CHAPTER I: THEORY OF METAL CUTTING

Introduction:

Almost all cutting tools used in metal cutting operations (turning, drilling, shaping, slotting, planning etc.) consist of a basic form of a wedge. A wedge may be defined as an object having inclined planes in the shape of a triangular prism (Fig. 1). The cutting edge must be oriented at certain required angles with the work surface depending on the nature of the operations to be performed. For example, for parting, the wedge must be set at a right angle to the work surface so that the driving or cutting force acts in the direction of parting (Fig. 1). But during chipping, the wedge must be set at an angle inclined to the work surface so that the separation of the chips can be done (Fig. 2).

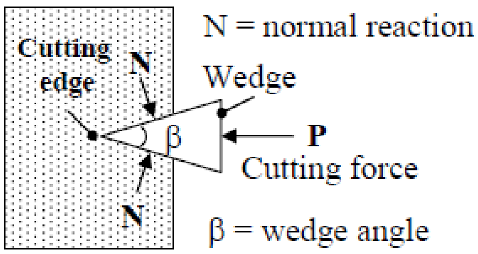
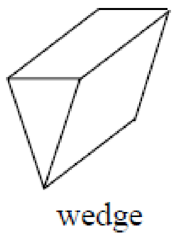


Fig. 1



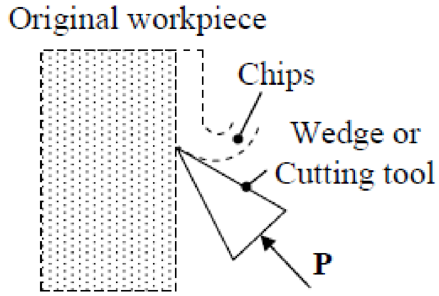


Fig. 2

Definition: Machining process is basically a chip forming metal cutting process in which the excess material is removed away in the form of chips in order to make the workpiece compatible with the desired shape, size and dimensional accuracy. However, in almost all metal cutting operations, a special wedge shaped element called **cutting tool** is used. Fig. 2 shows the basic scheme by which the cutting tool works during a machining operation.

Different Parts of a typical single point cutting tool (generalized)

The portion of the tool that takes part in cutting is called **tool point** or **point**. A cutting tool having one tool point is called a single point cutting tool. For example, turning tool, shaping tool etc. A cutting tool having more than one tool point is called multi-point cutting tool. For example, drill bit (drilling tool), milling cutter, saw etc.

A single point cutting tool consists of the following parts:

Rake Face (or Face): It is the top face/ surface of the tool point.
Flank: It is the surface of the tool below and adjacent to the cutting edge.
Cutting edge: It is the line or edge where face and flank meet.
Nose: It is the point where the face and flanks of the tool meet. It may be round having a radius of curvature.
Shank: It is main body of the tool, which is gripped by the tool holder during cutting operation.
Base: It is the bearing surface of the tool when it is held in a tool holder.
Heel: ....where the base and flank meet.
Principal/Major: Performs major portion of cutting or nearer to the cutting zone.
Auxiliary/ Minor: Performs minor portion of cutting or rearer to the cutting zone.

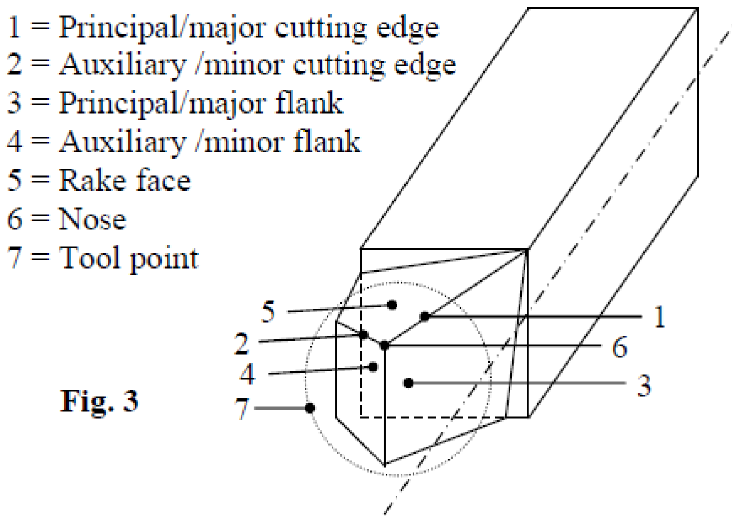


Fig. 3

* Right hand tool and Left hand tool:

Right hand tool moves from RHS to LHS and Left hand tool moves from LHS to RHS.

Tool Signature or Tool Nomenclature of a Single Point Cutting Tool:

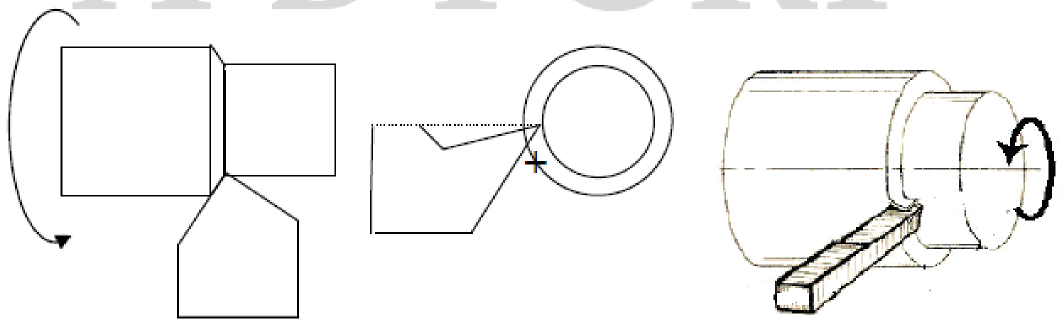
Six different angles and nose radius are arranged in a fixed sequence and is used to describe the geometry of the cutting part of a tool. This sequence is called tool signature or tool designation or tool nomenclature. There are five major systems of tool designation as follows:

i) Orthogonal Rake System (ORS)
ii) ASA or ANSI System (American Standards Association or American National Standards Institute)

iii) DIN System (German system)
iv) NRS or ISO system (Normal Rake System / International Standards Organisation)
v) MRS or British system (Maximum Normal Rake System)

****Note:** ISO: International Standards Organisation; SI: System International; IS: Indian Standard; BIS: Bureau of Indian Standard

Turning Operation: A Figurative Concept



Tool Signature or Tool Nomenclature in ORS system

The tool signature in ORS is as follows:

$$\lambda - \gamma - \alpha - \alpha_a - \phi_a - \phi - r \text{ mm}$$

λ = Inclination angle, it may be positive, negative or zero.
γ = Orthogonal rake angle, it may be positive, negative or zero.
α = Principal clearance (relief) angle
α_a = Auxiliary clearance (relief) angle
ϕ_a = Auxiliary plan approach angle or End cutting edge angle
ϕ = Plan approach angle or Principal cutting edge angle
r = Nose radius, mm
Angles are in degree and nose radius is in mm.

Geometry of a Single Point Cutting Tool in ORS

To realize the orientation of these seven elements in the tool signature of ORS, we require to define a few geometric planes as follows:

Tool Reference Plane or Principal Plane (Π_R): This plane lies perpendicular to the cutting velocity vector. It is horizontal plane.
Cutting plane (Π_C): It is tangential to the principal cutting edge and perpendicular to Π_R
Orthogonal plane (Π_O): It is perpendicular to Π_R and Π_C, and contains cutting velocity vector.
Π_C' = ..tangential to auxiliary cutting edge and perpendicular to Π_R.
Π_O' = Perpendicular to Π_R and Π_C'.

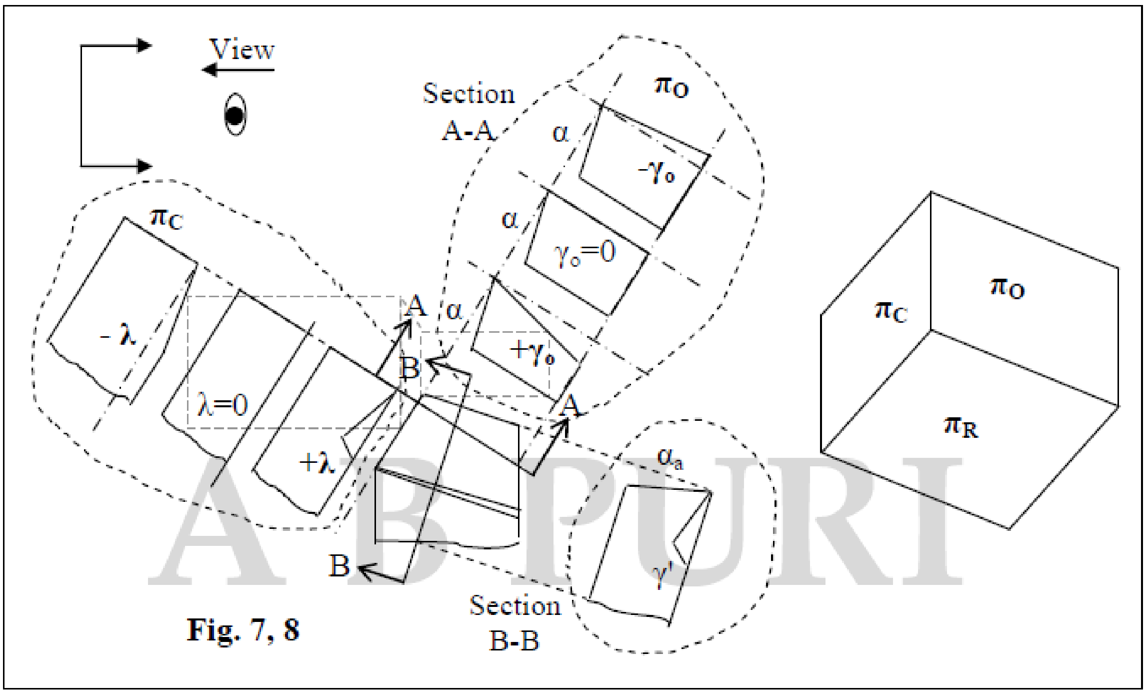


Fig. 7, 8

λ = It is defined as the angle of inclination of the face from tool reference plane, Π_R, and is measured in the cutting plane, Π_C.
γ = It is defined as the angle of inclination of the face from tool reference plane, Π_R, and is measured on orthogonal plane, Π_O.
α = It is defined as the angle of inclination of the principal flank from cutting plane, Π_C and is measured in the orthogonal plane Π_O.
α_a = It is defined as the angle of inclination of the auxiliary flank from the auxiliary cutting plane, Π_C', and is measured on the auxiliary orthogonal plane Π_O'.
ϕ_a = It is defined as the angle of inclination of the auxiliary cutting edge from the direction of conventional longitudinal feed and is measured on the tool reference plane, Π_R
ϕ = It is defined as the angle of inclination of the principal cutting edge from the direction of the conventional longitudinal feed and is measured on the tool reference plane, Π_R

Geometry of a Single Point Cutting Tool in ASA System:

The tool signature in ASA or ANSI system is as under:

$\boldsymbol{\gamma_y - \gamma_x - \alpha_y - \alpha_x - \phi_e - \phi_s - r}$ **mm**

γ_y : Back rake angle or top rake angle
γ_x : Side rake angle
α_y : Front clearance or end relief angle
α_x : Side clearance or side relief angle
ϕ_e : End cutting edge angle or auxiliary cutting edge angle (ϕ_a in ORS)
ϕ_s : Side cutting edge angle
r : Nose radius; Angles are in degree and nose radius is in mm.

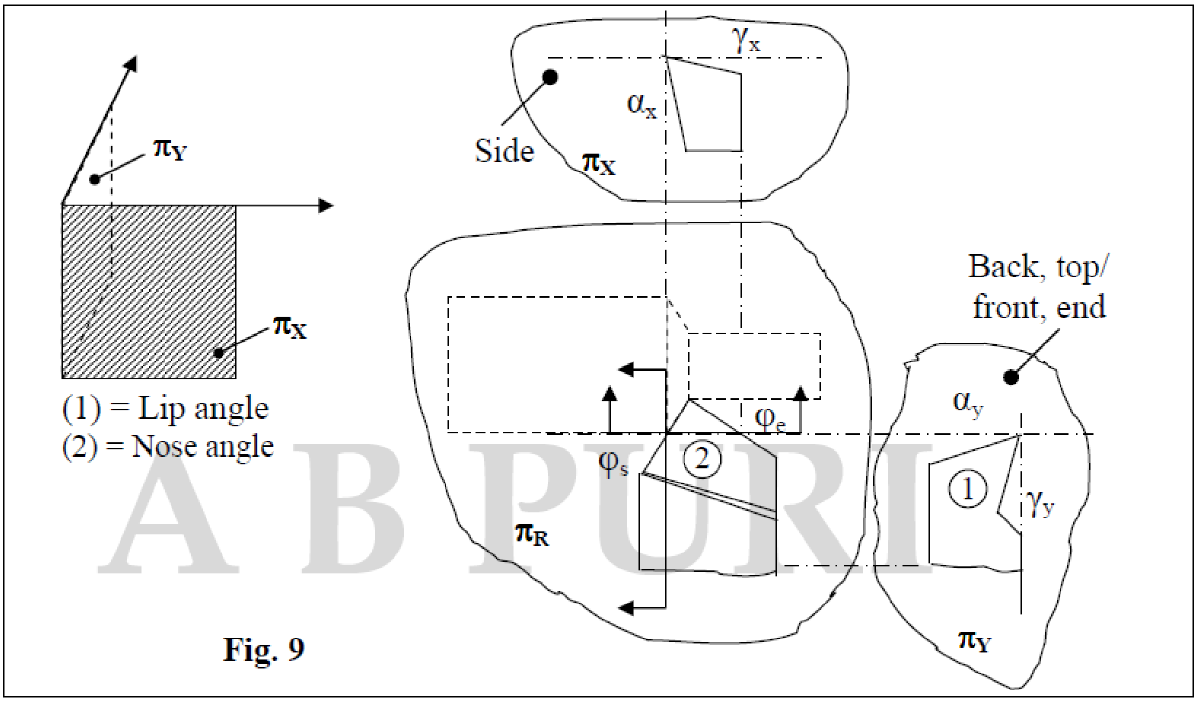


Fig. 9

To understand the orientation of these seven elements in the tool signature of ASA system, we require to define a few geometric planes as follows:

Tool Reference Plane or Principal Plane (Π_R): This plane lies perpendicular to the cutting velocity vector. It is horizontal plane.
Machine Longitudinal Plane (Π_X):It is the plane perpendicular to the horizontal plane and it contains the direction conventional longitudinal feed (X).
Machine Transverse Plane (Π_Y): It is the plane perpendicular to both Π_R and Π_X and contains the direction of conventional cross feed (Y).
γ_y : It may be defined as the angle of inclination of the face from Π_R and measured in on Π_Y.
γ_x : It may be defined as the angle of inclination of the face from Π_R and measured in on Π_X.
Π_Y and Π_X provide the orientation of the rake face.
α_y : It may be defined as the angle of inclination of the principal flank from Π_X and measured in on Π_Y.
α_x : It may be defined as the angle of inclination of the principal flank from Π_Y and measured in on Π_X.

Mechanism of Chip Fomation

The main factor governing the formation of chips is the plastic deformation of metal followed by shearing. As the tool makes contact with the metal, it exerts a pressure on it resulting in the compression of the metal near the tool tip. This leads to severe plastic deformation of the metal in a zone called primary shear zone. The deformed metal fails by the process of shear and starts flowing over the rake face in the form of chip. The strong adhesion between the rake face and the newly formed chip results in a tendency of sticking, and the chip undergoes another deformation. This zone is called secondary shear zone. The chip after sliding over the tool face is lifted away from the tool and the resultant curvature of the chip is termed as chip curl. However, the width of primary shear zone is of the order of 0.025 mm, i.e, it is very narrow. This zone width decreases with increase in cutting speed. In normal cutting speed, this zone is considered as a plane, called shear plane along which maximum shear force acts and metal failure occurs.

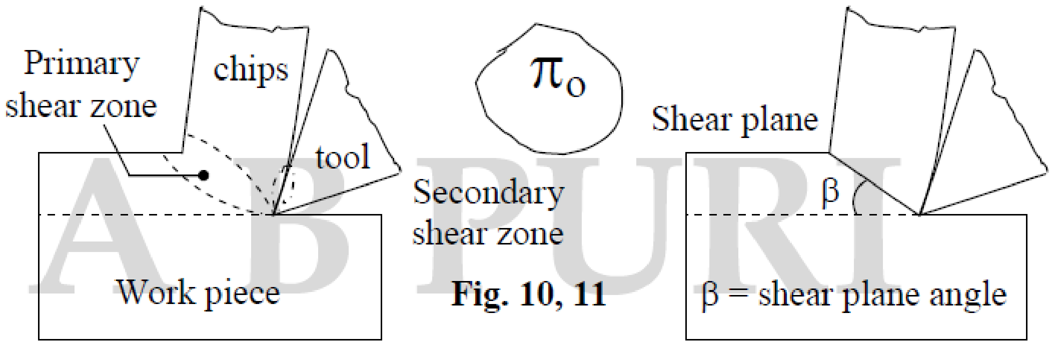


Fig. 10, 11

However, in cases of machining with higher cutting speeds, the width of shear zone is very small and is only about 1-10 μm. It confirms that the deformation of layer takes place in a small zone and is of local shearing in character. This idea enabled Piispanen to develop a model of card analogy where thin lamellae of the metal appears to move over the tool face one after another as shown in the figure. The process of formation of chips is represented here as a process of successive slip through shear of the sections of the layers being cut.

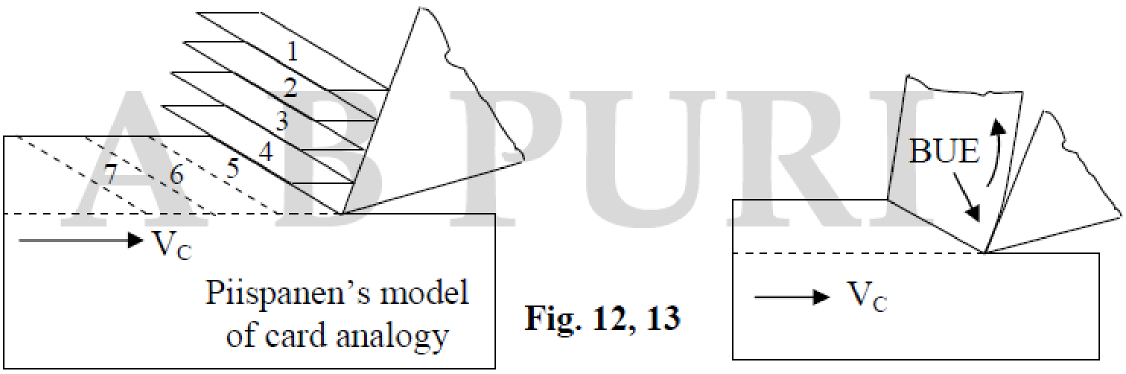


Fig. 12, 13

At a considerably high speed the temperature increases and the tendency of the plastically deformed material to adhere to the rake face increases and a lump is formed at the cutting edge. This is called built-up edge (BUE). It grows up to a certain size but ultimately breaks due to increased force on it by the adjacent flowing material. The BUE protects the tool rake face from the action of heat and friction wear. Thus, it may result in greater tool life but surface finish becomes poor as BUE interferes with the finished surface. The formation of BUE can be avoided with the use of suitable cutting fluid.

Heat Generation

1 = Major heat source in primary shear zone
2 = Second heat source in secondary shear zone (due to sliding motion of chip on rake face)
3 = Third heat source in tertiary shear zone (due to rubbing action of flank surface of tool against job.

However, 80% of the total heat goes away with the chip, 15% heat remains in tool (10% in case of carbide tools), 5% heat remains in workpiece ((10% in case of carbide tools).

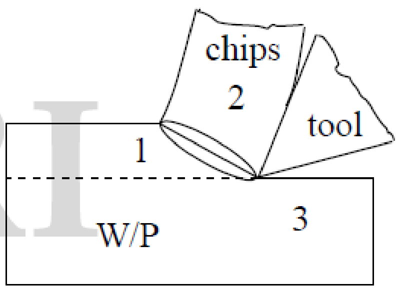


Fig. 14

Types of Chips

The chips produced in different machining processes can be classified into three categories. They are continuous chips without BUE, continuous chips with BUE and discontinuous chips or segmented chips.