MODULE-4

MECHANICS OF MACHINING PROCESSES

LESSON CONTENTS:

Introduction, Chip formation, Orthogonal cutting, Merchants model for orthogonal cutting, Oblique cutting, Mechanics of turning process, Mechanics of drilling process, Mechanics of milling process, Numerical problems.

OBJECTIVES:

- To Study the mechanism of chip formation and differentiate between orthogonal and oblique cutting.
- To obtain equations to calculate various cutting forces using merchants tool diagram.
- To study the mechanics of turning, drilling and milling process.

4.0 Introduction:

Metal removal process is a machining process in which excess amount of material is removed in the form of chips in order to shape the material to the required dimension and size.

Machining is not just one process; it is a group of processes. The common feature is the use of a cutting tool to form a chip that is removed from the work-part. To perform the operation, relative motion is required between the tool and work. This relative motion is achieved in most machining operations by means of a primary motion, called the cutting speed, and a secondary motion, called the feed. The shape of the tool and its penetration into the work surface, combined with these motions, produces the desired geometry of the resulting work surface.

4.1 Theory of chip formation:

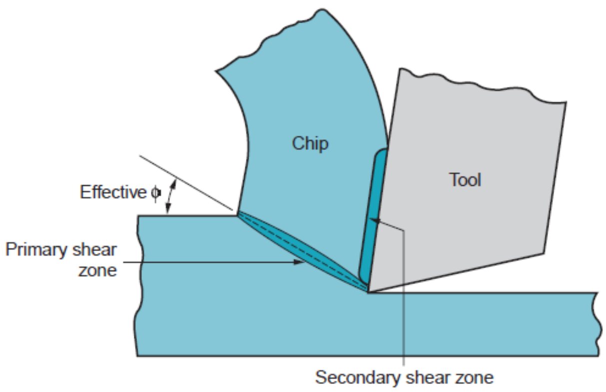

Figure 4.1: Formation of chip in metal cutting

The above figure illustrates the basic geometry of a to dimensional chip formation. When the cutting tool is forced to move against the workpiece, the tool exerts a compressive force on the workpiece. The material of the workpiece is stressed beyond its yield point causing it to deform plastically and shear off. The plastic flow take place in the localised region called Shear plane. The sheared portion of the metal begins to flow along cutting tool face in the form a small pieces called chips.

4.2 Mechanics of chip formation:

As the cutting tool pressed against the workpiece, the tool removes the material in the form a chip at shear zone. Three different types of chips are formed during the process. They are:

1. Continuous chips
2. Discontinues Chips
3. Continuous with built up edges.

Continuous chip: When ductile work materials are cut at high speeds and relatively small feeds and depths, long continuous chips are formed. A good surface finish typically results when this chip type is formed. A sharp cutting edge on the tool and low tool–chip friction encourage the formation of continuous chips. Long, continuous chips (as in turning) can cause problems with regard to chip disposal and/or tangling about the tool. To solve these problems, turning tools are often equipped with chip breakers.

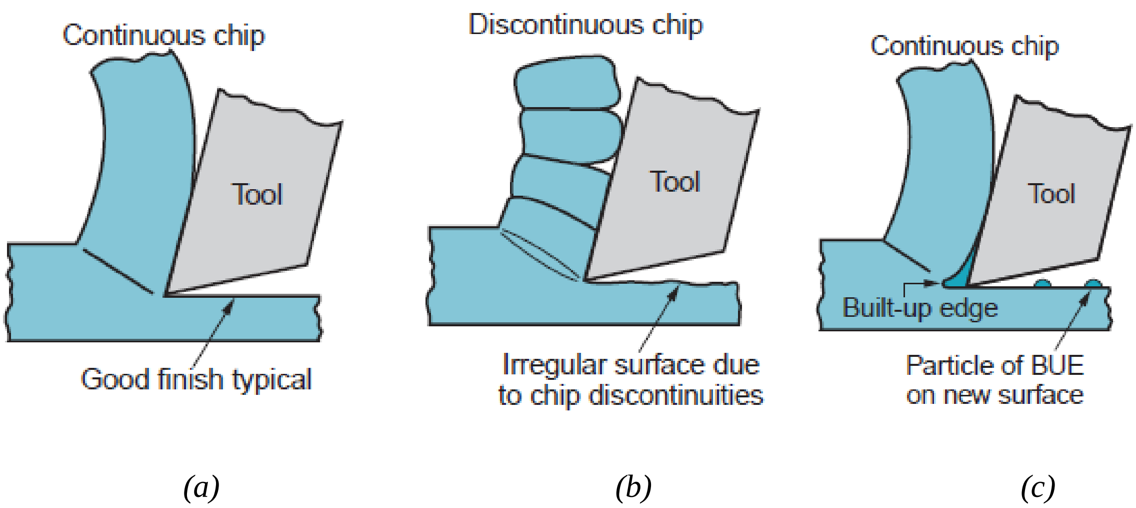

Figure 4.2: (a) Continuous (b) Discontinuous (c) Continuous with built up edges

Discontinuous chip: When relatively brittle materials (e.g., cast irons) are machined at low cutting speeds, the chips often form into separate segments (sometimes the segments are loosely attached). This tends to impart an irregular texture to the machined surface. High tool–chip friction and large feed and depth of cut promote the formation of this chip type.

Continuous chip with built-up edge: When machining ductile materials at low-to medium cutting speeds, friction between tool and chip tends to cause portions of the work material to adhere to the rake face of the tool near the cutting edge. This formation is called a built-up edge (BUE). The formation of a BUE is cyclical; it forms and grows, then becomes unstable and breaks off. Much of the detached BUE is carried away with the chip, sometimes taking portions of the tool rake face with it, which reduces the life of the cutting tool. Portions of the detached BUE that are not carried off with the chip become imbedded in the newly created work surface, causing the surface to become rough.

4.3 Orthogonal and Oblique cutting

4.3.1 Orthogonal Cutting Model:

In orthogonal cutting, the cutting edge inclination is zero and chip is expected to flow along the orthogonal plane. The cutting tool is passes such a way that the cutting edge is normal to the tool feed direction. In orthogonal cutting, the radial force is zero, and it involves only two component of force.

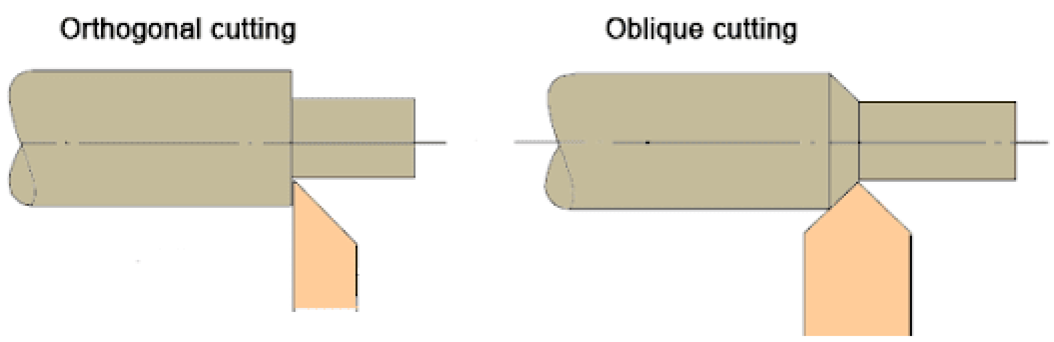

Figure 4.3: Orthogonal and oblique cutting

4.3.2 Oblique Cutting Model:

In oblique cutting, chip flow deviates from the orthogonal plane. Tool passes to workpiece at an acute angel to the tool feed motion. The analysis of cutting includes three mutually perpendicular component of force.

4.3.3 Comparison between Orthogonal and oblique cutting

Sl. No	Orthogonal metal cutting	Oblique metal cutting
1	Cutting edge of the tool is perpendicular to the direction of tool travel.	The cutting edge is inclined at an angle less than 90^o to the direction of tool travel.
2	The direction of chip flow is perpendicular to the cutting edge.	The chip flows on the tool face making an angle.
3	The chip coils in a tight flat spiral	The chip flows sideways in a long curl.
4	For same feed and depth of cut the force which shears the metal acts on a smaller area. So the life of the tool is less.	The cutting force acts on larger area and so tool life is more.
5	Produces sharp corners.	Produces a chamfer at the end of the cut
6	Smaller length of cutting edge is in contact with the work.	For the same depth of cut greater length of cutting edge is in contact with the work.
7	Generally parting off in lathe, broaching and slotting operations are done in this method.	This method of cutting is used in almost all machining operations.

4.4 Earnest Merchant's Tool equation:

- Merchant circle diagram is used to analyse the forces acting in metal cutting.
- The analysis of three forces system, which balance each other for cutting to occur. Each system is a triangle of forces.

Assumptions made in drawing Merchant's circle:

- Shear surface is a plane extending upwards from the cutting edge.
- The tool is perfectly sharp and there is no contact along the clearance force.
- The cutting edge is a straight line extending perpendicular to the direction of motion and generates a plane surface as the work moves past it.

- The chip doesn't flow to either side, that is chip width is constant.
- The depth of cut remains constant.
- Width of the too, is greater than that of the work.
- Work moves with uniform velocity relative tool tip.
- No built up edge is formed.

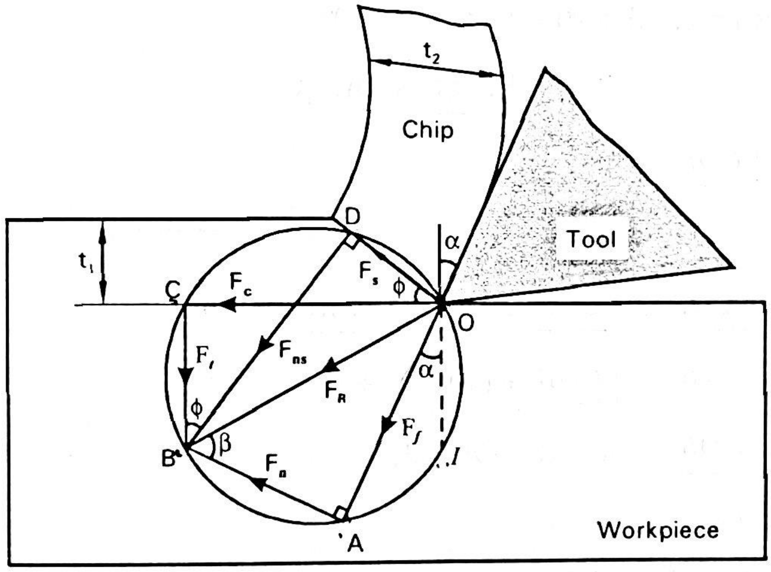

Figure 4.4. Merchant Tool Diagram

Shear plane angel = φ

Tool rake angel = α

Friction angel = β

Fn = normal force

Fs= Shear force

Fns= Force normal to shear force

Fc= horizontal cutting force

Ft= Thrust force

F_R= Resultant Force

From the figure,

$$\llcorner BOA = 90 - \beta$$

$$\llcorner COB = \beta - \alpha$$

$$\llcorner DOB = \varphi + \beta - \alpha$$

To find Fc and Ft:

From triangle BOC, cos(β-α) = Fc/Fr

Fc= Fr cos(β-α)

From triangle BOC, sin(β-α) = Ft/Fr

Ft = Fr sin(β-α)

To find Fs and Fns:

From triangle OBD, cos(φ+$\beta - \alpha$)=Fs/Fr

Fs=Fr cos(φ+$\boldsymbol{\beta - \alpha}$)

From triangle OBD, Sin(φ+$\beta - \alpha$)= Fns/Fr

Fns= Fr Sin(φ+β−α)

To find Ff and Fn, Ff and Fn are expressed in terms of Fc and Ft

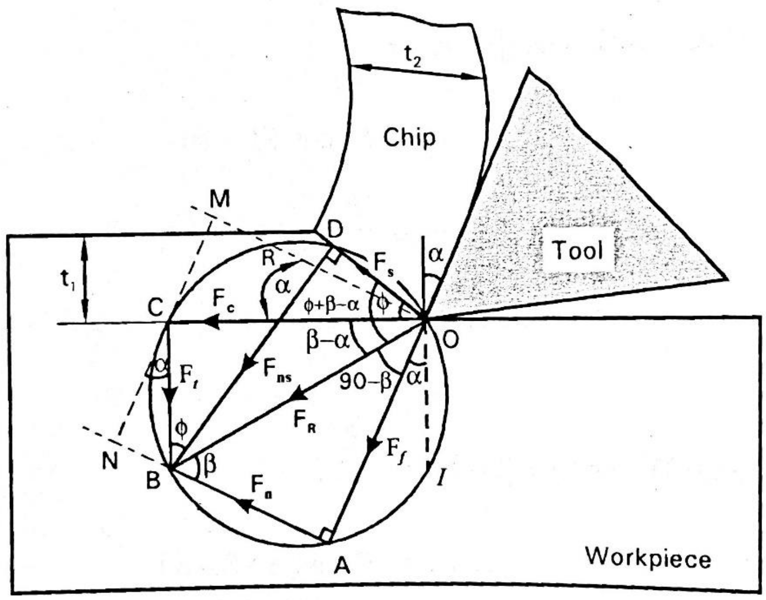

Figure 4.5: Merchants Tool diagram

From the diagram, Ff = OA= MN

Ff= MN= MC+CN

But from MC=? And CN=?

From triangle MCO, Sinα= MC/OC= MC/ Fc

To find CN=?

From triangle CNB cosα= CN/CB= CN/Ft

CN= Ft cosα

Therefore, Ff= Fc Sinα+Ft Cosα

Fn = AB = OR

Fn =OR = OM – MR

OM =? And MR =?

From triangle OMC cosα= OM/ OC = OM/ Fc

OM= Fc cosα

MR= NB

From triangle CNB, Sinα= NB/BC= NB/Ft

NB= Ft Sinα

Therefore, Fn= Fc Cosα+Ft Sinα

To calculate Co-efficient of friction,

Ff= μFn

μ = Ff/ Fn

$$\boldsymbol{\mu = \frac{Fc\ Sin\alpha + Ft\ Cos\alpha}{Fc\ Cos\alpha - Ft\ Sin\alpha}}$$

OUTCOMES:

- Students can understand the mechanism of chip formation and differentiate between orthogonal and oblique cutting.
- Students able to derive an expression for various cutting forces using merchants tool diagram.
- Students can solve numerical problems on various cutting forces through merchants diagram.

QUESTIONS:

1. Describe the mechanism of Chip formation.
2. Differentiate between orthogonal and oblique cutting
3. What are the different types of chips formed during machining orthogonal cutting?

4. Derive an expression to obtain cutting forces Fc, Ft, Fs, Fns, Ff, Fn and Coefficient of friction in orthogonal cutting using merchant tool diagram.

FURTHER READING:

1. “Metal cutting principles”, Milton C. Shaw, Oxford University Press, Second Edition,2005.
2. “Manufacturing Technology”, Vol 2, P N Rao, McGraw Hill Education, 3rd Edition

3. “Workshop Technology, Vol-II”, by Hazara Chowdary