Analysis of Single Point Cutting Tool of a Lathe Machine Using FEA

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***Abstract*— The geometry of cutting tool surfaces is one of the crucial parameters affecting the quality of manufacturing process and has been traditionally defined using the principles of projective geometry. The parameters of geometry defining the various cutting tool angles are described by means of taking appropriate projections of the cutting tool surfaces. Development in the field of computer Aided Geometric Design(CAGD) now provide more elegant approach for specifying the cutting tool surfaces as a set of biparametric surface patches. This study of machining processes involves analyzing the chip formation process. Years of research has conclusively shown that it a process involving plastic deformation in which large strains and strain rates are developed by localized shear deformation of work material immediately ahead of tool. Heat generated during the chip formation process as a result of plastic deformation and friction. The heat influences chip shape, tool wear, surface finish and cutting forces.**

Keywords*—Depth of cut, Rake angle, Nose angle, Back rake angle, feed, relief angle.

1. INTRODUCTION

Metal cutting, or simply machining, is one of the oldest processes for shaping the components in the manufacturing industry. It is estimated that 15% of the value of all mechanical components manufactured worldwide is derived from machining operations. However, despite its obvious economic and technical importance, machining remains one of the least understood manufacturing operations due to the low predictive ability of the machining models.

When machining metals and alloys most of the energy required to form the chips is converted into heat. Therefore, the temperature generated in the cutting zone is an important factor to take into consideration. This factor is of a major importance to the performance of the cutting tool and quality of the work piece. Temperatures in cutting zone depend on contact length between tool and chip, cutting forces and friction between tool and work piece material. A considerable amount of heat generated during machining is transferred into the cutting tool and work piece. The remaining heat is removed with the chips. The highest temperature is generated in the flow zone. Therefore, contact length between the tool and the chip affects cutting conditions and performance of the tool and tool life.

For the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. Because of nature of the metal cutting, determination of internal temperatures on the cutting tool are very difficult. For measuring of this temperatures generated in the cutting zone, several methods have been developed. Calorimetric method, thermocouple method, infrared photographic technique, thermal paints and PVD technique are some of them.

Chip removal in the metal-cutting process may be performed either by cutting tools having distinct cutting edges or by abrasives used in grinding wheels, abrasive sticks, abrasive cloth, etc. Single point cutting tools having a wedge-like action find a wide application on lathes, shaping and slotting machines.

The two basic methods of metal cuttings using a single point cutting tool are the orthogonal or two-dimensional, and the oblique or three dimensional. Orthogonal cutting takes place when the cutting face of the tool is 90^o to the line of action or path of the tool. If however, the cutting face is inclined at an angle less than 90^o to the path of the tool, the cutting action is known as oblique.

A. Single Point Cutting Tool Geometry

Cutting Forces

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 F as shown in fig 1.

Knowledge of the cutting forces is essential for the following reasons:

- Proper design of the cutting tools
- Proper design of the fixtures used to hold the work piece and cutting tool
- Calculation of the machine tool power
- Selection of the cutting conditions to avoid an excessive distortion of the work piece

Cutting force components usually in orthogonal cutting, the total cutting force F is conveniently resolved into two components in the horizontal and vertical direction, which can be directly measured using a force measuring device called a dynamometer. If the force and force components are plotted at the tool point instead of at their actual points of application along the shear plane and tool face, we obtain a convenient and compact diagram.

The two force components act against the tool:

Cutting force F_C: this force is in the direction of primary motion. The cutting force constitutes about 70~80 % of the total force F and is used to calculate the power P required to perform the machining operation,

$P = VF_C$

Thrust force F_D: this force is in direction of feed motion in orthogonal cutting. The thrust force is used to calculate the power of feed motion. In three-dimensional oblique cutting, one more force component appears along the third axis. The thrust force FD is further resolved into two more components, one in the direction of feed motion called feed force Ff, and the other perpendicular to it and to the cutting force FC called back force Fp, which is in the direction of the cutting tool axis.

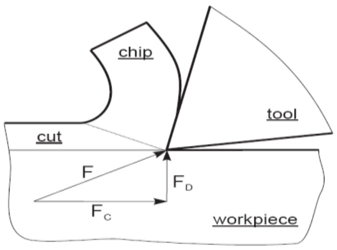

Fig 1: Total cutting force is resolved into two component horizontal component F_C vertical component FD

Chip formation during machining processes:

The chip formation process is the same for most machining processes, and it has been researched in order to determine closed-form solutions for speeds, feeds, and other parameters which have in the past been determined by the "feel" of the machinist.

With CNC machine tools producing parts at ever-faster rates, it has become important to provide automatic algorithms for determining speeds and feeds. The information presented in this section are some of the more important aspects of chip formation

Cutting Temperature

In cutting, nearly all of energy dissipated in plastic deformation is converted into heat that in turn raises the temperature in the cutting zone as shown in fig 2.

Since the heat generation is closely related to the plastic deformation and friction, we can specify three main sources of heat when cutting,

1. Plastic deformation by shearing in the primary shear zone (heat source Q1)
2. Plastic deformation by shearing and friction on the cutting face (heat source Q2)
3. Friction between chip and tool on the tool flank (heat source Q3)

Heat is mostly dissipated by,

- The discarded chip carries away about 60~80% of the total heat (q1)
- The work piece acts as a heat sink drawing away 10~20% heat (q2)
- The cutting tool will also draw away ~10% heat (q3).

If coolant is used in cutting, the heat drawn away by the chip can be as big as 90% of the total heat.

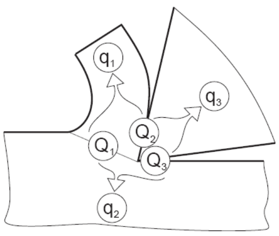

Fig 2: The balance of heat generation and heat dissipation in metal cutting

II. Experiment Details

A. Selection of Workpiece Material and Tool:

Experimentation has to be performed on lathe using High Speed Steel cutting tool for machining mild steel and aluminum workpiece. Workpiece(mild steel and aluminum) of diameter 25mm is selected and cutting is performed up to the length of 50 mm.

B. Grinding of Cutting Tool:

Depending on the machining of workpiece material, tool should have different geometry. So High Speed Steel billet is grinded as per the recommended tool geometry for machining Mild Steel and Aluminum workpiece.

C. Electron Discharge Machining (EDM) of Single Point Cutting Tool:

For measuring the temperature of the tool while machining, a hole is drilled using EDM machining process. The hole is drilled of diameter 2 mm and 12.5 mm depth, at 3 mm away from nose radius.

III. Measuring Cutting Force by Monitoring Elastic Strain Caused by the Force.

Increasing deflection, δ [10] enhances sensitivity of the dynamometer but may affect machining accuracy where large value of δ is restricted; the cutting forces are suitably measured by using the change in strain caused by the force. Fig. 10.5 shows the principle of force measurement by measuring strain, ε, which would be proportional with the magnitude of the force, F (say P_v) as,

$$\varepsilon = \frac{\sigma}{E} = \frac{M/Z}{E} = \frac{P_Z.l}{Z.E} = k_1 P_Z$$

where, M = bending moment
Z = sectional modulus (I/y) of the tool section
I = plane moment of inertia of the plane section
y = distance of the straining surface from the neutral plane of the beam (tool)

The strain, ε induced by the force changes the electrical resistance, R, of the strain gauges which are firmly pasted on the surface of the tool-holding beam as

$$\frac{\Delta R}{R} = G\varepsilon$$

where, G = gauge factor (around 2.0 for conductive gauges)
The change in resistance of the gauges connected in a Wheatstone bridge produces voltage output ΔV, through a strain measuring bridge (SMB) as indicated in Fig. 2.3.
Out of the four gauges, R_1, R_2, R_3 and R_4, two are put in tension and two in compression as shown in Fig. 2.3. The output voltage, ΔV, depends upon the constant, G and the summation of strains as,

$$\Delta V = \frac{GE}{4}\left[\varepsilon_1 - (-\varepsilon_2) + \varepsilon_3 - (-\varepsilon_4)\right]$$

where, ε_1 and ε_2 are in tension and - ε_3 and - ε_4 are in compression
The dynamometers being commonly used now-a-days for measuring machining forces desirably accurately and

precisely (both static and dynamic characteristics) are either

- Strain gauge type
- Piezoelectric type

Strain gauge type dynamometers are inexpensive but less accurate and consistent, whereas, the piezoelectric type are highly accurate, reliable and consistent but very expensive for high material cost and stringent construction. Turning dynamometers may be strain gauge or piezoelectric type and may be of one, two or three dimensions capable to monitor all of P_X, P_Y and P_Z.

For ease of manufacture and low cost, strain gauge type turning dynamometers are widely used and preferably of 2 – D (dimension) for simpler construction, lower cost and ability to provide almost all the desired force values.

IV. *EXPERIMENTAL SETUP*

Tool post of the lathe is removed and the dynamometer is mounted. The cutting tool is then mounted on the dynamometer. Dynamometer is then connected to the digital indicator by using probes. The cutting force, thrust force and radial forces are noted down at different cutting speeds, feeds and depth of cut.

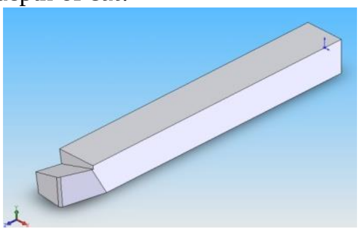

Fig 3: 3D Model of single point of cutting tool.

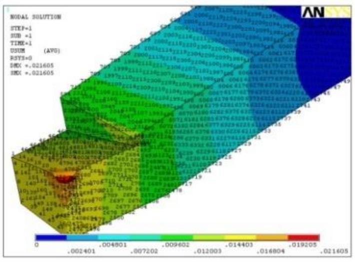

Fig 4: Deformation of cutting tool.

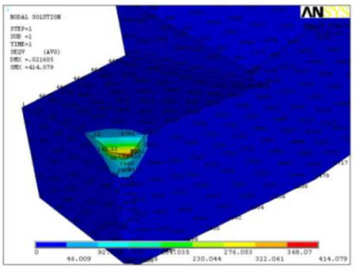

Fig 5: von mises stress of cutting tool

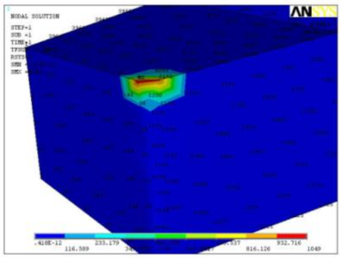

Fig 6: nodal temperature distribution of cutting tool

The above fig 3to fig 6 shows the deformation, stress and distribution of temperature, heat flux and thermal gradient in all directions. The maximum temperature is observed at tool-work piece interface at node 12 an 2131, i.e. 85 ^{0}c. The temperature at node 2132 is approximately equal to the temperature measured practically using thermocouple. The vector summation thermal gradient and thermal flux at node 12 and 2131 is maximum when compares to other nodes and distribution of heat takes place towards other nodes.

V. RESULTS AND DISCUSSION

Tool post of the lathe is removed and the dynamometer is mounted. The cutting tool is then mounted on the dynamometer. Dynamometer is then connected to the digital indicator by using probes. The cutting force, thrust force and radial forces are noted down at different cutting speeds, feeds and depth of cut and their corresponding results are shown in graphs in form of fig 7 to fig 12.

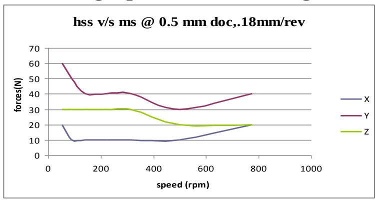

Fig 7: Graph representing the thrust force of hss vs ms

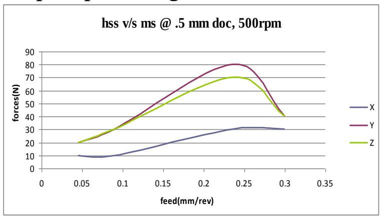

Fig 8: Graph representing the change in cutting force of hss vs ms

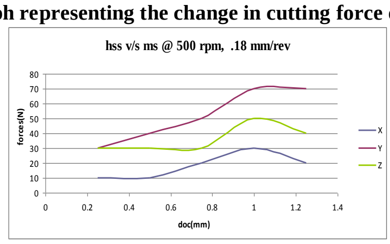

Fig 9: graph representing the thrust force w.r.t to depth of cut of hss vs ms

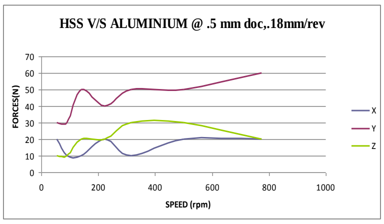

Fig 10: Graph representing the thrust force of hss vs Al

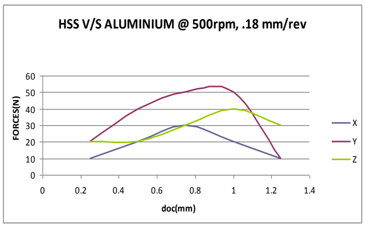

Fig 11: graph representing the thrust force w.r.t to depth of cut of hss vs Al

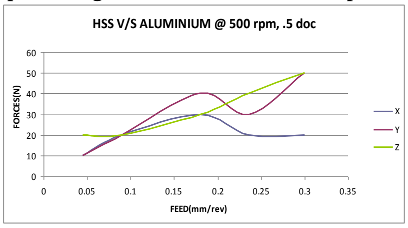

Fig 12: Graph representing the change in cutting force of hss vs ms

VI. CONCLUSION

The above experimentation is carried when the mild steel work piece is machined at different cutting speed and maintaining constant feed rate 0.18 mm/rev and depth of cut 0.5 mm. It is observed that, as the cutting speed increases the temperature of tool increases up to certain speed and then approximately remains constant. But the temperature of chip and work piece increases as cutting speed increases.

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