RELATIONSHIP BETWEEN TOOL WEAR AND SURFACE ROUGHNESS IN UP MILLING

Submitted by

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A thesis submitted to the Department of Industrial & Production Engineering, Bangladesh University of Engineering & Technology, Dhaka in partial fulfilment of the requirements for the degree of Master of Engineering (IP)

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RECOMMENDATION OF THE BOARD OF EXAMINERS

The board of examiners hereby recommends to the Department of Industrial & Production Engineering, BUET, Dhaka, acceptance of the thesis,"**RELATIONSHIP BETWEEN TOOL WEAR AND SURFACE ROUGHNESS IN UP MILLING**", submitted by **Mahbubunnesa**, in partial fulfillment of the requirements for the degree of Master of Engineering (IP).

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TO

MY PARENTS

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- AUTHOR

ABSTRACT

A lot of experimental and theoretical works have been carried out on tool wear and job surface roughness. But sufficient works have not yet been done to investigate the relationship between them. In the present work experiments have been carried out in an attempt to monitor the change of work-piece surface roughness as cutting time elapsed, caused by the increase of tool flank wear, in up-milling operation under constant feed, speed and depth of cut. The material machined was mild steel and tool material was half hardened HSS.

To investigate the relationship between tool wear and surface roughness one single tooth fly cutter of HSS was made. The single tooth fly cutter was overhung from the tool holder and was clamped by clamping screws. Flat surface was cut by up-milling operations using single tooth fly cutter mounted on a tool holder. Tool wear was measured along the flank surfaces of tools and at the same time surface roughness of a mild steel job was measured during up-milling operation. The relationship between tool wear and job surface roughness has been investigated.

The results show that the tool wear influences the surface roughness of work-piece as cutting time elapsed and the value of surface roughness can be used to establish the moment to replace the tool in milling operation. Experimental results show that at the beginning of machining surface roughness continues to improve though tool flank wear increases as cutting time elapses. But after tool wear reaches certain value, job surface roughness begins to increase again. The relation between tool wear and job surface roughness can also be used to determine the desired quality of job surface finish.

CHAPTER-1

INTRODUCTION AND LITERATURE SURVEY

1.1 GENERAL INTRODUCTION

Milling is a basic machining process by which a surface is generated progressively by the removal of chips from a workpiece as it is fed to a rotating cutter in a direction perpendicular to the axis of the cutter. In some cases the workpiece remains stationary and the cutter is fed to the work.

The milling operations can be broadly classified as plain (or peripheral) and face (or end) milling. When the cutter velocity during peripheral milling is in the opposite sense to the feed motion, the process is called conventional or up-milling as shown in (Fig.1.1) and when they are in the same sense (Fig.1.2) the operation is called down-milling. In up-milling the chip thickness is zero at the start of the cut and increases to a maximum value just before the tooth disengages the workpiece while in down-milling the chip thickness is maximum at the start of cut and drops to zero value at the end of cut.

Metal cutting by milling operation is a common operation in many manufacturing systems. Roughness of the machined surface is an important measure of quality in metal cutting, and it is important to monitor and control surface roughness over time during the machining operation. If the surface becomes too rough, the cutting tool has to be changed.

The roughness of a machined surface greatly affects the wear resistance of the surfaces of the part, its strength, corrosion resistance and the reliability of fixed joints of mating parts.

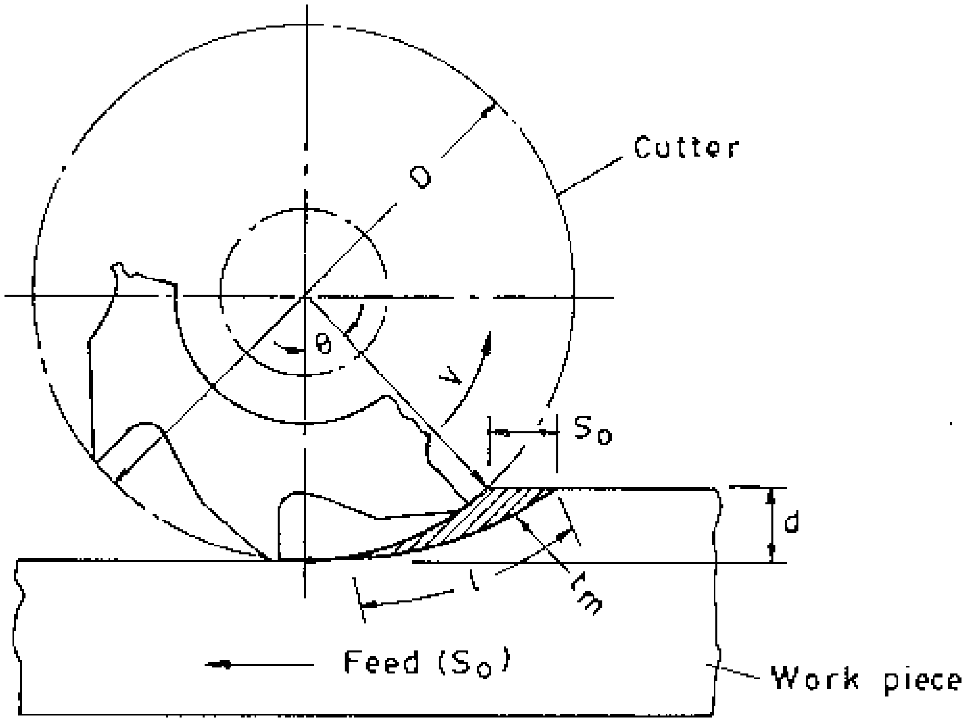


Fig.(1.1) UP MILLING

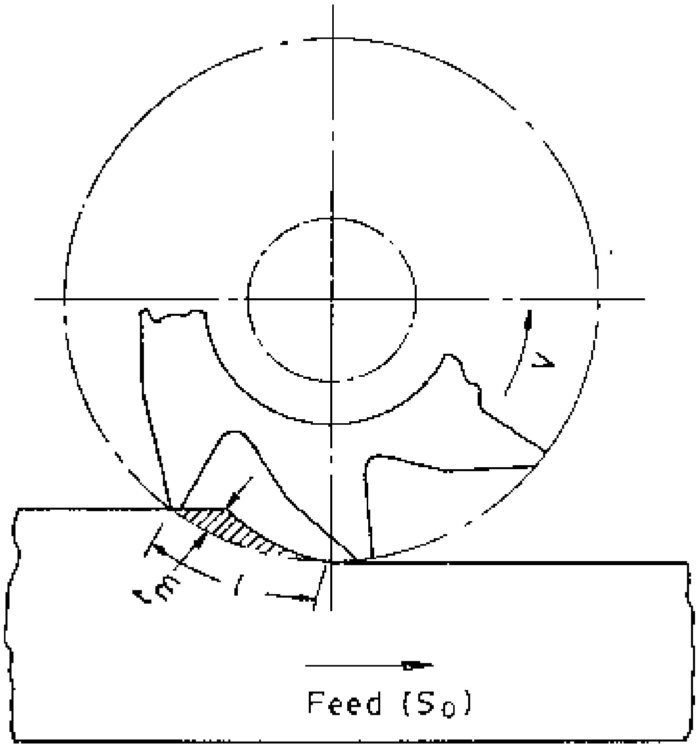


Fig.(1.2) DOWN MILLING

The surface which results from a milling operation is subjected to two types of defects, waviness and roughness. Waviness (Fig. 1.3a) involves surface imperfections of relatively long wave length that are repetitive. Surface roughness which involves random imperfections of surface geometry of shorter wave length is largely caused by the Built-Up-edge (BUE) (Fig. 1.3b) that forms at the tip of the cutting tool.

Tool wear on the flank upto a certain limit [0.5 or 1mm] below the cutting edge, the effect of wear on the roughness is insignificant. More wear, however, leading to a considerable increase in roughness of the cutting edge, radius and forces acting in the cutting process, may increase the height of the micro-irregularities of the machined surface (Fig. 1.4). If the machine-fixture-tool-workpiece complex is insufficiently rigid, tool wear may cause vibration which substantially deteriorates the micro geometry of the machined surface.

Tool wear influences on surface roughness of workpiece and the value of surface roughness is one of the main parameters used to establish the moment to replace the tool in milling operation. Therefore, it would be very useful to determine relation between tool wear and desired quality of job surface finish.

The geometry of tool wear causes change in job surface roughness as machining time elapses. Groove and flank wear are the two kinds of wear that most influence this change in surface roughness. Groove wear changes the tool nose curvature, and this is reflected in the workpiece surface. It also increases the chip side flow. After a certain limit surface is also greatly influenced by the flank wear. Frequently both groove and flank wear are the causes of growth of roughness.

In the present work experiments have been carried out in an attempt to monitor the change of workpiece surface roughness caused by the increase of tool flank wear during milling operation.

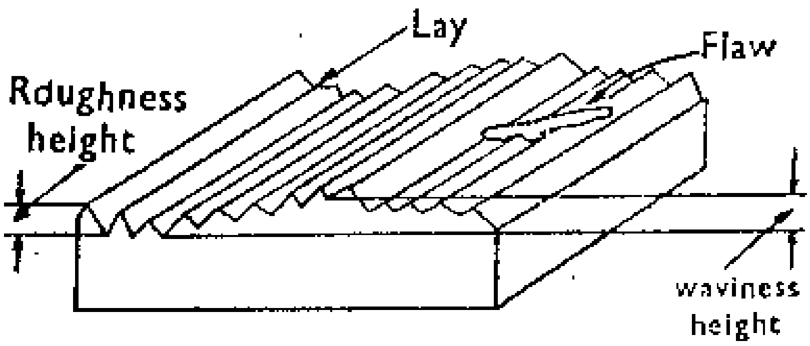


FIG. 1.3(a) A typical surface highly magnified.

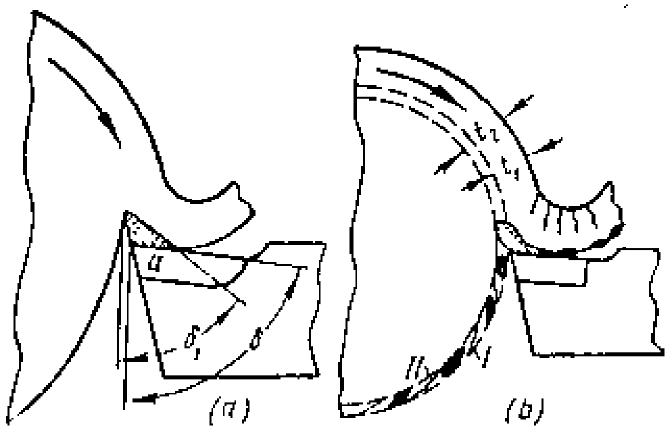


Fig. 1.3(b) *Built-up edge on a single-point tool: (a) stable BUE; (b) break down of the BUE*

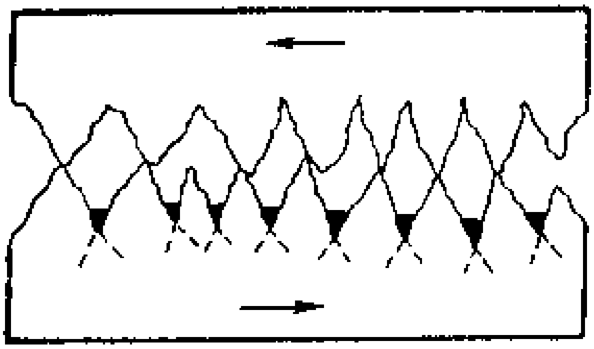


Fig. 1.4 *Contact of microirregularities*

1.2 LITERATURE SURVEY

M.E.R. Banifacio and A.E. Diniz [1] carried out experiments on job surface finish through variation of the vibration in finish turning. He also investigated the change of workpiece surface roughness caused by increase in tool wear, under different cutting conditions. These results shows that vibration of the tool can be resulted from higher degree of its wear considered as a limiting condition of tool wear for a certain level of job surface roughness in finish turning. These conceptions have been used in the present work.

Kai Yang and Angus Jeang [2] studied the statistical surface roughness checking procedure based on a cutting tool wear model. His study develops an efficient surface roughness monitoring and controlling procedure that combines statistical analysis and the physics of cutting tool wear mechanism.

Researcher Chisholm [3] studied the influence of cutting speed on surface roughness during turning and demonstrated that maximum roughness (H_{max} / R_{max}) height approaches the ideal value when cutting speed is increased.

Opitz and Moll [4] investigated the effect of feed and nose radius on job surface roughness in turning operation. An extensive survey on surface finish research has been made by spears [5].

The topographic characteristics of a surface texture have been extensively studied by Protevin [6], Nicolau [7], Peklenik & Kubo [8,10], Nakamura [9] and others.

Theoretical analysis on up-milling and down-milling has been done by Martellotti [11] who clearly showed that the path of a milling cutter tooth is trochoidal. Martellotti derived equations of this trochoidal tool path for the maximum undeformed chip thickness (t_m) which corresponds to the feed in turning operation, the undeformed chip length (l) from which the time of contact per tooth can be found, the inherent roughness height (h) lift over by milling process. The inherent roughness height (h) equation for trochoidal path are used to determine the characteristics of job surface roughness with change of tool wear.

Special contributions toward tool wear were made by the following researchers through their respective research work which should be regarded as the background study for this present work.

In the early 1900s, Frederic Taylor [12] and associated metallurgists developed high speed steel and revolutionized the whole metal cutting industry. His work enabled cutting tools to retain the hardness of cutting edges at elevated temperature of over 1000°F. Since then, lots of research had been carried out in this field over the decades with a view to improving metal cutting process and cutting conditions to formulate optimisational constraints for cutting conditions, to explain the mechanics of metal cutting and the interrelated effect of tool geometry, tool temperature, chip formation, cutting fluid and surface finish, vibration in metal cutting tool wear in cutting process.

Ernest and Merchant [13], Gilbert [14], Rozenberg [15] and Bekes, Jan B. [16], and so forth are the very famous researchers in this field.

In 1958, a research work had been conducted by Markov, A.D. [17] about tool wear and tool life. Later on Bhoothroyd, G. [18], Shaw, M.C. [19] Solaja, V [20] carried out research works on effect of tool wear on the temperature generated during metal cutting in 1967. Similarly other researchers like Tantalov, N.V. [21] Cherimoshnikov, [22] N.P. Kurchenco, A.I. [23] showed the influence of cutting speed on different characteristics of metal cutting process and tool wear. In 1970, Thime, I.A. [24] conducted an extensive research on "Resistance of Metal and Wood during Cutting".

His study gives the idea of cutting forces during cutting actions to overcome the resistance of the chip. Cutting speed has also great effect on cutting process which inturn affects on built up edge formation, its maximum height and disappearance. A good relationship between BUE formation and cutting speed has been given by a famous researcher Isaev, A. [25], by conducting a significant number of experiment.

Yeremin, A. [26] is another famous researcher who extensively studied the effect of cutting speed on the cutting angle produced by the built-up edge (BUE), chip contraction and tool wear.

Malkin, A. [27] studied the relationship between tool life and cutting speed for different tool materials. His study showed that tools of plain carbon steel and HSS have decreasing nature of tool life with increasing in cutting speed.

Relationship between cutting temperatures and cutting speed at various depth of cut had been studied by Danielyan, A. [28]. He showed that temperature increases with increase in cutting speed and depth of cut in general. He also studied the relationship between the cutting temperature and the cutting angle at various speeds.

From the literature survey made above it becomes clear that though many research works have been carried out on metal cutting process, sufficient works have not yet been done to investigate the relationship between change of job surface roughness resulted by the change of tool wear as cutting time elapsed during milling operation.

1.3 AIMS AND OBJECTIVES

The critical value of the flank wear (which indicates the moment of tool replacement) is commonly determined from tool wear vs. time curve. The present study was undertaken -

To investigate both the tool wear and job-surface roughness in relation to the machining time.

To study the relationship, if any, between tool wear and job surface roughness during up milling and to determine the critical flank wear.

In view of the above study, the aims and objectives of the present work were -

To develop a relationship between tool wear and job surface roughness as a function of cutting time.

To establish a relationship between job surface roughness and change of tool wear on the basis of experimental results.

CHAPTER-2

2.1 THEORETICAL ANALYSIS OF JOB SURFACE ROUGHNESS DURING MILLING PROCESS

The quality of a machined surface during milling is characterized by the accuracy of its manufacture in respect to the dimensions specified by the designer, its physico-mechanical properties and the roughness obtained in machining. The physico-mechanical properties of machined surfaces depend chiefly on the chemical composition of the given metal, its microstructure, strength, hardness, residual stresses, wear resistance and corrosion resistance.

The roughness of a machined surface - one of the main characteristics of its quality - greatly affects the wear resistance of the surface of the part, its strength, corrosion resistance and the reliability of fixed joints of mating parts.

The roughness of the machined surface is affected by the chip-formation process and some other factors which include cutting speed, properties of the metal being machined, tool geometry, cutting fluid, elastic deformation of the surface, roughness of the cutting edge on the tool and degree of tool wear. The present work is about the tool wear effect on job surface roughness.

A through analysis has been presented by "Martellotti" on job surface roughness who clearly showed that the path of a milling cutter tooth is trochoidal. Previous to this work the tooth path was considered to be a circular arc.

Ideal surface roughness in plain milling can be easily evaluated from (Fig. 2.1). It is generally found that superimposed waviness occurs for each revolution of the cutter. This waviness may be due to eccentricity in the spindle or variation in tooth heights.

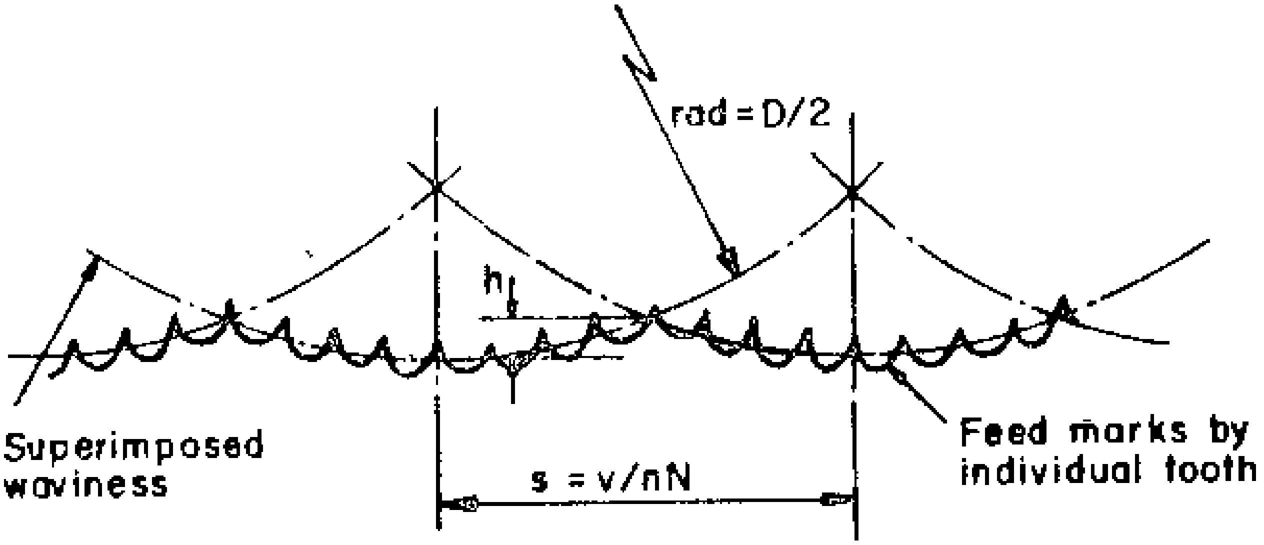


Fig. 2.1) Surface roughness in plain milling

For ideal surface roughness the surface generated by an individual tooth may be approximated by an arc of a circle of diameter equal to that of the cutter. The surface generated will also have the feed marks by individual tooth as shown in Fig. 2.1.

From Fig. (2.1)

$$\left[\left(\frac{D}{2}\right)^2-\left(\frac{D}{2}-h\right)^2\right]=\left(\frac{S_o}{2}\right)^2$$

It is also noticed that even when a circular path is assumed a number of approximations are required to arrive simple relations. Assuming a circular tooth path implies that the workpiece is stationary during a tooth engagement and then moves suddenly by feed per tooth (S_o) before the next tooth starts a cut.

When considering circular path, the inherent roughness height (h) is left over on the job during plain milling process depends on feed per tooth (S_o) and cutter diameter (D).

On simplification this relation can be expressed by the equation:

$$h=\frac{S_o^2}{4D}$$

Where,

S_o = feed per tooth

D = cutter diameter

When the trochoidal path is considered "Martellotti" showed that the inherent roughness height or height of tooth mark (h) depends on feed per tooth (S_o), cutter diameter (D) and number of tooth in cutter (Z). This relation can be expressed by the equation:

$$h = \frac{S_o^2}{D\left[\frac{D}{S_o}\right] \pm \frac{8Z}{\pi}}$$

The upper sign refers "up" milling and lower sign refers to down milling.

where,

S_o = feed per tooth

D = cutter diameter

Z = Number of tooth in cutter

h = height of tooth marks or surface roughness height left over plain milling process.

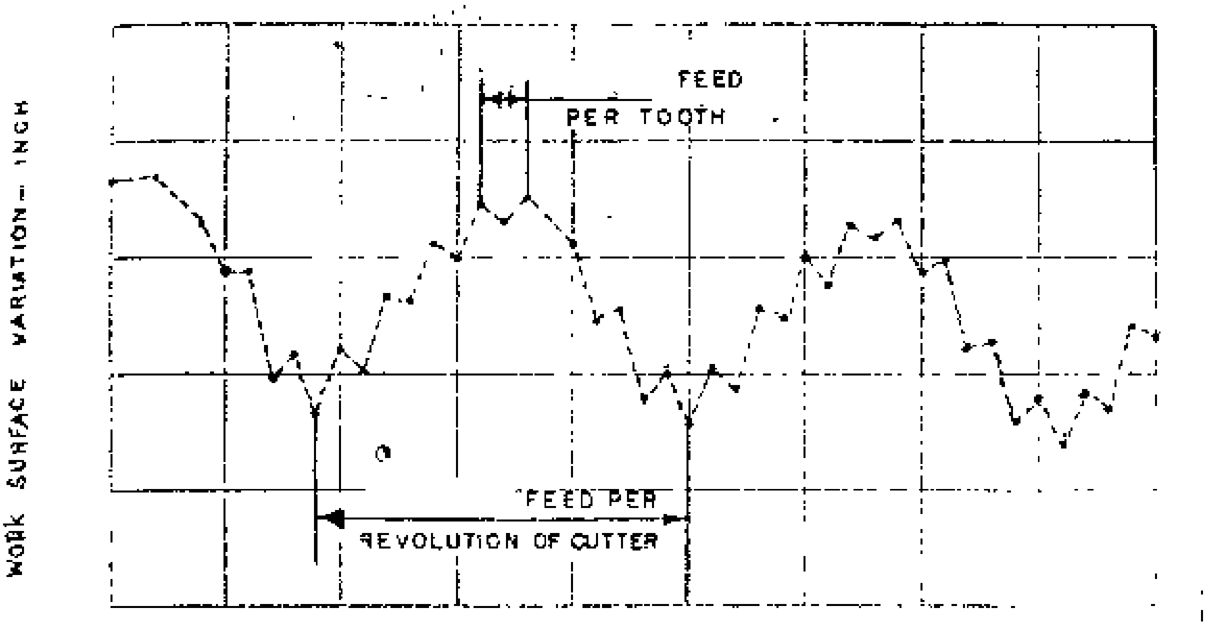
Quality of finish of a machined surface is generally affected by: (1) Tool marks: Tooth and revolution marks as shown in (Fig. 2.2) which depend on the tool geometry of the machining process used.

In up-milling tooth marks such as A, (Fig. 2.3) results from the engagement of a tooth with the work material. In down milling, a similar mark N' (Fig. 2.4) is generally produced.

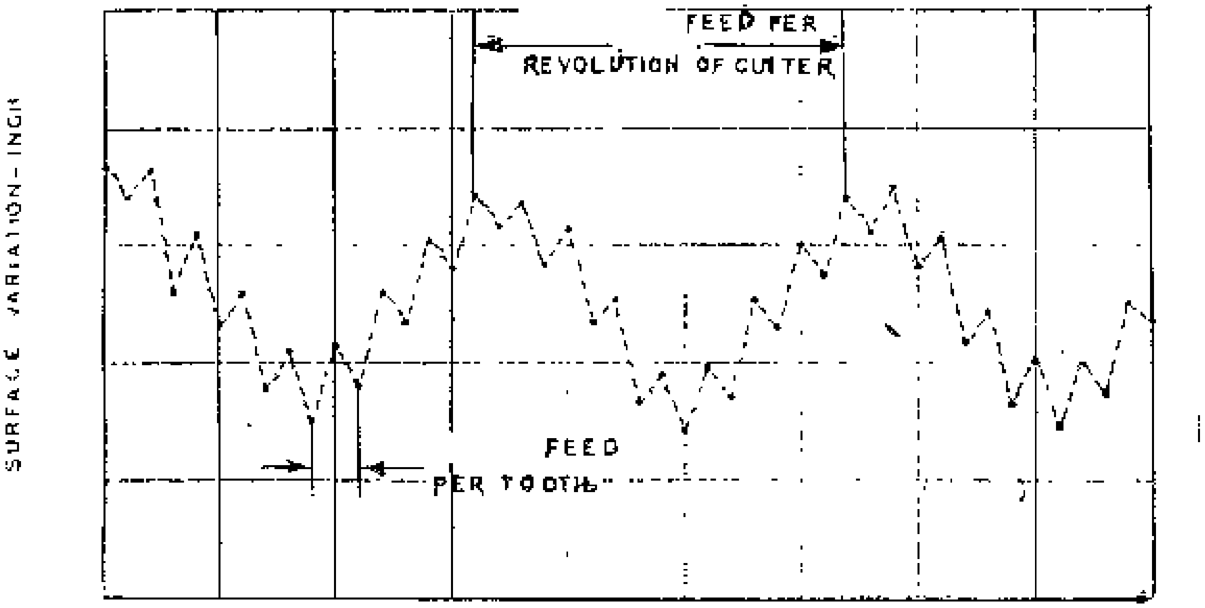
A milled surface may be generally considered as the result of innumerable elements of the tooth path of a length approximately equal to the feed per tooth.

The uniformity of the spacing depends on the location of the points such as AA' and NN' (Fig. 2.3 and Fig. 2.4), where the teeth intersect the path generated by the preceding teeth.

In addition to the tooth marks, a surface milled with a plain milling cutter may show periodic variations having a wavy appearance, and recurring with the frequency of the cutter revolutions per minute.



UP MILLING



DOWN MILLING

Fig. 2.2 Tooth and Revolution Marks on a Milled Surface

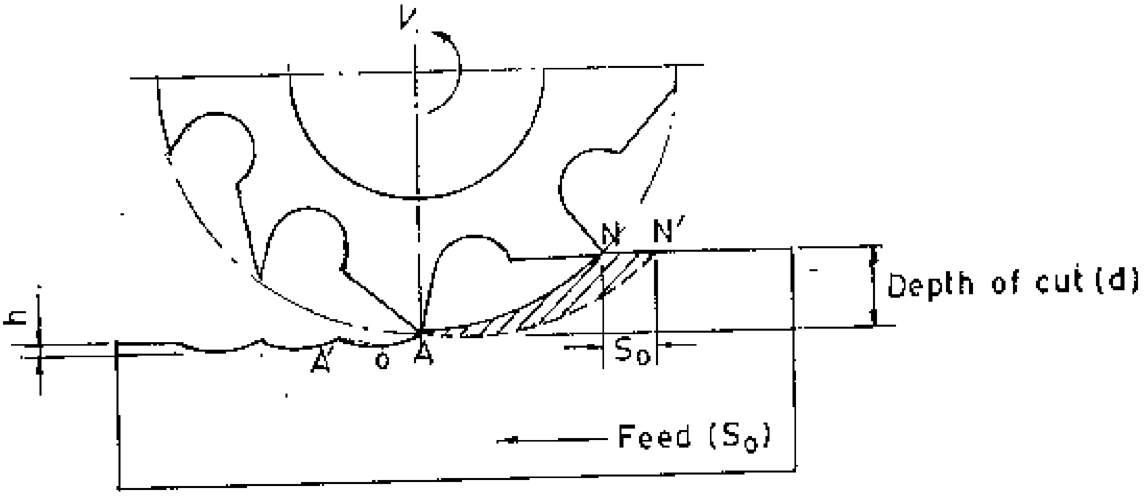
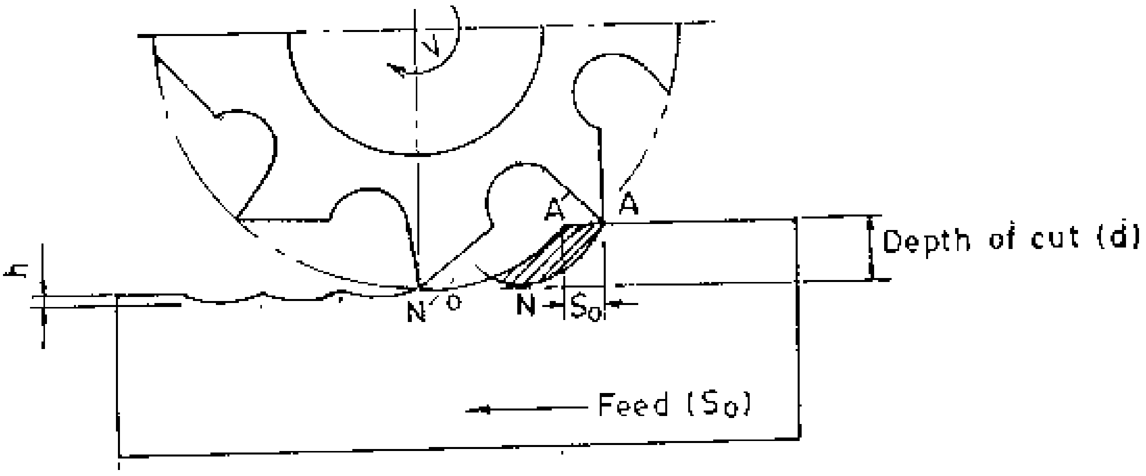


Fig.(2.3) UP MILLING



Fig(2.4 DOWN MILLING

The presence of one or the other or both types of marks alters the geometric conditions of the surface and, consequently, the quality of surface finish.

(2) Marks Produced in Formation of Milling Chips : Marks of microscopic dimensions resulting from the plastic flow of the material during the formation of chip.

For a short distance after the cutting edge contacts the work surface machined by up-milling is shiny in appearance and of uniformly good finish. The extent of this surface depends on the material being cut, chip thickness and rake angle and also on the presence on the cutting edge and adjacent surfaces of a film of molecular dimensions which prevents the chip material from bonding to the tooth and forming the built up edge.

In the present case (up milling process), the element of smooth surface produced at the beginning of chip formation is an element of the final surface. This condition ensures a surface of generally good finish and free from fragments of the built-up edge.

The quality of surface finish also may sometimes be affected by chip fragments adhering to the teeth and being dragged into the work in subsequent engagements.

2.2 ISO RECOMMENDATION FOR ASSESSMENT OF SURFACE ROUGHNESS.

In ISO recommendation three items are necessary for assessment of surface roughness. Those three items are:

i. R_a
ii. R_{max}
iii. R_z

i. R_a

R_a is the arithmetical average [CLA or Centre-Line-Average] value of the departure of the whole profile both above and below its centre line throughout the prescribed meter cut-off in a plane substantially normal to the surface. As shown in (Fig. 2.5). Mathematically, $h \text{ or } R_a = \frac{1}{l_s}\int_0^{l_s} |y| dx$.

ii. R_{max}

R_{max} is the maximum distance between two reference lines parallel to the mean line touching the highest and lowest points within the sampling length (l_s) as shown in (Fig. 2.6).

iii. R_z

R_z is a ten-point averaged height of irregularities. It is given by the difference between the average height of five highest peaks and five lowest peaks within the sampling length 'l_s' measured with respect to a datum parallel to mean line as shown in Fig. 2.7.

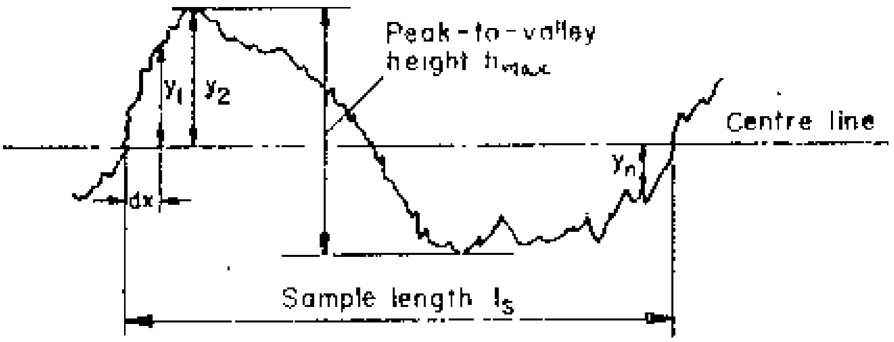


Fig. 2.5 Surface roughness profile

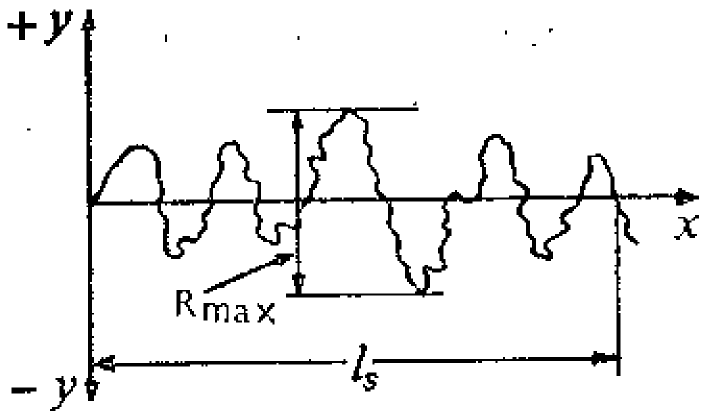


Fig. 2.6 R_{max} within a sampling length.

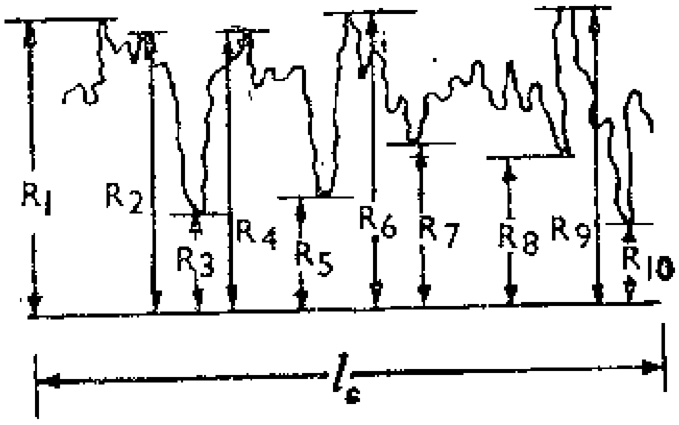


Fig. 2.7 Determination of ten-point averaged R_z.

Mathematically,

$$R_y = \frac{(R_1 + R_3 + R_5 + R_7 + R_9) - (R_2 + R_4 + R_6 + R_8 + R_{10})}{5}$$

The surface finish may also be specified in terms of peak to valley height, centre line average (CLA) or root mean square (RMS). The peak to valley height H_{max} is the root to crest value of surface roughness as shown in (Fig. 2.5).

The centre line average value is found by averaging the height of the surface above and below a centre line over the sample length l_s. The centre line is a line parallel to the general profile direction such that the profile areas below and above the centre line are equal. If the ordinates y or h are y_1, y_2 ....y_n or h_1, h_2 .. h_n then $h_{CLA} / h = \frac{1}{n}\sum_{i=1}^{n}|y_i|$.

The RMS value is defined as the square root of the mean of the squares of the ordinates of the surface from the centre line. Thus,

$$h_{RMS} = \left[\frac{y_1^2 + y_2^2 + \ldots\ldots y_n^2}{n}\right]^{1/2}.$$

2.3 THEORETICAL ANALYSIS OF TOOL WEAR DURING MILLING OPERATION

There are various ways in which tool failure can be identified e.g.., wear land size, depth of crater, tool wear volume, magnitude of cutting forces, change in component size, total destruction of tool, surface finish value etc. The main objective of this work is the tool failure identification by surface finish quality.

The rapid increase of wear at the end of tool life, causes a sharp increase of surface roughness and leads to more vibration.

The geometry of tool wear causes a change in surface roughness as machining time elapses Groove and flank wear are the two kinds of wear that shows significant influence on change in surface roughness.

In milling operation during revolution of cutter tooth most of its path passes through the air without doing any cutting. This cools the tooth and has a favorable effect on tool life. To continue the chip formation process along the work, the tooth must enter the cutting zone again. This is accompanied by an impact of the cutting edge against the layer of stock to be removed. Such impact loads shorten cutter life and in some cases lead to complete failure of the cutting edge.

In up milling the gradual increase in load on the tooth could be cited as another advantage if the tooth could begin the cut exactly at the theoretical point of tooth entrance K (Fig. 2.8). However since the cutting edge can not be absolutely sharp and is rounded over to a minute radius (ρ), the tooth actually begin the cut at point M. The tooth is subjected to heavy friction in sliding over the cut surface from K to M and since this surface is work hardened by the action of the preceding tooth intence flank wear occurs.

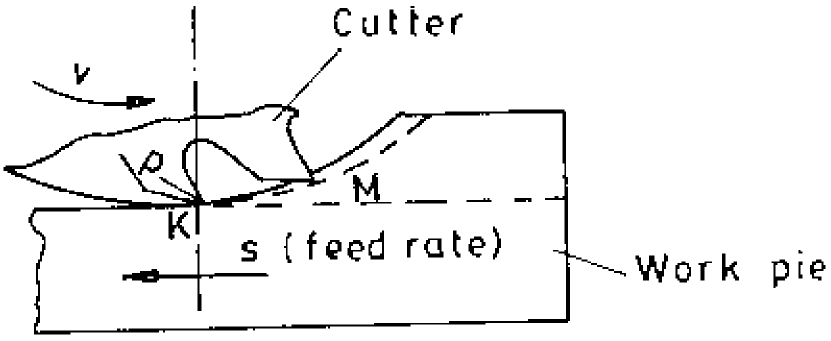


Fig.(2.8) Tooth entrance in up milling

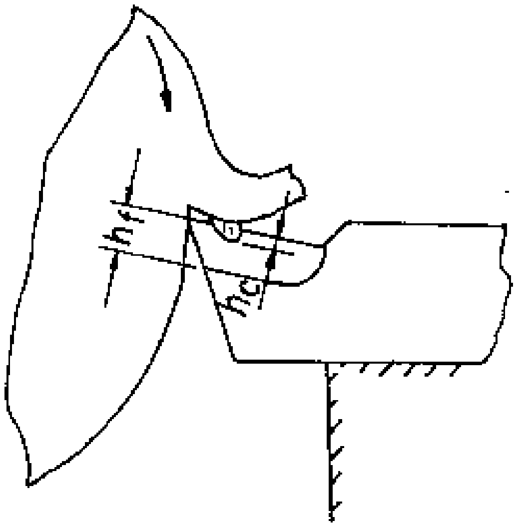


Fig (2.9) Flank wear

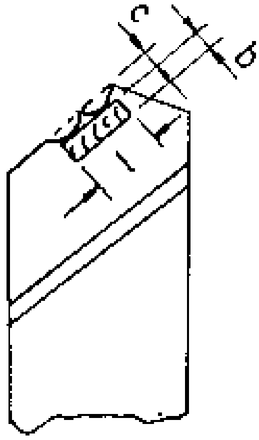


Fig (2.10) Crater we

In the process of cutting metals the tool is worn as a result of friction of the chip on the tool face and of the tool flanks on the work-piece. Tool wear involves abrasion and the removal of micro-particles from the surface, as well as microscopic chipping of the cutting edge.

The physical phenomenon of tool wear in metal cutting is extremely complicated. It involves abrasive, molecular and diffusive wear. Abrasive wear results from scoring - the cutting away of microscopic volumes of the tool material by the inherently hard structural constituents of the material being machined. A skin on casting or scale on forging also produces a severe abrasive effects.

Molecular wear results from the action of the considerable forces of molecular adhesion between the work material and the tool. As the chip slides it tears away minute particles of the tool material. Diffusion wear occurs as a result of the mutual dissolution of the reacting materials of the work tool pair.

Tool wear depends upon many factors: Physico mechanical properties of the material being machined and of the tool material, conditions of the surfaces and cutting edges of the tool, kind of cutting fluid used and its physico chemical properties, cutting variables, condition of the machine tool, rigidity of the machine-fixture-tool-workpiece complex and other machining factors.

In the general case tool wear occurs both on the face and flank but depending upon the machining conditions, one of these types of wear may predominate.

Flank wear is characterized by the height (h_f) of the wear land (Fig. 2.9). Face wear is characterized mainly by the depth h_c and the width `b' of the wear crater (Fig. 2.10); the change in the length of the crater is `l' negligible. Flank wear is nonuniform along the active section of the cutting edge on tools having a nose radius. Flank wear can be measured by micrscope. The height h_f of the land below the cutting edge with a relief angle equal to 0^0, is the more typical and is more frequently the limiting factor. The larger this land, the more friction between the tool and work and greater the cutting forces required.

The dependence of flank wear on time of tool operation is expressed by the flank wear vs. time curve (Fig. 4.2) that can be divided into three sections.

Section I is the wear in period (initial wear) which occurs due to higher pressure per unit on contact surface between the tool and the workpiece.

Section II is the period of normal wear. It is characterized by gradual wear with the operation time. When a certain degree of wear has been reached, the frictional conditions changes (mainly due to the sharp rise in cutting temperature) and period III begins. This can be called the period of rapid (destructive) wear.

Certain characteristics features of flank wear growth may be observed from (Fig. 4.2). Upto point `I', the region I denotes the zone of initial wear. The sharp edge rapidly breaks down due to plastic deformation and consequential temperature rise and the point `I' is reached. After that the wear rate process is more or less uniform until a point `J' has been reached. The IJ region shown as region II in Fig. (4.2) is the mechanical wear region. Beyond `J' the rapid growth of wear process ensures and the cutting tool fails very soon after reaching this point of inflexion J. This point `J' is often called as critical point of flank wear characteristics or simply `critical flank wear'.

In machining tough (ductile) metals, tool wear will proceed in a more complex manner. Flank wear predominates at low cutting speeds, when there is no built up edge (BUE). The reason for this is that the sliding speed on the flank about the workpiece is higher than that of the chip on the tool face (because of chip contraction).

When flank wear reaches a certain value, cutting force increases, the cutting temperature is raised, the finish of the machined surface deteriorates, machining accuracy is lowered and vibration is caused.

CHAPTER-3

EXPERIMENTAL PROCEDURE

Metal cutting by milling operation is a common operation in many manufacturing system and surface roughness is an important measure of quality in metal cutting. If the surface becomes too rough, the cutting tool has to be replaced.

To develop a relationship between tool wear and job surface roughness as a function of cutting time and to establish a relationship between job surface roughness and change of tool wear on the basis of experimental results the following procedure was followed.

i. A flat surface was machined by milling operation on mild steel using HSS tool.

ii. Flank wear of the tool and roughness of the job surface were periodically measured after a definite interval of time of machining (6.5 min).

iii. Tool wear was measured along the flank surface of the tool using a microscope. Relation of wear characteristics with time was investigated.

iv. Surface roughness was measured on the surface milled by HSS tool. This was done using a surface roughness measuring equipment. Relation of surface roughness characteristics with time was investigated.

v. Relationship between change of job surface roughness resulted by the change of tool wear as the cutting time elapsed during milling operation was investigated.

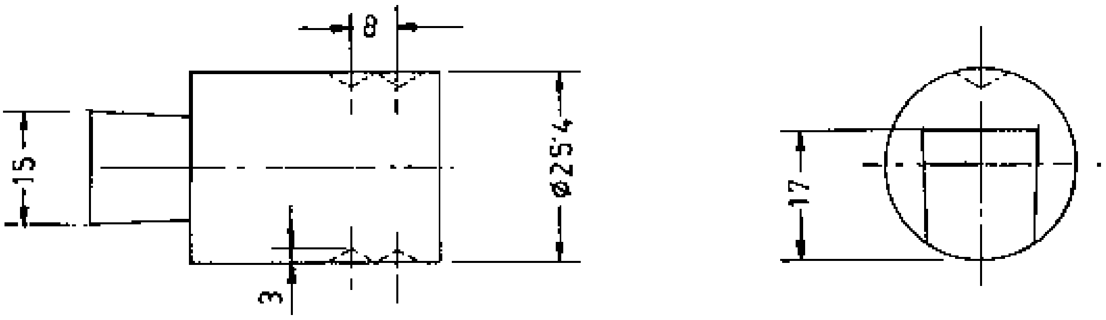
3.1 DESIGN OF A SINGLE TOOTH FLY CUTTER AND TOOL HOLDER

To investigate tool wear a single tooth fly cutter was designed. Detailed design of the fly cutter and the tool holder are shown in (Fig. 3.1).

During designing of the single tooth fly cutter the recommended values of relief angle and back rake angle were taken as 9° and 4° respectively. The tool holder was made of mild steel. One single tooth fly cutter of high speed steel (HSS) was made, which was used in milling (up milling) process. The tool was half hardened and the hardness was about 50-55 RC.

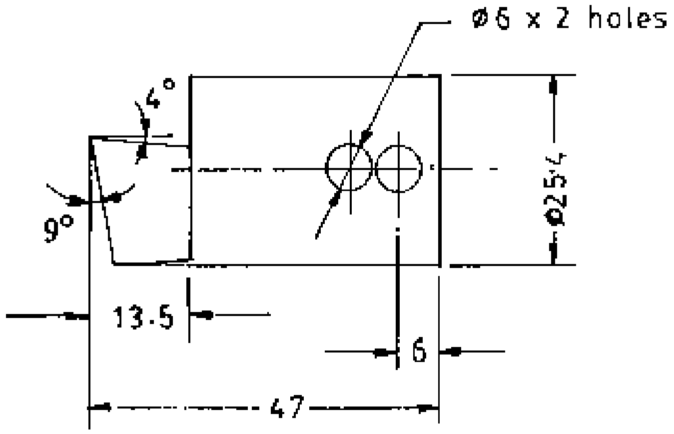
The single tooth fly cutter (2) was overhangs from the tool holder (1) and was clamped by clamping screws (3, 4). The diameter and length of cutter were 25.4 mm and 47.0 mm respectively. The diameter and length of the tool holder were 66mm and 49.5mm respectively.

Arrangement was done to adjust the overhanged of the tool from the tool holder so that diameter of the cutter could be varied. Experiments on tool wear were conducted for a fixed diameter of the cutter. Detailed drawings of single tooth fly cutter and single tooth fly cutter mounted on the tool holder are shown in Fig. 3.1 and 3.2 respectively. The dimension of the workpiece is shown in Fig. 3.3.



FRONT VIEW

L.H.S VIEW



TOP VIEW

Fig. 31 Single tooth fly cutter

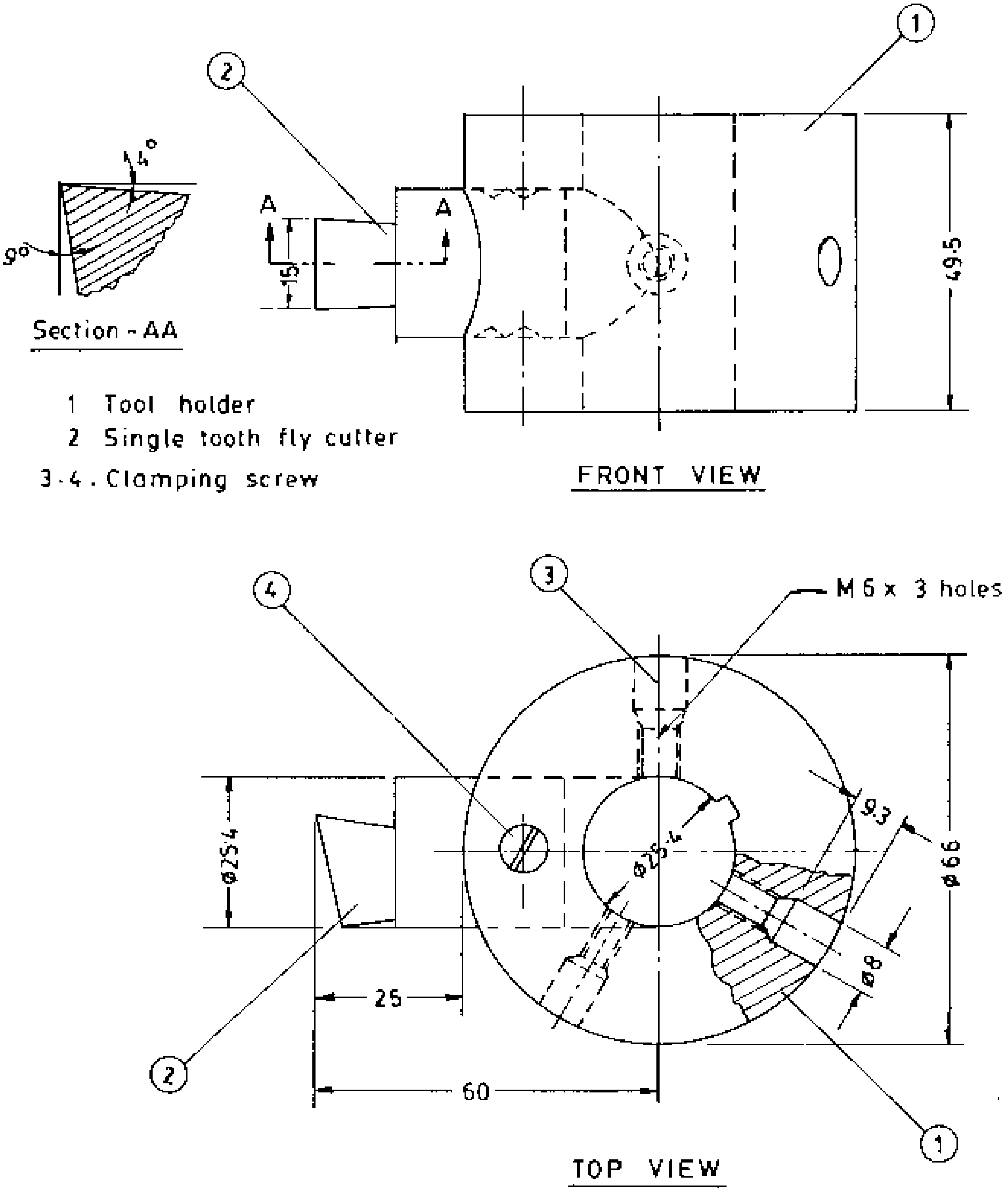


Fig.3.2 Single tooth fly cutter mounted on the tool holder

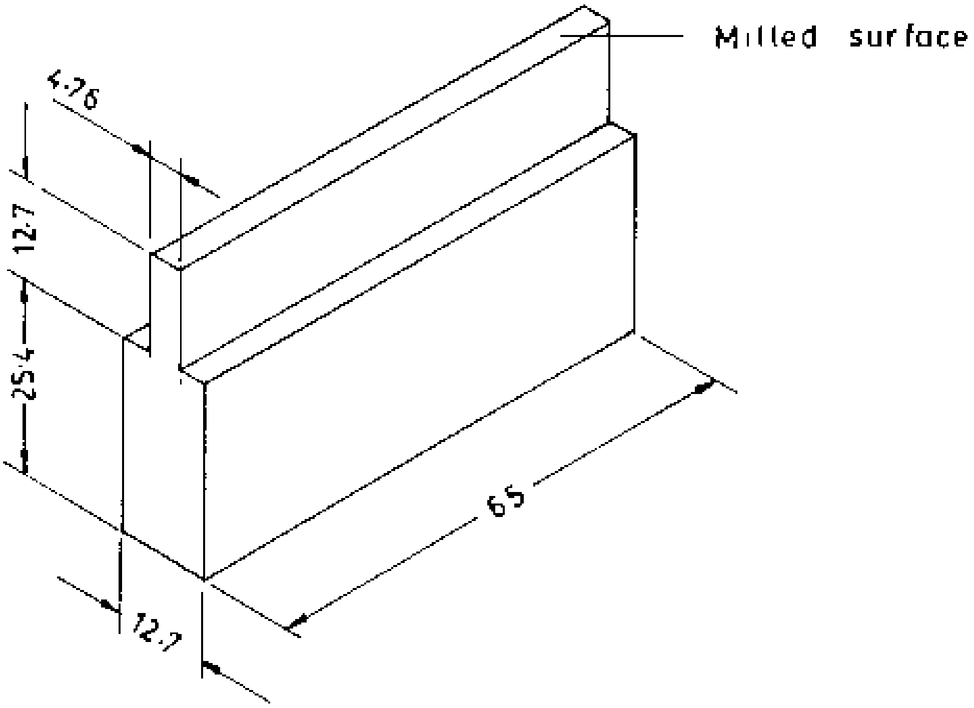


Fig. 3.3 Work piece

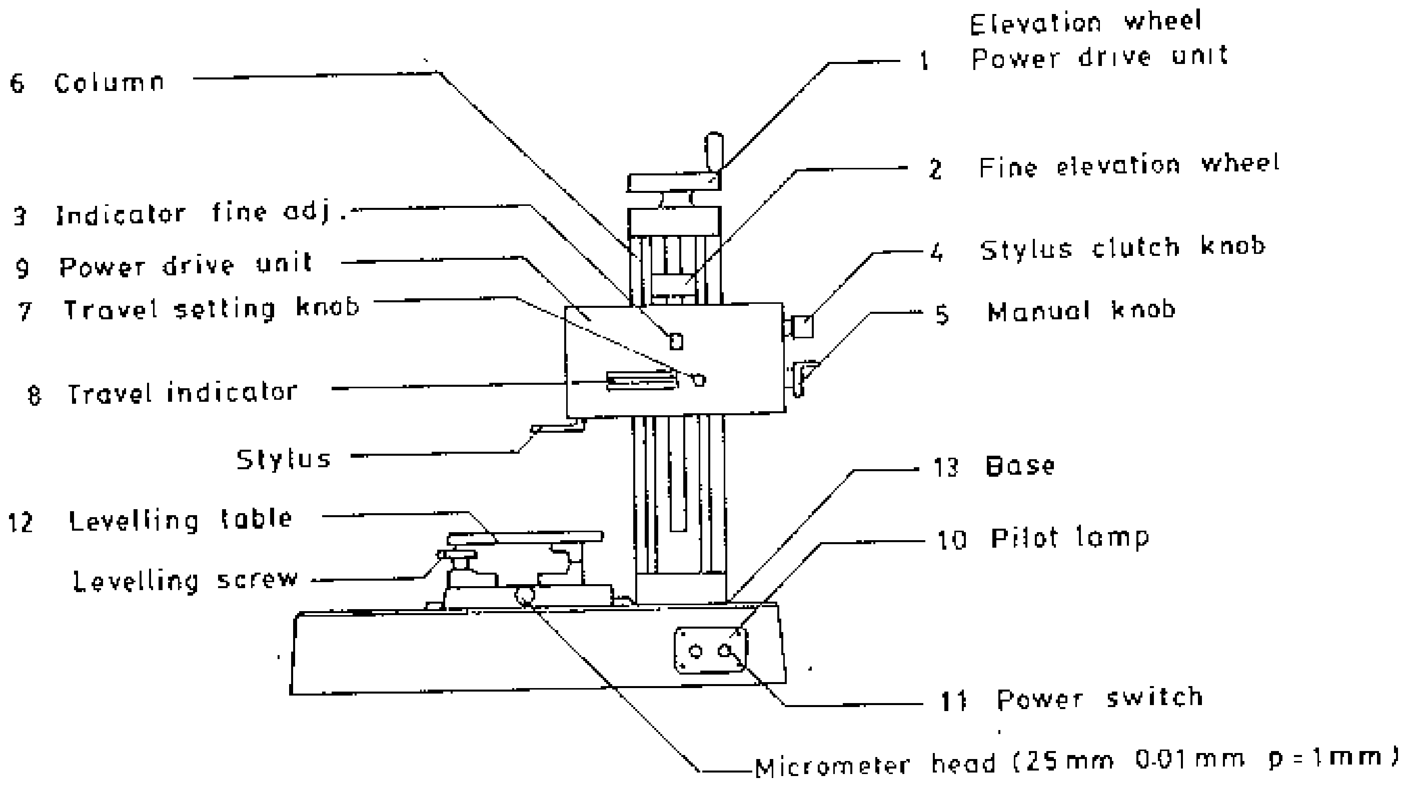
3.2 A BRIEF DESCRIPTION OF THE SURFACE ROUGHNESS MEASURING EQUIPMENT

Surface roughness was measured on surfaces machined by milling process using HSS tool. This was done using a surface roughness measuring equipment (surface test AB-5 machine, Fig. 3.4, 3.5, 3.6). The surface test AB-5 is a stylus type surface roughness measuring instrument, designed to have accurate measurement of surface texture with high magnification. The level of the irregularity concerning surface - texture can be represented as deviation from the nominal surface in terms of roughness, waviness and straightness.

Surface test AB-5 machine is also applicable for measurement of deviation from the nominal surface. The surface test AB-5 machine consists of a measuring unit and amplifier/recording unit. As the stylus passes over the surface its rises and falls (mechanical displacement) by amount proportional to surface roughness. The mechanical displacement of the stylus is converted into electrical responses thru strain gage of bridge circuit and it amplified in the amplifier/recording unit into a desired vertical magnification as shown in Fig 3.7. The horizontal magnification is determined by the stylus speed and chart feed speed. Specification of the surface roughness measuring equipment is given in Appendix-I.

1. Furnished Accessories of Surface Roughness Measuring Equipment

i. Leveling table (± 5^{0})
ii. Workpiece holding device
iii. Small vice
iv. Precision reference specimen (12 μm, in height, about 160^{0})
v. Recording chart (3 folds)



FRONT VIEW

Fig (3·4) Surface roughness measuring equipment (surf. test AB-5 machine)

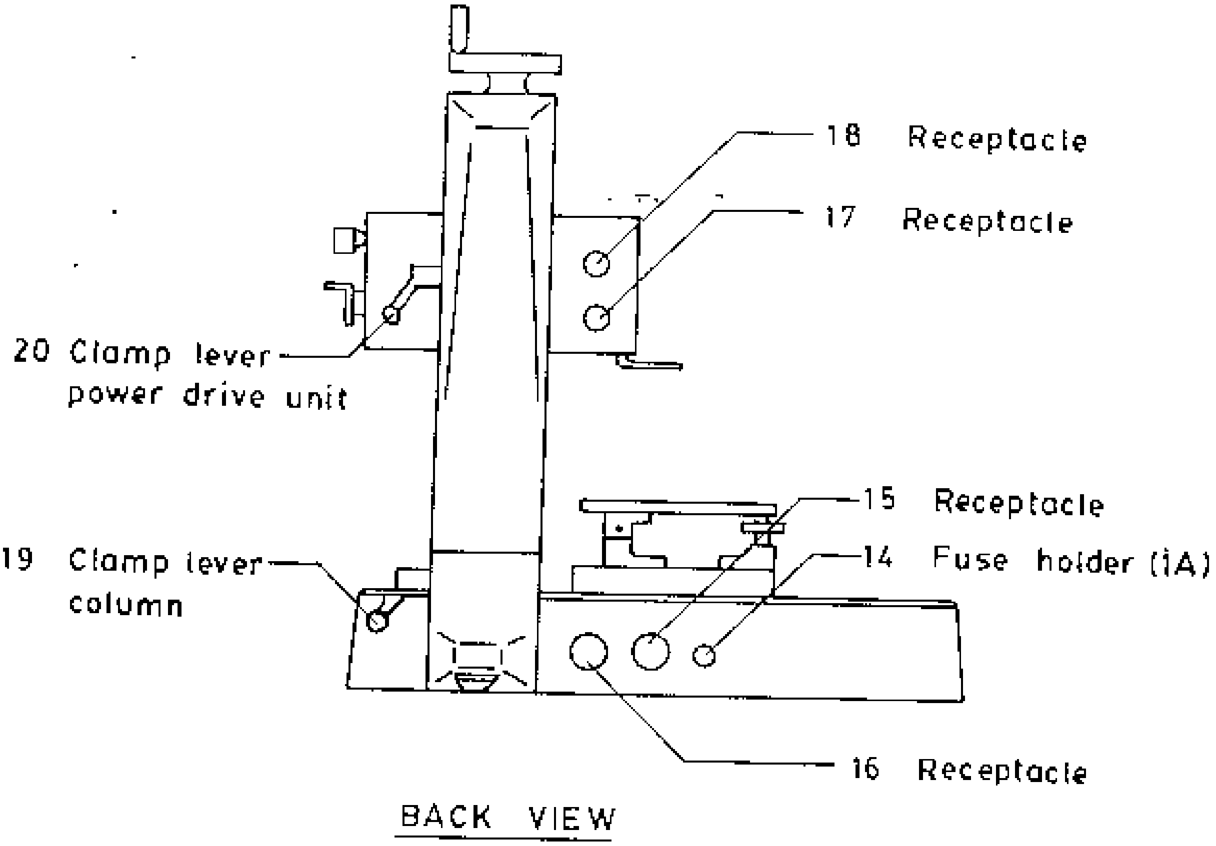


Fig. (3.5) Surface roughness measuring equipment (surf. test AB-5 machine)

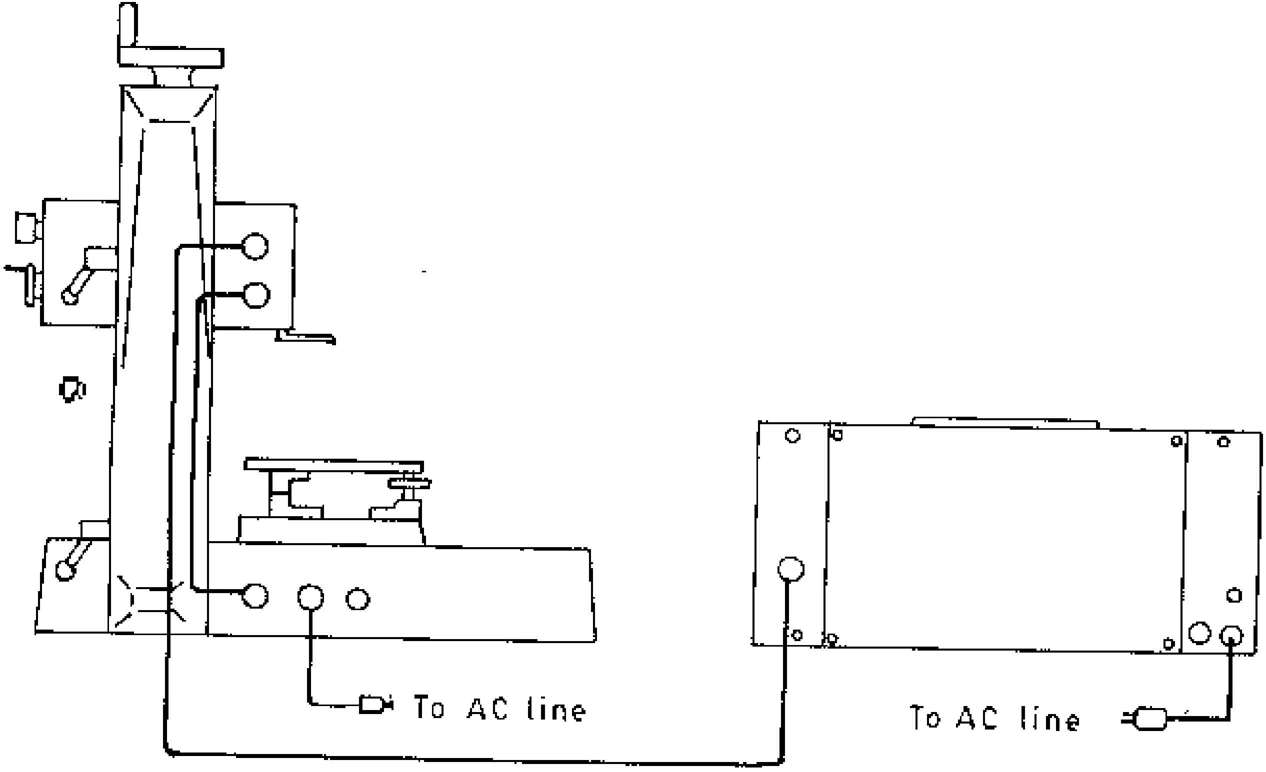


Fig (3.6) Surface roughness measuring equipment (surf. test AB-5 machine)

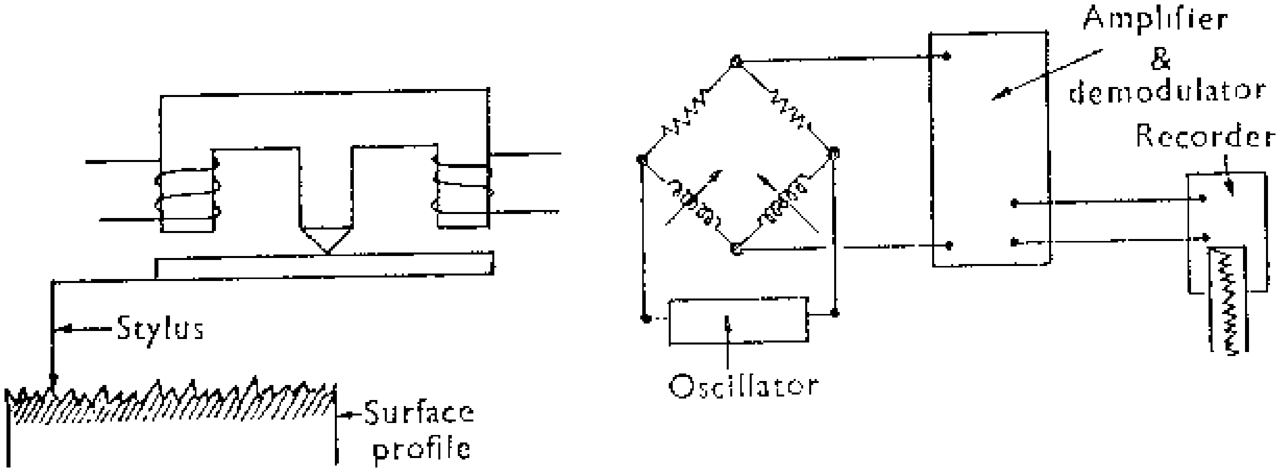


Fig. 3.7 Basic scheme of inductive-bridge type instrumentation for surface roughness measurement.

vi. Fuse (1A 2 PC's)

vii. Power supply cord (3-pin) measuring unit

viii. Connecting cord (4-pin) power drive unit to base

ix. connecting cord (10-pin) power drive unit to recorder

x. Ink (red) 5 cartridges

Pen cleaning wires 10 pcs

Blower

Injector

2. MEASURING UNIT OF SURFACE ROUGHNESS MEASURING EQUIPMENT

1. Elevation Wheel Power Drive Unit

Elevation wheel is used to move the power drive unit in the range of about 180mm for positioning the stylus on the workpiece to be measured.

2. Fine Elevation Wheel

The fine elevation wheel is used to elevate the power drive unit finely in the range of 7 mm. Clockwise rotation is used to move the power drive unit upward, and counter-clockwise rotation is used to move it downward.

3. Indicator, Fine Adjustment

The fine elevation of the power drive unit is indicated in this indicator.

4. Stylus Clutch Knob

The clutch can be dis-engaged by turning the knob. When the clutch is disengaged, the manual knob can be used for manual driving of the stylus for leveling or quick positioning.

5. Manual Knob

When the stylus clutch is dis-engaged, the manual knob becomes effective for manual stylus drive in forward or backward direction. It is used for leveling the workpiece and quick positioning of the stylus to the measured point of the workpiece.

6. Column

Column contains power drive unit elevation screw and can be turned by about 270 degrees for measuring workpiece which can not be mounted on the base.

7. Travel Settling Knob

The travel range of the stylus can be adjusted to a desired length within the range of 50mm. The stylus will automatically stop its travel at the predetermined end of range set by this knob. Chart feed will also stop when the stylus stops.

8. Travel Indicator

It contains two indicating wheel one for traverse movement of the stylus and the other for the limit of the travel range.

9. Power Drive Unit

The power drive unit pivots the instrument and contains stylus drive mechanism and detector of stylus displacement.

10. Pitot Lamp

At `ON' of the power switch, the pitot lamp lights.

11. Power Switch

At `ON' of this switch, the measuring unit is energized with pitot lamp and the stylus will begin to travel.

12. Leveling Table

For leveling the workpiece placed on this table within the range of ± 5 degrees (counter-clockwise rotation of leveling screw for up, and clockwise rotation for down). The leveling table is furnished with micrometer head (25mm range, 0.01 mm graduation) for positioning the workpiece in cross direction to the stylus travel. Table size: 146 x 126 mm with two clips for workpiece holding.

13. **Base:** Reference surface for workpiece.

14. **Fuse Holder:** Contains 1A fuse.

15. **Receptacle:** For power supply cord.

16 & 17. **Receptacle:** To supply electric power to power drive unit.

18. Receptacle

To be connected to Amplifier/ Recording unit to give electric signals to amplifier.

19. Clamp Lever, Column: To clamp the column at desired angle.

20. Clamp Lever, Power Drive Unit:

The clamp lever is used when transporting the instrument.

3. SET UP FOR MEASUREMENT OF SURFACE ROUGHNESS MEASURING EQUIPMENT

1. Precautions Before Measurement

i. Installation

a. The instrument should be installed in a place free from vibration. The vibration will cause abnormal movement of the recording pen.

b. The instrument should be installed in a place where temperature is controlled at a certain level like in inspection room. At least should be avoided the place with rapid temperature fluctuation. The detector adhors high temperature and high humidity.

ii. Cord Connection

The cords should be connected referring to the fig 3.6 and should be made sure electric grounding from terminal of the recorder and from power supply cord of measuring unit.

a. Connection and disconnection of cords should be made with power switch at 'OFF'.

b. The power supply cords should be connected to the AC-line isolated from other electric equipment, although the input circuit of the instrument is furnished with high performance filter, excessive noise, if flows into, can be a cause for swing of pen or can affect the accuracy.

c. The instrument is set to the frequency (50 H_Z or 60 H_Z) with the AC-line before shipment.

3.3 MEASURING OF JOB SURFACE ROUGHNESS

Job surface roughness was measured by surface roughness measuring equipment (Surface test AB-5 machine). This equipment was designed to have accurate measurement of surface roughness at high magnification.

For leveling, the workpiece was placed on this table within the range of ± 5 degrees (counter-clockwise rotation of leveling screw for up, and clockwise rotation for down). The leveling table was furnished with micrometer head for positioning the workpiece.

During job surface roughness measurement switch was selected for vertical magnification 10000X. The value of one division for 10000X magnification is 0.2 μm (as shown in Appendix-I). After levelling the stylus comes in contact with the workpiece (mounted on the levelling table).

The movement of the stylus from the initial position (selected) to final position (selected) was the recorded job surface roughness height. Reading was taken at different positions of the surface milled and measure roughness as h_1, h_2 ..... h_5. By averaging the height at different point the actual height (h) was found. The whole procedure was repeated for other readings of job surface roughness height (h). The results of measure surface roughness are listed in Table-2.

3.4 MEASURING OF TOOL WEAR

Experiment on tool wear were conducted in the workshop at BUET. To investigate tool wear, one single tooth fly cutter of high speed steel (HSS) was made and used in milling a workpiece of mild steel as shown in Fig 3.3.

A flat surface was milled by up milling process using single tooth fly cutter mounted on the tool holder. After milling the workpiece at a depth of cut (t) = 0.1524 mm, feed rate (s) = 9.525 mm /min, cutter diameter (D) = 120 mm, cutter RPM (N) = 33 rpm, the cutting tool was taken under the microscope to observe flank wear of the tool. During milling operation actual cutting time was recorded. The subsequent procedures were repeated with same cutting parameters and tool dimensions until tool wear reaches the critical value. The results of measurements of flank wear are listed in table-1.

CHAPTER-4

4.1 EXPERIMENTAL RESULTS OF JOB SURFACE ROUGHNESS AND TOOL WEAR WITH MACHINING TIME

A flat surface was milled by up-milling process on mild steel using high speed steel tool. Wear was measured along the flank surface of tool using a microscope. Experimental results on tool wear are presented in Table-1.

Surface was milled with the following cutting parameters:

Rotation of the spindle (N) = 33 rpm
Feed rate of the work-piece (S) = 9.525 mm/min.
Depth of cut (t) = 0.1524 mm
Cutter diameter = 120 mm

Figure 4.1 shows the variation of surface roughness with time. This graph shows that there is an increased amplitude of the surface roughness at the beginning of cut, a decreased tendency in the middle region and again an increased tendency at the end of time.

The dependence of tool wear on the time of tool operation is expressed by the wear vs. time curve (Fig. 4.2) that can be divided into three sections. Section-I is the wear-in-period (initial wear) during which heavy abrasion of the most salient parts of the surface occurs.

Section-II is the period of normal wear. It is characterized by gradual wear with the operation time.

When a certain degree of wear has been reached, period III begins. This can be called the period of rapid (destructive) wear.

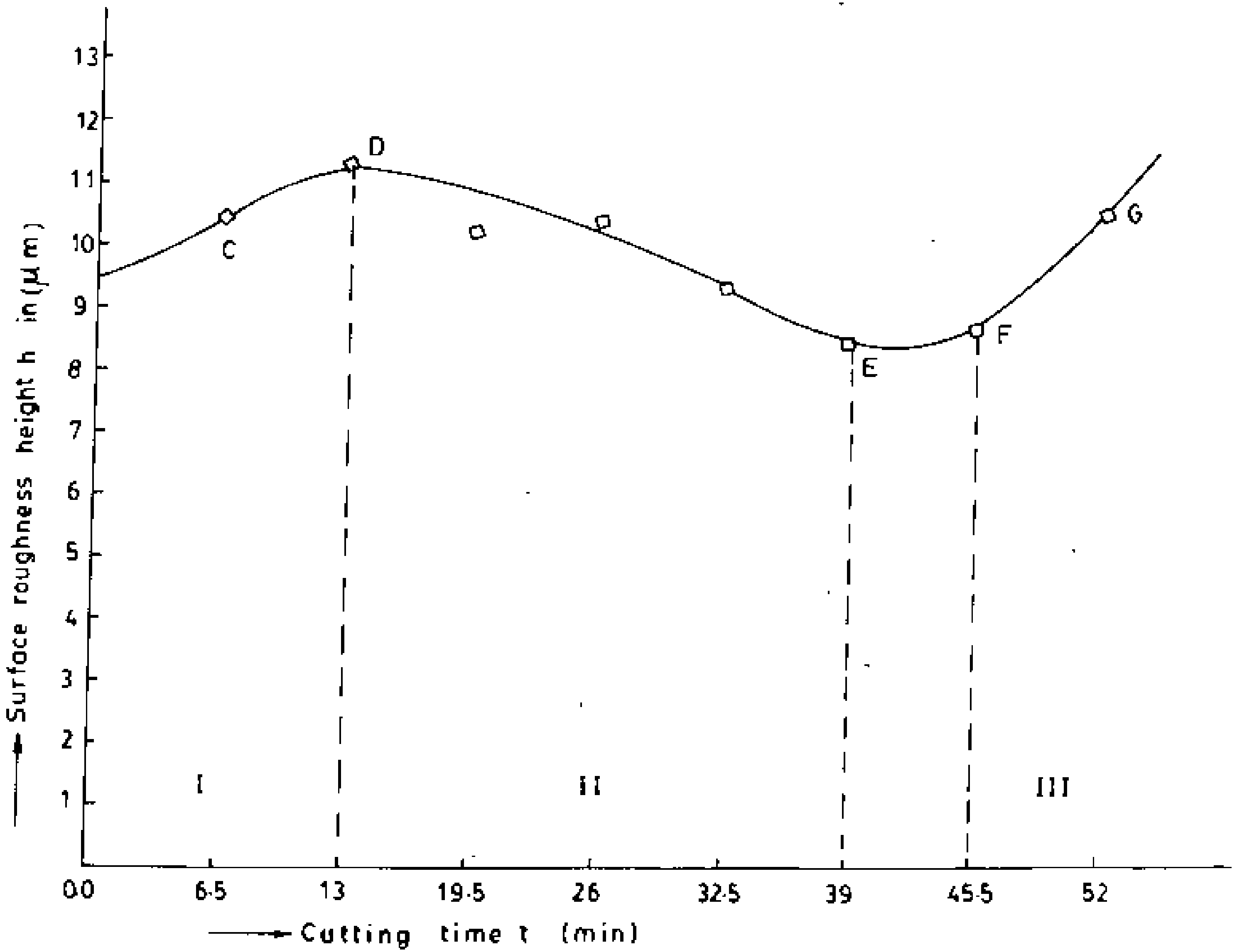


Fig. 4.1 Surface roughness height vs cutting time

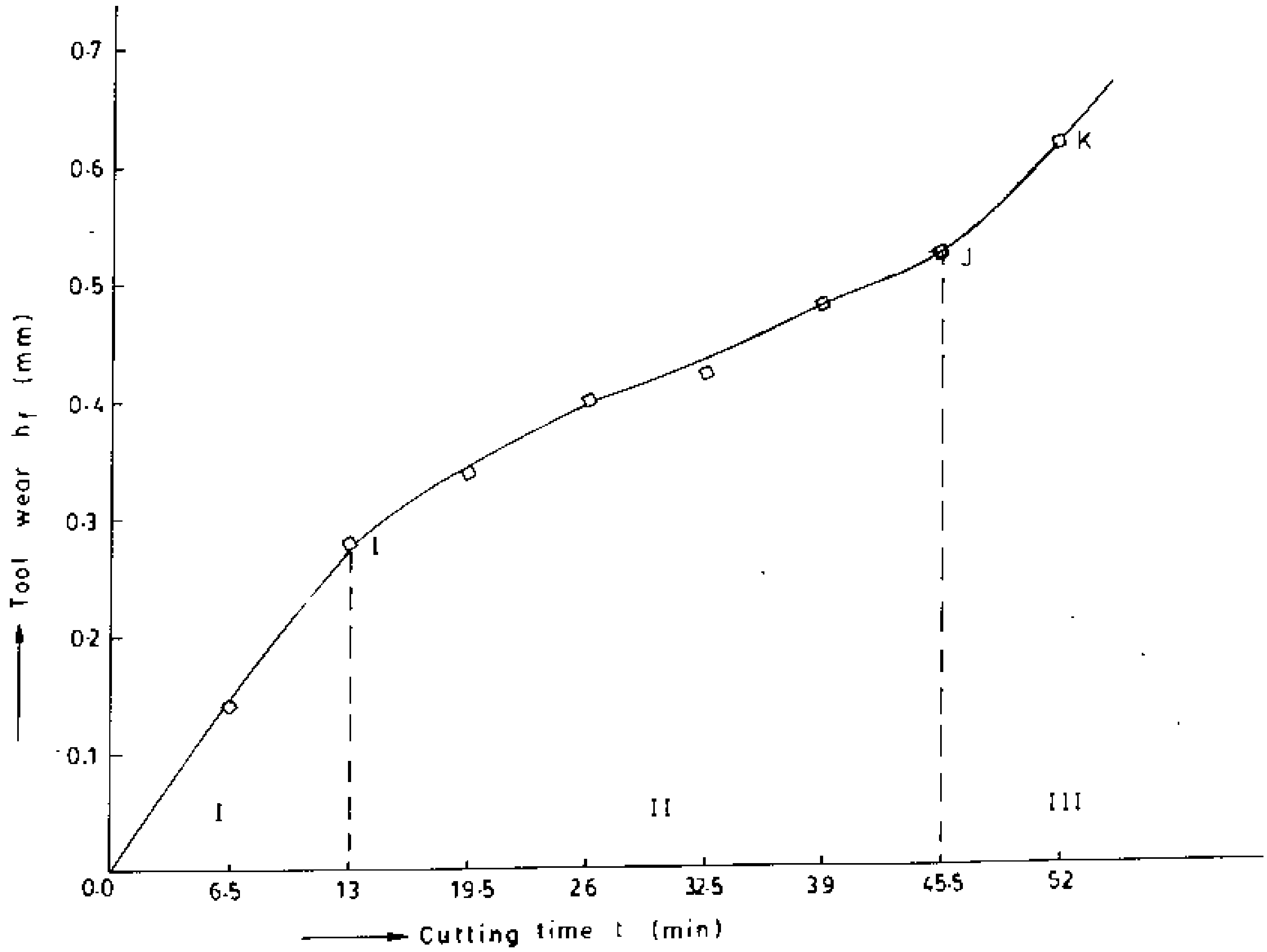


Fig. 4.2 Tool wear vs cutting time

From (Fig. 4.1 and Fig. 4.2) a common relationship was identified between tool wear (h_l) and surface roughness height (h) with time as shown in (Fig. 4.3a and Fig. 4.3b). Curve-4.3(a) and Curve-4.3(b) shows the variation of tool wear and height of surface roughness with cutting time respectively and they can be divided into three sections.

From tool wear vs. time curve as shown in (Fig. 4.3a) it is seen that section-I is the wear period of initial wear which occurs due to the sharp cutting edge and higher per unit pressure on contact surface between the cutting tool and the work piece. The sharp edge, due to plastic deformation and consequential temperature rise breaks down rapidly.

In section-I initially tool was very sharp and tool wear occurs rapidly, the surface roughness height in this region (C'D') also increases (as shown in Fig. 4.3b).

Because at the beginning of machining the cutting edge was very sharp and due to high pressure per unit area on the cutting edge, micro-volumes were broken off from the cutting edge. Again, the micro-volume removed off along the cutting edge is not uniform which causes vibration and increase in job surface roughness.

Section-II, Fig. (4.3a) is the period of gradual wear with the operation time as the sharpness of the tool reduces gradually. In this section there is a decreased tendency of the surface roughness because the vibration of the tool at this stage is less than that of the first region which results better surface finish. Also wear growth in this region is less steeper than the initial region (gradual wear region).

When a certain degree of wear has been reached, the frictional conditions change (mainly due to the sharp rise in cutting temperature) and period-III begins. This can be called the period of rapid (catastrophic) wear.

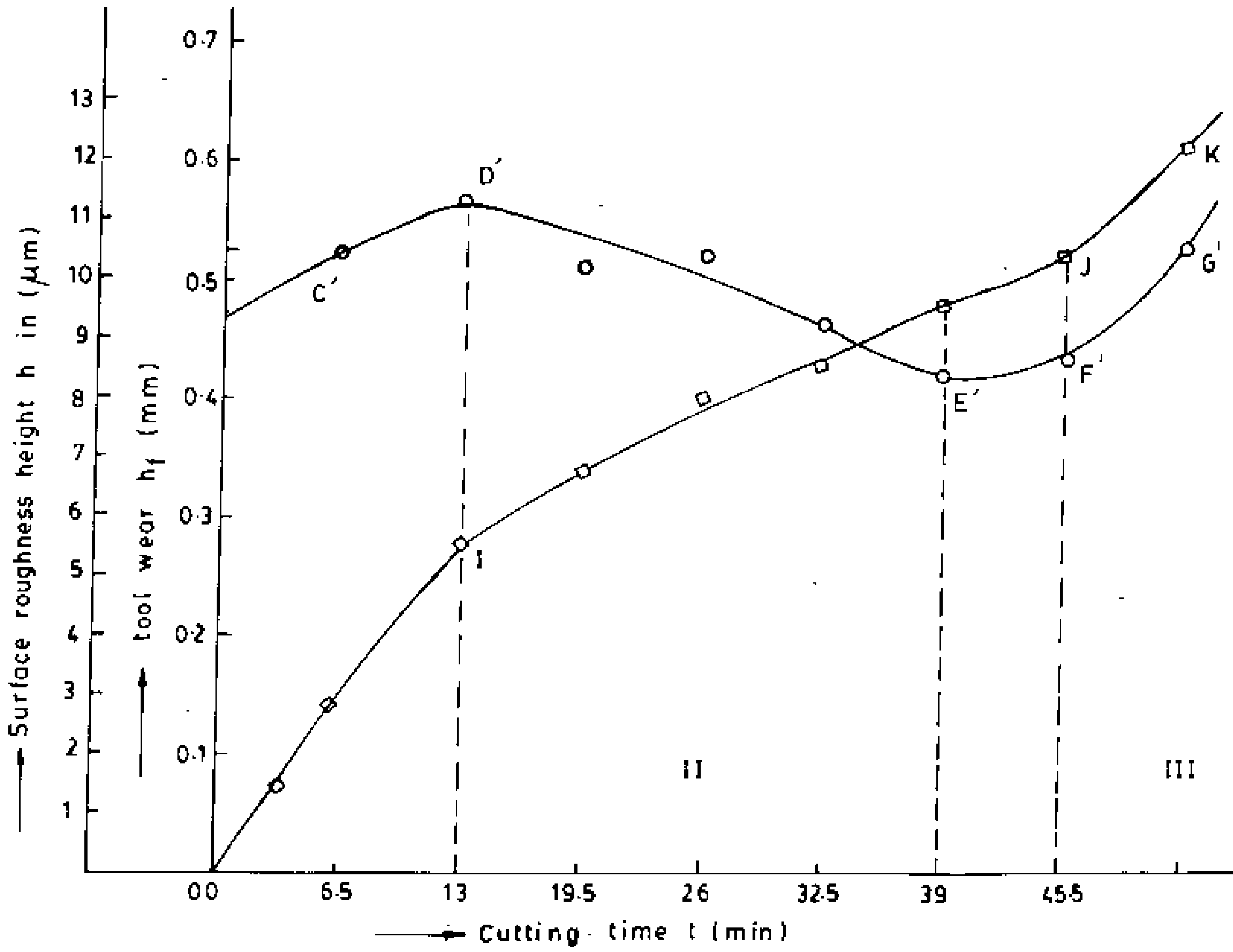


Fig. 4.3 Surface roughness height and tool wear vs cutting time

In section-III surface roughness again shows a steeper increasing tendency as the tool flank wear reaches a critical value and a rapid deterioration of the tool happens.

In Figure (4.3b) section-II begins from point "D" and the corresponding roughness value is 11.3316 x 10^{-6} m. In Figure (4.3a) section-II begins from point "I" and the corresponding wear and time are 0.275 mm and 13 minutes respectively.

In Figure (4.3b) section-III begins from point "F" and the corresponding roughness value is 8.55 x 10^{-6} m. In Figure (4.3a) section-III begins from point "J" and the corresponding wear and time are 0.52 and 45.5 minutes respectively.

From flank wear vs. time curve it can be seen that the cutting tool has to be changed after attaining a flank wear value of 0.52 mm. From relationship between tool wear and job surface roughness with machining time, tool life was found 45.5 min which is lower than the practical case. Because in the present work half hardened tool was used to get the experimental results quickly. Also from surface roughness vs. tool wear curve it was seen that the surface roughness height (h) suddenly increases more rapidly after a wear value of 0.52 mm. At this stage more friction and severe vibration occur which results poor surface finish. Because of high friction cutting forces as well as power consumption increases. When job surface roughness height reaches a value of 8.55x 10^{-6} m (though it is less than the maximum value) corresponding to flank wear 0.52 mm the cutting tool has to be replaced to get better surface finish.

TABLE-1

DETERMINATION OF TOOL FLANK WEAR (h_f) DURING MILLING OPERATION (UP-MILLING)

No. of Observation	Depth of Cut (mm)	Time t(min)	Initial Reading (mm)	Final Reading (mm)	Actual Flank Wear (h_f) mm	Actual Surface Roughness Height (h) in m
1	0.1524	6.5	5.26	5.40	0.14	10.425×10^{-6}
2	0.1524	13.0	6.10	6.375	0.275	11.3316×10^{-6}
3	0.1524	19.5	6.10	6.44	0.34	10.24×10^{-6}
4	0.1524	26.0	7.33	7.73	0.4	10.44×10^{-6}
5	0.1524	32.5	8.26	8.68	0.42	9.27×10^{-6}
6	0.1524	39.0	9.12	9.60	0.48	8.346×10^{-6}
7	0.1524	45.5	11.38	11.90	0.52	8.55×10^{-6}
8	0.1524	52.0	12.13	12.74	0.61	10.45×10^{-6}

TABLE-2

MEASUREMENT OF SURFACE ROUGHNESS HEIGHT (h) IN MILLING OPERATION (UP-MILLING)

No. of Observation	1st Reading $h_1 = \frac{\sum y_i}{n}$ (µm)	2nd Reading $h_2 = \frac{\sum y_i}{n}$ (µm)	3rd Reading $h_3 = \frac{\sum y_i}{n}$ (µm)	4th Reading $h_4 = \frac{\sum y_i}{n}$ (µm)	5th Reading $h_5 = \frac{\sum y_i}{n}$ (µm)	Average Reading (µm)	Actual Reading (h) in (m)
1	36.3	25.09	58.57	74.18	66.5	52.128 x 0.2 = 10.4256	10.425×10^{-6}
2	13.2	71	75	78.43	45.66	56.658 x 0.2 = 11.332	11.3316×10^{-6}
3	68.28	35.4	69.18	46.78	36.4	51.2 x 0.2 = 10.24	10.24×10^{-6}
4	77.5	56.5	23	42.2	61.4	52.12 x 0.2 = 10.424	10.424×10^{-6}
5	95.70	33.75	42.71	13.69	46.0	46.372 x 0.2 = 9.27	9.27×10^{-6}
6	32.4	30.4	51.76	67	27.1	41.732 x 0.2 8.346	8.346×10^{-6}
7	33.1	34.4	18.28	75.33	52.842	42.79 x 0.2 = 8.55	8.55×10^{-6}
8	62.167	48.47	75.22	37.33	38	52.237 x 0.2 = 10.4475	10.4475×10^{-6}

4.2 EXPERIMENTAL RESULTS OF JOB SURFACE ROUGHNESS AND ITS RELATIONSHIP WITH TOOL WEAR

Job surface roughness was measured on surface machined by milling (up-milling) process. These was done by using a surface roughness measuring equipment. Experimental results on job surface roughness are presented in Table 2. Roughness was measured at different point of milled surface and the actual value was obtained by taking their average to get the more accurate results.

The theoretical value of job surface roughness height (h) by "Martellotti's" equation, (as shown in Chapter-2) with the following cutting parameters:

Cutter diameter (D) = 120 mm
Feed per tooth (So) = 0.2886 mm
Cutting speed (N) = 33 rpm
Number of tooth in cutter (Z) = 1

are found to be 5.784 x 10^{-6} mm.

Relation of surface roughness characteristics with tool wear was investigated. Experimental results are presented in Table-2 and Curve-4.4.

The dependence of surface roughness on tool wear is presented by the surface roughness vs. tool wear curve [CDEFG] that shown in Figure-4.4 and can be divided into three sections.

In section-1, there is a small increased amplitude of the surface roughness at the beginning of cut. The geometry of tool wear causes a small change in surface roughness. At the beginning of machining the cutting edge was very sharp and due to

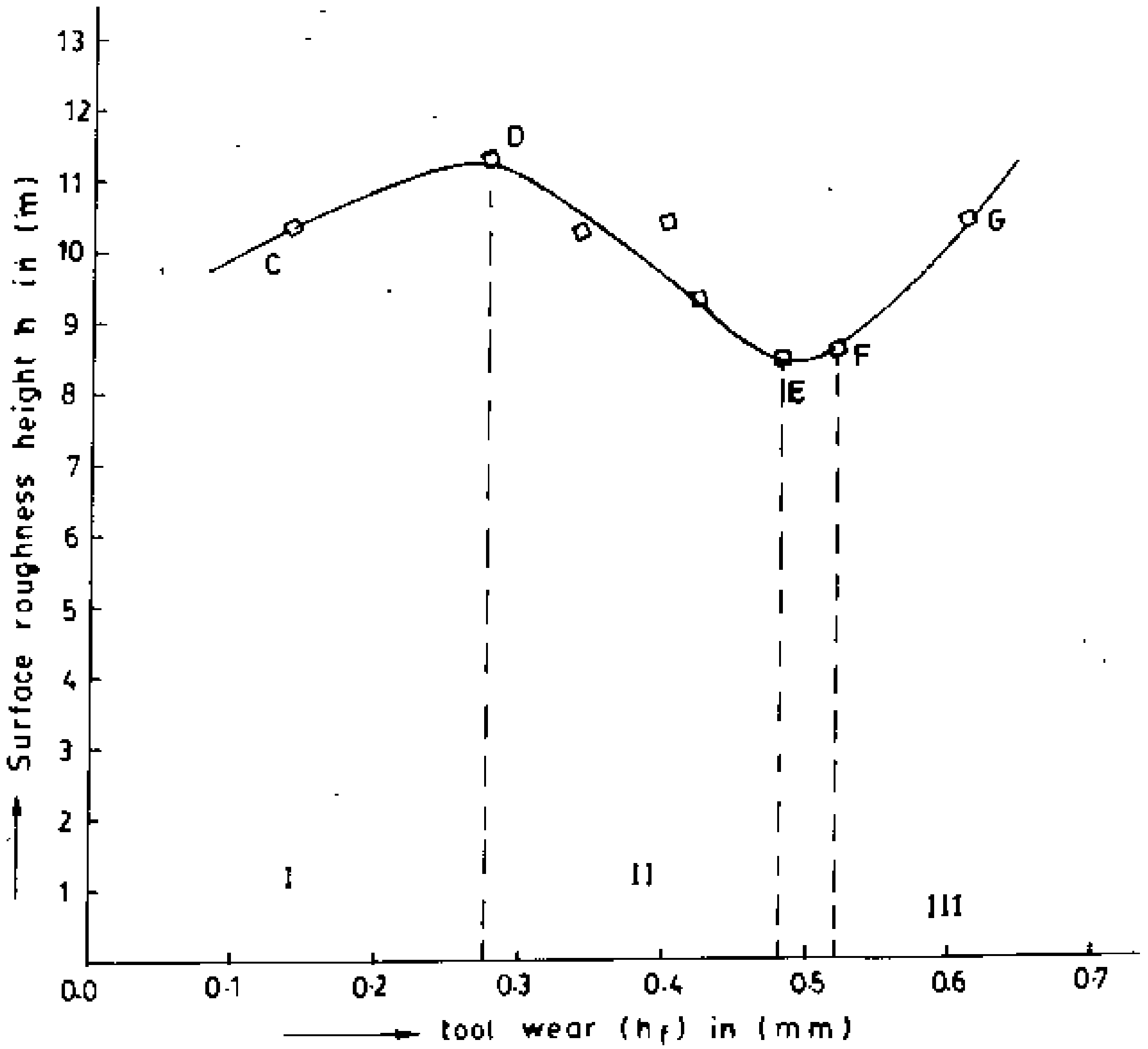


Fig. 4.4 . Surface roughness height vs tool wear

high pressure per unit area on the cutting edge, micro-volume were broken off from the cutting edge. Again the micro volume removed off along the cutting edge is not uniform which causes vibration and increase in job surface roughness.

In section-II (in the middle region) a decreasing tendency of the surface roughness was observed, which was caused by the fact the cutting edge has attained an optimum radius. Tool wear in this region is more or less uniform. Also the vibration of the tool at this stage is less than that of the initial region and results better surface finish.

In section-III, the surface roughness again shows an increasing tendency at the end of the tool life as wear increases more rapidly.

Initially flank wear does not show significant influence on surface roughness. When flank wear reaches a critical value (about 0.48 to 0.52 mm) friction of the work-piece with the tool flank increases and the surface roughness increases steeply.

In the present experimental work the starting point of this steep growth of roughness (though it is less than maximum roughness 11.3316×10^{-6} m) is associated with the moment of tool change or regrinding. Where flank wear value varies from 0.48 mm to 0.52 mm and surface roughness value vary from 8.346×10^{-6} m to 8.55×10^{-6} m where as theoretical roughness value is 5.78×10^{-6} mm [By the equation of Chapter-2].

The permissible flank wear value recommended for high-speed steel plain milling cutters for machining steels is: $h_f = 0.4$ to 0.6 mm. Where as in the present work when tool having wear between 0.48 mm to 0.52 mm results better surface finish.

Tool wear with a value more than 0.48 mm to 0.52 mm, the effect of flank wear on job surface becomes more significants and causes more friction and greater temperature rise along the cutting zone. Due to more friction more vibration occurs which results steep increase in tool wear and more power consumption. As a result, the quality of the machined surface deteriorates, roughness increases more rapidly, machining accuracy becomes poorer. This can be defined as the moment of tool replacement.

From surface roughness vs. tool wear curve it is seen that section-II begins from point D, where the value of the surface roughness is 11 336 x 10^{-6} m and the value of the flank wear is 0.275 mm.

Section-III begins between point E to F where value of flank wear from 0.48 mm to 0.52 mm and the value of the roughness between point 8.34 x 10^{-6} m to 8.55 x 10^{-6} m.

It can be said that in working with the tool having wear less than 0.48 mm to 0.52 mm the quality of surface finish will be better and working with tool having wear more than the above value will give a poorer surface finish, more friction and vibration increases the cutting forces and results more power consumption. So this value indicates the moment of tool replacement. For other combination of tool and job material the value of the critical flank wear may vary.

Therefore, it can be concluded that besides from the tool wear vs. time curve we can determine critical flank wear (0.52 mm) also from roughness vs. wear curve.

CHAPTER-5

5.1 DISCUSSION

A milling machine is a very versatile one. It can be used to machine flat and irregularly shaped surface, to drill, bore, cut gears, generate helical shapes. produce cams and be adapted for slotting work.

Metal cutting by milling operation is a common operation in many manufacturing systems, so roughness of the machined surface is an important quality measure in metal cutting and it is important to monitor and control surface roughness over time during milling operation. When the surface becomes too rough, the cutting tool has to be changed or reground.

Roughness of a machined surface also reduces the reliability of fixed joints between two parts because when one part is pressed into the other, the ridges are crushed, reducing the design interference of the fit.

It follows from the consideration that the roughness of the machined surfaces plays an important role in performance of machine parts.

The service life of present day high speed and powerful machinery depends not only on the kind, quality and heat treatment of metals of which its component parts are made, but also on the surface quality obtained in machining the parts. In the present work the relationship between tool wear and job surface roughness has been investigated.

Also the relationship between tool wear and job surface roughness with machining time was investigated.

In order to carry out experimental procedure a single tooth fly cutter mounted on a holder was designed. A flat surface was machined by up milling operation on mild steel work-piece using HSS tool. Tool wear was measured along the flank surface of tool using a microscope. The microscope by which reading were taken, was not a sophisticated one. The magnification system of the microscope was not high enough to get more perfect reading. In the present work surface roughness was measured only by vertical magnification i.e., by range switch. Because of coagulation of ink at the pen tip it was not possible to record horizontal magnification on the chart paper. For these reason some error may be incorporated during wear recording by microscope and roughness recording by SURF TEST AB-5.

In up milling the tooth of the cutter is subjected to heavy friction in sliding over the cut surface. Therefore, intense flank wear occur in up milling. There are several other numbers of causes that influence on tool wear. Tool wear involves abrasion and the removal of micro particles of the surface as well as microscopic chipping of the cutting edges of tool.

Chipping of the tool, as the name implies is removal of relatively large discrete particles of tool material. Built-up-edge (BUE) formation also has a tendency to promote tool chipping. BUE is never completely stable but it periodically breaks off and takes away some particle of the tool material with it.

Tool wear influences the surface roughness of work-piece and the value of surface roughness is one of the main parameters used to specify the moment to replace the tool in milling operation. So it would be very useful to establish a relationship between tool wear and desired quality of job surface roughness.

The relationship between job surface roughness with machining time shows that there is an increasing amplitude of the surface roughness at the beginning of cut, a decreasing tendency in the middle region and again an increasing tendency with sharp turn.

These relations show that the obtained tool life is 45.5 min and corresponding surface roughness and tool wear are 8.55 x 10^{-6} m and 0.52 mm respectively. The life of the tool that obtained in the present work was lower than the practical tool, because half hardened tool was used to get the experimental results quickly.

The relationship between tool wear and cutting time shows that tool wear initially increases rapidly due to the sharp cutting edge and higher per unit pressure on contact surface between the cutting tool and the work-piece. Due to plastic deformation and consequential rise in temperature, the sharp edge micro volumes were broken off from the cutting edge. Moreover, the micro-volume removed off along the cutting edge these procedure is not uniform. This causes vibration and increases in job surface roughness, as shown in tool wear vs. surface roughness curve.

From the middle period of cutting time it was observed that tool wear occurred gradually as sharpness of the tool reduces gradually. During this period of tool wear there is a decreasing tendency of the surface roughness as found from the relation of tool wear and surface roughness. Because the vibration of the tool at this stage is less than the initial period.

From the relation between tool wear and cutting time it is seen that when a certain degree of wear is reached, wear increases steeply with time. At this stage more friction occurs resulting in greater temperature rise. This can be called the period of "rapid wear". From the relationship between surface roughness and tool wear it was found that at this stage surface roughness also increases steeply. Due to the sharp rise of tool wear severe vibration and more friction occur leading to greater power consumption.

The maximum permissible flank wear value recommended for high speed steel plain milling cutters for machining steels is $h_f = 0.4$ to 0.6 mm. In the present work it was found that for flank wear upto 0.48 to 0.52 mm below the cutting edge the effect of wear on the job surface roughness was less pronounced.

Upon further wear beginning with $h_f = 0.48$ mm to 0.52 mm and the corresponding roughness height between 8.346×10^{-6} m into 8.55×10^{-6} m, the effect of flank wear on job surface roughness becomes more significant. After that the quality of the machined surface deteriorates, roughness increases steeply, machining accuracy becomes poorer and severe vibration occurs. The large increase of wear at the end of tool life causes a large increase of surface roughness and can be defined as the moment of tool replacement or regrinding. The theoretical value of job surface roughness height (h) during up milling was found to be 5.784×10^{-6} mm for the given tool and cutting parameters.

The height of job surface roughness or height of tooth marks affect the quality of finish. The height of tooth marks or job surface roughness height can be reduced by increasing radius of the cutter and decreasing the feed per tooth.

In machining tough (ductile) metals tool wear will proceed in a more complex manner. Flank wear predominates at low cutting speeds, when there is no built-up edge. The reason for this is that the sliding speed on the flank about the workpiece is higher than that of the chip on the tool face (because of chip contraction).

When flank wear reaches a certain value (0.48 mm o 0.52 mm), cutting force increases which raises power consumption the cutting temperature is raised the finish of the machined surface deteriorates, machining accuracy is lowered and vibration is caused.

Flank wear was not found to be uniform along the cutting edges of the tool. This is not absolutely unusual. As already mentioned (in chapter-2), the physical phenomena of tool wear in metal cutting are extremely complicated and the resultant tool wear involves abrasive, molecular and diffusive wear. Thus the deviation of actual wear profile is likely to occur due to complex phenomena of the wear process during cutting action.

In the present work cutting fluid was not used. But cutting fluid or coolant has considerable influence on cutting conditions. Simply speaking, it reduces the cutting forces by minimizing the friction between the tool and work-piece during machining. It also removes the heat that is generated during cutting action and reduces tool wear. Coolant was not used through out the experiment because of formation of rust on the flank surface which causes problem in taking reading under microscope.

Experiments on tool wear were conducted using high speed tool, because tool material for most of the milling cutters is of high speed steel (HSS). If the carbon content is low, the steels have high impact resistance. If the carbon content is high, they have high abrasion resistant qualities. Because of their extremely high hardenability characteristics, they may be oil or air hardened without tear of the steel cracking or distorting. To get the experimental results quickly half hardened HSS tool was used throughout the experiment. The hardness of the tool was about 50-55 RC. But practically high speed steel tools acquire a hardness of 62-63 RC when correctly heat treated and operate efficiently at cutting speeds two or three times higher than those allowed for carbon steel tools. High speeds steels contain from 8.5 to 19 percent tungsten and from 3.8 to 4.6 percent chromium. They do not lose their cutting ability even when they are heated to 600°C in the cutting process.

All experiments with a view to give 100% accurate result need ideal atmosphere which can never exist in practice. Therefore some assumptions must be made.

Assumption made for this experiment are as follows:

i. The properties of the tool material over its entire length are uniform.

ii. The properties of the work material remain unchanged during operations.

iii. Different points along the length of the cutting edges of tool have the some cutting speeds.

iv. The effect of vibration on tool wear and job surface roughness has been ignored.

v. The effect of temperature on change of hardness of the tool has been ignored.

5.2 CONCLUSIONS

From this study the following conclusions can be drawn.

i. It can be said that in working with tool having wear between 0.48 to 0.52 mm results better surface finish. Tool having wear more than 0.48 to 0.52 mm causes more friction, results more power consumption and greater temperature rise along the cutting zone and also causes more vibration. As a result tool wear increases steeply resulting rapaid increase of surface roughness. So the wear between 0.48 to 0.52 mm and corresponding surface roughness value indicates the time of tool replacement i.e., the life of the tool.

a. The maximum permissible flank wear value recommended for high-speed steel plain milling cutters for machining steel is 0.4 to 0.6 mm which is very close to the obtained result 0.48 mm to 0.52 mm.

b. The values of maximum permissible tool wear 0.48 to 0.52 mm based on the criteria of surface roughness values and on the criteria of time are similar. Therefore besides from the tool wear vs. time curve critical flank wear can also be determined from roughness vs. wear curve.

c. The surface roughness and tool wear present a similar behaviour at the beginning of cut as cutting time elapses i.e., both increases slightly. They also show similar behaviour at the end of cut when the time to change the tool is close, i.e., both increase steeply.

ii. Tool wear influences the surface roughness of the work-piece and the value of surface roughness is one of the main parameters used to establish the moment to replace the tool. There is an increasing amplitude of roughness with tool wear at the beginning of cut, a decreasing tendency in the middle region and again an increasing tendency at the end of cut as cutting time elapsed.

CHAPTER-6

6.1 SCOPE OF FUTURE WORKS

The following suggestions regarding the further continuation of this study can be given for future works:

i. This study had been conducted with a single tooth fly cutter. This study can be revised using multiple-tooth cutter.

ii. This study had been conducted with a particular type of tool material and work-piece material, which can be performed for different tool and work-piece materials.

iii. Cutting fluid was not used during experiments. Therefore, the wear and job surface roughness characteristics can be restudied using cutting fluid during cutting operation.

iv. In the present work the cutting variables like, feed, speed and depth of cut was constant. The study can be revised by changing the cutting variables.

APPENDIX - I

Specifications for Surface Roughness Measuring Equipment.

1. Measuring range:

Vertical	0 - 300 mm
Horizontal	0 - 50 mm (adjustable by knob)

2. Magnification:

Vertical	500X, 1000X, 2000X, 5000X, 10000X, 20000X
Horizontal	10X, 20X, 50X, 100X, 200X, 500X, 1000X

3. Magnification Accuracy:

Recorded Length	Less than 125 mm	Over 125 mm
Vertical	± 1 mm	± 2 mm
Horizontal	± 1 mm	± L/125 mm

L = Recorded length in mm

4. Stylus speed : 0.5 mm and 2.5mm / min (switchable by clutch)

5. Chart speed : 25 mm, 50 mm, 250 mm and 500 mm / min.

6. Stylus :

Stylus force	0.198 mN/µm (0.2 gf/µm)
Material	diamond
Tip angle	60 degrees
Tip radius	5 mm

7. Recording chart :

Length	15 m
Width	250 mm (effective)
Graduation	2 mm x 2 mm

The value of one division for each magnification

Vertical	500X	1000X	2000X	5000X	10000X	20000X
Value (mm)	4	2	1	0.4	0.2	0.1

Horizontal	10X	20X	50X	100X	200X	500X	1000X
Value (mm)	0.2	0.1	0.04	0.02	0.01	0.004	0.002

8. Power drive unit:

Elevation	about 180 mm (feed screw P = 3 mm) 7 mm for fine adjustment (feed screw P = 0.5 mm)

9. Column rotation : About 270 degrees with clamp.

10. Base size : 460 (W) x 185 (D) mm with T-slot.

11. Calibration range for vertical magnification: 10 mm and 100 mm

12. Response speed of recording pen: 50 cm/sec.

13. Ambient temperature : -10°C to +50°C.

14. Line voltage : AC100, 117, 200, 220 or 240 V (specify for wiring)
50/60 hz. (switchable).

15. Power consumption : 25 VA

16. Dimensions and weight :

Measuring unit	: 480(W) x 372(D) x 582(H) mm, 37 kg
Amplifier/recording unit	: 430(W) x 255(D) x 200(H) mm, 10 kg

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