A STUDY ON KINEMATIC GEOMETRICAL PARAMETERS OF A TOOL, ITS WEAR AND JOB SURFACE FINISH DURING UP MILLING AND DOWN MILLING

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).

April, 1996.

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ACKNOWLEDGEMENT

The author would like to express his profound gratitude and indebtness to Dr. Ahsan Ali Khan, Associate Professor, Department of Industrial and Production Engineering, Bangladesh University of Engineering & Technology, Dhaka, who despite his extremely busy schedule has provided with continued guidance, valuable and constructive suggestious in every step of the execution, preparation and compliation of this thesis. The author deeply appreciates the time and effort he took to provide the valuable critiques which often extended beyond the normal working hours.

A special note of thanks and sincere guidance are due to Dr. A.K.M. Nurul Amin, Associate Professor, Department of Industrial and Production Engineering for his deep involvement, continued assistance, advice and encouragement at different stages of this research that helped the author to get through his work with ease and confidence.

The author is grateful to Dr. M. Anwarul Azim, Professor and Head, Department of Industrial and Production Engineering for his valuable advice and suggestions from time to time.

The author wishes to express his gratitude to his parents and his brother and sister who provided him with moral support and encouragement throughout this work.

Finally thanks to those who helped the author directly or indirectly during different stages of this work.

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ABSTRACT

In the present work the method of up milling is compared with that of down milling on the basis of change of geometrical parameters of cutting edges of tool, tool wear and job surface finish.

A mathematical model for determining the dynamic value of the relief angle of cutting tool depending on the change of contact angle of the cutting tooth with the workpiece has been developed. With the help of the mathematical model it has been established that in up milling the change of relief angle of cutting tool is less than that in the case of down milling. For this reason when considering change of geometrical parameters of cutting tool, the cutting condition is more favourable in up milling than in down milling.

To investigate tool wear two single tooth fly cutters of high speed steel of same dimensions were made, one of which was used in up milling process and the other was used in down milling process. The single tooth fly cutter was overhung from the tool holder and was clamped by clamping screws. Slots were cut both by up milling and down milling on mild steel nsing single tooth fly cutter mounted on tool holder. Tool wear was measured along the flank surfaces of tools during up milling and down milling. Tool wear was found to be higher in up milling than in down milling. Therefore cutter life is longer in down milling than in up milling.

Experiments were conducted on job surface roughness machined by up milling and down milling. Job surface roughness height was measured for up milling and down milling. Job surface roughness height was found to be higher in down milling than in up milling. Therefore up milling produces better surface finish than in case of down milling.

CHAPTER I: INTRODUCTION & LITERATURE SURVEY

1.1 INTRODUCTION

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

In nearly all cases a multiple-tooth cutter is used so that the material removal rate is high. Often the desired surface is obtained in a single pass of the cutter or work and because very good surface finish can be obtained, milling is particularly well suited and widely used for mass production work.

In milling surfaces can be generated by two distinctly different methods. Up milling is the traditional way to mill called conventional milling, the cutter rotates against the direction of feed of the work piece as shown in figure (1.1). In down milling the rotation is in the same direction as the feed as shown in figure (1.2).

The method of chip formation is completely different in the two cases. In up milling the chip is very thin at the beginning where the tooth first contacts the work and increases in thickness becoming a maximum, where the tooth leaves the work.

The cutter tends to push the work along and lift it upward from the table. This action tends to eliminate any effect of looseness in the feed screw and nut of the milling machine table and results in a smooth cut. However the action also tends to loosen the work from the clamping device so that greater clamping forces must be employed.

In down milling maximum chip thickness occurs close to the point at which the tooth contacts the work. Because the relative motion tends to pull the work piece into the cutter, all possibility of looseness in the table feed screw must be eliminated if down milling is to be used.

It should never be attempted on machines that are not designed for this type of milling, virtually all modern milling machines are so equipped.

Up milling is used if there is trouble some blacklash in the tabled feed. The cutter teeth must first by passing a sharp edge over the material until pressure is sufficient to force the cutter to bite into it.

Down milling tends to pull the work into the cutter and can not be used when blacklash is considerable. If down milling is performed on milling machines not equipped with a blacklash eliminator, the motion of the table will be unsteady and characterized by a series of jerks.

Up milling gives a slightly smaller maximum undeformed chip thickness (t_m), a larger undeformed chip length (l) and smaller inherent surface roughness height (h) than down milling because of the smaller average radius of curvature of the chip when down milling.

The surface which results from a milling operation is subjected to two types of defects, waviness and roughness. Waviness 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) that forms at the tip of the cutting tool.

From Martellotti's equation (as shown in chapter-2) it is seen that the inherent surface roughness height (h) or height of tooth marks is less in up milling than that of down milling.

On this basis up milling produces better surface finish than that of down milling.

Ductile material too, usually requires down milling, because the work-piece must be forced against the worktable or fixture.

Down milling must not be used on castings with surface sand inclusions because the cutter teeth will be in constant contact with this surface scale.

Up milling, because of its work-hardened effects at the start of each tooth cut, is recommended neither for work-hardening materials nor for heat treated alloy steels.

Intensive flank wear occurs in up milling than down milling. Therefore cutter life is longer in down milling than up milling. At the same cutter life, down milling can be performed at higher cutting speeds with a corresponding higher output.

Another advantage of down milling is that the cutting force tends to hold the workpiece against the machine-table, permitting lower clamping forces.

Down milling is not recommended on light machines or on larger older machines that are not in top condition or fitted with an anti blacklash. Since down milling is desirable as long as it can be done safely, some milling machines are designed for it. Blacklash must be eliminated, so called "manufacturing type" milling machines are ordinarily designed so that down milling can be performed.

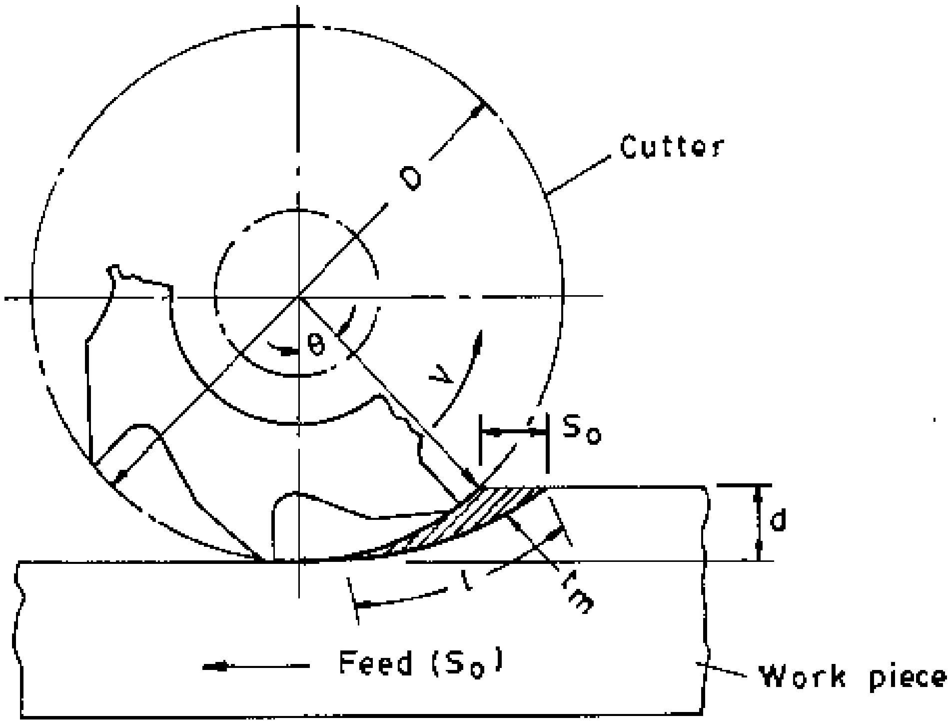


Fig.(1.1) UP MILLING

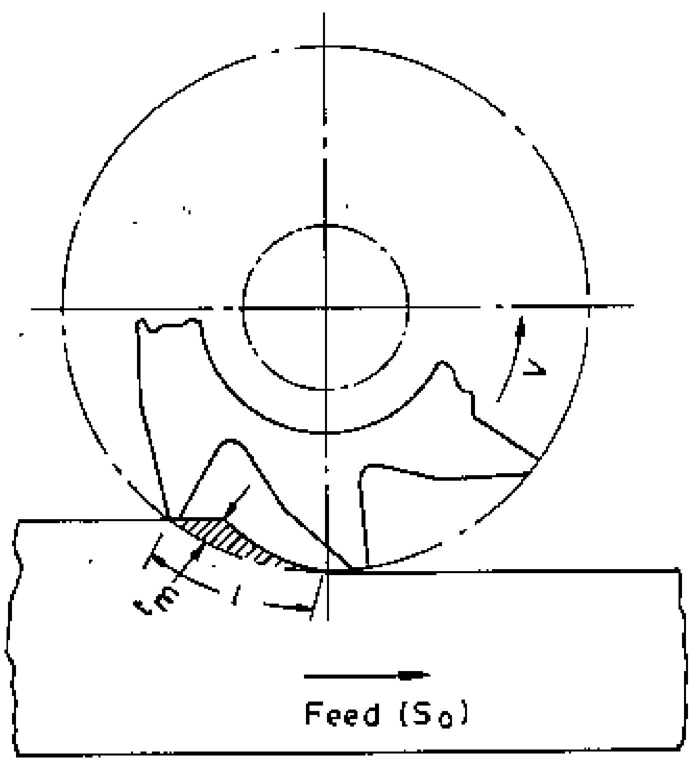


Fig.(1.2) DOWN MILLING

1.2 LITERATURE SURVEY

Theoritical analysis on up milling and down milling has been done by Martellotti [1] who clearly showed that the path of a milling cutter tooth is trochoidal. Martellotti derived the equation of this trochoidal tooth path and used it in comparative analysis between up milling and down milling.

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

In the early 1900s, Frederic Taylor [2] and associated metallurgists developed high speed steel and very nearly revolutionised the whole metal cutting industry. His work enabled cutting tools first to retain their cutting edge 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 improve metal cutting process and cutting conditions, to formulate optimisation 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 etc.

Ernest and Merchant [3], Gilbert [4], Rozenberg [5] and Bekes, Jan B. [6], and so forth are the very famus researchers in this line.

In 1958, a research work had been conducted by Markov, A.D. [7] about Tool wear and tool life. Later on Bhoothroyd, G. [8], Shaw, M.C. [9] Solaja, V. [10] carried out a research on effect of tool wear on the temperature generated during metal cutting in 1967. Similarly in another research, Tantalov, N.V. [11] Cheriomoshnikov, [12] N.P. Kurchenco A.I. [13] showed the influence of cutting speed on different characteristics of metal cutting process and tool wear. In 1970, Thime, I.A. [14] conducted an extensive research on "Resistance of Metal and Wood during Cutting". His study gives the idea of cutting force during cutting actions to overcome the resistance of the chip. Cutting speed has also great effect on the cutting process which intern 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. [15], by conducting a significant number of experiment.

Yeremin, A. [16] 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. [17] should studied the relationship between tool life and cutting speed for different tool materials. His study showed that tools of plain carbon steel and high speed steel have decreasing nature of tool life with increasing in cutting speed.

Relationship between the cutting temperatures and cutting speed at various depth of cut had been studied by Danielyan, A. [18], and 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 speed.

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 yet been done on comparative analysis between up milling and down milling.

1.3 AIMS AND OBJECTIVES

The aim of the present work is to compare the characteristics of up milling and down milling. To achieve this aim the following objectives have been set on the present work.

a. To determine the change of geometrical parameters of tool during up milling and down milling.

b. To determine the characteristics of tool wear during up milling and down milling.

c. To determine job surface roughness produced during up milling and down milling.

CHAPTER 2: THEORITICAL ANALYSIS OF TOOL GEOMETRY, TOOL WEAR AND JOB SURFACE ROUGHNESS DURING UP MILLING AND DOWN MILLING

2.1 THEORITICAL ANALYSIS OF TOOL GEOMETRY OF CUTTERS DURING UP MILLING AND DOWN MILLING PROCESS

In up milling as shown in (Fig. 2.1) the cutter rotates with velocity "V", against the direction of the feed rate (S) and the minimum thickness is at a point A (Fig. 2.1), where the tooth comes in contact with the workpiece and the maximum at the point B (Fig. 2.1), where the tooth leaves the work-piece.

In down milling as shown in (Fig. 2.2) the cutter rotates with velocity "V" as the same direction of the feed rate (S) and the maximum thickness is at a point C (Fig. 2.2), where the tooth comes in contact with the workpiece and the minimum thickness at the point D (Fig. 2.2), where the tooth leaves the same.

The resultant cutting velocity (R) can be found from the peripherial speed of the cutter and the feed motion of the work-piece as shown in the vector diagram. The contact angle of the cutter with the work-piece is denoted as θ. The static relief angle of the cutter (α_{static}) is the angle between the direction of peripherial speed of the cutter (V) and the tangent to the surface of the tooth at the point of consideration in cutter (Fig. 2.1). The real relief angle of the cutter (α_{real}) is the angle between the resultant cutting velocity (R) and the tangent of the tooth in cutter (Fig. 2.1).

In up milling at a point A (Fig. 2.1), the direction of the peripherial speed of the cutter (V) and the direction of the resultant cutting velocity (R) coincide. Therefore at point A, the value of α_{real} and α_{static} are the same. When the tooth comes in contact at a point B′ (Fig. 2.1), the direction of the peripherial speed of the cutter (V) and the direction of the resultant cutting velocity (R) do not coincide. So at point B, the value of real relief angle of the cutter (α_{real}) is different from the value of static relief angle of the cutter (α_{static}). The change of relief angle of the cutter is denoted as $\Delta\alpha$.

From Vector Diagram:

$$\frac{V}{\sin(\theta - \Delta\alpha)} = \frac{S}{\sin\Delta\alpha}$$

$$=> V\sin\Delta\alpha = S\sin(\theta - \Delta\alpha)$$

$$=> V\sin\Delta\alpha = S[\sin\theta\cos\Delta\alpha - \cos\theta\sin\Delta\alpha]$$

$$=> \frac{V}{S} = \frac{\sin\theta}{\tan\Delta\alpha} - \cos\theta$$

$$=> \frac{V}{S} + \cos\theta = \frac{\sin\theta}{\tan\Delta\alpha}$$

$$=> \tan\Delta\alpha = \frac{\sin\theta}{\frac{V}{S} + \cos\theta}$$

$$\therefore \Delta\alpha = \tan^{-1}\left[\frac{\sin\theta}{\frac{V}{S} + \cos\theta}\right] \qquad [1]$$

From (Fig. 2.1), it can be written:

$$\alpha_{real} = \alpha_{static} - \Delta\alpha$$

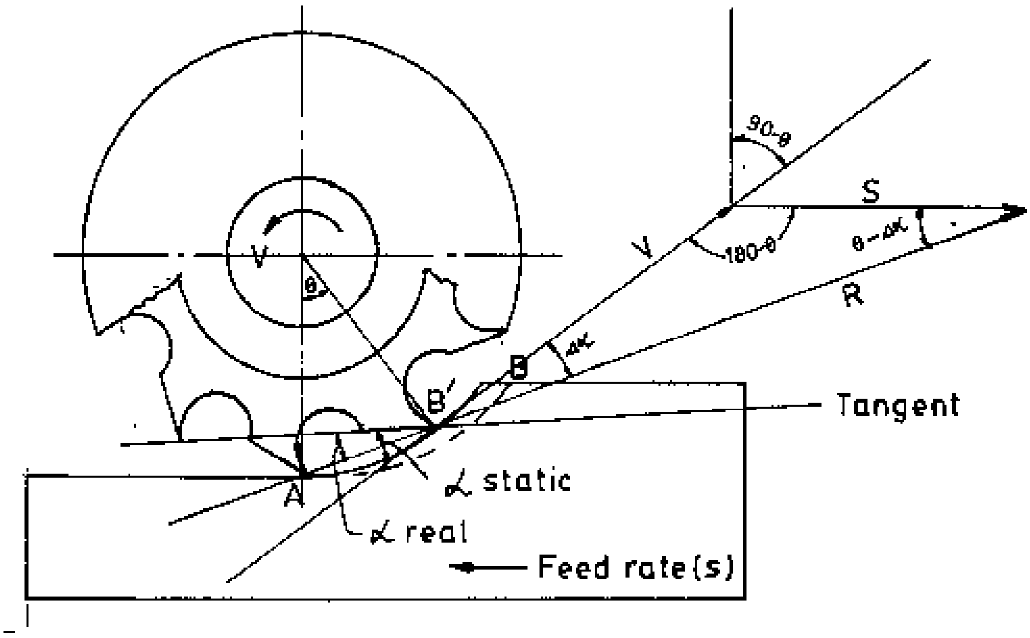
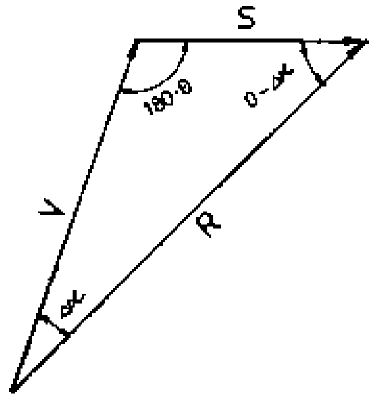


Fig.(2.1) UP MILLING



VECTOR DIAGRAM

$$\therefore \alpha_{real} = \alpha_{static} - \tan^{-1}\left[\frac{\sin\theta}{\frac{V}{S} + \cos\theta}\right] \qquad [2]$$

In down milling at a point C (Fig. 2.2), the direction of the peripherial speed of the cutter (V) and the direction of the resultant cutting velocity (R) do not coincide. Therefore, at point C (Fig. 2.2), the value of the real relief angle of the cutter (α_{real}) is different from the value of static relief angle of the cutter (α_{static}). When the tooth comes in contact with the point D (Fig. 2.2) the direction of the peripherial speed of the cutter (V) and the direction of the resultant cutting velocity (R) coincide. Therefore, at point D value of the real relief angle of the cutter (α_{real}) and the the value of static relief angle of the cutter (α_{static}) are the same. The change of relief angle of the cutter is denoted as $\Delta\alpha$.

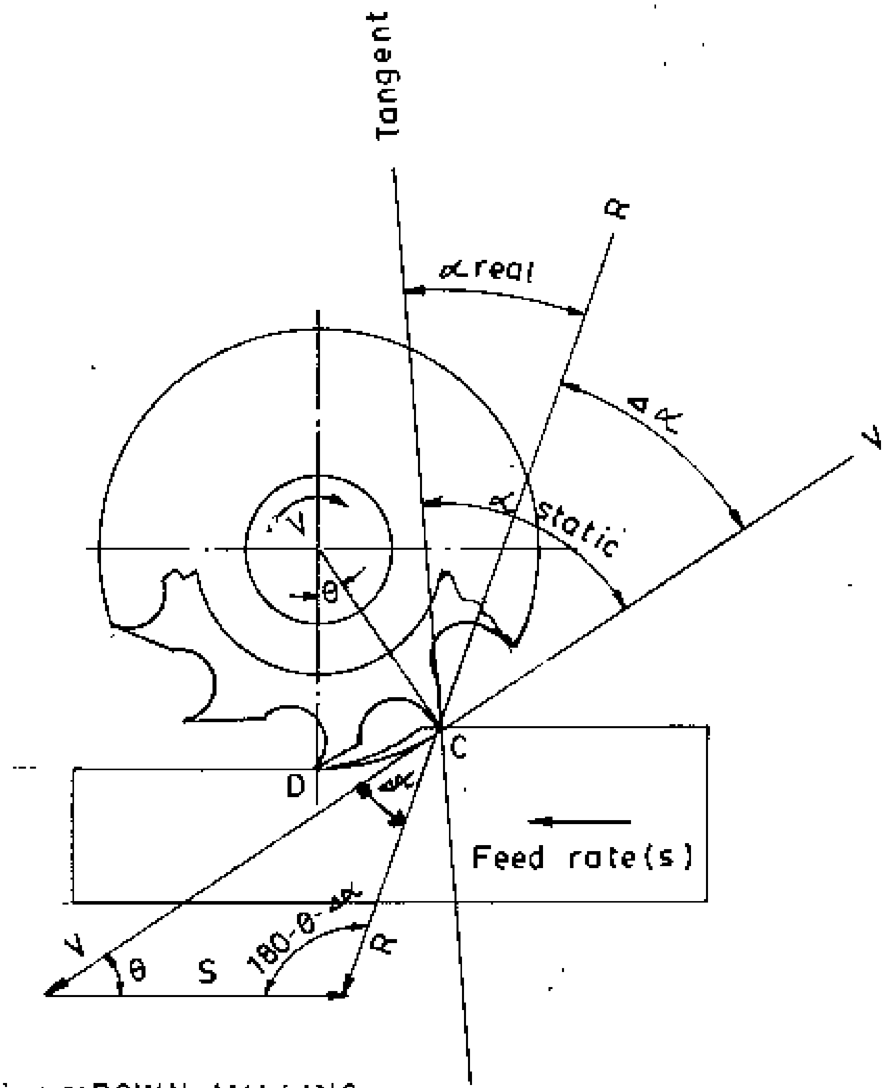
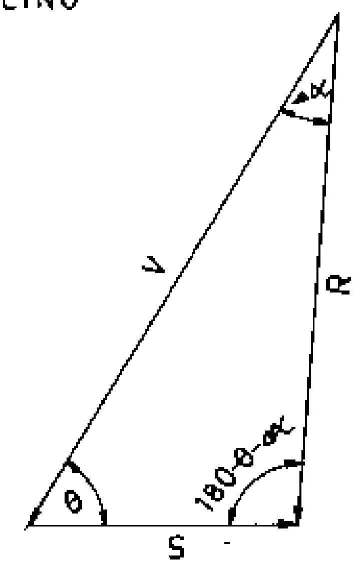


Fig.(2.2) DOWN MILLING



VECTOR DIAGRAM

From Vector Diagram:

$$\frac{V}{\sin(180-\theta-\Delta\alpha)}=\frac{S}{\sin\Delta\alpha}$$

$$\frac{V}{\sin(\theta+\Delta\alpha)}=\frac{S}{\sin\Delta\alpha}$$

$$=> V\sin\Delta\alpha = S\sin(\theta+\Delta\alpha)$$

$$=> V\sin\Delta\alpha = S[\sin\theta\cos\Delta\alpha+\cos\theta\sin\Delta\alpha]$$

$$=> \frac{V}{S}=\frac{[\sin\theta\cos\Delta\alpha+\cos\theta\sin\Delta\alpha]}{\sin\Delta\alpha}$$

$$=> \frac{V}{S}=\frac{\sin\theta}{\tan\Delta\alpha}+\cos\theta$$

$$=> \frac{V}{S}-\cos\theta=\frac{\sin\theta}{\tan\Delta\alpha}$$

$$=> \tan\Delta\alpha=\frac{\sin\theta}{\frac{V}{S}-\cos\theta}$$

$$\therefore \Delta\alpha=\tan^{-1}\left[\frac{\sin\theta}{\frac{V}{S}-\cos\theta}\right] \quad [3]$$

From (Fig. 2.2), it can be written:

$$\alpha_{real}=\alpha_{static}-\Delta\alpha$$

$$\therefore \alpha_{real}=\alpha_{static}-\tan^{-1}\left[\frac{\sin\theta}{\frac{V}{S}-\cos\theta}\right] \quad [4]$$

A mathematical model for change of relief angle of cutting tool ($\Delta\alpha$) and its real relief angle (α_{real}) with the change of contact angle of the cutting tooth with the work-piece (θ) are developed.

These established mathematical equation of change of relief angle of cutting tool ($\Delta\alpha$) and real relief angle of cutting tool (α_{real}) are shown in equation (1), equation (2) for up milling and equation (3), equation (4) for down milling process.

Different values of change of relief angle of cutting tool ($\Delta\alpha$) and real relief angle of cutting tool (α_{real}) are presented in Table (1) based on the following parameters:- peripherial speed of the cutter (V) 40 ft/min, feed rate of the work-piece (S) 6 inch/min, static relief angle of cutting tool (α_{static}) 12^o and contact angle of the cutter with the work-piece ($\theta = 0^o, 5^o, 10^o, 15^o, 20^o, 25^o, 30^o, 35^o$).

Change of relief angle of cutting tool ($\Delta\alpha$) with respect to contact angle of the cutter with the work-piece (θ) is shown in (Fig. 2.3).

Change of relief angle of the cutter ($\Delta\alpha$) has considerable influence on the cutting condition during up milling and down milling process. The greater relief angle of cutting tool, the less friction of the cutting tool on the work-piece or job and less deformation and less heat generation takes place.

Change of relief angle of the cutter ($\Delta\alpha$) during up milling is different from down milling process. In up milling change of relief angle of the cutter ($\Delta\alpha$) is less than that of down milling process. For this reason in up milling process, friction of the tool on the workpiece is less and consequently heat generation takes place.

When considering change of geometrical parameters of cutting tool, the cutting condition is more favourable in up milling than that for down milling process.

TABLE - 1

Change of Geometrical Parameters of Tool during Up Milling and Down Milling.

Contact angle of the cutter with the work-piece (θ)	Change of relief angle of the cutter (Δα) (Degrees) for Up Milling	Real relief angle of the cutter (α_{real}) (Degrees) $\alpha_{real} = \alpha_{static} - \Delta\alpha$ for Up Milling	Change of relief angle of the cutter (Δα) (Degrees) for Down Milling	Real relief angle of the cutter (α_{real}) (Degrees) $\alpha_{real} = \alpha_{static} - \Delta\alpha$ for Down Milling
0°	0	12	0	12
5°	0.062	11.938	0.063	11.937
10°	0.123	11.877	0.126	11.874
15°	0.183	11.817	0.188	11.812
20°	0.242	11.758	0.248	11.752
25°	0.299	11.701	0.306	11.694
30°	0.354	11.646	0.362	11.638
35°	0.407	11.593	0.415	11.585

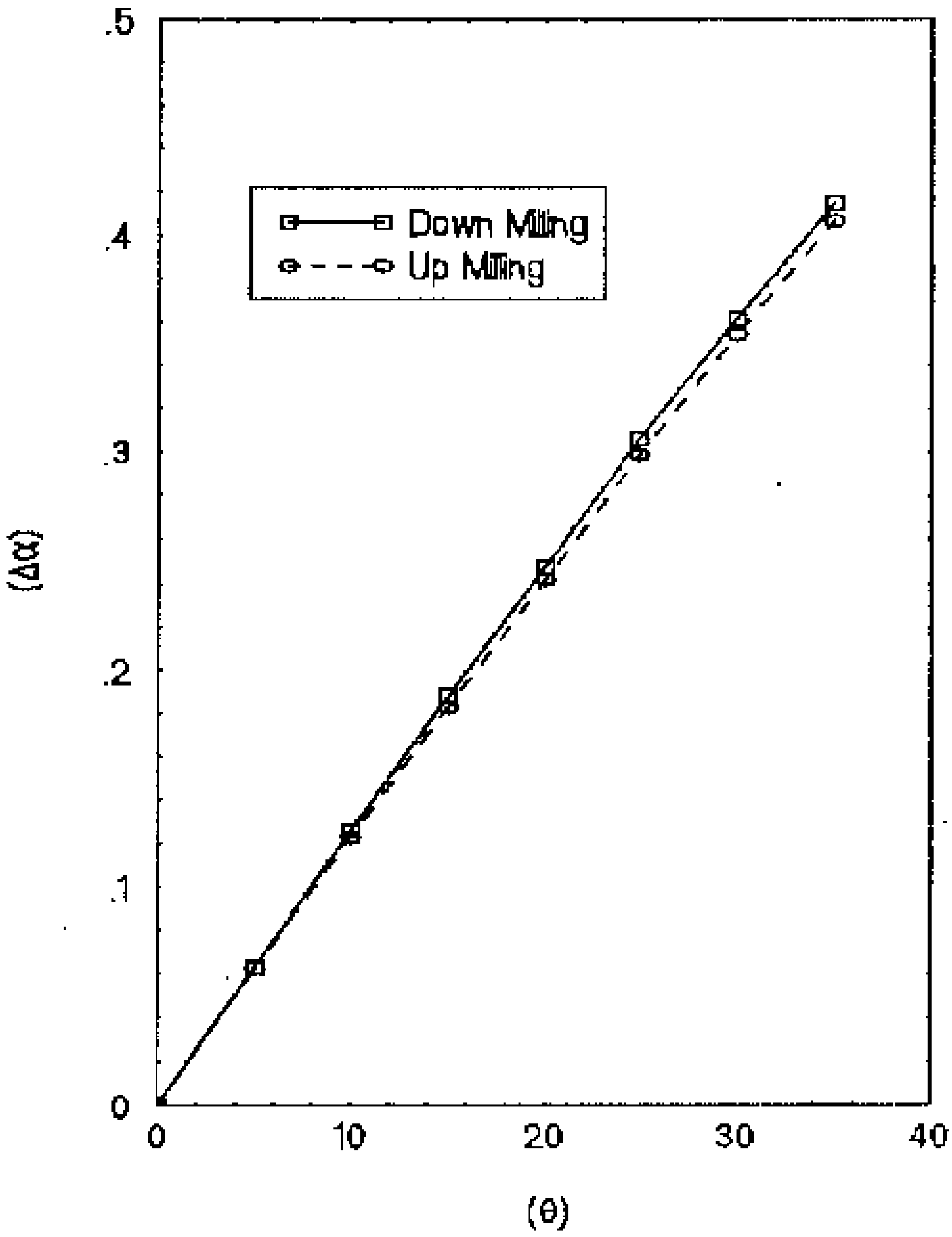


Fig. 2.3 Change of relif angle of cutting tool (Δα) with respect to contact angle of the cutter with the work piece (θ)

2.2 THEORITICAL ANALYSIS OF TOOL WEAR DURING UP MILLING AND DOWN MILLING PROCESS

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

In up milling the load on the tooth grows gradually since the thickness of the uncut chip varies from zero at tooth entrance to a maximum at tooth exit from the cut. The tooth begins the cut from under the foundry or forging skin "breaking it up" from underneath. The cutting forces are generally directed upward so that cutter tends to lift the work-piece from the table or fixture. These forces also tend to lift the work-table increasing the clearances between the table and bed or saddle ways.

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 theoritical point of tooth entrance K (Fig. 2.4). 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 preceeding tooth intence flank wear occurs.

In down milling the cutting forces are usually directed downward so that the work-piece is pushed into the fixture or towards the table and the table is held firmly against the bed or saddle ways. The cutter tooth enters the cutting zone at maximum uncut chip thickness and is thus subjected to maximum load from the very beginning.

Consequently if the work-piece has no foundry skin or other unfavourable surface cutter life is longer in down milling (where the tooth enters the cut without sliding) than up milling. At the same cutter life down milling can be performed at higher cutting speeds with a corresponding higher output.

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 of 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 castings or scale on forgings also produces a severe abrasive effect.

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 the 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 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 band (Fig. 2.5). Face wear is characterized mainly by the depth h_c and the width b of the wear crater (Fig. 2.6); 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 microscope. The dependence of flank wear (both in up milling and down milling) on the time of tool operation is expressed by the flank wear vs time curve (Fig. 4.1) that can be divided into three sections.

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

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 friction 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. 4.1). Up to point Q_1, Q_2, the region I denotes the zone of initial wear. The sharp edge due to plastic deformation and consequential temperature rise rapidly breaks down and the point Q_1, Q_2 is reached. After that the wear process is more or less uniform until a point F_1, F_2 has been reached. The Q_1-F_1, Q_2-F_2 region shown as region II in Fig. (4.1) is the mechanical wear region. Beyond F_1, F_2, the rapid growth of wear process ensures and the cutting tool fails very soon after reaching this point of inflexion F_1, F_2. This point F_1, F_2 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 is higher than that of the chip on the tool face (because of chip contraction).

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

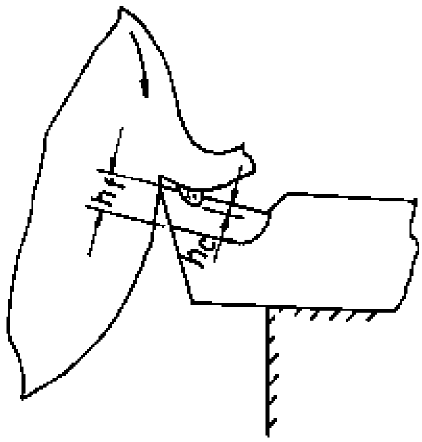


Fig (2·5) Flank wear

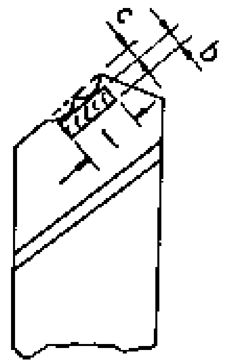


Fig (2·6) Crater wear

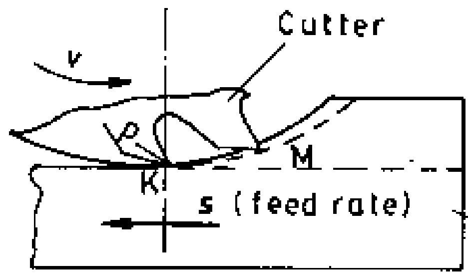


Fig.(2·4) Tooth entrance in up milling.

2.3 THEORITICAL ANALYSIS OF JOB SURFACE ROUGHNESS RESULTING FROM UP MILLING AND DOWN MILLING PROCESS

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.

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 impiles that the work-piece 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 tooth path, the inherent roughness height (h) is left over on the job during up milling and down milling process depends on feed per tooth (S_o) and cutter diameter (D).

This relation can be expressed by the equation:-

$h = S_o^2/4D$ (for up milling and down milling)

where,

S_o = feed per tooth

D = cutter diameter

When the trochoidal tooth 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:-

$$h = \frac{S_o}{8\left(\frac{D}{2S_o} + \frac{z}{\pi}\right)} \text{ (for up milling)}$$

$$h = \frac{S_o}{8\left(\frac{D}{2S_o} - \frac{z}{\pi}\right)} \text{ (for down milling)}$$

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 up milling and down milling

Quality of finish of a machined surface is generally affected by marks of microscopic dimension from the plastic flow of the material during the formation of the chip and tooth marks.

In up milling tooth marks such as A (Fig. 2.7) result from the engagement of a tooth with the work material.

In down milling, a similar mark N' (Fig. 2.8) is generally produced. In down milling, therefore, an element of the machined surface is generally not produced by the direct action of the cutting edge on the work material.

A milled surface therefore 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′ (Figure 2.7 and 2.8), where the teeth intersect the path generated by the preceeding teeth.

On this basis a better finish will result in up milling, since the roughness height (h) between the corresponding to the tooth marks and the point O, is less in up milling than in down milling.

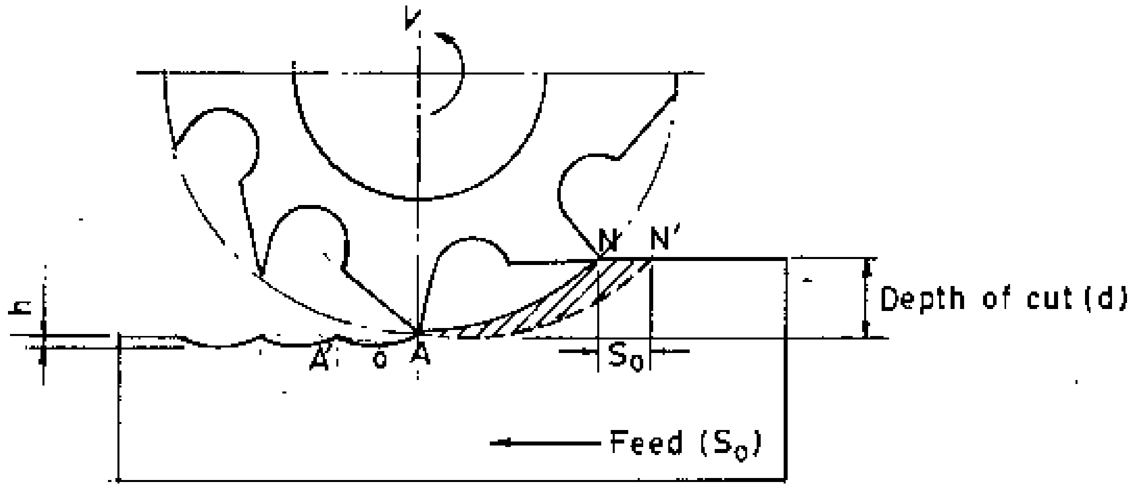


Fig.(2-7) UP MILLING

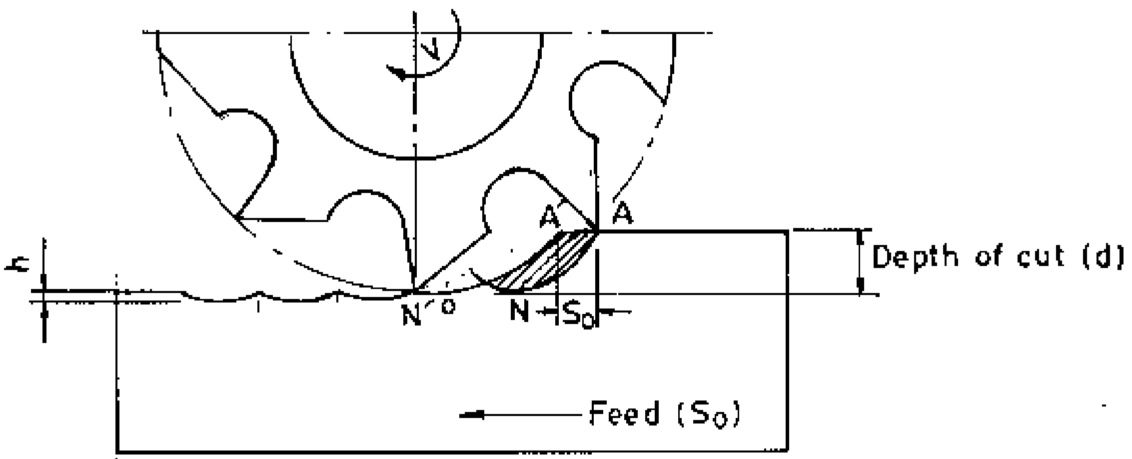


Fig (2-8) DOWN MILLING

CHAPTER 3 : EXPERIMENTAL PROCEDURE

Both up milling and down milling are practiced for machining different surfaces. In order to make a comparativeanalysis between them regarding tool wear, surface finish and geometrical parameters of cutting edges of milling cutters, the following procedure was followed.

a. Slots were cut both by up milling and down milling process on mild steel using a single tooth fly cutter of high speed steel (Fig. 3.1, 3.2). Relation of wear characteristics with time was investigated. Wear was measured along the flank surfaces of tools using a microscope.

b. Surface roughness was measured on job surfaces machined by up milling process and down milling process. This was done using surface roughness measuring equipment.

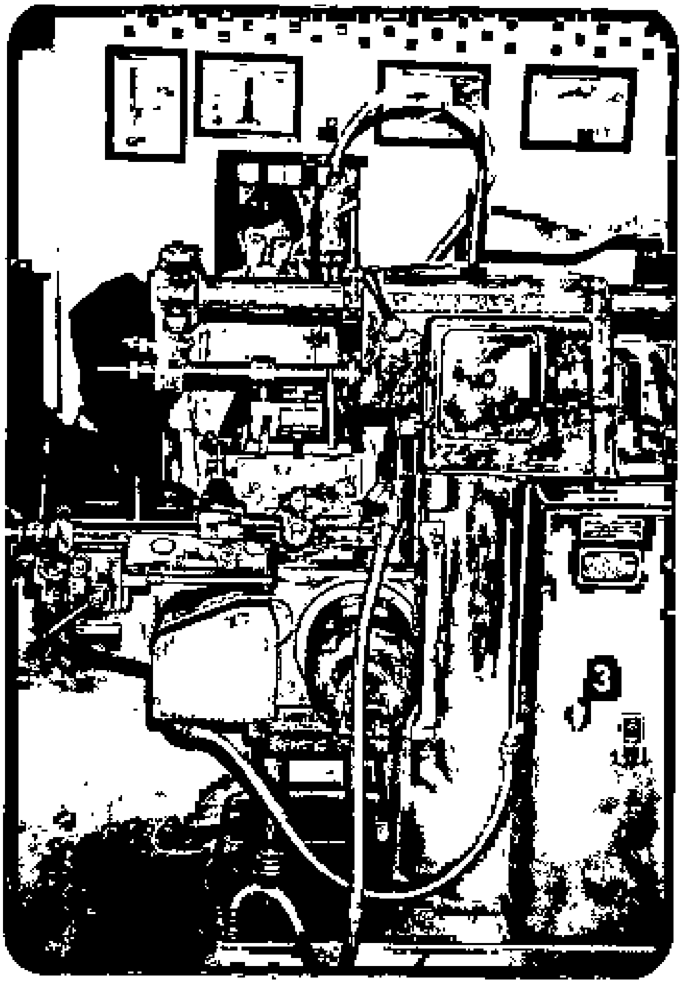


Fig 3·1 Experimental setup during upmilling

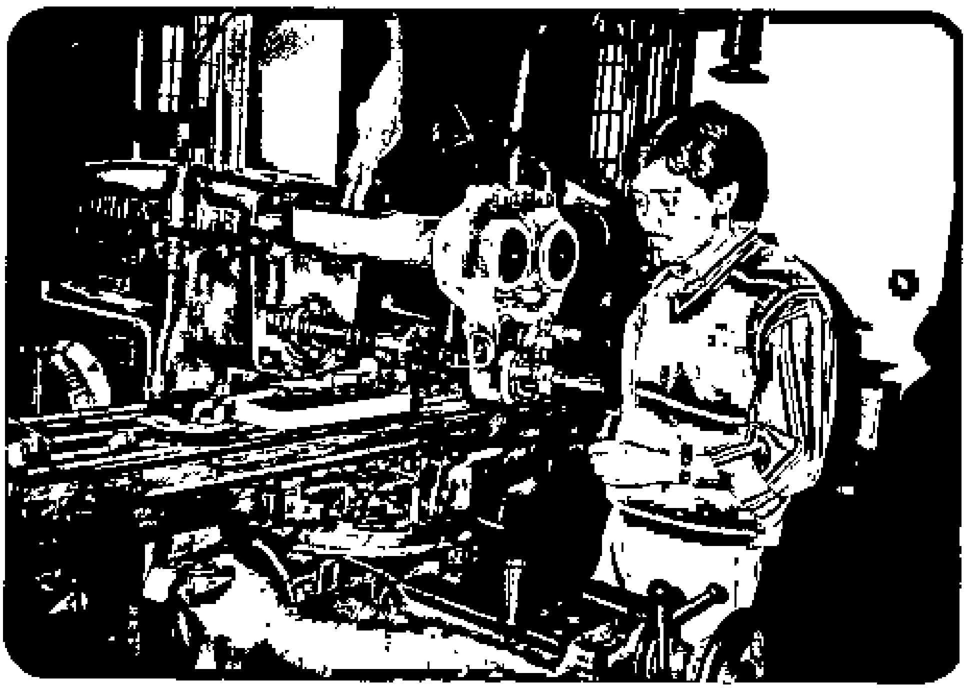


Fig.3·2 Experimental setup during down milling

3.1 DESIGN OF 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. (3.3).

During designing of the single tooth fly cutter the recommended values of relief angle and back rake angle were taken as 12°, 8° respectively. The tool holder was made of mild steel. Two single tooth fly cutters of high speed steel (HSS) of same dimensions were made, one of which was used in up milling process and the other was used in down milling process.

The single tooth fly cutter (2) was overhanged from the tool holder (1) and was clamped by clamping screws (3, 4). The diameter and length of cutter was 25.4mm and 47mm respectively and diameter and length of the tool holder was 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. (3.3).

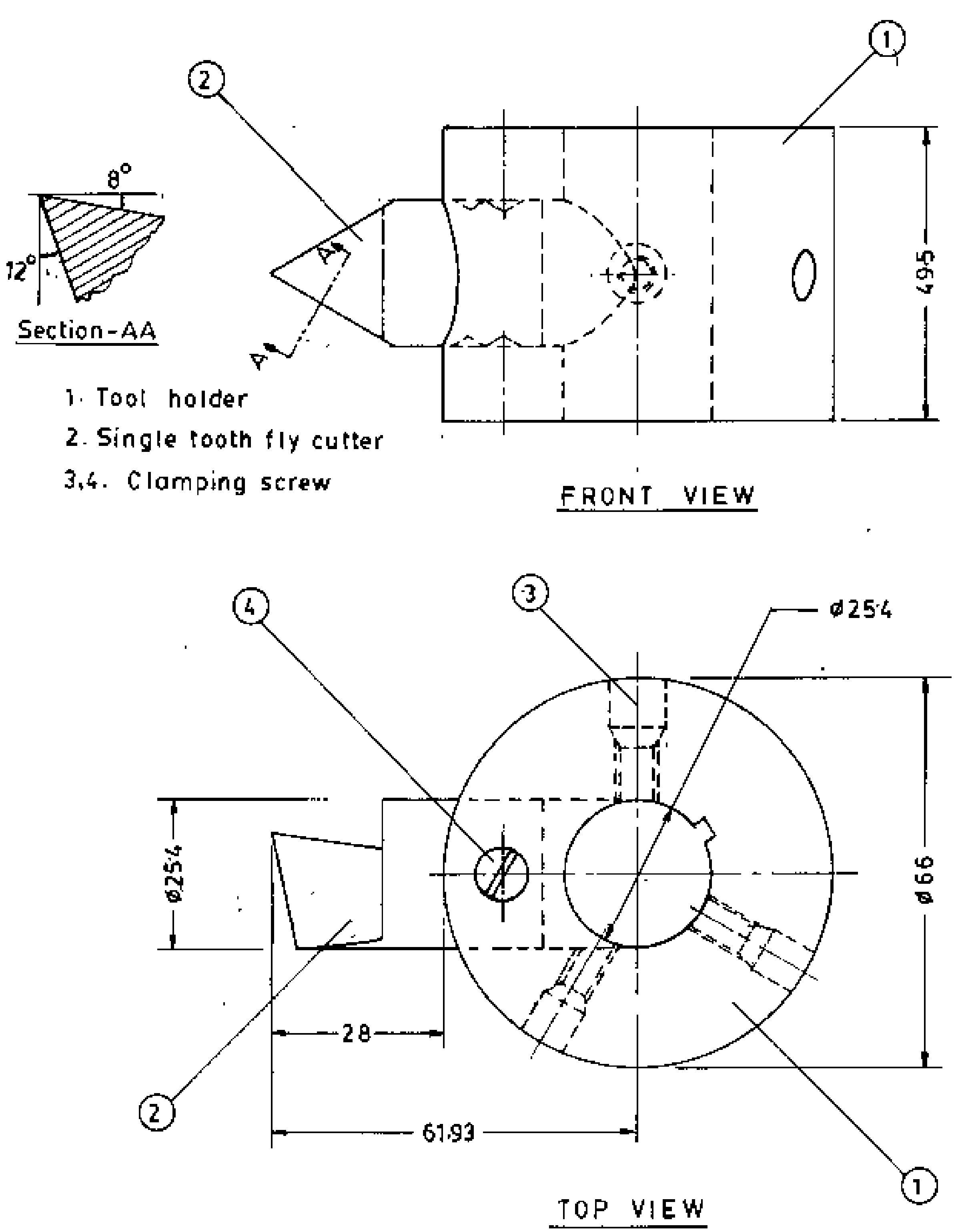


Fig.(3.3) Single tooth fly cutter mounted on the tool holder

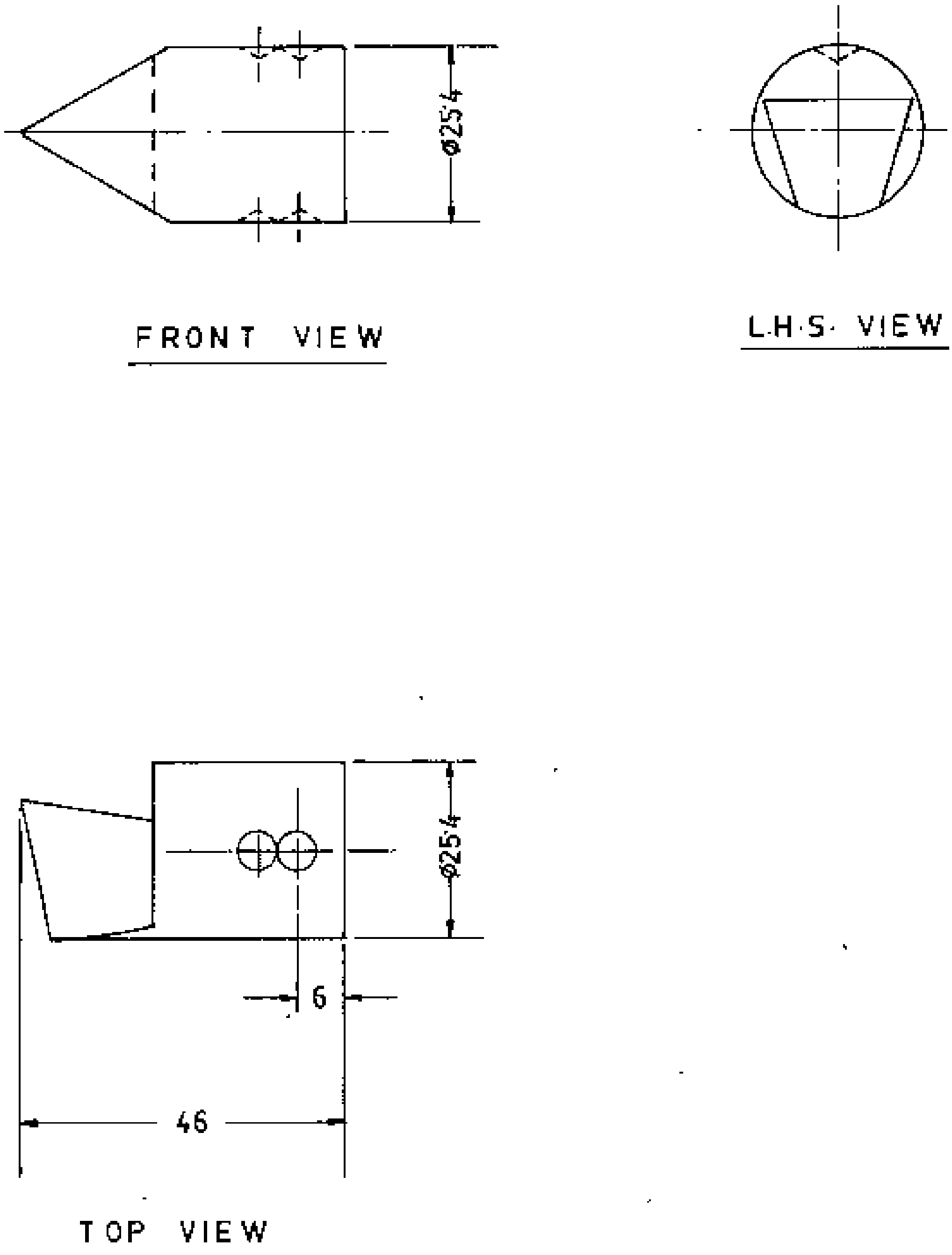


Fig.(3.4) Single tooth fly cutter

3.2 MEASUREMENT OF TOOL WEAR

Experiments on tool wear were conducted in the workshop at BUET. To investigate tool wear, two single tooth fly cutters of high speed steel (HSS) of same dimensions were made, one of which was used in up milling process and the other was used in down milling process. Two work-pieces of mild steel of same dimensions (25cm x 15cm x 2.4cm) were taken, one of which was used in up milling process and the other was used in down milling process.

Slots were cut both by up milling and down milling process on the work-piece using single tooth fly cutter mounted on the tool holder. In up milling after cutting slot on work-piece, say for depth of cut (t) = 0.1mm, feed rate (S) = 9.525 mm/min, cutter diameter (D) = 123.86 mm, cutter RPM (N) = 79 rpm, the cutting tool was taken under the microscope to observe the flank wear of the tool (Fig. 3.5). During slotting, operation 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 (3). Then the whole process was repeated during down milling process and the results are listed in table (4).

Fig 3.5 Experimental setup during measurement of tool wear

3.3 MEASURING SURFACE ROUGHNESS

3.3.1 BRIEF DESCRIPTION OF THE SURFACE ROUGHNESS MEASURING EQUIPMENT

Surface roughness was measured on surfaces machined by up milling and down milling process.

This was done using a surface roughness measuring equipment (surf. test AB-5 machine, Fig. 3.6, 3.7). The surf. 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.

Those three characteristics are evaluated from recorded surface profile: roughness as R-max waviness as WEM and straightness as deviation from geometrical line.

Surf. test AB-5 machine is also applicable for measurement of deviation from the nominal surface. The surf. test AB-5 machine consists of a measuring unit and amplifier/recording unit, the mechanical displacement of the stylus given while travelling measured surface is converted into electric quantity thru strain gage of bridge circuit to be amplified in the amplifier/recording unit to a desired vertical magnification. 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

i. Levelling table (± 5^o)

ii. Workpiece holding device

iii. Small vice

iv. Precision reference specimen (12µm in height, about 160^o)

v. Recording chart (3 folds)

vi. Fuse (1A 2 pcs)

vii. Philip screw driver and plain screw driver (one each)

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

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

x. Connecting cord (10-pin) ... power drive unit to recorder

xi. Ink (red) ... 5 cartridges

Pen cleaning wires ... 10 pcs

Blower

Injector

2. Measuring Unit

(1) <u>Elevation wheel, power drive unit</u>

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

(2) Fine elevation whell

The fine elevation wheel is used to elevate the power drive unit finely in the range of 7mm. 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 disengaged by turning the knob. When the clutch is disengaged, the manual knob can be used for manual driving of the stylus for levelling or quick positioning.

(5) Manual knob

When the stylus clutch is disengaged, the manual knob becomes effective for manual stylus drive in forward or backward direction. It is used for levelling 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 setting 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 hands: one for traverse of the stylus and the other for the limit of the travel range.

(9) Power drive unit

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

(10) Pilot lamp

At ON of the power switch, the pilot lamp lights.

(11) Power switch

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

(12) Levelling table

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

(13) Base: Reference surface for work-piece.

(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

(1) Precautions before measurement

1. 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 abhors high temperature and high humidity.

(2) Cord connection

The cords should be connected referring to the Fig. (3.8) 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 switches 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 (50Hz or 60Hz) with the AC-line before shipment.

3.3.2 SURFACE ROUGHNESS MEASURING PROCESS

Job surface roughness was measured by surface roughness measuring equipment (Surf.test.AB-5 machine). This equipment was designed to have accurate measurement of surface roughness at high magnification. For levelling, the work-piece was placed on this table within the range of ±5 degrees (counter-clockwise rotation of levelling screw for up, and clockwise rotation for down). The levelling table was furnished with micrometer head for positioning the work-piece.

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 work-piece (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 (h). The whole procedure was repeated for another reading of job surface roughness height (h).

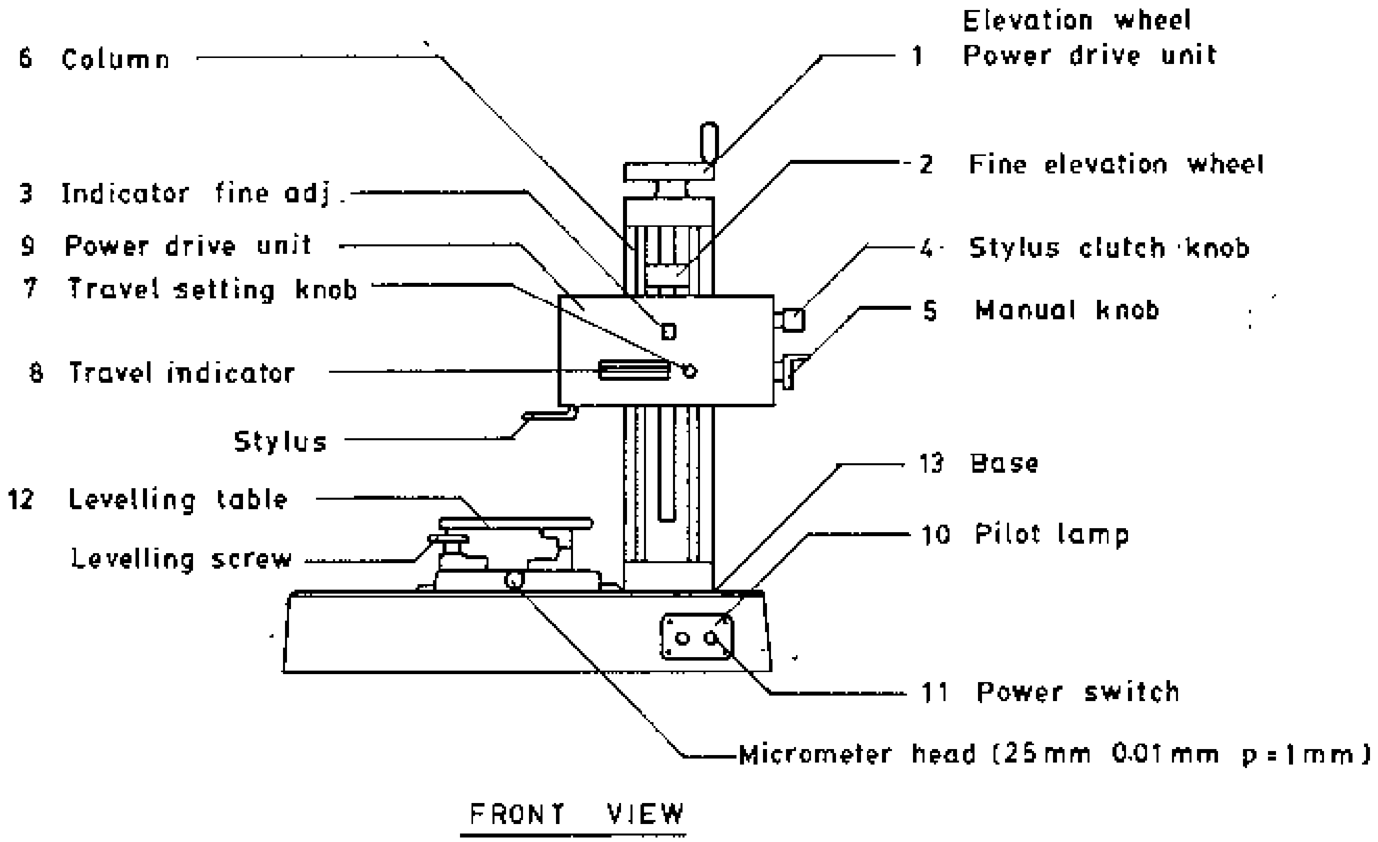


Fig (3-6) Surface roughness measuring equipment (surf. test AB-5 machine)

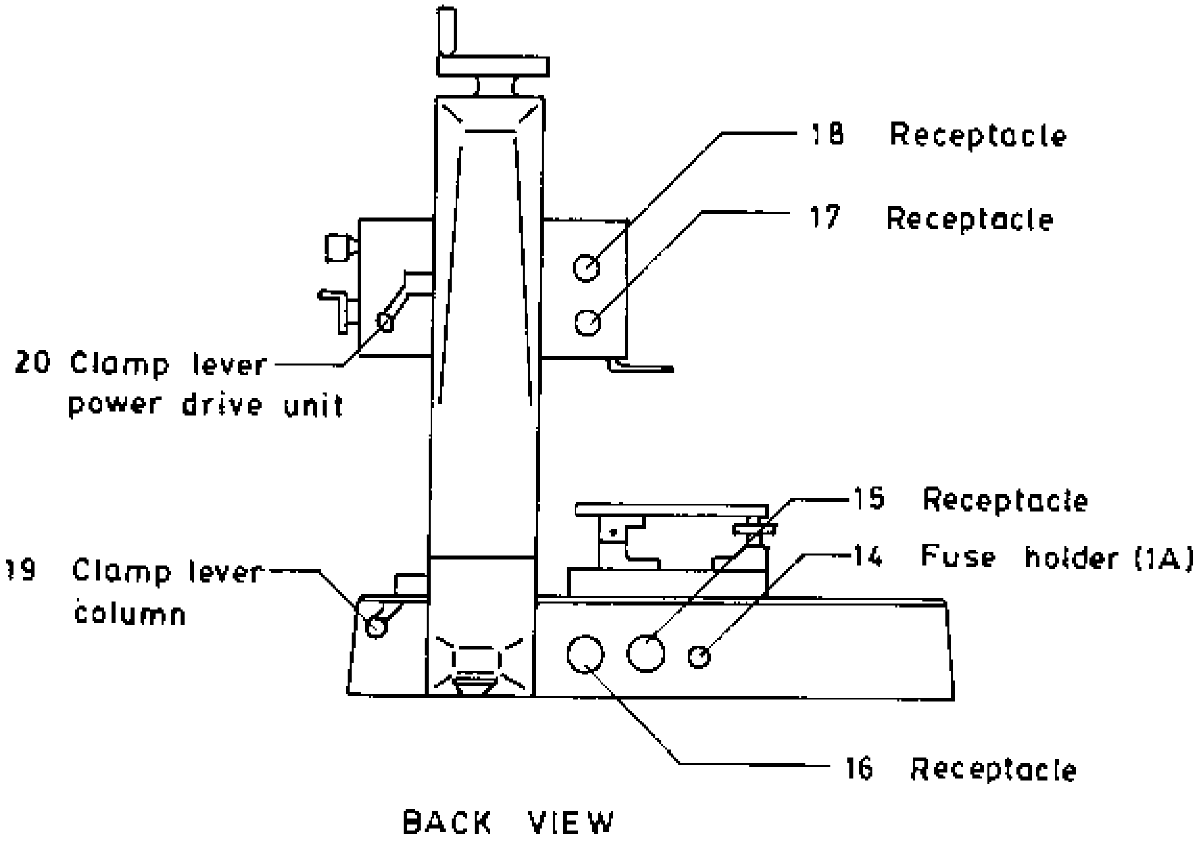


Fig. (3-7) Surface roughness measuring equipment (surf. test AB-5 machine)

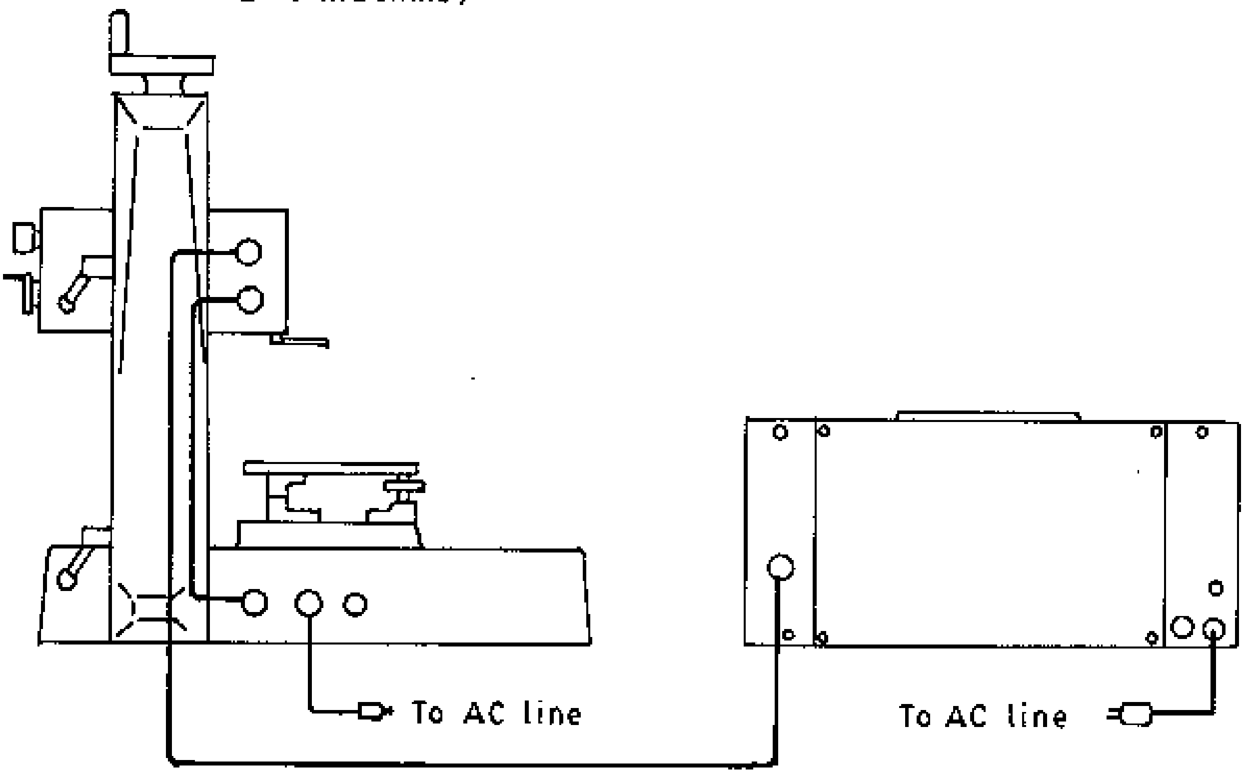


Fig (38) Surface roughness measuring equipment (surf. test AB-5 machine)

CHAPTER 4: EXPERIMENTAL RESULT

4.1 EXPERIMENTAL RESULTS ON TOOL WEAR DURING UP MILLING AND DOWN MILLING PROCESS

Slots were cut both by up milling and down milling process on mild steel using high speed steel tool. Wear was measured along the flank surfaces of tools using a microscope.

Slots were cut with the following cutting parameters:-

Cutting speed (N) = 79 rpm

Feed rate of the work-piece (S) = 9.525 mm/min.

Depth of cut (t) = 0.1 mm

Cutter diameter = 123.86 mm

Relation of wear characteristics with time was investigated. Experimental results are presented in tables (2) and curve (4.1). From the experimental data it is seen that tool wear is less in the case of down milling than that in the case of up milling.

The dependence of flank wear (both in up milling and down milling process) on the time of tool operation is presented by the flank wear vs. time curve (Fig. 4.1) that can be divided into three sections.

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

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

When a certain degree of wear has been reached, the friction 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.

From flank wear vs. time curve (Fig. 4.1) it is seen that section II begin from point (Q_1, Q_2) where the value of flank wear are 0.72mm and 0.56mm for up milling and down milling respectively with respect to operation of time 26 minutes.

Section- III begin from point (F_1, F_2) where the value of flank wear are 1.75mm and 1.52mm for up milling and down milling respectively with respect to operation of time 130 minutes.

TABLE - 2

Flank Wear for Up Milling and Down Milling

Depth of Cut (mm)	Time (minute)	Flank Wear (mm) for Up Milling	Flank Wear (mm) for Down Milling
0	0	0	0
0.1	26.00	0.72	0.56
0.1	52.00	1.10	0.86
0.1	78.00	1.37	1.14
0.1	104.00	1.58	1.36
0.1	130.00	1.75	1.52
0.1	156.00	2.24	1.76
0.1	182.00	2.92	2.32

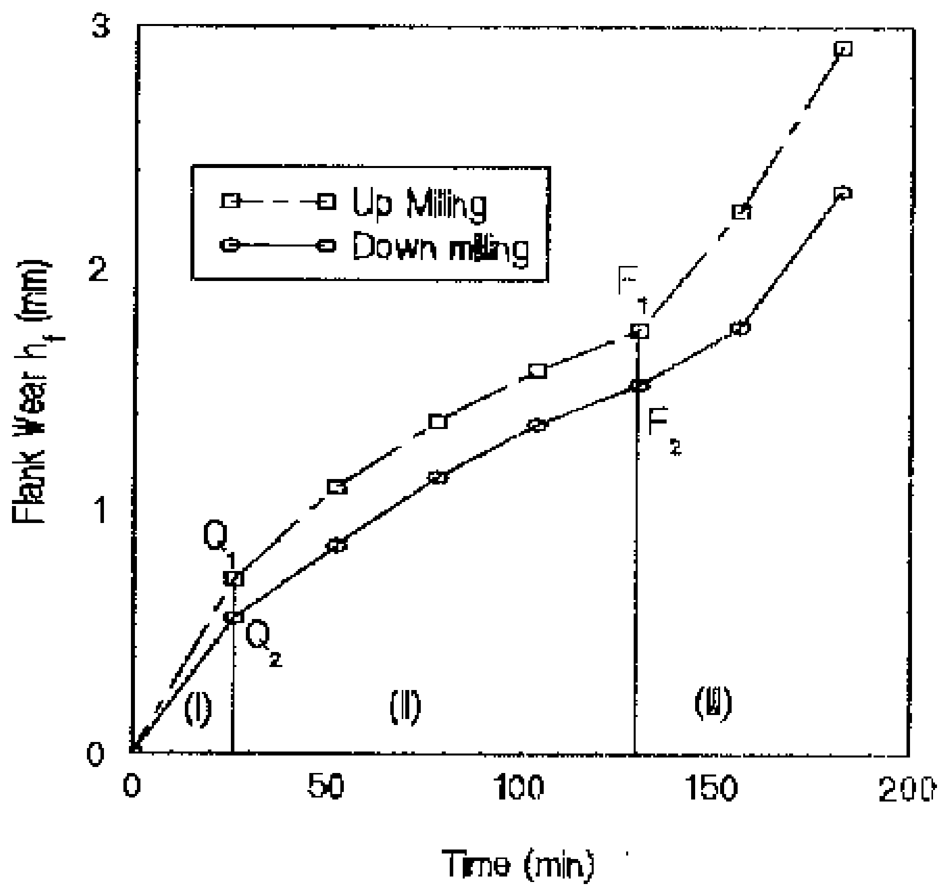


Fig.4.f. Flank wear vs time curve

4.2 EXPERIMENTAL RESULTS ON JOB SURFACE ROUGHNESS DURING UP MILLING AND DOWN MILLING PROCESS

Job surface roughness was measured on surfaces machined by up milling and down milling. These were done by using a surface roughness measuring equipment. Experimental results on job surface roughness are presented in tables (3, 4). From experimental data it is seen that the height of surface roughness is less in up milling than in down milling.

The height of surface roughness is less in up milling because a flatter arc of trochoid was produced in up milling than in down milling.

From experimental data, the average surface roughness height in up milling was found to be 1.32×10^{-5} m and that in down milling to be 2.02×10^{-5} m.

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

cutter diameter (D) = 123.86 mm

feed per tooth (S_0) = .1205 mm

cutting speed (N) = 79 rpm

number of tooth in cutter (Z) = 1

are found to be 2.929×10^{-5} mm in up milling and that in down milling to be 2.933×10^{-5} mm.

From experimental data and theoritical value of surface roughness height (h), it is also seen that the surface roughness height is less in up milling than in down milling process.

Therefore considering surface roughness up milling is more favourable than down milling.

Table- 3

Surface Roughness Height (h) for Up Milling

Observation No.	Movement of Stylus in the Left side (μm)	Movement of Stylus in the Right side (μm)	Actual Reading h, (Difference between movement of Stylus in left side & right side (m)
1	10.4	24.4	1.4×10^{-5}
2	27.6	42.0	1.44×10^{-5}
3	28.4	41.4	1.3×10^{-5}
4	28.4	40.6	1.22×10^{-5}
5	32.8	48.0	1.52×10^{-5}
6	36.0	48.6	1.26×10^{-5}
7	34.4	45.4	1.1×10^{-5}
8	33.6	47.0	1.34×10^{-5}

Table- 4

Surface Roughness Height (h) for Down Milling

Observation No.	Movement of Stylus in the Left side (µm)	Movement of Stylus in the Right side (µm)	Actual Reading h, (Difference between movement of Stylus in left side & right side (m)
1	16.0	42.0	2.6×10^{-5}
2	13.6	30.4	1.68×10^{-5}
3	15.2	43.2	2.8×10^{-5}
4	20.4	37.4	1.7×10^{-5}
5	29.6	45.0	1.54×10^{-5}
6	29.2	48.0	1.88×10^{-5}
7	9.6	33.2	2.36×10^{-5}
8	22.4	38.4	1.6×10^{-5}

CHAPTER 5: DISCUSSION

A milling machine is a very versatile one. It can be used to machine flat and irregularly shaped surfaces, to drill, bore, cut gears, generate helical shapes, produce cams and be adapted for slotting work. Milling operations fall into two distinct methods:- up milling and down milling.

In up milling the work-piece is fed into the roating cutter. The chip is at minimum thickness at the start of the cut and is so small that the cutter has a tendency to slide over the work-piece until sufficient pressure is build up to bite into the work. In down milling the work-piece moves in the same direction as the rotation of the cutter.

To measure tool wear, a single tooth fly cutter mounted on the holder was designed. Slots were cut both by up milling and down milling on mild steel using single tooth fly cutter. Tool wear was measured along the flank surface of tools using a microscope. The microscope by which readings were taken, was not a sophisticated one. For this reason some error may be incorporated during wear recording by that microscope.

In up milling the tooth of the cutter is subjected to heavy friction in sliding over the cut surface. Therefore intence flank wear occurs in up milling whereas in down milling, the tooth of the cutter enters into the workpiece without sliding. For this reason tool wear should be less in down milling than in up milling. However, tool wear cannot be analysed by this phenomenon only. From experimental data (Table- 2) flank wear in up milling was found to be 1.75 mm and that in down milling to be 1.52 mm when the operation time was 130 minute.

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 impiles 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. Each time some of BUE material is removed.

Tool wear occurs in two areas. The major tendency for wear is on the tool face a short distance from the cutting edge. The second area of wear is on the flank below the cutting edge. Flank wear first appears on the clearance face of the tool in the form of a wear land and is mainly due to the result of friction and abrasion of the tool about the work-piece. Adhesion is another factor due to high pressure and temperature, which involves welding of the tool to the chip material causing the formation of BUE which takes away particles of the tool material with it.

Thermal cracking due to thermal shock is also a cause of breakdown of small particles from the flank surface, leading to flank wear. Crater wear and flank wear affect the performance of the cutting tool in various ways.

The cutting forces are normally increased by wear of the tool, although cutting forces can be controlled by proper selection of feed, speed and depth of cut. Tool temperature is closely related to cutting speed. With increased cutting speed, the rate of energy input into the cutting zone increases rapidly. This results in temperature rise, loss of tool properties and decrease tool life.

Flank wear was not found 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 is 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 wear process during cutting action.

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 steel tool, because tool material for most of the milling cutters is 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 fear of the steel cracking or distoring.

High speed 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. High speed steel tools acquire a hardness of 62-63RC when correctly heated and operate efficiently at cutting speeds two or three times higher than those asllowed for carbon steel tools.

Change of geometrical parameters of cutting tool from their static values were done analytically. This gave the actual geometric parameters of cutting edges during up milling and down milling. Effect of different factors on the change of geometrical parameters were investigated.

A mathematical model on change of relief angle of cutting tool ($\Delta\alpha$) and its real relief angle (α_{real}) with the change of contact angle of the cutting tool with the work-piece (θ) had been developed. The change of relief angle of cutting tool ($\Delta\alpha$) with respect to contact angle of the cutting tooth with the work-piece (θ) is shown in (Fig. 2.3).

Certain characteristics features of change of relief angle of cutter ($\Delta\alpha$) may be observed from (Fig. 2.3). Change of relief angle of cutting tool ($\Delta\alpha$) has considerable influence on cutting conditions during up milling and down milling process. The greater relief angle of cutting tool, the less friction of the tool on the work-piece and less heat generation takes place which ultimately causes less tool wear.

Change of relief angle of cutting tool ($\Delta\alpha$) in up milling process was different from that of down milling process.

In up milling change of relief angle of cutting tool ($\Delta\alpha$) was less than that in case of down milling. For example (Table 1) in up milling the value of change of relief angle of cutting tool ($\Delta\alpha$) was found to be 0.354 degrees and in down milling to be 0.362 degrees, when the contact angle of cuuting tool with the work-piece, $\theta = 30^{o}$.

When relief angle is increased it reduces the cutting forces at the cutting edges of tool. Relief angle of more than 12^{o} will weaken the cutting edges of tool. If the relief angle is too small, a vertical flat land may develop rapidly just under the cutting edges of tool. Such a land makes the relief angle zero resulting quick failure of the tool. It should be remembered that the relief angle is provided to ensure that the cutting edge will be free to cut as the relative movement between the work-piece and the tool takes place. For this reason during designing of single tooth fly cutter the recommended value of relief angle was taken as 12^{o}.

Experiments were conducted on job surface roughness machined by up milling and down milling.

A flatter arc of trochoid was produced in up milling than in down milling. Therefore the height of tooth makes or job surface roughness height was less in up milling than in down milling. The experimental value and theoritical value of the average job surface roughness height(h) in up milling was found to be $1.32x10^{-5}$m and 2.929×10^{-5}mm respectively and that in down milling to be $2.02x10^{-5}$ m and 2.933×10^{-5} mm respectively. In up milling a better job surface finish was produced than that of down milling. The height of job surface roughness or height of tooth marks affect the quality of finish. The height of tooth marks or job surface rougness height can be reduced by increasing radius of the cutter and decreasing the feed per tooth.

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. Assumptions were made for this experiment are as follows.

(i) The properties of the tool material over its entire length are uniform. Therefore, the properties of two cutters used in up milling and down milling were taken from a single rod are identical.

(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 same cutting speed.

CHAPTER 6: CONCLUSIONS & SUGGESTIONS FOR FUTURE WORKS

6.1 CONCLUSIONS

From this study the following conclusions can be drawn:

(1) Change of relief angle of cutting tool ($\Delta\alpha$) with respect to contact angle of the cutting tooth with the work-piece (θ) is less in up milling than in down milling. For this reason, when considering the change of geometrical parameters of cutting tool, the cutting condition is more favourable in up milling than in down milling.

(2) The height of tooth marks or height of job surface roughness (h) is less in up milling than in down milling. Therefore up milling produces better job surface finish than in down milling.

(3) Tool wear was found to be higher in up milling than in down milling. So cutter life is longer in down milling than in up milling. For the same cutter life, down milling can be performed at higher cutting speeds with a corresponding higher output.

The selection of one or the other methods of milling however should be dictated by proper consideration of the job on hand and the various factors contributing to its economic production.

6.2 SUGGESTIONS FOR FUTURE WORKS

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

(1) This study had been conducted with a single tooth fly cutter. This study can be revised using multiple tooth cutter.

(2) 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.

(3) Tool angles may be optimised for minimum tool wear by conducting a large number of successive experiments.

(4) Cutting fluid was not used during experiments. Therefore, the wear characteristics can be restudied using cutting fluid during cutting operation.

Appendix-I

Specifications for Surface Roughness Measuring Equipment.

1. Measuring range:

    Vertical .... 0 - 300μm

    Horizontal .... 0 - 50mm (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 125mm	over 125mm
Vertical	± 1mm	± 2mm
Horizontal	± 1mm	± L/125mm

L = recorded length in mm

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

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

6. Stylus :

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

7. Recording chart :

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

The value of one division for each magnification .....

Vertical	500X	1000X	2000X	5000X	10000X	20000X
Value (µm)	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 180mm (feed screw p = 3mm)
   7mm for fine adjustment (feed screw p=0.5mm)

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: 10µm and 100µm

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 240V (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, 37kg
    Amplifier/recording unit .... 430(W) x 255(D) x 200(H)mm, 10kg

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