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A Study on Principles of Metal Cutting: Review

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ABSTRACT

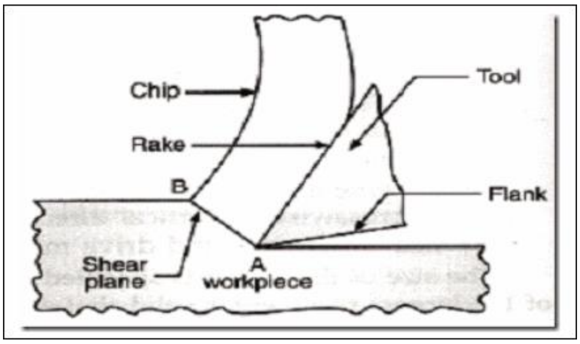
In this paper, the review of this paper pertaining to the present research topic has been carried out to gain knowledge and to become familiar with the established techniques and methodology for metal cutting. Principle of Metal Cutting covers a large collection of manufacturing processes designed to remove unwanted material, usually in the form of chips, from a work-piece. The term machining is used to describe various processes which involve removal of material from the work piece. Almost every manufactured product has components that require machining. This article covers basic elements of metal cutting, types of metal cutting process, various factors affecting on metal cutting process and different types of chips formation.

Keywords: *Metal cutting; Principles; Lathe operations; Lathe; Turning; Facing; Knurling.*

1.0 Introduction

Metal cutting is the process of removing unwanted material in the form of chips, from a block of metal, using cutting tool. A person who specializes in machining is called a machinist. A room, building or company where machining is done is called a Machine Shop. Figure 1 shows the schematics of a typical metal cutting process in which a wedge shaped, sharp edged tool is set to a certain depth of cut and moves relative to the workpiece.

Figure 1: Metal Cutting Process



Under the action of force, pressure is exerted on the workpiece metal causing its compression near the tip of the tool. The metal undergoes shear type deformation and a piece and layer of metal gets repeated in the form of chip. If the tool is continued to move relative to workpiece, there is continuous shearing of metal ahead of the tool. The shear occurs along a plane called the shear plane. All machining processes involve the formation of chips; this occurs by deforming the work material on the surface of job with the help of a cutting tool. Depending upon the tool geometry, cutting conditions and work material, chips are produced in different shapes and sizes. The type of chip formed provides information about the deformation suffered by the work material and the surface quality produced during cutting.

2.0 Basic elements in metal cutting

(i) A block of metal (work piece)
(ii) Cutting Tool
(iii) Machine Tool
(iv) Cutting Fluid
(v) Cutting speed (Primary Motion)
(vi) Feed (Secondary Motion)
(vii) Chips
(viii) Work holding and Fixturing
(ix) Force and Energy Dissipated, and
(x) Surface Finish

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2.1 Essential conditions for successful metal cutting

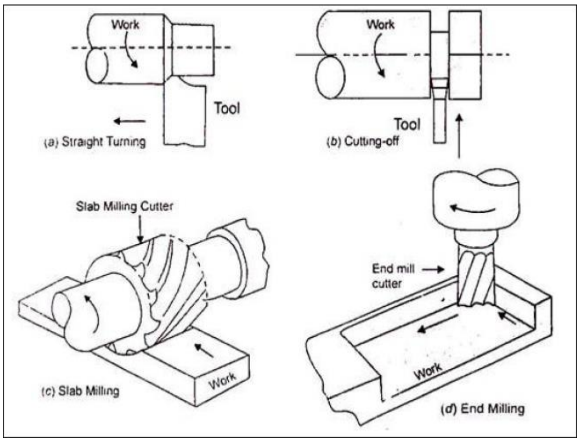
a. Relative motion between work and cutting tool.
b. Tool material must be harder than work material.
c. Work and tool must be rigidly held by jig and fixtures.
d. Sharp Cutting edge of cutting tool.
e. Primary Motion (Cutting Speed).
f. Secondary Motion (Cutting Feed).

Almost all the products produced by metal removal process, either directly or indirectly. The major disadvantages of the process are loss of material in the form of chips.

2.2 Types of cutting processes (operations)

Machining is not just one process; it is a group of processes. There are many kinds of machining operations. Each of which is specialized to generate a certain part geometry and surface finish quality. Some of the more common cutting processes are shown by Figure 2.

Figure 2: Common Cutting Process



2.2.1 Turning

Turning is used to generate a cylindrical shape. In this process, the work piece is rotated and cutting tool removes the unwanted material in the form of chips. The cutting tool has single cutting edge. The speed motion is provided by the rotating work piece, and the feed motion is achieved by the cutting tool moving slowly in a direction parallel to the axis of rotation of the work piece.

2.2.2 Drilling

Drilling is used to create a round hole. In this process, the cutting tool is rotated and feed against the work piece fixed in a holding device. The cutting tool typically has two or more cutting edges. The tool is fed in a direction parallel to its axis of rotation into the work piece to form the round hole.

2.2.3 Boring

Boring is used to enlarge an already drilled hole. It is a fine finishing operation used in the final stage of product manufacture.

2.2.4 Milling

Milling is used to remove a layer of material from the work surface. It is also used to produce a cavity in the work surface. In the first case it is known as slab-milling and in second case it is known as end- milling. Basically, the milling process is used to produce a plane or straight surface. The cutting tool used has multiple cutting edges. The speed motion is provided by the rotating milling cutter. The direction of the feed motion is perpendicular to the tool's axis of rotation.

2.2.5 Cutting-off

Cutting-off is used to cut the metal into two parts. In this operation, the work piece is rotated and cutting tool moves radially inward to separates the components.

3.0 Factors Influencing Metal Cutting Process

Various factors or parameters that affects the cutting process and so surface finish and accuracy of part geometry, are given in Table 1.

3.1 Independent variables

The major independent variables are:

a. Cutting tool material, shape, geometry, angles.
b. Work piece material, condition, temperature.
c. Cutting parameters, such as speed, feed, and depth of cut.
d. Cutting fluids.
e. Machine tool specifications.
f. Work holding and Fixturing.

3.2 Dependent variables

Dependent variables are influenced by changes in independent variables.

The major dependent variables are:

a. Types of chips formed.
b. Temperature zone at work tool interface.

c. Tool wear and failures.
d. Surface finish.
e. Force and energy in cutting process.

Table 1: Factors Affecting Cutting Process

S.No.	Parameter	Influence
1.	Cutting parameters	Energy, force, power, temperature rise, tool life, type of chips, surface finish.
2.	Cutting fluid	Surface finish, heat disipation.
3.	Tool geometry	Type of chips, chip flow direction, cutting force.
4.	Tool wear	Dimensional accuracy, surface finish, temperature rise, force and power requirement.
5.	Temperature rise	Thermal damage of workpart, dimensional accuracy, tool life, tool wear.
6.	Machinability	Tool life, force and power, surface finish.
7.	Continuous chips	Good surface finish, steady cutting forces.
8.	Built-up edge chips	Poor surface finish, thin stable built-up edge can protect tool surface.
9.	Dis-continuous chips	Fluctuating cutting forces, desirable for ease of chip disposal, vibrations and chatter.

3.3 Methods of metal cutting

There are two basic methods of metal cutting based on cutting edge and direction of relative motion between tool and work:

i. Orthogonal cutting process (Two Dimensional)
ii. Oblique cutting process (Three Dimensional)

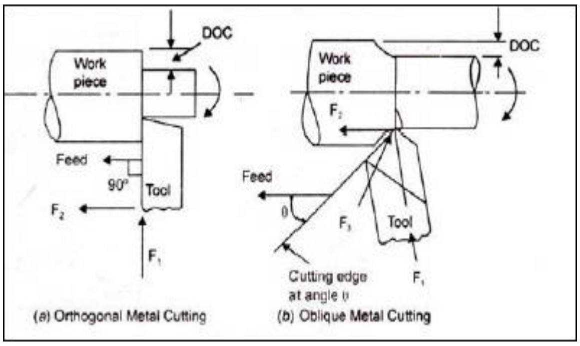
3.3.1 Orthogonal cutting process

In orthogonal cutting process, the cutting edge is perpendicular (90 degree) to the direction of feed. The chip flows in a direction normal to cutting edge of the tool. A perfectly sharp tool will cut the metal on rack surface.

3.3.2 Oblique cutting process

In oblique cutting process, the cutting edge is inclined at an acute angle (less than 90 degree) to the direction of feed. The chip flows sideway in a long curl. The chip flows in a direction at an angle with normal to the cutting edge of the tool.

Figure 3: Oblique Cutting Process



3.4 Principle of metal cutting

A typical metal cutting process by single point cutting tool is shown in Figure. In this process, a wedge-shaped tool moves relative to the work piece at an angle a. As the tool makes contact with the metal, it exerts pressure on it. Due to the pressure exerted by the tool tip, metal will shear in the form of chips on the shear plane AB. A chip is produced ahead of the cutting tool by deforming and shearing the material continuously, along the shear plane AB.

The shear plane is actually a narrow zone and extends from the cutting edge of the tool to the surface of the work piece. The cutting edge of the tool is formed by two intersecting surfaces. A detailed about various terminologies is given below.

3.4.1 Rack surface

It is the surface between chip and top surface of the cutting tool. It is the surface along which the chip moves upwards.

3.4.2 Flank surface

It is the surface between work piece and bottom of the cutting tool. This surface is provided to avoid rubbing with the machined surface.

3.4.3 Rack angle (α)

It is the angle between the rack surface and the normal to work piece. Rack angle may be positive or negative.

3.4.4 Flank angle/clearance angle/relief angle (γ)

It is the angle between the flank surface and the horizontal machined surface. It is provided for some clearance between flank surface and machined surface of work piece to avoid rubbing action of cutting tool to the finished surface.

5.4.5 Primary deformation zone

It is the zone between tool tip and shear plane AB.

3.4.6 Secondary deformation zone

It is the zone between rack surface of the tool and chip.

3.4.7 Tertiary deformation zone

It is the zone between flank surface of the tool and machined surface of work piece. Almost all the cutting processes involve the same shear-deformation theory. The cutting tool used in cutting process may be single-point or multi-point cutting tool. Turning, threading, and shaping, boring, chamfering, and facing are some cutting operations done by single point cutting tool. Milling, drilling, grinding, reaming and broaching are some cutting operations done by multi-point cutting tool.

3.5 Types of chips produced in machining

The chips produced in metal cutting process are not alike. The type of chip produced depends on the material being machined and the cutting conditions. These conditions include:

a. Type of cutting tool used.
b. Speed and rate of cutting.
c. Tool geometry and cutting angles.
d. Condition of machine.
e. Presence/Absence of cutting fluid, etc.

The study of chips produced are very important because the type of chips produced influence the surface finish of the work piece, tool life, vibrations, chatter, force and power requirements, etc.

It is important to note that a chip has two surfaces:

a. Shiny Surface-It is the surface which is in contact with the rake face of the tool. Its shiny appearance is caused by the rubbing of the chip as it moves up the tool face.
b. Rough Surface- It is the surface which does not come into contact with any solid body. It is the original surface of the work piece.

Its rough appearance is caused by the shearing action, as shown in Fig.5. There are three types of chips commonly observed in practice as shown in Fig.5, as:

i) Continuous chips.
ii) Continuous chips with built-up edge.
iii) Discontinuous or Segmental chips.

3.5.1 Continuous chips

Continuous chips are produced when machining more ductile materials such as mild steel, copper and aluminium. Due to large plastic deformation possible with more ductile materials, longer continuous chips are produced. It is associated with good tool angles, correct speeds and feeds, and the use of cutting fluids.

3.5.2 Advantages

1. They generally produce good surface finish.
2. They are most desirable because the forces are stable and operation becomes vibration less.
3. They provide high cutting speeds.

3.5.3 Limitations

1. Continuous chips are difficult to handle and dispose off.
2. Continuous chips coil in a helix and curl around the tool and work and even may injure operator if sudden break loose.
3. Continuous chips remain in contact with the tool face for a longer period, resulting in more frictional heat is used to break the continuous chip into small sections so that the chips cannot curl around the cutting tool.

The simplest form of chip breaker is made by grinding a groove on the tool face a few millimetres behind the cutting edge. Sometimes, a small metal plate stick with cutting tool face is used as a chip breaker.

3.6 Favourable cutting conditions

The favourable cutting conditions for production of continuous chips are following:

i. Machining more ductile materials such as copper, aluminium.
ii. High cutting speed with fine feed.
iii. Larger rake angle.
iv. Sharper cutting edge.
v. Efficient lubricant.

3.6.1 Continuous chips with built-up edge

Continuous chips with Built-Up Edge (BUE) are produced when machining ductile materials under the conditions as:

i. High local temperature in cutting zone.
ii. Extreme pressure in cutting zone.
iii. High friction at tool-chip interface.

The above machining conditions cause the work material to adhere or stick to the cutting edge of the tool and form Built-Up Edge (BUE). The built-up edge generates localized heat and friction, resulting in poor surface finish, power loss. The built-up edge is commonly observed in practice. The built-up edge changes its size during the cutting operation. It first increases, then decreases, and then again increases, etc. This cycle is source of vibration and poor surface finish.

3.6.2 Advantages

Although built-up edge is generally undesirable, a thin, stable BUE is usually desirable because it reduces wear by protecting the rake face of the tool.

3.6.3 Limitations

i. This is a chip to be avoided.
ii. The phenomenon results in a poor surface finish and damage of the tool.

Figure 5: Chips Produced in Metal Cutting

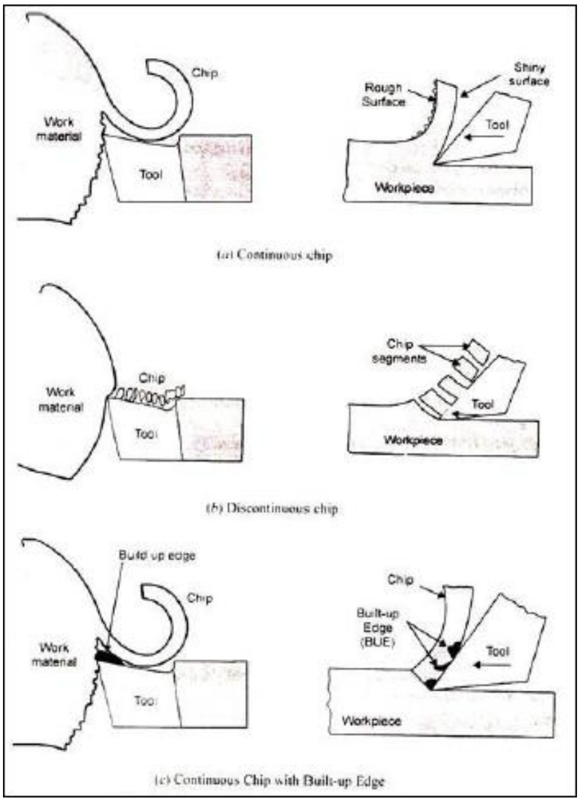
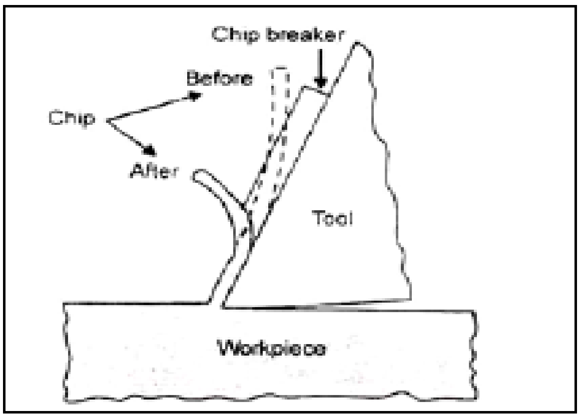


Figure 6: Action of Chip Breaker



3.6.4 Favourable cutting conditions

The favourable cutting conditions for production of continuous chips with built-up edge are following:
i. Low cutting speed.
ii. Low rake angle.
iii. High feed.
iv. Inadequate supply of coolant.
v. Higher affinity (tendency to form bond) of tool material and work material.

3.6.5 Reduction or elimination of BUE

The tendency to form BUE can be reduced or eliminate by any one of the following practices:
i. Increasing the cutting speed.
ii. Increasing the rake angle.
iii. Decreasing the depth of cut.
iv. Using an effective cutting fluid.
v. Using a sharp tool.
vi. Light cuts at higher speeds.

3.7 Discontinuous or segmental chips

Discontinuous chips are produced when machining more brittle materials such as grey cast iron, bronze, brass, etc. with small rake angles. These materials lack the ductility necessary for appreciable plastic chips deformation. The material fails in a brittle fracture ahead of the tool edge along the shear zone. This results in small segments of discontinuous chips. There is nothing wrong with this type of chip in these circumstances.

3.7.1 Advantages

i. Since the chips break-up into small segments, the friction between the tool and the chip reduces, resulting in better surface finish.
ii. These chips are convenient to collect, handle and dispose of.

3.7.2 Limitations

a. Because of the discontinuous nature of chip formation, forces continuously vary during cutting process.
b. More rigidity or stiffness of the cutting tool, holder, and work holding device is required due to varying cutting forces.
c. Consequently, if the stiffness is not enough, the machine tool may begin to vibrate and chatter. This, in turn, adversely affects the surface finish and accuracy of the component. It may damage the cutting tool or cause excessive wear.

3.7.3 Favourable cutting conditions

The favourable cutting conditions for production of discontinuous chips are following:

1. Machining brittle materials.
2. Small rake angles.
3. Very low cutting speeds.
4. Low stiffness of machine tool.
5. Higher depth of cuts.
6. Inadequate lubricant.

4.0 Conclusions

Metal cutting process is most important in design of machine in industries. Many components produced by primary manufacturing processes need machining to get their final shape, accurate size and good surface finish. The term machining is used to describe various processes which involve removal of material from the workpiece Definition of Machining (or Metal cutting) Machining is an essential process of finishing by which jobs are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s). Different types of methods are used for metal cutting and various factors affect on metal cutting process. Different types of chips are formed. All the operations which discussed in this article are necessary for every raw metal and these operations are useful to make material more attractive, to give proper size and shape, to make more convenient and to protect from damage.

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