cutting forces. The processes are based on removal of small amounts of metal from the work piece by using a cutting tool in the form of chip. The experiments were performed on 3 axis lathes that have various cutting speeds. The cutting forces depend on tool geometry, tool material, work material, feed rate, depth of cut, cutting speed etc. A variation of cutting forces with respect to indicated parameters caused during machining operations on the lathe is observed. The cutting forces are influenced by cutting speed or spindle speed and hence it will affect the production rate. If the cutting process is unstable, the amplitude of vibrations can start increasing exponentially until a value similar to chip thickness is reached. This leads to destructive oscillating cutting forces which create vibration marks on the machined surface. Uneven cutting forces can reach values several times higher than those achieved by normal cutting process. This drastically shortens cutting tool and machines durability, can cause cutting tool breakage. The tangential motion cause relative motion between tool and work piece. Feed motion along with the tangential motion leads to continuous chip removal and creation of machined surface with desired geometric characteristics. During the cutting operation, cutting speed and cut dimensions are constant and rotation of work piece can be changed by changing spindle speed. Cutting forces generated during metal cutting have a direct influence on generation of heat and thus accuracy of work piece, quality of machined surface and tool wear. The knowledge of effects of various cutting parameters on cutting forces is necessary and helps the designer or manufacturer of machine tools. The three components of force in three directions acts on tool and described as follows:

CUTTING FORCE (F_C):

This force has primary effect on motion and has 70%-80% of total force over the operation and used to calculate power for machining.

FEED FORCE (FF):

This force works in the direction of feed motion. Cutting forces changes linearly with feed at high speed but change is exponential at slower speed.

THRUST FORCE (F_T):

Thrust force works in the direction perpendicular to both feed force F_f and cutting force F_c. This force has less significant effect compared to the other two forces.Various cutting parameters have their influence on cutting forces and the considered cutting parameters for the present study are as follows:

SPINDLE SPEED:

Spindle speed influence the cutting forces as cutting force increases with the increase of cutting speed. But after a certain limit the cutting forces deceases due to high temperature which makes material plastic.

FEED:

It has greater influence on cutting force as at higher feed cutting force changes linearly but at slower speed change is exponential.

DEPTH OF CUT:

Cutting force increases same as that of depth of cut. Depth of cut has more influence on cutting forces as compared to spindle speed. The effect of all the three cutting force components on machining, as tangential (main) component gives cutting power, the radial and in feed components controls tool deflection, tool wear, dimensional errors and form errors of work piece. The estimation of cutting forces for various machining processes has been investigated by many researchers in various operations by formulation of appropriate models. Theoretical cutting forces calculations cannot produce accurate results due to complex tool configurations, cutting conditions of metal cutting operations and unknown factors and stresses. From the results of previous researches it was found that tool breakage, tool wear and work piece deflection are strongly related to cutting forces. Therefore, experimental measurement of cutting forces is unavoidable.

Lathe tool dynamometer was used to measure the three components of cutting force for the present experimental work.

2. EXPERIMENTAL SETUP:

The measurement of cutting force by varying different cutting parameters was conducted entirely experimentally. The main objective in these tests was to study the effects of various cutting parameters on cutting force. Spindle speed, feed and depth of cut during cutting were considered as major parameters. The experiments were carried out using Mild Steel as work materials and High Carbon Steel as tool material on a conventional lathe. Cutting force, radial force and axial thrust were recorded during machining. The experiments were performed at constant feed 0.06 mm/rev, spindle speed 52 rpm for varying depth of cut from 0.25 mm to 1 mm in the step of 0.25mm. All cutting forces were recorded for the above set of condition. Similar experiments were performed for spindle speed 150, 250 and 420 rpm data of cutting force, radial force and axial thrust were recorded during machining. Turning tests were performed on LTM 20 lathe and the test set up is as shown in Fig.1. All cutting forces were measured continuously by Lathe Tool Dynamometer during cutting. Calibration tests were performed using a force dynamometer to determine the cutting forces in all three directions.

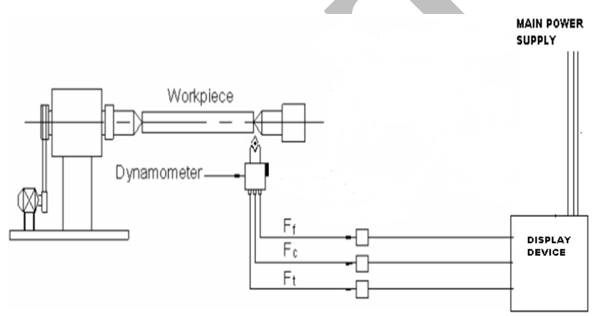

Figure 1: Schematic Diagram of Experimental Setup

The properties of work material, tool material are shown in Table 1 and cutting parameters for experimental work are shown in Table 2.

Table 1: Material Properties

Object	Material	Density kg/m^3	Elasticity MPa
Work piece	Mild Steel	7861.093	210,000
Tool	High speed steel	7900	225000

Table 2: Cutting Parameters

Feed (mm/rev.)	Spindle Speed (rpm)	Depth of Cut (mm)
0.06	52	0.25
	150	0.50
	250	0.75
	420	1.00

Length and diameter of the work piece are 100 mm and 32 mm respectively. Cutting force (F_c), Feed force (F_f) and Axial thrust (F_t) were measured by lathe tool dynamometer at different length i.e. 25 mm, 50 mm and 75 mm during the machining for constant feed and constant spindle speed. The average of all measured forces, at different length of work piece was taken and shown in Table 3 to 6. The data of all forces at constant feed 0.06 mm/rev and spindle speed 52 rpm at varying depth of cut is shown in Table 3. Similarly the data of all forces at constant feed 0.06 mm/rev with varying depth of cut and for spindle speed 150 rpm, 250 rpm and 420 rpm are shown in Table 4, 5 and 6 respectively. For the present study only cutting force (F_c) data are considered.

3. RESULTS AND DISCUSSIONS:
The experimental results of cutting force (kg) as given in tables are also plotted on graph and shown in Figure 2. The following results were obtained by close study of data given in all tables and plotted on graph.

Table 3: Variation of forces by varying depth of cut at spindle speed 52 rpm

Feed (mm/rev)	Spindle Speed (rpm)	Depth of Cut (mm)	Cutting Force F_c (kg)	Feed Force F_f (kg)	Axial Thrust F_t (kg)
0.06	52	0.25	4.8	1.8	4.2
0.06	52	0.50	22.6	5	-18.4
0.06	52	0.75	40.2	9	-19.4
0.06	52	1.00	51.2	26.4	2.6

Table 4: Variation of forces by varying depth of cut at spindle speed 150 rpm

Feed (mm/rev)	Spindle Speed (rpm)	Depth of Cut (mm)	Cutting Force F_c (kg)	Feed Force F_f (kg)	Axial Thrust F_t (kg)
0.06	150	0.25	15.4	05	-4.2
0.06	150	0.50	28.2	9.2	-21.2
0.06	150	0.75	28.2	9.4	-17.6
0.06	150	1.00	47	14.6	-25.8

Table 5: Variation of force by varying depth of cut at spindle speed 250 rpm

Feed (mm/rev)	Spindle Speed (rpm)	Depth of Cut (mm)	Cutting Force F_c (kg)	Feed Force F_f (kg)	Axial Thrust F_t (kg)
0.06	250	0.25	12.6	5	11
0.06	250	0.50	17.6	7.4	1.4
0.06	250	0.75	23.8	11	4.6
0.06	250	1.00	27.2	12.2	1.4

Table 6: Variation of forces by varying depth of cut at spindle speed 420 rpm

Feed (mm/rev)	Spindle Speed (rpm)	Depth of Cut (mm)	Cutting Force F_c (kg)	Feed Force F_f (kg)	Axial Thrust F_t (kg)
0.06	420	0.25	12.8	5	2.2
0.06	420	0.50	17.2	5.8	0.8
0.06	420	0.75	34	16.8	6.4
0.06	420	1.00	54.8	28.6	-0.2

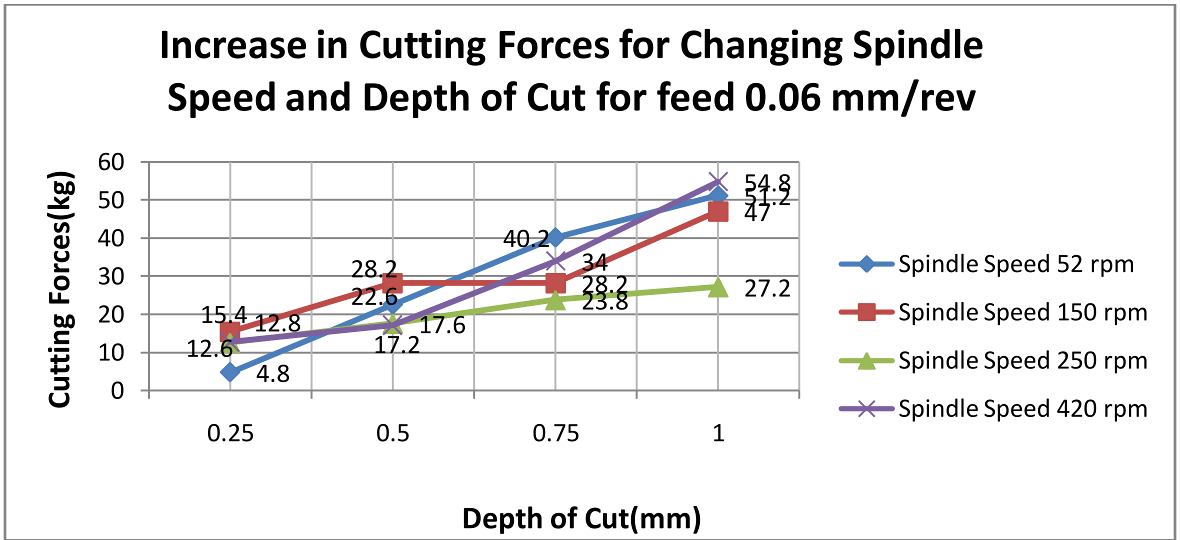

Figure 2: Variation of cutting force by depth of cut at all spindle speeds

1. The value of cutting force is 4.8 kg for depth of cut 0.25 and spindle speed 52 rpm and the value of cutting force is 51.2 kg at depth of cut (1 mm) and same spindle speed (52 mm). Similarly for all other considered spindle speed the cutting force shows the same pattern as shown in Figure 2. As the depth of cut increases more amount of material is to be removed by tool from the work piece. Hence, the cutting force increases as the depth of cut increases for all spindle speeds.
2. The variation of cutting force is from 4.8 kg to 15.4 kg for depth of cut 0.25 mm at different considered spindle speed and variation of cutting force is from 27.2 kg to 54.8 kg for depth of cut 1 mm on the same considered spindle speed as shown in Figure 2. Hence, the cutting force increases as spindle speed increases irrespective of depth of cut.
3. The variation in cutting forces is more for higher and lower depth of cut, whereas, the cutting forces are more stable for medium depth of cut.

4. CONCLUSIONS:

The above experimental study is concluded with the following conclusions:

1. The cutting force increases as the depth of cut increases irrespective of spindle speeds.
2. The cutting force increases as spindle speed increases irrespective of depth of cut.

Hence it is concluded that for lower cutting force, lower depth of cut and lower spindle speed is advisable to enhance the tool life.But at the same time lower depth of cut and lower spindle speed is not advisable for good surface quality and higher production rate

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