UNIT-1

Metal cutting theory

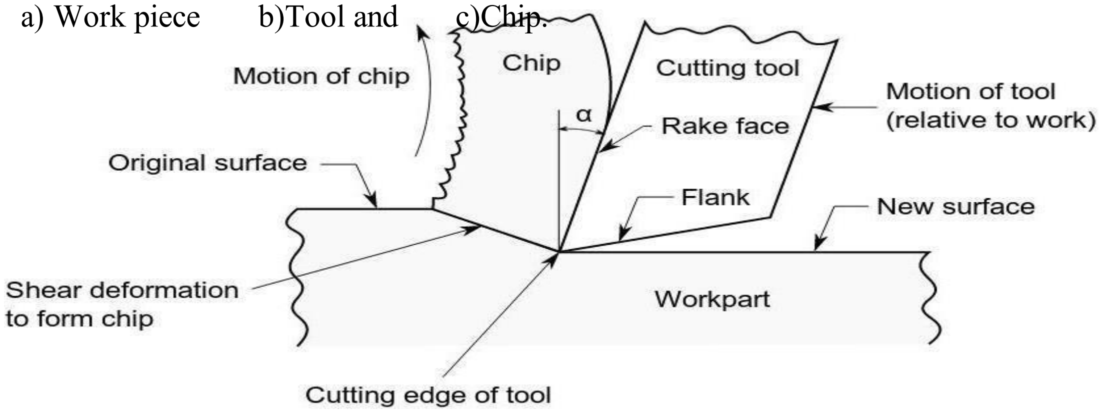
1. Economical manufacture of Machine parts ------------Growing competition.

2. Basic objectives of efficient and Economical machining practice.

   a) Quick metal removal.
   b) High class of surface finish.
   c) Economy in tool cost.
   d) Less power consumption.
   e) Economy in the cost of replacement and sharpening tools.
   f) Minimum idle time of machining tools.

3. Basic elements of machining.

   a) Work piece b)Tool and c)Chip.



The relative motion between the tool and work piece is necessary for effecting the cutting action. The relative motion can be provided by both keeping the workpiece stationary and moving the tool or by keeping the tool stationary and moving the work or by moving both in relation to one another.

The work piece provides the parent metal, from which unwanted metal is removed by cutting action of tool to obtain shape and size of the component. Chemical composition and physical properties of work piece material will have significant effect in machining.

The type and geometry of chip formed are greatly affected by the metal of work piece, geometry of cutting tool and method of cutting. Chemical composition and rate of flow of cutting fluid have considerable influence over the machining operation.

Orthogonal And Oblique Cutting:

The process of metal cutting is divided into two main classes: Orthogonal and Oblique cutting. In Orthogonal cutting, cutting edge of tool remains normal to the direction of tool feed or work feed.

The direction of chip flow velocity is normal to the cutting edge of the tool.

The angle of inclination of the cutting edge of the tool with normal to the velocity$_c$ is zero.

The chip flow angle β i.e the angle between the direction of chip flow and normal to the cutting edge of the tool is zero. Cutting edge is longer than the width of the cut.

Oblique cutting:

The cutting edge of the tool always remains inclined atana cute angle to the direction of tool feed or work feed.

The direction of chip flow velocity is at an angle β with normal to the cutting edge of the tool. The angle is known as chip flow angle.

The cutting edge of the tool is inclined atanangle with the normal to the direction of tool feed or work feed.

Three mutually perpendicular components of the cutting forces act at the cutting edge of the tool.The cutting edge may or may not be longer than the width of cut.

Mostofthemetalcuttingiscarried outthroughobliquemethod.

ClassificationofCuttingTools

Singlepointtools: Thosehavingonlyonecutting edge.Ex.Lathetools,Shapertools, Planer tools, Boring tools etc.

Multi-Ponttools:-Thosehaving morethanonecuttingedgeEx.Millingcutters, Drills, Broachers, Grinding wheels.

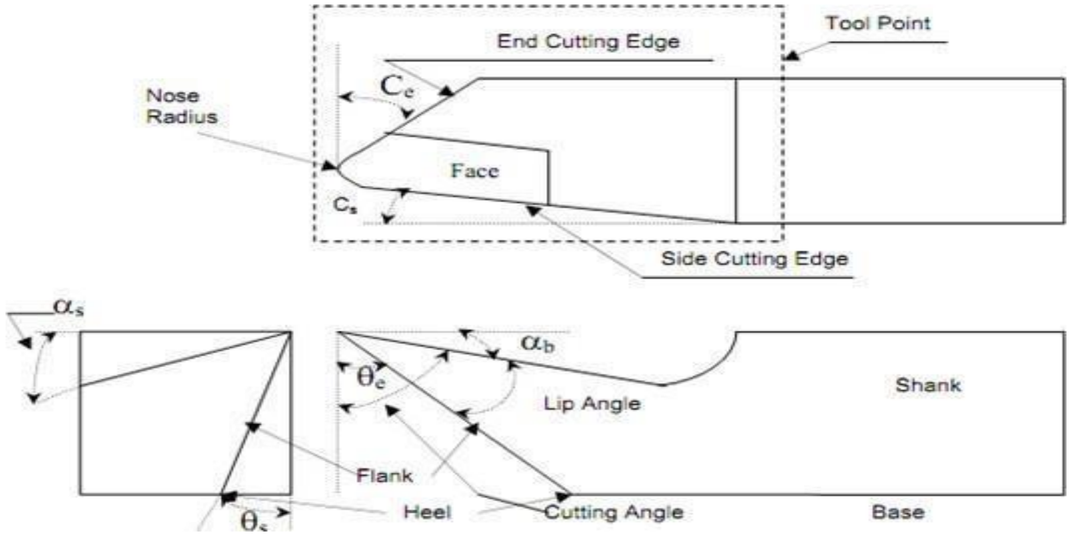
Cutting Tools Can Also Be Classified According To The Motion As:

Linearmotiontools: Lathe,Boring,Broaching,PlanningandShapingtools.

Rotary motion tools: Milling cutters, grinding wheels.

LinearAndRotaryTools: Drills,HoningTools,BoringHeadsEtc.

GeometryofSinglePointTools:



1. Rakeangle: It istheangle formedbetweenfaceofthetoolandplaneparallelto itsbase. If thisinclinationis towards shank,itis known asbackrakeortop rake. Whenitismeasured towards side of the tool, itis called side rake. These rake angles guide the chipsaway from the cutting edge, thereby reducing the chip pressure on the face and increasing the keennessof the tool, so that less power is required for cutting. An increased rake angle willreduce the strength of cutting edge. Therefore tools used for cutting hard materials are given small rake angles, whereas those used for soft metals contain large rake angles.

2. Negative rake angle: The above rake angles are called positive rake angles. When no rake is provided on the tool, it is said to have zero rake angle. When the face of the tool is so ground that it slopes upwards from the point, it is said to contain a negative rake. It reduces keenness of the tool and increases the strength of cutting edge. Such rake is usually provided on carbide tipped tools when they are used for machining extra- hard surfaces, hardened steel parts and for taking intermittentcuts. The values of negative rake on these tools normallyvary from 5to 10.

3. Lip angle: The angle between the face and flank of the tool is known as Lip angle. It is also called angle of keenness of the tool. Strength of the cutting edge or point of the tool is directly affected by this angle. Larger the lip angle, stronger will be cutting edge and vice-versa. This angle varies s the rake angle. It is only for this reason that when harder metals are to be machined a stronger tool is required, the rake angle is reduced and consequently the lip angle is increased. This calls for reduced cutting speeds, which is dis- advantage. The lip angle is therefore kept as low as possible without making the cutting edge so weak that it becomes unsuitable for cutting.

4. Clearance angle: It is the angle formed by the front or side surface of the tool which are adjacent and below the cutting edge when the tool is held in a horizontal position. It is the angle between one of these surfaces and a plane normal to the base of the tool. When the front surface is considered it is called front clearance and when the surface below cutting edge is considered, the angle formed is known as side clearance angle. The purpose of providing front clearance is to allow the tool to cut freely without rubbing against the surface of the job. The side clearance is to direct the cutting thrust to the metal area adjacent to the cutting edge.

5. Relief angle: It is the angle formed between flank of the tool and a perpendicular drawn from the cutting point to the base of the tool.

6. Cutting angle: The total cutting angle of the tool is the angle formed between the tool face and a line drawn through the point, which is a tangent to the machined surface of the work at that point .Its correct value depends up on the position of the too which it is held in relation to the axis of the job.

7. Nose radius: If the cutting tip of a single point tool carries a sharp cutting point, the cutting tip is weak. It is therefore highly stressed during the operation, may fail or loose its cutting ability soon and produces marks on the machined surface. In order to prevent these harmful effects the nose is provided with a radius, called Nose radius. It enables greater strength to cutting tip, a prolonged tool life and superior surface finish onthe work piece. As the value of this radius increases, a higher cutting speed can be used.

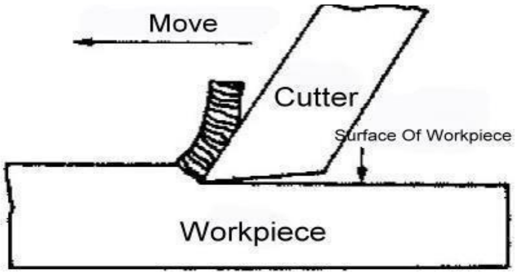
If it is too large, it may lead to chatter. So a balance has to be maintained. Its value normally varies from 0.4mm to 1.6mm depending upon several factors like depth of cut, amount of feed, type of cutting and type of tool.

Chip Formation:

Chips are formed due to tearing and shearing. In the chip formation by tear, the work piece material adjacent to the tool face is compressed and crack runs aheadof the cutting tool and towards body of the work-piece. The chip is highly deformed and the work- piece material is relatively under formed. Cutting takes place intermittently and there is no movement of the work piece material over the tool face.

Inchipformationbyshear,there isageneralmovementofthechip overtoolface.

The grains of metal ahead of cutting edge of tool start elongating along line AB and continue to do so until they are completely deformed along line CD. The region between the lines AB and CD is called shear zone. After passing over shear zone, the deformed metals along the tool face due to the Velocity of the cutting tool.

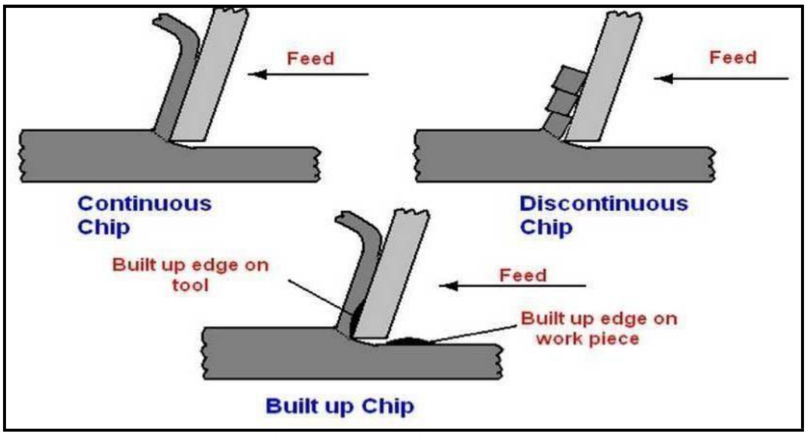


Chip Formation

The angle made by plane of shear with the direction of tool travel is known as shear angle φ.Its value depends on the material being cut and the cutting conditions .If is φ small, path of shear will be long, chips will be thick and the force required to remove the layer of metal of given thickness will be high and vice-versa.

Typesofchips:

Every machining operation involves the formation of chips, the nature of chips differs fromoperation to operation, properties of work-piece material and cutting condition.



Chips are formed due to cutting tool, which is harder and more wear resistant than the work-piece material, relative motion between tool and work-piece, sufficient force and power to overcome the resistance of work-piece material. The chips are formed by the deformation of the metal lying ahead of cutting tool edge by a process of shear. Basically there are threetypes of chips

1. **Discontinuous chips:** This type of chips is produced during machining of brittle materials like cast-iron and bronze. These chips are produced in the form of small segments.

In machining ofsuch materials, asthe tooladvances forward,the shear-plane angle gradually reduces until the value of compressive stress acting on the shear plane becomes too low to preventrupture.Atthisstage,any furtheradvancementof thetool resultsinthefracture of the metal ahead of it, thus producing a chip. With further advancement of the tool, the processes of metal fracture and production of chips goes on repeatedly producing discontinuous chips. Such chips are also sometimes produced in machining of ductile materials, when low cutting speeds are used and adequate lubrication is not provided. This causes excessive friction between the chip and tool face, leading to fracture of chip in small segments. This will also result in excessive wear on the tool and poor surface finish on the work-piece. Other factors responsible for production of discontinuous chips are smaller rake angle on the tool and too much depth of cut.

2. Continuous chip: This type of chip is produced while machining a ductile material, like mild steel and copper at very high cutting speed and minimum friction between the chip and the tool face. The friction at the chip-tool inter face can be minimized by polishing the tool face and adequate use of coolant. The basis of production of a continuous chip is the continuous plastic deformation of the metal ahead of the cutting tool, the chip moving smoothlyupthetoolface. Other factorsresponsiblearebigger rakeangle, finer feedandkeen cutting edge of the tool.

3. Continuous chip with built-up edge: It is very similar to the continuous type and not as smoothas continuous chip. It has a built-up edge adhering onnoseofthe tool, whichchanges the effective geometry of cutting. It is obtained by machining ductile metals with high speed tools at ordinarycutting speeds, thus introducing high friction betweenthe chip and toolface. The formand size of such an edge depends largelyon the cutting speed, being absent at very low and very high cutting speeds. This type ofchip results in poor surface finish. The normal reactionofthe chip onthe toolface is quite high, and is maximumat the cutting edge or nose of the tool. This gives rise to an excessively high temperature and the compressed metal adjacent totoolnose gets welded to it. The chip is also sufficiently hot and getsoxidized as it comes off the tool and turns bluein colour. The extra metal welded to tool nose or point of the tool is called **built-up edge**.

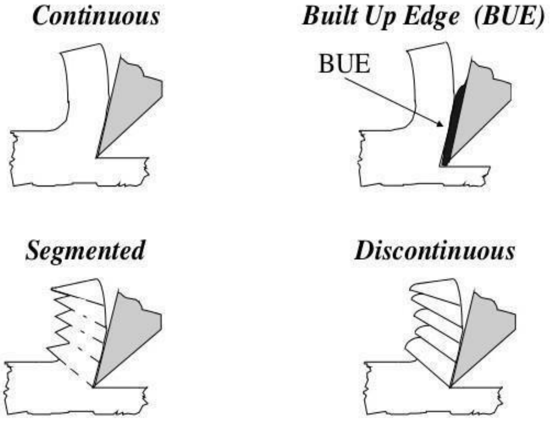
This metal is highly strain hardened and brittle. With the result, as the chip flows up the tool,the built-up edge isbroken and carried away with the chipwhile the rest of it adheres to the surface of the work-piece, making it rough. Due to the built-up edge the rake angle is also altered and so is the cutting force. The common factorsresponsiblefor formationofbuilt-up edge are low cutting speed, excessive feed, smallrake angle and lack of lubricant.

Adverseeffectsofbuilt-upedgeformation:

a) Roughsurfacefinishonthework-piece.

b) Fluctuating cutting force, causing vibrations in cutting tool.

c) Chances of carrying away some material from the tool by the built-up surface, producing crater on the tool face and causing tool wear.



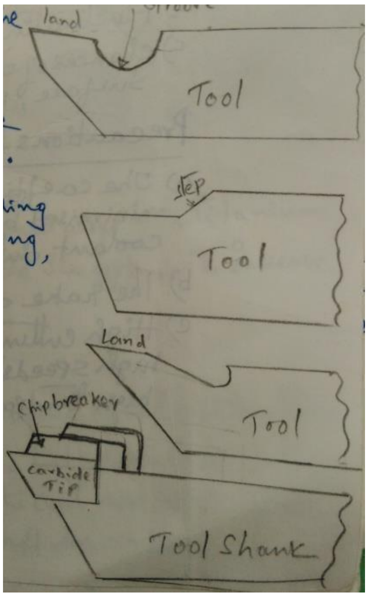
Precautionsforavoiding theformationofbuilt-upedge:

a) The co-efficient of friction at the chip-tool interface should be minimized by means of polishing the tool face and adequate supplyof coolant during the cutting operation.

b) Therakeangleshouldbekeptlarge.

c) High cutting speeds and low feeds should be used, because at high speeds the strength of the weld becomes low. Similarly, at very high temperature also the strength of the weld becomes low.

Chip-Breakers:



The chips produced during machining at higher speeds in machining of high tensile strength materials, need to be effectively controlled. Carbide tipped tools are used in case of higher speeds and due to hightemperaturethe chip willbe continuous ofblue colour and take the shape of coil. Such a chip, if not broken in to parts and removed from the surroundings of the metal cutting area, will adversely affect the machining in the fallowing way.

a) Adversely affecttoollifeby spoilingthecuttingedge,creating crater and raising the temperature.

b) Leadtopoorsurfacefinishonthe work-piece.

c) Thechipsgetcurledaroundtherotatingwork-pieceandcutting tool, it may be hazardous to the machine operator.

d) Iflargeandcontinuouscoilisallowedtobe formedit mayendangerthe machineandeven the work place.

e) Verylargecoilsofferalotofdifficultyintheirremoval.

While machining materials like brassand cast-iron continuous chips of above type are not produced. But in case of continuous chips, by using chip breakers, we can overcome the above difficulties and adverse affects. The chip breakers break the produced chips in to small pieces. The work hardening of the material of the chip makes the work of the chip breakers easy.

Thecommonmethodsusedforchipbreakingare:

i) Bycontroloftoolgeometry i.e.grindingproperbackrakeandsiderakeanglesaccording to the speeds and feeds used.

ii) Byobstruction method i.e. byinterspposingametallicobstructioninthepathofthecoil. The

fallowing types of chip breakers are commonly used:

a) Groovetype: Itconsistsofagrindinggrooveonthefaceofthetool,behindthecutting edge, leaving a small land near the tip.

b) Steptype: It consistsofa grinding a stepontheface ofthe tool,adjacentto the cutting edge.

c) Secondaryraketype: Itconsistsofprovidingasecondaryrakeonthetool,through grinding, together with a small step.

d) Clamp type: This type of chip breaker is very common with the carbide tipped tools. The chip breaker is a thin and small plate, which is either brazed to or held mechanically on the tool face.

CuttingSpeed,FeedAndDepthOfCut:

Cutting speed of a tool can be defined as the rate at which its cutting edge passes over the surface of the work-piece in unit time. It is normally expressed in terms of surface speed in meters per minute.

In machining it is important as it considerablyaffectsthe tool life and efficiency of machining.Selectionofpropercutting speed hasto be made veryjudiciously.Ifit istoo high, thetoolgetsover heated and itscutting edge may fail, needing regrinding. Ifit istoo low,too much time is consumed in machining and full cutting capacities of the tool and machine are not utilized, resulting in lowering of productivityand increasing the production cost.

Feed of the cutting tool can be defined as the distance it travels along or in to the work-piece for each pass of its point through a perpendicular position in unit time. In turning operation of lathe, it is equal to the advancement ofthe toolcorresponding to each revolution ofwork. In planning it is the work, which is fed and not the tool. In milling work, the feed is considered per tooth of the cutter.

Thecuttingspeedandfeedofacuttingtoolis largelyinfluencedbythefollowingfactors:

1. Materialbeingmachined.
2. Materialofthecuttingtool.
3. Geometryofthecuttingtool.
4. Requireddegreeofsurfacefinish.
5. Rigidityofthemachinetoolbeingused
6. Typeofcoolantbeingused

Depth of cut: It is indicative of the penetration of the cutting edge of the tool in to the work-piece materialin eachpass, measured perpendicularto the machined surface i.e. it determines the thickness of metal layer removed by the cutting tool in one pass.

Example:Inturningoperationona lathe it isgivenby

Depth of cut $=\frac{D-d}{2}$

WhereD=Originaldiameterofthework-pieceinmm

D=Diameterobtainedafterturninginmminone pass.

Coolants:coolantsareusedinmetalmachiningtoperformthefollowingmainfunctions.

1. Theycoolthetoolandtheworkpiece.

2. Theyprovidelubricationbetweenthetoolandworkpieceandtoolandchips.

3. Theypreventtheadhesionofchipstothetoolorworkpieceorboth.

Cooling of the tool and work piece in required in order todissipate the heat generated during machining. The sources of heat generation during metal cutting are the following.

1 Friction: A lot of friction always takes place between the cutting tool and the work piece and between the tool face and the chips passing over it. The total amount of heat generated depends upon many factors viz. cutting speed, feed, tool material, depth of cut and metal being machined. The heat so generated is known as heat of friction.

2. Plastic deformation of metal: Cutting tool exerts high pressure on the adjacent metal grains which due to this pressure start slipping along their planes of weakness. This causes deformation of all of them. The action of slipping of these grains in contact with one another causes friction, leading to the generation ofthe heat ofdeformation. The totalamount of heat generated again depends upon the cutting speed, feed, depth of cut and the metal being machined. Higher speeds, feeds, more depth of cut, tougher materials contribute to greater heat generation.

3. Chip distortion: In machining, as the cut proceeds and the chips curl out, the inside and the outside grain of the chip metal are subjected to compression and tension respectively.This causes distortion of the chip grains are the chips leading to a sort of internal friction amongst the grains andconsequently generation of heat of chip distortion. The amount ofheat generated depends on feeds and depth of cut. Heavier the feed and deeper the cut, the longer will be the area of cross-section of the chip and more distortion amongst the grains, resulting in higher amount of heat generation.

Machinability: Gives the idea of ease with which it can be machined. The parameters influencing the machinability of a material are:

1. PhysicalPropertiesofmaterial.
2. MechanicalPropertiesofmaterial.
3. Chemicalcompositionofmaterial.
4. Micro-Structureofmaterial
5. Cuttingconditions.

Machinabilityofthematerialdependsonvariousvariablefactorssuchas

1. ToolLife: Longer toollife, it enables at a givencutting speed onthe speed the better is the machinability.

2. Surface finish: It indirectly proportional, i.e. better surface finish the higher in machinability.

3. Power Consumption: Lower power consumption per unit of metal removal-better machinability.

4. Cutting Forces: Lesser amount of cutting force required for removal of higher volume of metal under standard conditions, the higher will be the machinability.

5. Shearangle:Largershearangledenotesbettermachinability.

6. Rateofmetalremovalunderstandardcuttingconditions.

ToolLife:

Toollifecanbedefined onthetime intervalfor eachtoolworkssatisfactorilybetween into successive grindings. These are three common ways of expressing Tool life.

1. Astimeperiodinminutesbetweentwosuccessivegrindings.

2. Intermsofno.ofcomponentsmachinedbetweentwo successivegrindings.

3. Intermsofthevolumeofthe materialremovedbetweentwosuccessivegrindings.

Themethodofassessingtoollifeintermsofthevolume materialremovedper unit of time in a practical one.

Volumeofmetalremoved/min=$\prod$Dt fNmm^3/min

Where D = Dia of work piece in mm

t=depthofcutinmm f

= feed rate mm/rev

N=no.ofrevolutionsofworkpermin.

IfT be the times in minutes to tool failure = $\prod$ D t fN T mm^3

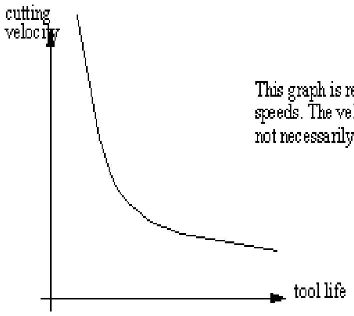
We know the cutting speed $V = \frac{\prod DN}{1000}$ $\prod DN = V*1000$

TotalVolumeofmetalremovedtotoollife=V1000t fT mm^3

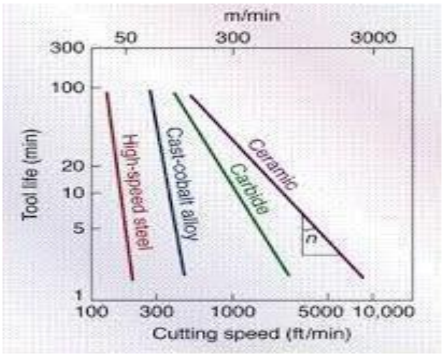
ThereforeToollifeT_L=V x1000xtxfxT(mm^3)

FactorsaffectingToolLife:

1. CuttingSpeed.
2. FeedandDepthofcut.
3. ToolGeometry.
4. ToolMaterial.
5. WorkMaterial.
6. NatureofCutting.
7. RigidityMachinetoolandwork.
8. Useofcuttingfluids.



This graph is representative for most reasonable cutting speeds. The velocities at the high and low ranges do not necessarily exhibit the same relationship.



1. Effectofcuttingspeed:

Thetoollife variesinverselyoncuttingspeed i.e.higherthecuttingspeedthesmaller the tool life.

$$VT^n = C$$

V=Cuttingspeedm/min. T

= Tool life minutes.

n=Anexponent –Itsvaluedependsonthetoolmaterial. C =

Machining Constant.

n=0.1to0.15	HSSTools
=0.2to0.5	CarbideTools
=0.6to1.0	CeramicTools.

2. Effectoffeedrateanddepthofcut: Itwillappreciablyeffectinreduction intoollife.

$$V = \frac{257}{T^{0.19}\ f^{0.36}\ t^{0.8}} \text{ m/min}$$

V=CuttingSpeedm/min T

= Tool Life in min

F=Feedrate mm/min

t =Depthofacutinmm

ForagivenToollife $V = \frac{C}{f^a\ t^b}$ C=Constant

If the tool life in considered on constant, the cutting speed will decrease if the feed rate and depth of cut are increased.

3. The Geometry: Geometrical parameters (Tool angles) of a cutting tool influence its performance. The Rake angle has mixed effect. If it is increased, the amount ofheat generated are reduced and help in increasing the life ofcutting tool. But if it is very large the cutting edge is weakened and also its capacity to conduct the heat is reduced results in reductioninmechanicalstrengthand loweringtoollife. Foreffectiveeconomicaltoollife it is necessary to strike a balance. The optimum value of rake angle needs to be used. This value varies from -5^0 to $+10^0$. The minus sign indicates negative rake i.e. rake angle sloping up words from Tip. Tools carrying negative rake angle provide a stronger cutting edge andhence a stronger tool. Carbide and ceramic tools are generallyprovided – ve angle.

Similarly relief angle or clearance angle bn influence the tool performance. These angles are provided on cutting tools to prevent the rubbing of tool flank against the machine work surface. They thus help in lowering the amount of heat generated and therefore increasing the tool life. But very large reliefangles beyond certain levelresults in weakening of tool resulting in reduction of tool life.

Therefore a balance needs to be struck and only optimum value should be used. The angles normally varyfrom5^0 to 8^0 but in specialcauses as carbide tipped tools up to 10^0.

The two cutting edge angels also have their influence on tool performance. The front cutting edge angle/end cutting edge angle effects the tool wear. Up to a certain optimum value an increase in this angle permits the higher speeds without an adverse effect on tool life. But an increase beyond certain value will resultin reduction of tool life. It generally varies from $5^0$to 8^0. If the side cutting edge angle is smaller the higher speeds can be used. However it has complex effect on Tool life. A larger end cutting edge angle increases tool life.

I. Inclinationangle:Toollife increaseswiththe increase inthisangleuptoanoptimum value.
II. Noseradius:Whileit increasestheabrasion,italsohelpsinimprovingsurfacefinish and tool strength and hence tool life.

4. <u>Tool material</u>: The main characteristics of good cutting tool material are its hot hardness, wear resistance, impact resistance, abrasionresistance, heat conductivityand strengthetc. An ideal tool material is the one which will remove the largest volume of work material at all speeds. It is not possible to get truly ideal tool material. The tool material which can with stand max cutting temperature without loosing its principal mechanical properties (splly hardness) and geometry will ensure max tool life. The higher hot hardness and toughness in tool material, the longer the tool life.

5. <u>Work Material</u>: The micro-structure of work material is significant as it directly effects the hardness of material. Higher the hardness of the work material greater will be the tool wear and shorter will be the tool life. In machining pure metals, because of their tendency to stick to the tool face. Specially at high temperatures results in more friction and high amount wear on tool and therefore shorter tool life.

6.<u>Nature of cutting</u>: Toollife is affected bynature ofcutting i.e. whether it is continuous or intermittent. In the intermittent cutting the tool is subjected to impact loads and may give away much earlier than expected until it is made strong and tough. In continuous cutting similar tool will have relatively longer life.

7. <u>Rigidity of machine tool and work</u> : Both the machine tool and work – piece should remain rigid during the machining operation. If not vibrations will take place and the cutting toolwill be subjected to intermittent cutting, instead ofcontinuous cutting. This willresult in impact loading of tool and therefore shorter life.

8. <u>Use of cutting fluids</u>: Cutting fluids are used in machining work for helping the efficient performance of the operation. They are used either in liquid or gaseous form. They assist the operation by cooling the tool and work, reducing the friction, improving the surface finish, helping in breaking the chips and washing them away etc. These factors helpin improvingthetoollife, permitting higher metalremovalrate and improving the qualityofsurface finish.

CharacteristicsOfCuttingToolMaterials:

Thematerialsusedformanufactureofcuttingtoolsshouldpossessthefollowing characteristics:

1. Abilitytoretainitshardnessat elevatedtemperaturescalledhothardness.

2. Abilitytoresistshock,calledtoughness.

3. Highresistancetowearto ensurelongertoollife.

4. Low co-efficient offriction at the chip –tool interface, so that the surface finish good and wear in minimum.

5. Shouldbecheap.

6Shouldbeabletobefabricatedandshaped easily.

7. If it is to be used in the form of brazed tips, its other physical properties like tensile strength, thermal conductivity, co efficient of thermal expansion and modulus of elasticity etc. should be as Close To The Shank Material As Possible To Avoid Cracking.

CuttingToolMaterials

The following materials are commonly used for manufacturing the cutting tools, selection of a particular material willdepend on the type of service it is expected to perform.

1. High Carbon Steel: Plain carbon steels having a carbon percentage as high as 1.5% are in common use as tool materials for general class ofwork. For high production work they are not considered as they are not able to withstand very high temperature, hence they can‟t be used at high speeds. The required hardness is lost bythemat temperature 200^0- 250^0 C. They are also not highly wear resistant. Theyare used mainly for hand tools as they are less costly, easily forgeable and easy to heat treat.

High carbon medium alloy steels are more effective than plain high carbon steels. These steels in additions to carbon content are provided better hot hardness, higher impact resistance, higher wear resistance by adding small amount of Tungsten, Chromium, Molybdenum, Vanadium etc. Which improves the performance and able to operate temperatures of 350^0C.

2. High Speed Steel: It is a special alloy-steel containing the alloying elements like Tungsten, Chromium, Vanadium, Cobalt and Molybdenum up to 25%. These alloying elements increase its strength, toughness, wear resistance, cutting ability and retains it‟s hardness at elevated temperature of 550^0c -600^0 c on account of these added properties the high speed steeltools are capable ofoperating at 2to 3times higher cutting speeds than high carbon steel tools.

The most commonlyused highspeed steelhas compositionalloying elements as 18-4- 1 i.e. 18%W, 4%Cr, and 1%V.

3. Cemented Carbides: These Carbides are formed by the mixture of Tungsten, Titanium with Carbon. The carbides in the powder form are mixed with Cobalt which acts as binder. The mixture with powder metallurgy process, sintered at high pressures of 1500kg/sq cm to 4000kg/sq cmand temperatures of above 1500^0C is shaped in to desired forms of tips. These Carbide tips are then brazed or fastened mechanically to the shank made of medium Carbon steel. These cemented carbides possess a very high degree of hardness and wear resistance. They are able to retain this hardness at temperature up to 1000^0C with the result, the tools tipped with cemented carbide tips are capable of operating at speeds 5 to 6 times higher than those of high speeds.

4. **Stellite:** It is a non ferrous alloy mainly of Cobalt, Tungsten and Chromium. Other elements added in varying proportions are Tantalum, Molybdenum and Boron. It has good shock and wear resistance and retains its hardness at a red heat up to 920^0C. It is used for machining materials like hard bronzes, cast and malleable Ironetc. Tools made ofStellite are capable of operating atspeed up to2 times more than those of common high speed steel tools. Only grinding can be used for machining it effectively.

Asatellitemaycontain40-50%Co,15-35%Cr,12-25%Wand 1-4%Carbon.

5. **Ceramics:** The introduction of ceramic material as a cutting tool material is a latest development in the field of tool metallurgy. It mainly consists of Aluminum oxide which is comparatively much cheaper than any of the chief constituents of cemented Carbides. Boron nitrides in powdered form are added and mixed with Aluminum oxide powder and sintered together at a temperature of 1700^0C. They are then compactedin to differenttip shapes. Tools made of ceramic material are capable of withstanding high temperatures, without loosing their hardness up to 1200^0 C. They are much more wear resistant than cemented carbide tools. Theyare more brittle and low resistance to bending. Theycan‟t be used for rough machining work and mainly used for finishing operations. They are capable of removing 4 times more materialthanTungstencarbidetoolsand2-3 times highcutting speeds under similar conditions. No coolant is needed while machining with ceramic tools.

6. **Diamond:**It is the hardest material known and used as cutting tool material. It is brittle and low resistance to shock but it is highly wear resistant. Diamonds are used for only light cutson materials like Bakelite, Carbon, Plastics, Aluminumand Brass etc. Because oflow co efficient of friction they produce a high grade of surface finish. Because of high cost only limited use in tool industry.

❖ **CarbideTips:**

Q : What are the throw away carbide tips? What are their advantages? What are the basic requirements?

Throw away Carbide tips are made in a variety of shapes and vary in thickness from 3mm to 12mm and size from 10 to $15mm^2$ (mm square). Proper arrangements in the form of holes etc are made to secure them on the tool holders.

Positive rake Carbide tips have 3 or4 cutting edges, whichare ground to produce 5to 8^0 relief angle. These can be used individually before tip becomes unusable.

In negative rake Carbide tips, the relief angle in created by placing them suitably on the tool holder. These thus have the advantage of providing 6to 8 usable edges, becauseall the edges are prepared at right angles. However the second side of the tip can be used only if the first side has not become rough due to wear as otherwise it can‟t be flat againstthe loading surface on the tool holder.

Throw away Carbide tips are quite cheap and as 4 to 6 edges can be used before it is thrown, there is lot of economy in using them.

The basic requirements of Carbide tips are: A pocket on the tool holder to locate the carbide tip positively and take the side longitudinal and end radial thrust from the cutting forces and also to ensure that new tip will cut to the same size.

I. Asolid seatforthebottomofthecarbidetip totakethetangentialforceand also to ensure that new tip will cut to the same size.

II. Aclamptoholdthetipformallyagainstthebottomofthepocketanditformbeing pulled out.

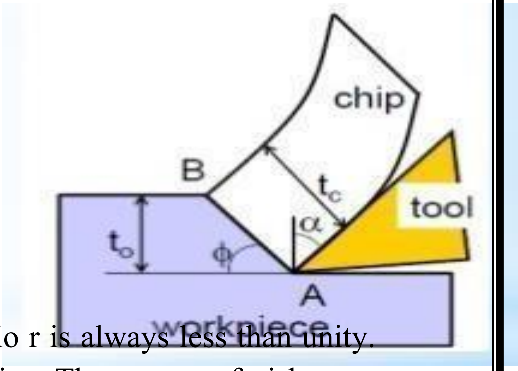
ChipThicknessRatio:

During cutting action of a metal, the thickness of the deformed or upward flowingchip in morethantheactualdepthofcut. It is becausethechip flowsupwardsat aslower rate than the velocity of the cut. The velocity of the chip flow is directly affected the shear plane angle. The smaller the shear plane angle the slower will be the chip flow – velocity and therefore longer will be the thickness of the chip.

t=chipthicknesspriorto deformation

t_c=chipthicknessafterdeformation

$t_c > t$,Thechipthickness ratior= $\frac{t}{t_c}$



Since t_c in always greater than t, the value of chip thickness ratio r is always less than unity. The higher the value of r, the better is supposed to be cutting action. The reverse of r isknown as chip reduction co efficient. If k is the chip reduction co efficient

$$K = \frac{i}{r}$$

In orthogonal cutting the width of the chip equals the width of the cut. Considering specific gravity ofthe metalas constant, the volume ofthe chip produced will be equal to the volume of the metal cut. Width of both being equal, the product of the chip thickness and its length will, therefore be equal to the product of the thickness of the metal cut and length of metal cut. If L_1 and L_2 are lengths of the metal cut and chip respectively.

$$t \times L_1 = t_c \times L_2$$

$$\frac{t}{t_c} = \frac{L_2}{L_1} \qquad \text{But} \quad \frac{t}{t_c} = r$$

$$r = \frac{t}{t_c} = \frac{L_2}{L_1}$$

$$k = \frac{1}{r} = \frac{t}{t_c} = \frac{L_2}{L_1}$$

WehavetworightangledtrianglesOAPandOBP

Considering the orthogonal triangle OAP

$$\frac{AP}{OP} = \sin\emptyset \qquad OP = \frac{AP}{\sin\emptyset} = \frac{t}{\sin\emptyset} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_(1)}$$

ConsideringtherightangledtriangleOBP

$$\frac{BP}{OP} = \text{Sin BOP} = \text{Sin}(90 - \emptyset + \propto) = \text{Cos}(\emptyset - \propto)$$

$$OP = \frac{BP}{\text{Cos}(\emptyset - \propto)} = \frac{t_c}{\text{Cos}(\emptyset - \propto)} \qquad \underline{\hspace{4cm}}(2)$$

Nowbyequations (1)&(2)

$$OP = \frac{t}{\text{Sin}\emptyset} = \frac{t_c}{\text{Cos}(\emptyset - \propto)}$$

$$\frac{t}{t_c} = \frac{\text{Sin}\emptyset}{\text{Cos}(\emptyset - \propto)} \qquad \text{i.e.r=} \quad \frac{\text{Sin}\emptyset}{\text{Cos}(\emptyset - \propto)} \qquad \underline{\hspace{4cm}}(3)$$

$$r = \frac{\text{Sin}\emptyset}{\text{Cos}\emptyset\text{Cos}\propto + \text{Sin}\emptyset\text{Sin}\propto}$$

$$r(\text{Cos}\emptyset\text{Cos}\propto) + r\ (\text{Sin}\emptyset\text{Sin}\propto) = \text{Sin}\emptyset$$

$$r\ \frac{\text{Cos}\emptyset\text{Cos}\propto}{\text{Sin}\emptyset} + r\,\frac{\text{Sin}\emptyset\text{Sin}\propto}{\text{Sin}\emptyset} = 1$$

$$r\ \frac{\text{Cos}\propto}{\tan\emptyset} + r\ \text{Sin}\propto = 1$$

$$r\ \frac{\text{Cos}\propto}{\tan\emptyset} = 1 - r\text{Sin}\ \propto$$

$$\tan\emptyset = \frac{r\ \text{Cos}\propto}{1 - r\ \text{Sin}\propto} \qquad \underline{\hspace{4cm}}(4)$$

$$\tan\emptyset = \frac{\frac{t}{t_c}\text{Cos}\propto}{1 - \frac{t}{t_c}\text{Sin}\propto} \qquad \underline{\hspace{4cm}}(5)$$

- **MerchantsForceDiagram:**

F_H= Horizontalcuttingforceexertedbythetoolonworkpiece.

F_V=Verticalortangentialforcewhichhelpsinholdingthe toolinpositionandactson tool nose.

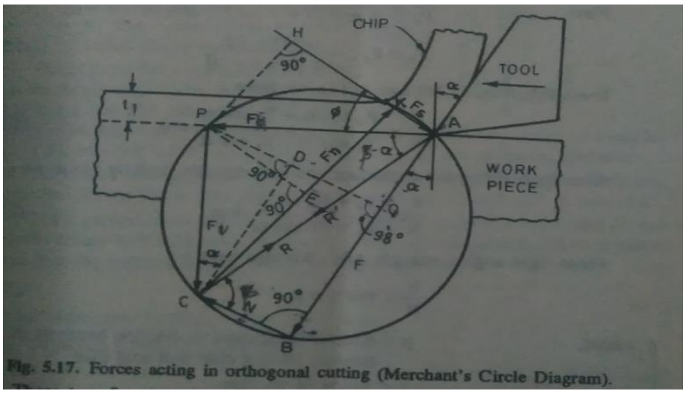


Fig. 5.17. Forces acting in orthogonal cutting (Merchant's Circle Diagram).

Merchantforcediagram

$$F = AQ - QB = AQ - DC \qquad = F_H\ \text{Sin}\propto - F_V\text{Cos}\propto \qquad \underline{\hspace{2cm}}(1)$$

$$N = QD \qquad = PQ - PD \qquad = F_H\text{Cos}\ \alpha - F_V\ \text{Sin}\ \alpha \qquad \underline{\hspace{2cm}}(2)$$

F_S= AH –HK= AH – PE $F_H \cos\emptyset - F_V \sin\emptyset$

$= F_V \cos\emptyset + F_H \sin\emptyset$

N=CE+EK=CE+PH $F_H\ (\beta - \alpha)$ $= (\beta - \alpha)$

= AC Cos $(\emptyset + \beta - \alpha)$ =RCos

F_S= R Cos $\frac{F_H}{F_S} = \frac{R\cos(\beta-\alpha)}{R\cos(\emptyset+\beta-\alpha)}$

$$F_H = F_S\ \frac{\cos(\beta-\alpha)}{\cos(\emptyset+\beta-\alpha)}$$

The tool face components are importance they enable the co efficientto friction for the tool face (μ=tanβ) to be determines β is the angle of friction at therank surface.

$$\mu = \frac{F}{N} = \frac{F_A \sin\propto + F_V \cos\propto}{F_H \cos\propto - F_V \sin\propto}\ \frac{\cos\propto}{\cos\propto}$$

$$= \frac{F_H \tan\propto + F_V}{F_H - F_V \tan\propto}$$

μiscoefficientoffrictionbetweentoolfaceandupwardslidingchip.

$$\frac{F_V}{F_H} = \tan(\beta - \alpha)$$

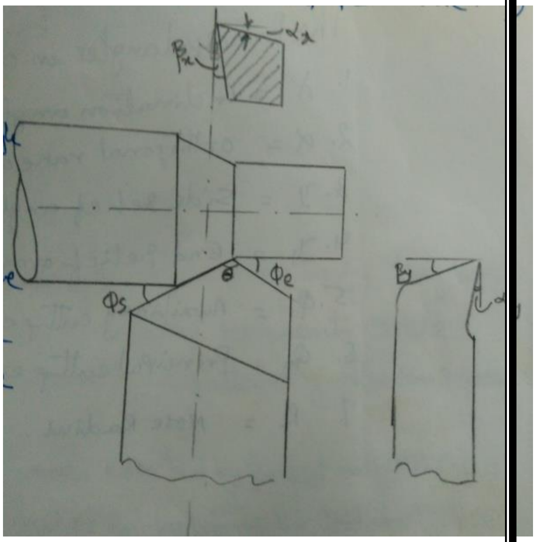
F_V and F_H canbeeasilymeasuredbystraingaugesorforcedynamometers.

❖ ToolSignature

The term tool signature is used to denote a standardized system of specifying the principle tool angels of a single point cutting tool.

Somecommonsystemsare:

1. American(ASA)System.
2. BritishSystem.
3. ContinentalSystem.
4. InternationalSystem.



I. Reference Planes: The following two systemsofreferences planes are used to describe the geometry and locate the different parameters of a single point cutting tool.

1. The Co-Ordinate System: This system consist of three principal reference planes. The horizontal plane which contains the base ofthe shank ofthe cutting toolis knownas the **Base Plane**. The second reference plane is a verticalplane, normal to the base plane, and parallel to the direction of feed (f) of the cutting tool. It is called **Longitudinal Plane** (x, x^I). The third reference plane called the **Transverse Plane** (y, y^1) is perpendicular to both the above reference planes and is parallel to the transverse motion of the tool. i.e. the depth of cut(d).

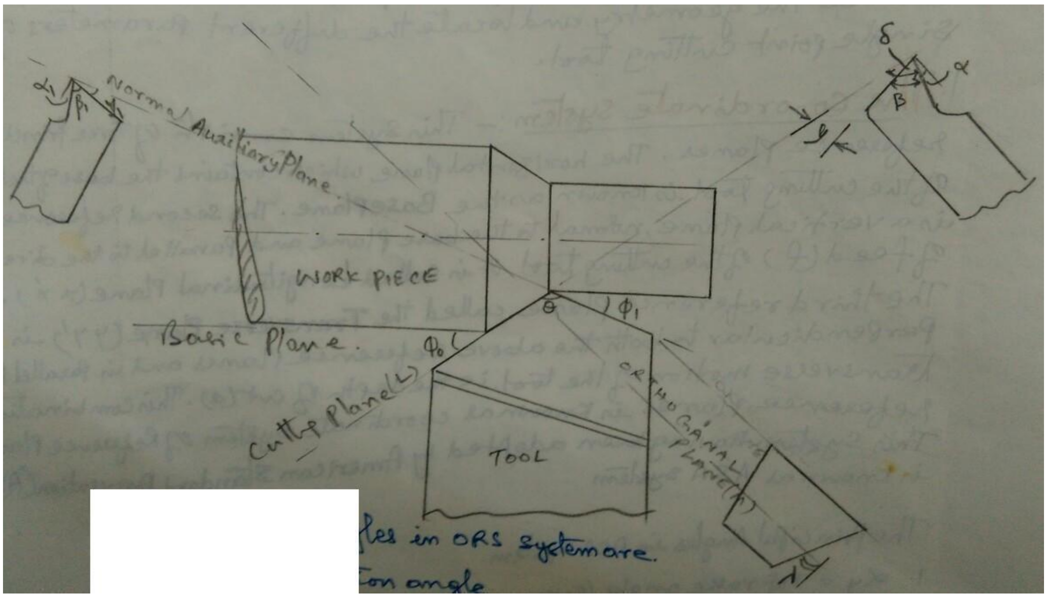
This combination of reference planes is known as co ordinate system of reference planes. This system having been adopted by American **Standard Association (ASA)** is known as ASA System.

The principle angel sin System.

1. α_y=Top rake angle /Back rake angle.
2. α_x=Side rake angle.
3. β_y=End relief/Clearance angle.
4. β_x=Side relief/Clearance angle.
5. $\emptyset_e$ =End cutting edge angle.
6. $\emptyset_s$ =Side cutting edge angle.
7. θ =Nose radius/ angle.

2. THEORTHOGONALSYSTEM:(OR)ORTHOGONALRAKESYSTEM(ORS):

In this system of reference planes it is assumed that the cutting tool is operating against the work piece. There are three main reference planes. The HorizontalPlane, contains the base of the cutting tool and is known as **Base Plane.** The second plane, which is perpendicular to the base plane, contains the principal cutting edge (c) and is called the **Cutting Plane.** The third plane which is perpendicular to boththe above planes, is known as Orthogonal System of Reference Planes or Orthogonal Rake System (ORS).

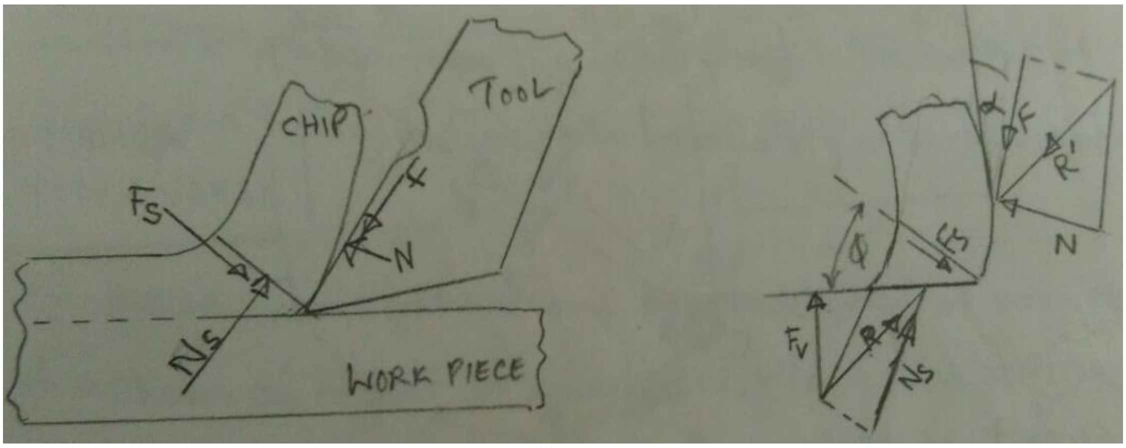


Theprincipalangles inORSSystemare.

1. λ=Inclinationalangle.
2. α=OrthogonalRakeAngle.
3. y=Sidereliefangle.
4. y_1=Endreliefangle.
5. $\emptyset_1$ =Auxiliarycuttingedgeangle.
6. $\emptyset_0$=Principalcuttingedgeangle/approachangle.
7. R=NoseRadius.

FORCERELATIONSHIPINORTHOGONAL CUTTING:

Anumber offorcesact onthechip duringmetalcutting. Therelationship amongthese forces were established by merchant.



Theforcesactingonthechip inorthogonalcuttingarerepresentedasfollows. F_S= Metal resistance to shear in chip formation, acting along shear plane.

N_S=Backingup forceexertedbytheworkpieceonthechip,actingnormaltoshearplane. N = Force exerted bythe tool on the chip, acting normal to tool face.

F=µN=Frictionalresistanceofthetoolagainst thechip flow, actingalongthetoolface. µ being the co-efficient of friction between tool face and chip.

$$\mu = \frac{F}{N}$$

It willbe observed that $F_S$and N_S canbe easilyreplaced bytheir resultant r and force Fand N by their resultant R^I. Thus all these forces are resolved to only two forces R and R^I. For equilibrium, these forces R and R^I should be equal, act opposite to each other and should be collinear i.e.

$$\overrightarrow{R^I} = \vec{F} + \vec{N}$$

$$\vec{R} = \overrightarrow{F_S} + \overrightarrow{N_S}$$

$$= \overrightarrow{F_H} + \overrightarrow{F_V}$$

$$\vec{R} = \overrightarrow{R^I}$$

The two triangles of forces of the above free body diagram have been combined together one called “Merchant Circle Diagram” of cutting forces in which the following new components figure.

F_H=Horizontalcuttingforceexertedbythetoolonwork piece.

F_V= Verticalforcewhichhelpsin holdingthe toolinpositionandactsonthetoolnose.

Thesetwoforcescanbeeasilybefoundoutwiththehelp ofstrainguagesor

Forcedynamometers.Theangleisalsoisaknownquantity.

αistherakeangleofthetool. ∅ alsocanbedeterminedwiththehelpoftheequation $Tan\emptyset = \frac{r\,Cos\alpha}{1-r\,Sin\alpha}$. When all these four values i.e. F_H, F_v, α and ∅ areknown, allother forces can be easily calculated with the help of merchant circle diagram.

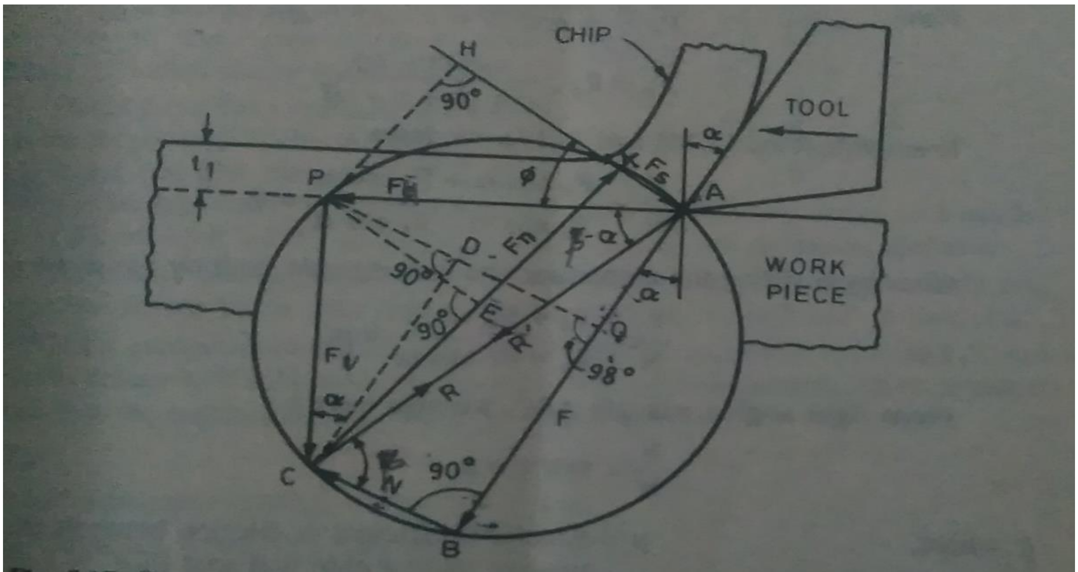


Fig. 5.17. Forces acting in orthogonal cutting (Merchant's Circle Diagram).

$F = AQ+QB = AQ + DC = F_H Sin\alpha + F_V Cos\alpha$ ______________(1)

$N = QD = PQ - PD = F_H Cos\alpha - F_V Sin\alpha$ ______________(2)

F_S =AH– HK= AH –PE=F_HCos- F_VSin ∅ ______________(3)

N_S=CE+EK= CE+PH= F_VCos ∅ + F_HSin∅ ______________(4)

$F_H = AC Cos(\beta-\alpha) = R Cos(\beta-\alpha)$ ______________(5)

F_S= ACCos(+β∅-α)=RCos(+β-α)∅ ______________(6)

$\frac{F_H}{F_S} = \frac{R\,Cos(\beta-\alpha)}{R\,Cos(\emptyset+\beta-\alpha)}$ $F_H = F_S \frac{Cos(\beta-\alpha)}{Cos(\emptyset+\beta-\alpha)}$ ______________(7)

Equation(1)&(2)we have

$\frac{F}{N} = \frac{F_H\,Sin\alpha + F_V\,Cos\alpha}{F_H Cos\alpha - F_V Sin\alpha}\,\frac{Cos\alpha}{Cos\alpha} = \frac{F_V+F_H Tan\alpha}{F_H-F_V Tan\alpha}$ ______________(8)

FromΔABC $\frac{F}{N} = Tan\beta = \mu$ ______________(9)

$$\beta = Tan^{-1}\frac{F}{N} = Tan^{-1}\mu$$

μ =Kineticco efficientoffrictionbetweenchipandtoolface. β =

Angle of friction

$\frac{CP}{AP} = \text{TanPAC}$ $\frac{F_V}{F_H} = \tan(\beta - \alpha)$

Further __________(10)

- **KinematicDrivesOfMachineTools**:

Every machine tool is required to perform one or both of the following functions kinematic functions:

1. Totransmitmotionfromtheinputshafttotheoutputspindle.

2. Totransformrotarymotionintotranslatororreciprocatingmotionorvice-versa

These transformations in a machine toolare achieved through a chine higher or lower pairs, which consist of the machine tool drive or drive mechanism. The term**"Drive"** includes all the systems of the transmission used in a machine tool to import cutting and feeding motions.

<u>TypesofDrives</u>:Machinetooldrives,basedondifferentcriteria,canbeclassifiedasfollows:

1. Accordingtothemodeofpowersupply:

   a) IndividualDriveorSelf-ContainedDrive

   b) GroupDriveorCommonDrive

2. Accordingtothesystemoftransmission:

   a) MechanicalDrives–Belt&pulleys, Geartrains, PowerScrewsandnuts,Chainsetc.
   b) ElectricalDrives
   c) HydraulicDrives
   d) PneumaticDrives

3. Accordingtothetypeofmotionimportedbythedrive:

   a) RectilinearDrive–StraightlineMotion.
   b) RotaryDrive–CircularMotion.

4. Accordingtotheregulationofspindlespeeds:

   a) SteppedDrive.
   b) SteplessDrive.

Selection of drive depends upon production time, surface finish andaccuracy required, optimum efficiency, power to weight ratio, simplicity of design with respect to maintenance, repair and control.