MACHINE TOOL APPLICATION

MILLING MACHINE

Traditionally, any machine we see is produced with the he help of another machine. These machines which are used to produce other machines are called MACHINE TOOLS.

The very first machines however were manually made by highly skilled men who could work within the required accuracy.

With time however, higher and consistent degree of accuracy came into demand, together with greater forces required, and with increased rate of production due to demand, machines became a requirement in the production process.

INTRODUCTION TO DIMENSION CONTROL AND INSPECTION

Any complete machine is composed of numerous parts, which are produced separately and then assembled. The processes of producing each of those parts involve careful dimension control to suit the required type of fit. When assembled, the two parts are fitted while bearing either of the following two points in mind:-

1) A fit that allows relative movement between the two -(clearance fit)
2) A fit that does not allow relative movement between the two -(interference fit)

There are three ways of achieving this.

1) Using individual assembly method,
2) Using selective assembly method,
3) Using Systems of Limits and Fits.

INDIVIDUAL ASSEMBLY

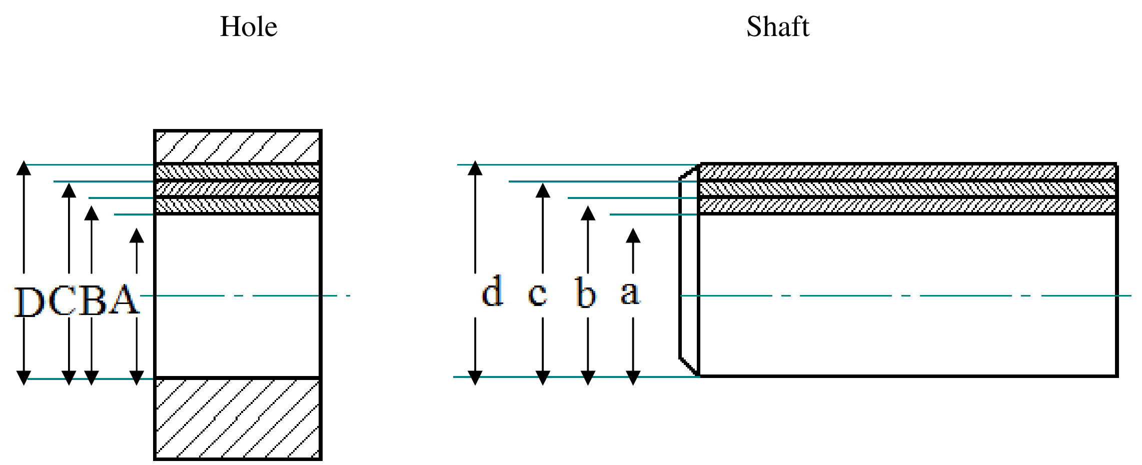
In this approach, one of the two parts to be assembled is first machined as close as possible to the required dimension in the working drawing. The second part is then machined while testing using the first piece until when the required fit is attained (clearance or interference).

The disadvantage of this method is that it is slow due to the numerous stoppages required for the frequent checks. It also needs highly skilled personnel for operating the machine. The parts are made for each other and may not fit properly with any other part made for the same purpose. All the above reasons make this method very costly.

SELECTIVE ASSEMBLY

This approach takes into account the fact that it is impossible to produce a particular size on many components and be consistently exact, yet the small variations do not necessarily render the work piece useless. All parts with sizes that fall within acceptable range (tolerance) must therefore be used by selecting the pairs, which fit with each other for the required fit (clearance or interference).

For this reason, all parts produced are carefully measured to find out the range of sizes in which they fall. It therefore becomes possible to sort them according to sizes that fall within the same range and therefore be able to determine which ones do produce the right fit when assembled.



For clearance fit		For interference fit	
B fits with a	(Red)	A fits with b	(Yellow)
C fits with b	(Black)	B fits with c	(Green)
D fits with c	(Blue)	C fits with d	(Grey)

Holes and shafts of particular ranges of sizes are separated in groups, which are marked, tagged or color-coded to make them readily identifiable. Groups of shafts and holes, which give the right fit when assembled, bear the same mark, tug or color code.

Much as this method may not require very high skill from a machine operator, making it slightly faster, it demands very high skill at the sorting stage, with measuring instruments of higher degree of accuracy. These instruments are also expensive.

Because parts are selected according to groups during assembly, for machines produced using this method, replacement of broken parts during repair are done by replacing the part with a whole assembly, which includes the broken part. If for example, the hole is worn out and the shaft is still in good condition, even the shaft is replaced.

SYSTEMS OF LIMITS AND FITS

In this method, sizes of all components are determined by the designer at the designed stage and given *limits* within which a particular size on a component must fall.

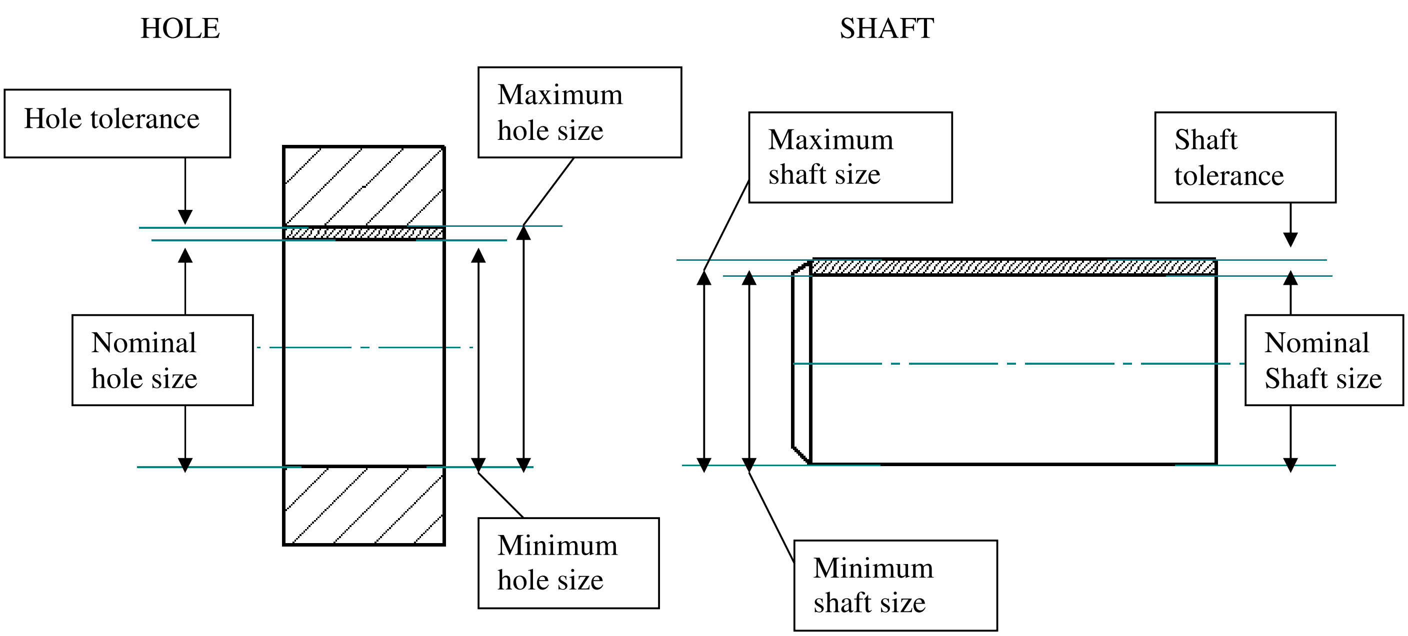
All these take place in the mind of the designer only. It becomes known to any other person only after the designer has put it down in drawing. This however can be transformed into components only if the designer produces a *working drawing* with the right limits determined by him.

What are limits?

Because of machine error that depends on the machine condition and human error that depends on several factors, it is impossible to do machining and produce a size and say with certainty that the size obtained is the actual size, because even if the size has actually been got, there is human error in taking the measurement from the work piece onto the measuring instrument and another in reading correctly to get the size indicated on it. On top of that is the error of the instrument, which depends on its accuracy.

The problem is even compounded when dealing with hard materials like metals, since small size variations in the order of thousands of a millimeter do matter a lot at assembly stage, and obtaining the right fit may not be possible.

This is why setting limits is very important. It is only the designer who knows what limits to set for a particular size in order to obtain a fit, which works best on the machine when properly assembled.



Dimension control during material removal is directly related to the amount (volume or weight) of material that remains on the final product (the component). Therefore, by setting limits, the designer sets the maximum and minimum size (and therefore weight or volume) of a component. This makes it possible to produce from one working drawing any number of that component, and all of them will be acceptable to the designer as long as their sizes fall within the limits specified in the working drawing.

The implication is that the component has conditions of maximum amount of material acceptable *(maximum metal condition)*, and minimum amount of material acceptable *(minimum metal condition)*.

It is then up to the machine operator to use the working drawing and produce components with sizes that fall within these limits for them (the components) to be acceptable.

There are three ways of controlling the sizes:-

1) Direct measurements using measuring instruments of the right accuracy.
2) Gauging using limit gauges.

3) Comparing using comparators.

DIRECT MEASUREMENTS

In order to produce components whose sizes lie within the specified limits, the machine operator must not only know how to operate the machine for metal removal purposes, but also know how to take measurements properly using the instrument, and read the instrument down to the required accuracy. In this process, the operator stops the machine after passes of metal removal and takes the size of the remaining material *(shaft or hole)*. The main aim is to see if the size falls within the one specified in the drawing. However with each pass of metal removal one of the following three situations is likely to result in both shaft and hole cases:-

For shafts,

1) The size is above the upper limit, meaning that the component is not yet acceptable because the weight or volume is still more than the one specified and the metal removed is insufficient. The next action from the operator is to remove more material.
2) The size is within the limits, meaning that sufficient metal has been removed and the component is acceptable. The next action is to remove it from the machine and it is ready for use or storage.
3) The size is below the lower limit, meaning that the metal removed is in excess and the component has less weight or volume than the one specified. The next action is to remove the component from the machine and discard it off, it is scrap.

For holes,

1) The size is above the upper limit, meaning that the material removed is in excess and the component has less weight or volume than the one specified. The next action is to remove the component from the machine and discard it off, it is scrap.
2) The size is within limits, meaning that sufficient metal has been removed and the component is acceptable. The component is removed from the machine and it is ready for use or storage.
3) The size is below the lower limit, meaning that the component is not yet acceptable because the weight or volume is *still* more than the one specified and the metal removed is insufficient. The next action from the operator is to remove more material.

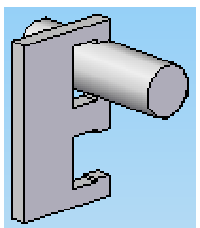
The main thing to note about direct measurement is that the *actual size* of the component is known because the operator reads it on the instrument to make sure that it falls within the required limit before accepting it. The operator must therefore be highly skilled.

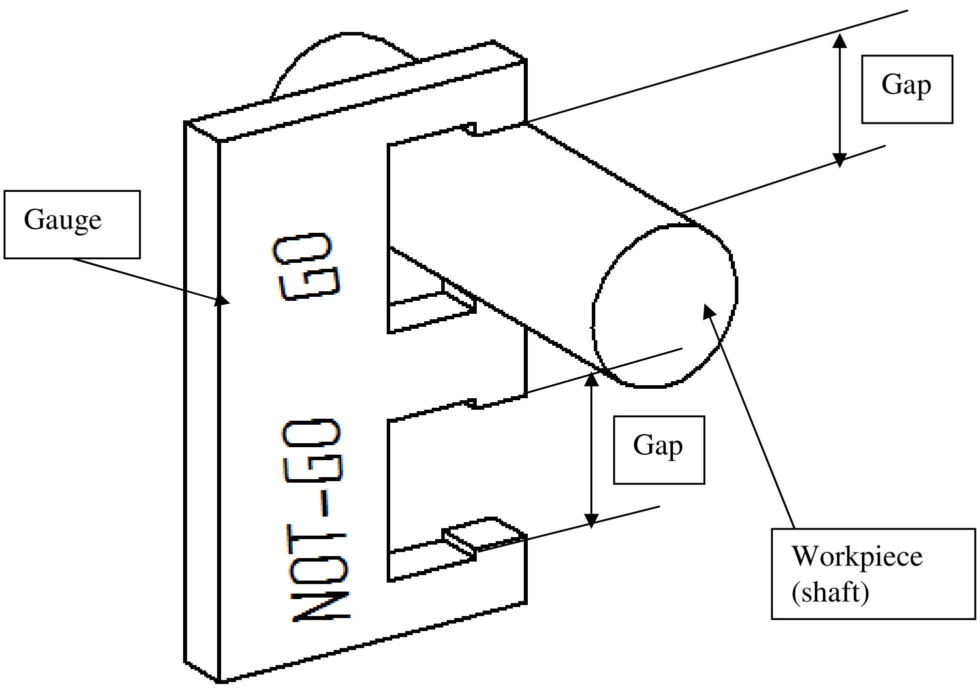
The next two methods however only check whether or not the size falls within the specified limit. The operator does not know the real size.

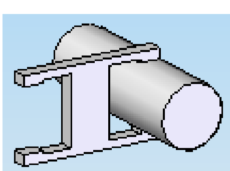
GAUGING

This is done using a special instrument called *gauge*, which has two sizes available on it. One size corresponding to the upper limit and the other one corresponding to lower limit. It is therefore possible to gauge using this instrument to see if the size produced on the component falls within the specified limit before accepting it.

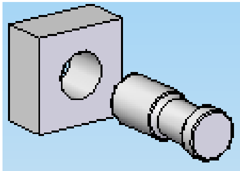
Using this method requires many gauges since every size must have its own gauge with the right limits.

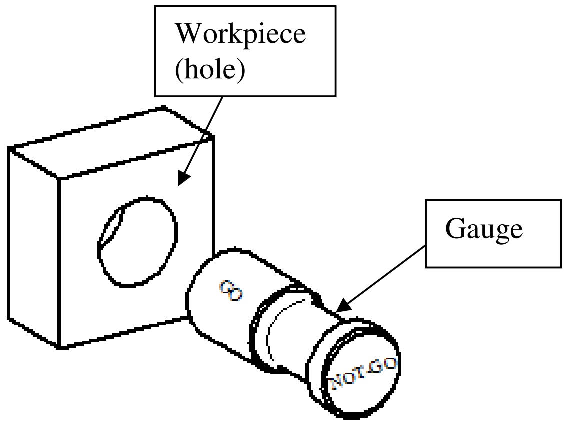




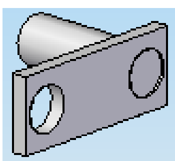


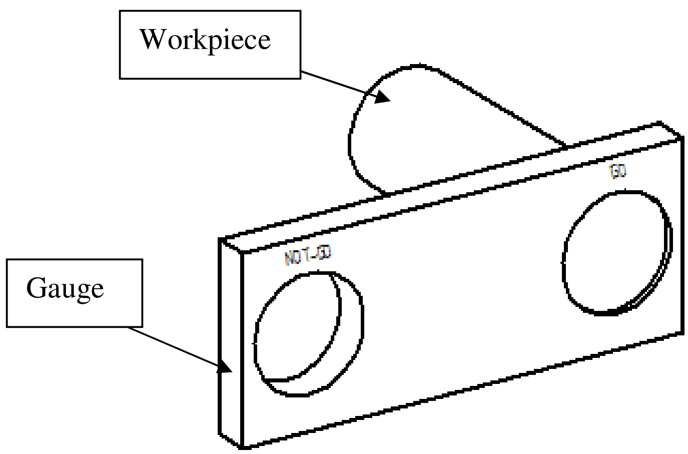
Gap gauge





Plug gauge





Ring gauge

The gauge is put in use during the metal removal process at the machining stage by the operator.

After some metal removal passes, the operator *offers* the *GO* side the gauge to the size being machined on the component. In so doing, the operator is expecting this side of the gauge to be accepted at the machined dimension. The process goes on in conjunction with metal removal until this side actually *goes.* This then marks the end of metal removal process for this dimension.

The big question is whether or not the size obtained falls within the limits specified by the designer. The answer to this question depends on what happens when the *NOT-GO* side of the gauge is offered to the same size on this work piece being machined and the work piece is still on the machine. This is what the operator wants to find out immediately, so he offers the *NOT-GO* side of the gauge to the dimension expecting it to either GO or NOT-GO depending on how much material he took care to remove in the *last* metal removal *pass* during the time he was checking the size using the *GO* side of the gauge. This is a crucial decision making moment and is done *only* by the machine operator who must interpret correctly the status of the work piece when the *NOT-GO* side of the gauge is offered to this machined size, *he must also be sincere* because any bad component taken as acceptable at this stage will be very difficult to detect with the naked eye. The effect can only be felt when it is put to use.

The act of checking with the *NOT-GO* side of the gauge is to make sure that this side of the gauge actually does not *go,* for the component to be acceptable because it will mean that the size produced as a result of metal removal in the last *pass* falls within the required limits.

If it happens so (does not go), the component is removed from the machine as a finished product, which is ready for use or storage.

The other observation expected by the operator when checking with the *NOT-GO* side of the gauge is for this side to also *go* the way the *GO* side did *go.* This would mean that the amount of metal removed in the last metal removal *pass* was in excess of what he should have, and therefore the size produce as a result falls outside the required limits. The component is a reject (SCRAP).

Since all components are made from some material whose original *weight* or *volume* is either *equal* or *more* than that of the component, it is not difficult to see that the *condition* in which the original material, *the work piece,* is left in is either the same or less in weight or volume. Where metal removal is not involved only the shape or the original material changes whereas both weight and volume remain the same. This means that the *condition* of the original material has not changed in terms of weight and volume. However where metal removal is involved, both weight and volume must *reduce*. Sizes therefore play a big role in determining *metal condition* of the finished component in terms of weight and volume. The limits set by the designer, in fact, set the maximum and minimum *metal condition* of the component.

These two conditions are therefore very easily checked using the gauge since the *GO* gauge checks the *maximum metal condition* acceptable by the designer and the *NOT-GO* gauge checks the *minimum metal condition* allowed. This is true for ALL gauges be it for shafts or for holes. Dimension control using gauges does not require high skill and it is fast and easy. However, the initial cost or capital input is enormous due to the total cost of gauges required since each size requires a separate gauge and gauges are very expensive. This method of dimension control is recommended only for mass production.

Comparators are more advanced measuring instruments, which are used, for either inspection in mass production of components produced using universal machine tools, or continuous dimension control in automatic machines tools or *machining centers.*

Their working principle is basically comparison. For a given dimension, the instrument is set using two sample pieces. One sample piece has the actual size equal to the *upper limit* size of the component and another sample with the actual size equal to the *lower limit* size of the component. Since the two sizes are different, the indicator on the instrument will assume *one* position when the sample with lower limit size is used and *another* position when the sample with the upper limit size is used. The signal from the sample is magnified, making it possible to see with the naked eye the difference between the sizes of the two sample pieces. This becomes a *zone* that represents the limits set by the designer on the working drawing. It therefore becomes very easy to compare the size of a component with the ones used for setting the two limits. Any size, which falls within the zone, is acceptable. Those that fall outside the zone are either corrected or scrapped.

In existence are mechanical, electrical, pneumatic and hydraulic comparators. Attempts are made to make the zone clearly visible using color zone or color liquid.

It is obvious, the fact that these instruments are very expensive although very easy to use and are very accurate. Just like in the case of using gauges, comparators are used only for quality control and mass production.

What are fits?

Parts are made to work together after assembling a complete machine. During assembly, the worker must pay attention to the fact that some parts are assembled to allow relative movement between each other and others do not allow relative movement.

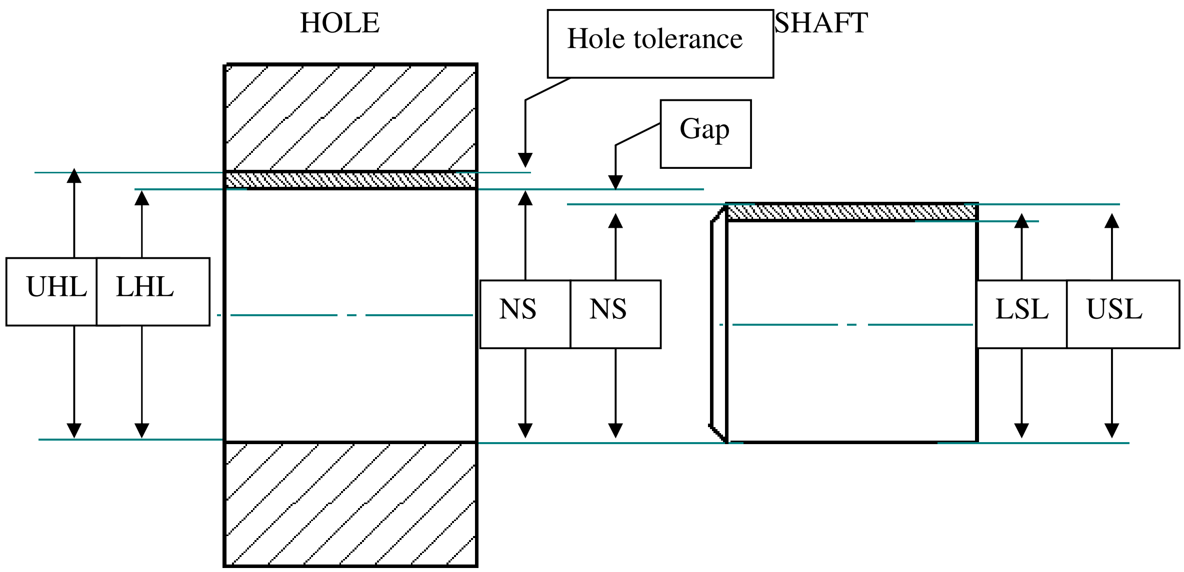
In individual assembly, this is taken care of by the machine operator who is himself skilled.

In selective assembly, this is done at the sorting stage where parts are matched or selected and color-coded for storage. It is important to note that there are no rejects here since all parts are matched according to how they fit best.

In the system of limits and fits however, this is taken care of at the design stage by the designer who sets limits for every size. Therefore, ALL parts produced within their limits are *interchangeable,* and will fit perfectly during assembly and fully serve the purpose for which the machine was designed. This is because *only* parts whose sizes fall within the limits set by the designer are cleared as good by the machine operator. There are three types of fits technically known as CLEARENCE FIT, INTERFERENCE FIT and TRANSITION FIT.

The term FIT refers to *shaft* assembled with *hole* to produce either relative movement between each other or no relative movement at all between each other. The designer knows where relative motion is required and where it is not required. He therefore sets limits, which guarantees either free movement or no movement in the right places. It is therefore logical to try to see what goes on inside the designer's mind at this stage by studying the types of fit in detail.

CLEARENCE FIT



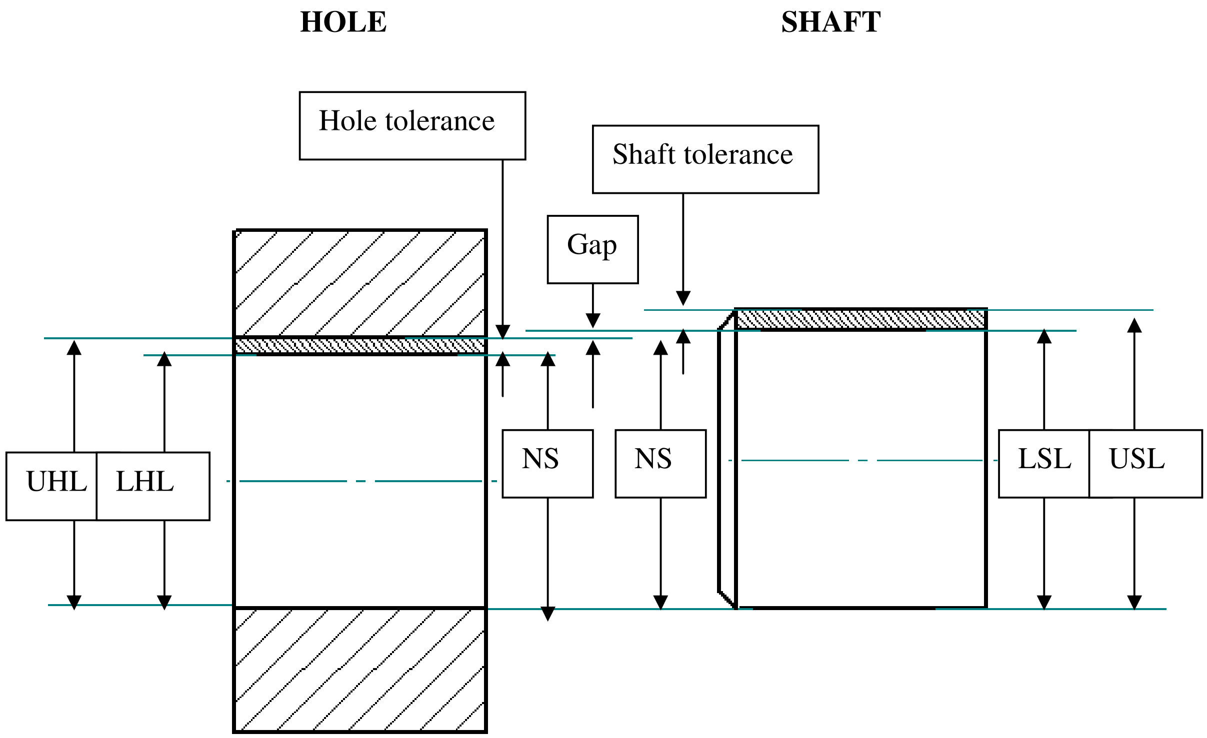
UHL= Upper hole limit NS= Nominal size USL= Upper hole limit

LHL= Lower hole limit LSL= Lower shaft limit

The *tolerance* zone of the hole is *above* that of the shaft and between them is a gap, which is a minimum *allowance* chosen by the designer to *guarantee* clearance fit between the two during assembly. Clearance fit is therefore an imaginary arrangement of shaft and hole working drawings brought together and assembled to show that the largest acceptable shaft is still *smaller* than the smallest acceptable hole or the smallest acceptable hole is still *larger* than the largest acceptable shaft. Designers know that this fit *allows relative* movement between the two parts.

Since any *shaft* or *hole,* whose size falls within the limits is acceptable it can easily be seen that the *minimum clearance allowance* possible for this fit is the difference between the smallest hole and the biggest shaft, and the *maximum clearance allowance* is the difference between the biggest hole and the smallest shaft. The magnitude of the allowance is very important and the designer takes care to make sure that the minimum allowance is there but as small as possible and the maximum allowance is big enough but does not affect the performance of the assembly. When clearance allowance is too big, some parts acceptable as good do assemble with too much ease to make very loose joints with short life span and very noisy when put to use.

INTERFERENCE FIT



UHL= Upper hole limit   NS= Nominal size   USL= Upper shaft limit

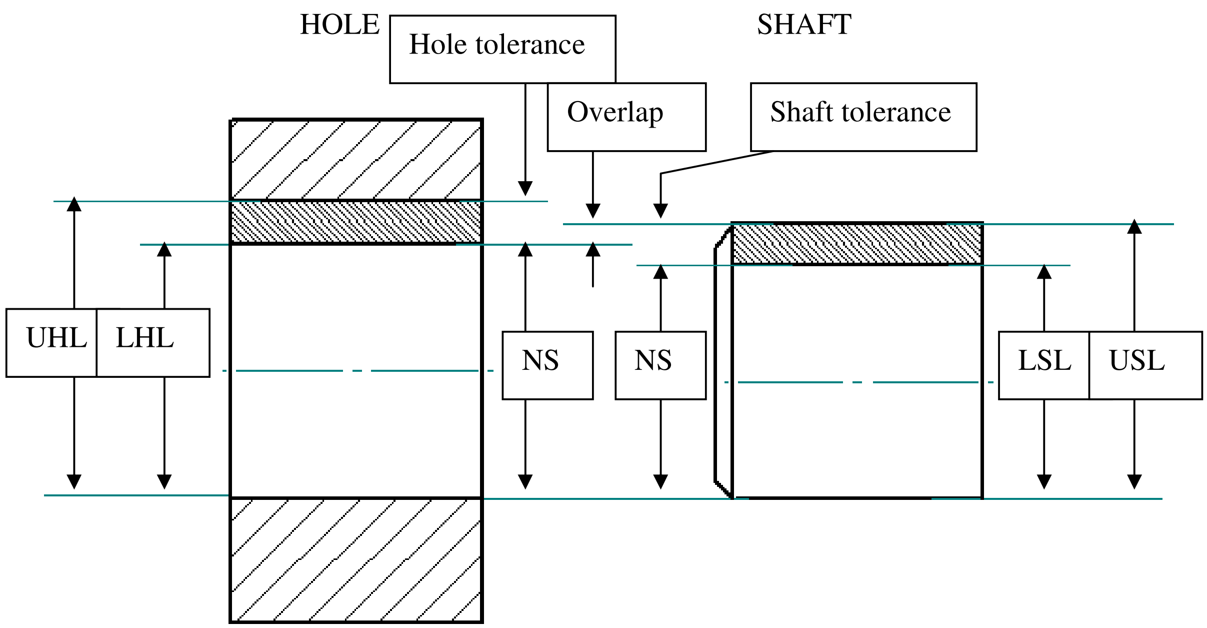
LHL= Lower hole limit   LSL= Lower shaft limit

The *tolerance* zone of the hole is *below* that of the shaft and between them is a gap, which is a minimum *allowance* chosen by the designer to *guarantee* interference fit between the two during assembly. Interference fit is therefore an imaginary arrangement of shaft and hole working drawings brought together and assembled to show that the smallest acceptable shaft is still *larger* than the largest acceptable hole or the largest acceptable hole is still *smaller* than the smallest acceptable shaft. Designers know that this fit *does not allow relative* movement between the two parts.

Since any *shaft* or *hole* whose size falls within the limits is acceptable, it can easily be seen that the *minimum interference allowance* possible for this fit is the difference between the biggest hole and the smallest shaft, and the *maximum interference allowance* is the difference between the smallest hole and the biggest shaft. The magnitude of the allowance is very important and the designer takes care to make sure that the minimum allowance is there but as small as possible and the maximum allowance is just enough and does not affect the assembly process or the performance of the assembly. When interference allowance is too big, some parts acceptable as good are impossible to assemble and if they do, the component with the hole is overstressed leading to either its cracking or excess strain to adjacent moving parts like balls or rollers of bearings. This can affect the performance of the assembly in many ways.

Usually the efficiency is reduced and there is overheating which can drastically reduce the life of the machine. It also overloads the prime mover.

TRANSITION FIT



UHL= Upper hole limit NS= Nominal size USL= Upper shaft limit

LHL= Lower hole limit LSL= Lower shaft limit

The *tolerance* zones of hole and shaft overlap. Transition fit is therefore an imaginary arrangement of shaft and hole working drawings brought together and assembled to show that the biggest hole is *bigger* than the smallest shaft and the smallest hole is *smaller* than the biggest shaft.

Designers know that this fit exists only on the working drawing because in reality during assembly only clearance and interference fits are obtained with no effect at all on the performance of the machine.

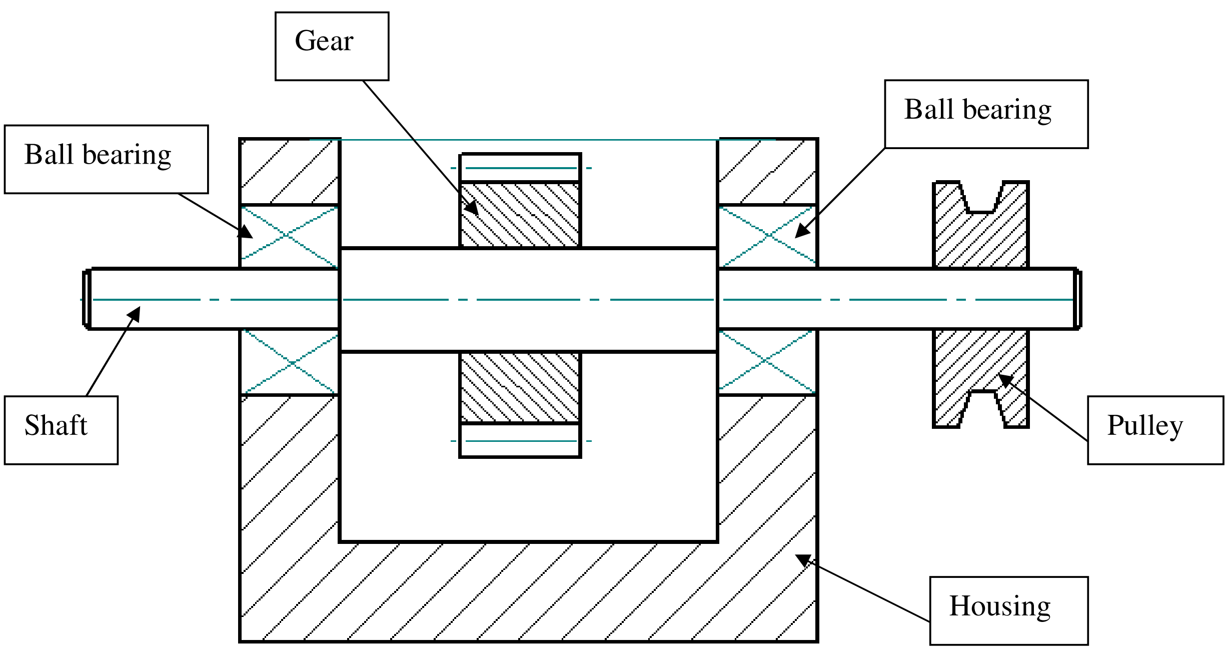
Since any *shaft* or *hole* whose size falls within the limits is acceptable, it can easily be seen that the *maximum clearance allowance* possible for this fit is the difference between the biggest hole and the smallest shaft, and the *maximum interference allowance* is the difference between the smallest hole and the biggest shaft.

Because of the overlap between the hole and shaft tolerance zones, there is no minimum clearance or minimum interference. Theoretically, however there is a possibility of obtaining *zero* clearance or interference. This happens only if the shaft and hole are of the *same* size, and is possible only within the area of *tolerance zone overlap*.

When shafts and holes are produced on machine tools available to the designer, tolerance limits can easily be controlled to produce components with the sizes required for the right fit. Machine building however involves the use of ready-made components like bearings and plain shafts. The designer then finds himself in a situation where he can control the limits of only one of the two parts involved in the fit. Holes are also produced easily and more accurately using standard size tools like reamers. Systems therefore refer to the methods used to obtain the required fit, either clearance or interference, when one size is already available and on machining operation is required, or when one size is produced using a standard size tool.

There are two systems for obtaining fits and they are based on either the hole or the shaft depending on which one is already available with its fixed size.

Hole basis system



Between ball bearings and shaft is interference fit.

Between gear and shaft is transition fit (either clearance fit or interference fit).

Between shaft and pulley is clearance fit.

Sizes of the holes already exist:-

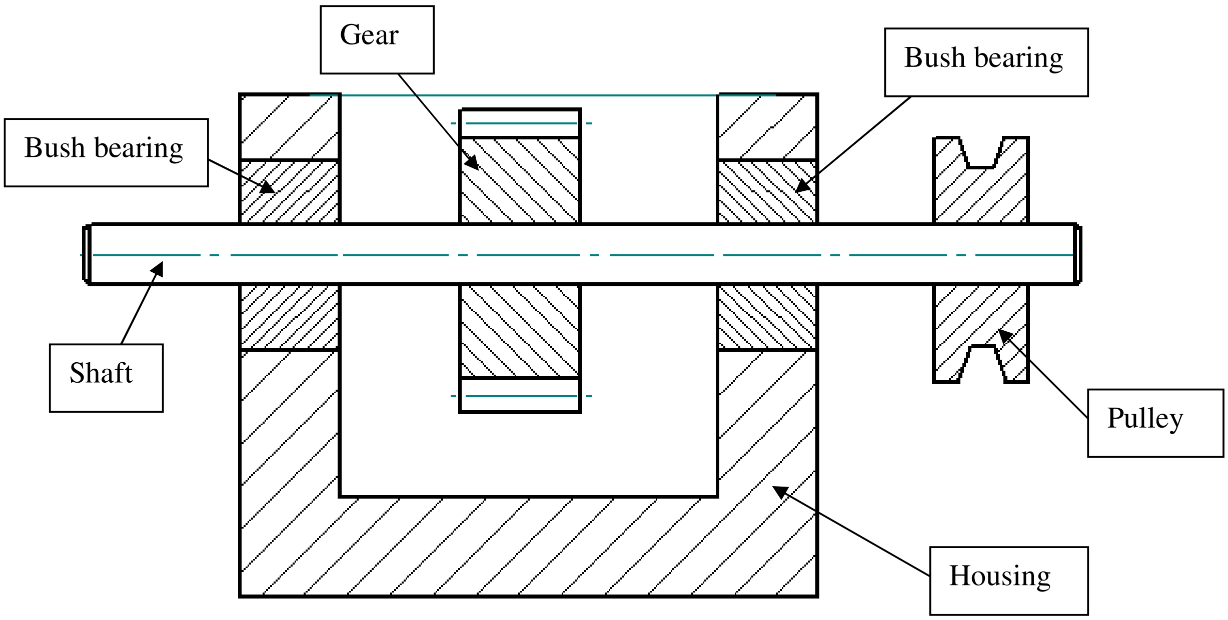
Ball bearings are ready made.

The hole in the gear is reamed using standard size reamer.

The hole in the pulley is reamed using standard size reamer.

The right fit is obtained by machining the shaft to the right size.

Shaft basis system



Between bush bearing and shaft is clearance fit.

Between gear and shaft is transition fit.

Between pulley and shaft is clearance fit.

The shaft is a plain one of standard size.

The required size is obtained by machining:-

The bush bearing for clearance fit

The gear for interference fit.

The pulley for clearance fit.

INSPECTION

In this section, inspection will refer to dimensions only. The methods used to inspect the sizes depend on the type of dimension control used in the production process.

Individual assembly method does not require any inspection since the operator does the right thing either independently or under supervision. Nothing is produced for storage, so there are no parts lying around for inspection. Vital components are stored in an assembled form.

Selective assembly method does require minimum inspection. This is because during the sorting process there are skilled personnel using more accurate measuring instruments. It is an extension of dimension control that ended during the machining stage since each and every component is again measured.

Catastrophic errors however do happen, either by reading the measuring instrument wrongly or marking a component with wrong color code and therefore putting it in a different size group.

The use of limits and fits system however require strict inspection since the parts made within limit are assumed to work interchangeably with any other part made within limits for it. Because of this interchangeability concept, parts that are passed as good by the worker are taken straight for use or storage for sale.

Bearing in mind the fact that the workers are semi skilled, inspection methods used should minimize or bring to zero the number of bad components accepted as good and therefore put to use, sold or stored.

Here the most common approach is the use of gauges. The inspection gauges are more accurate than the ones used during production. Since gauges are also manufactured, they are also given tolerances, but the tolerance zones of inspection gauges are smaller and fall within the tolerance zones of the size being checked.

The GO side of the gauge always wears with time and begins accepting *holes of smaller sizes* and *shafts of bigger sizes*.

This can be minimized or brought down to zero using different methods, depending on the volume and method of production. In general, active GO gauges should *never* be allowed to wear up to the *maximum tolerance size limits of shafts*, and *minimum tolerance size limits of holes*. Gauges must therefore be checked frequently using very accurate measuring instruments and replaced before they begin to accept sizes which are outside the tolerance limits.

The other approach is *random sampling* of finished components and replacing the measuring gauge if *a size* is found to fall *close* to the extreme limits of the sizes.

In this case, there is a possibility of *a wrong* size slipping through to assembly line, or even Sales Department.

In the assembly line, these cases are spotted out and handled either *individually* or *selectively*. However in the Sales Department, this is a source of *bad* reputation, which must be avoided at all costs.

Modern approach in production has introduced methods which require constant monitoring of sizes as they are being produced, and the measuring instruments best suited for this are comparators. They are fitted directly on the machine, making the constant size monitoring process possible.

Once the machine is set for a particular size, only tool wear remains basically the only factor in the size variations. As shafts become bigger and holes become smaller, a signal that switches off the machine is sent from a command within the machine before sizes that fall outside tolerance limit zone are produced and the tool is replaced.

Elements of inspection here are therefore the settings on the machine and the settings on the tool, and all parts produced are absolutely interchangeable and can be used, stored or soled without any worry.

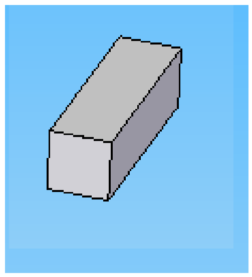
MACHINING PRINCIPLES AND METAL CUTTING TOOLS

The following are daily life principles that equally do apply to machining of metals and cutting tools:-

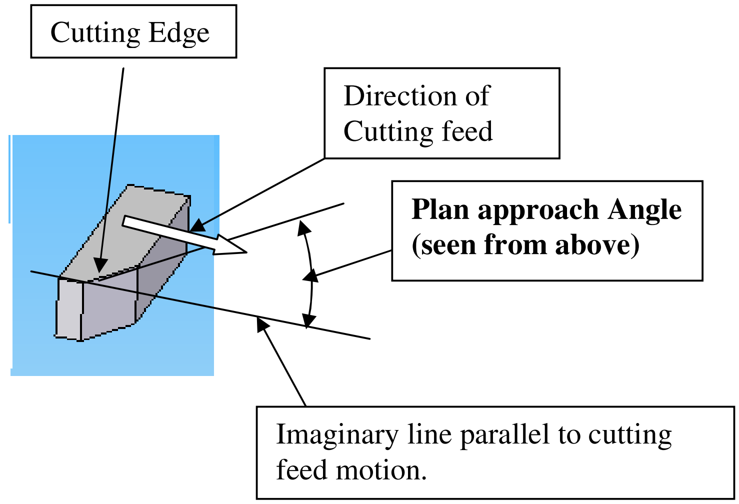
1) For any tool to be able to cut another material, the tool must be harder than that material, just like knife cuts bread because it is harder than bread.
2) Two materials or objects will never occupy the same space at any one given time. If an attempt is made to force them into that one space, there must be collision or accident and the stronger material displaces the weaker one and occupies the space.
3) The tool must have angles around the cutting edge to make the cutting edge stand alone in space so that it touches the material at the cutting edge only for maximum cutting or tearing effect.
4) There must be an effective work holding provision, a device that leaves the work firm and rigid on the machine.
5) There must be an effective tool holding provision, a device that leaves the tool firm and rigid on the machine.
6) There must be controlled motions on the machine, to force work and tool into each other, with contact between work piece and tool at cutting edge only.

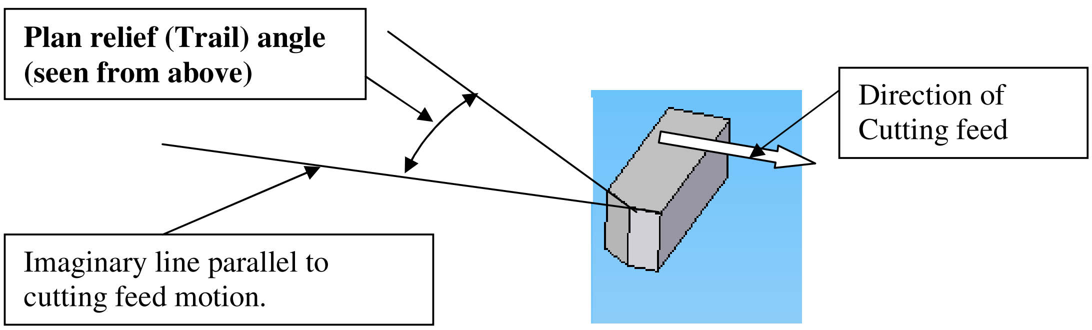
TOOL ANGLES

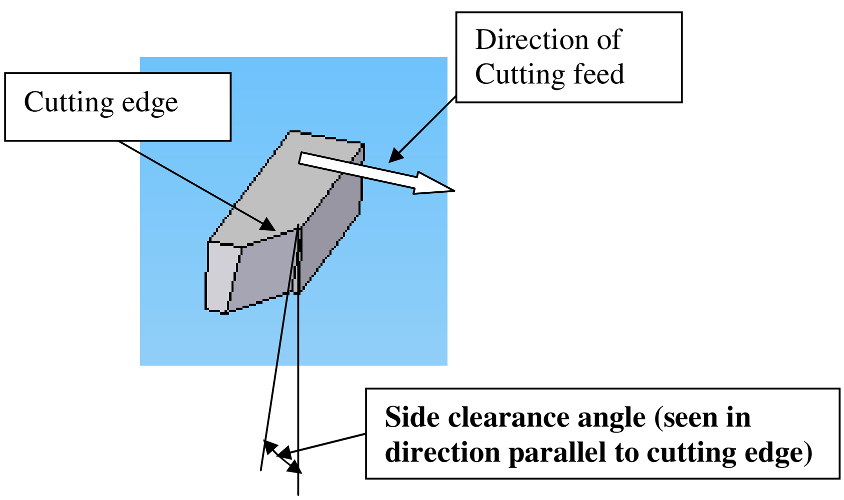
All attempts must be made to understand the position or location of the following angles in relation to the cutting edge of the tool and some particular motions on the machine. The angles are PLAN APPROACH angle, PLAN RELIEF (or TRAIL) angle, FRONT CLEARANCE angle, SIDE CLEARANCE angle, FRONT RAKE, and TRUE RAKE angles. These angles are shone on the turning tool below, but they can be identified on any other metal cutting tool.

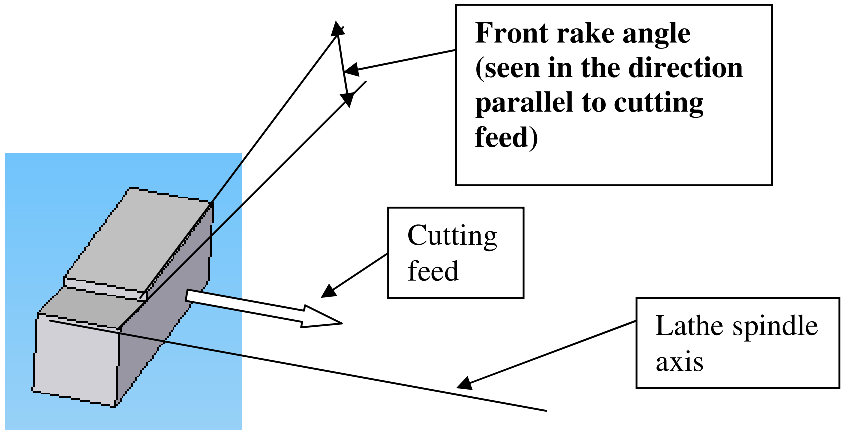


New tool without cutting edge

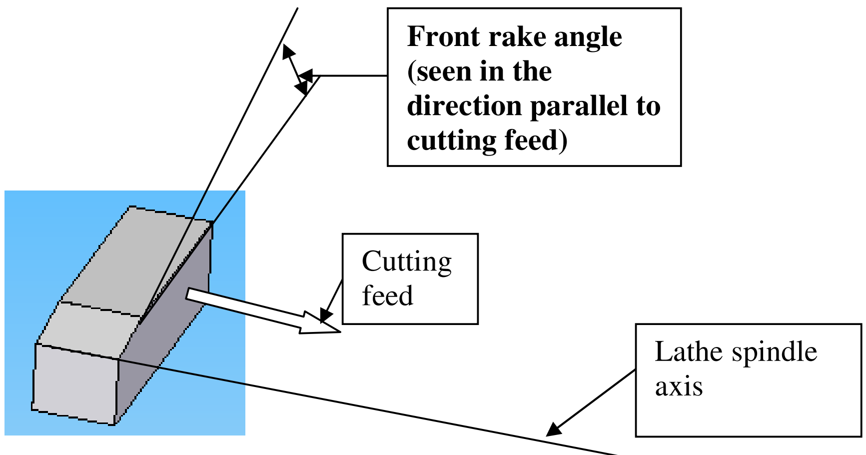




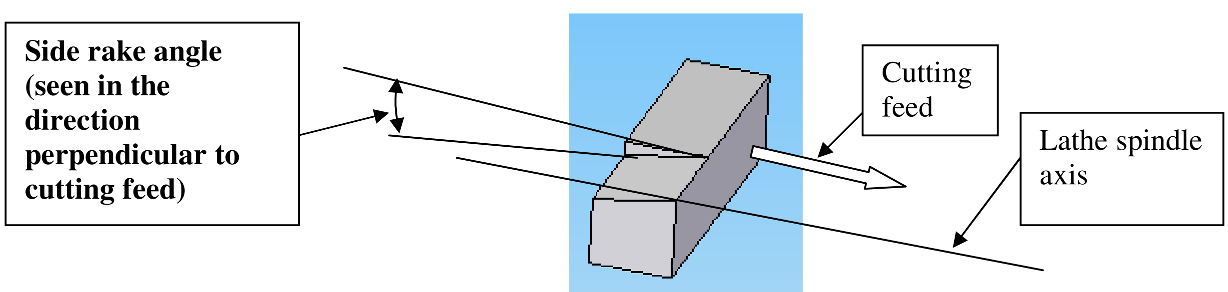




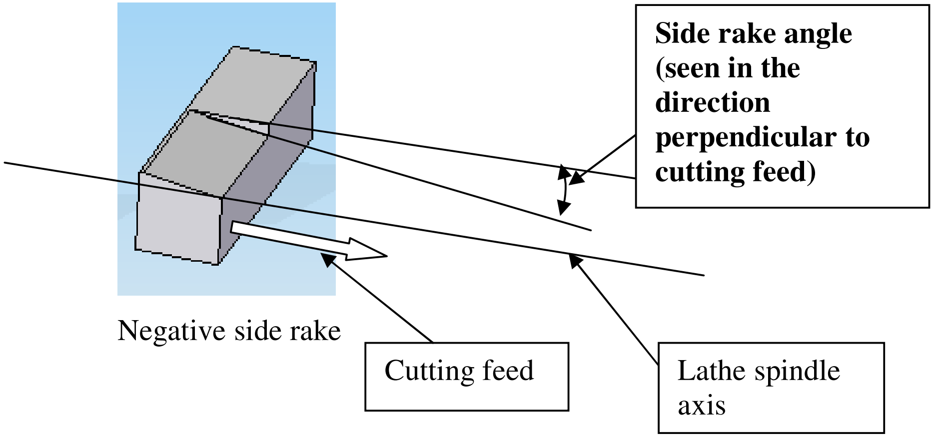
Positive front rake

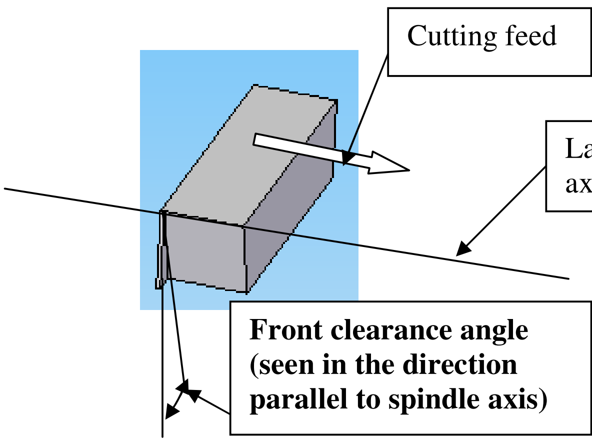


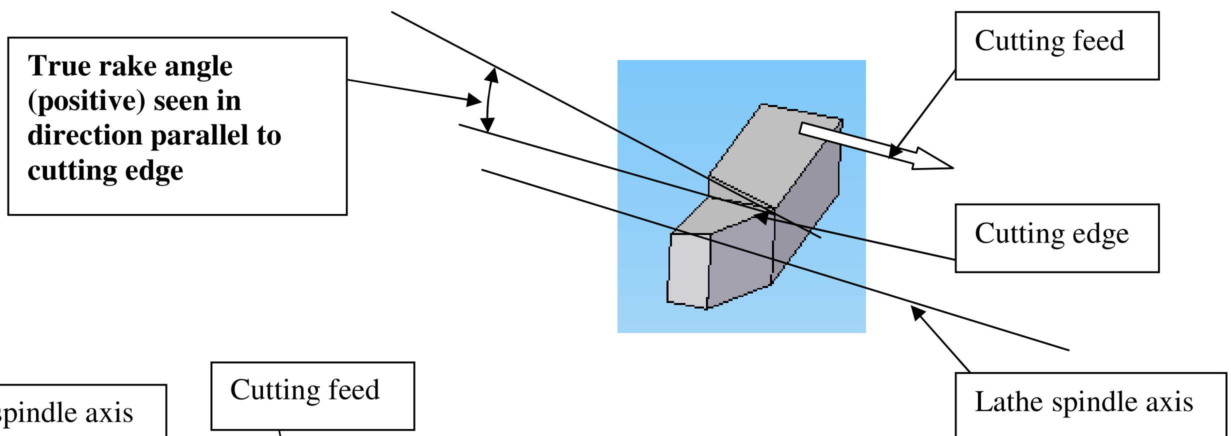
Negative front rake

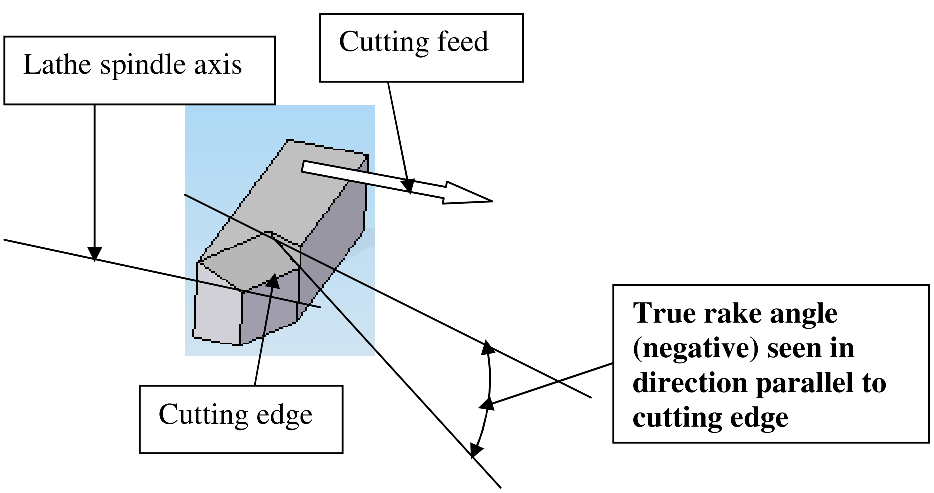


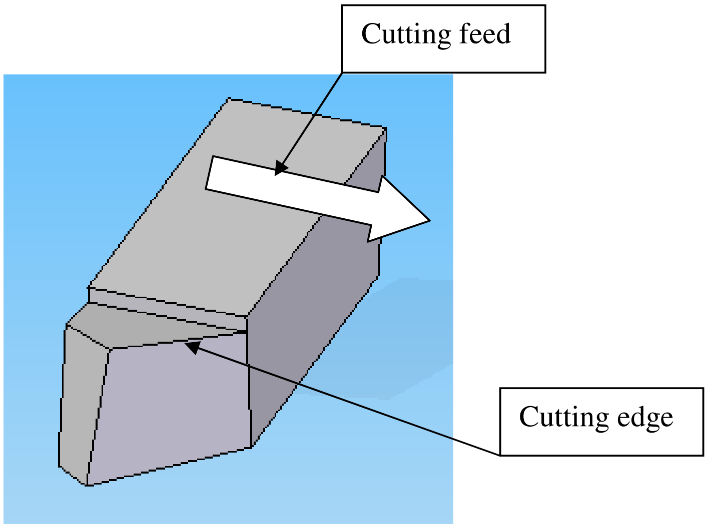
Positive side rake


Side rake angle (seen in the direction perpendicular to cutting feed)
Negative side rake
Cutting feed
Lathe spindle axis


Cutting feed
Lathe spindle axis
Front clearance angle (seen in the direction parallel to spindle axis)


True rake angle (positive) seen in direction parallel to cutting edge
Cutting feed
Cutting edge
Lathe spindle axis


Lathe spindle axis
Cutting feed
True rake angle (negative) seen in direction parallel to cutting edge
Cutting edge



Finished tool

MILLING MACHINES

There are two types of this machine, classified as:-

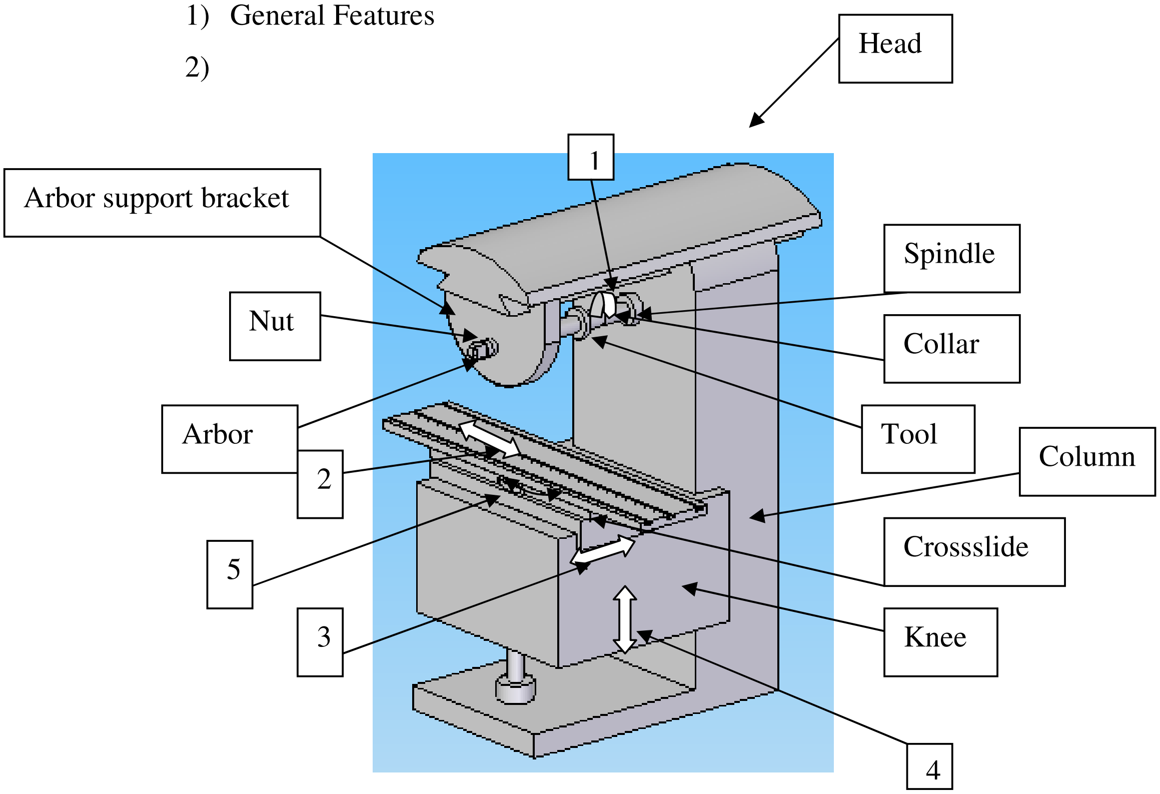
1) Horizontal milling machine.
2) Vertical milling machine.

The name is after the spindle axis position.

If the axis is horizontal, the machine is horizontal milling machine.

If the axis is vertical then the machine is vertical milling machine.

1) General Features
2)



2) Motions.

Motion 1- Rotary spindle motion. This is the main motion.

Motion 2- Linear longitudinal table motion parallel to spindle axis and its own surface. This motion is horizontal.

Motion 3- Linear transverse table motion parallel to table surface and spindle axis and perpendicular to motion 2. This motion is also horizontal.

Motion 4- Linear motion of the knee perpendicular to table surface, spindle axis and motions 1 and 2.

Motion 5- Angular motion of table for setting angle of table motion.

3) Work Holding.

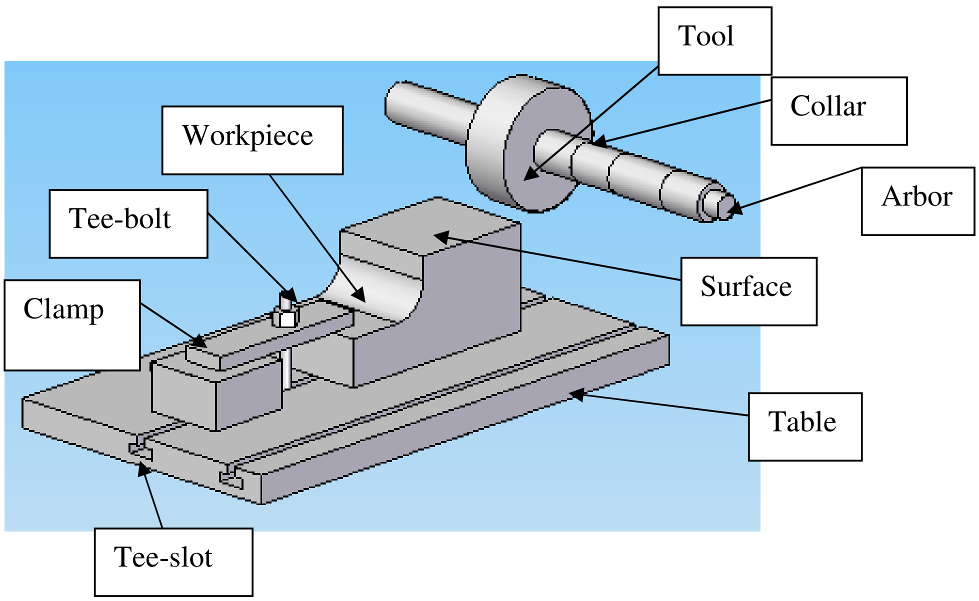
Directly on the table.

The tee-slots on the table are used to hold the work directly on the table using either clamps, for work pieces without holes or only tee-bolts, for those with holes.

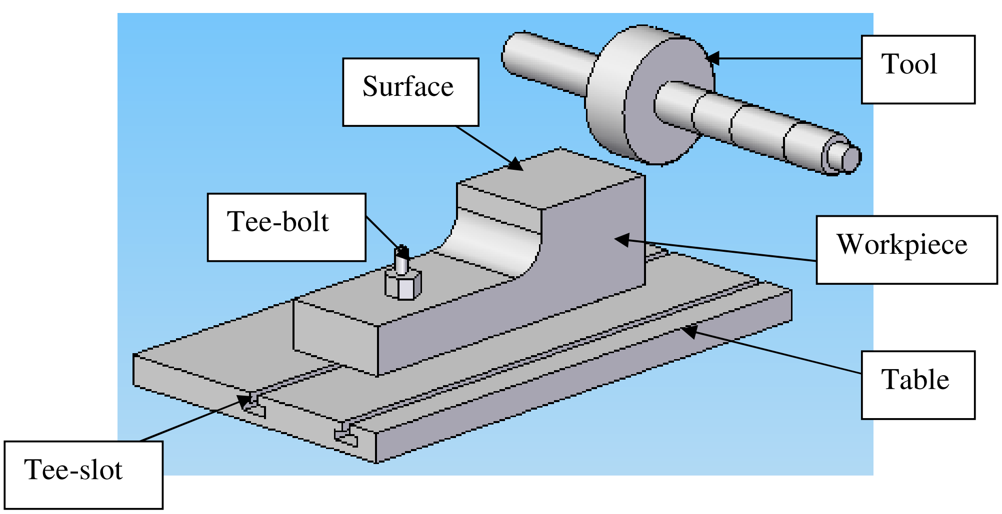
The central tee-slot is machined very accurately parallel to motion 2 and perpendicular to motion 3. It can therefore be used to align a job during clamping and the job automatically aligns with those motions.

For example, a shaft can be clamped along the slot for cutting a keyway and the keyway will be parallel to the shaft axis.

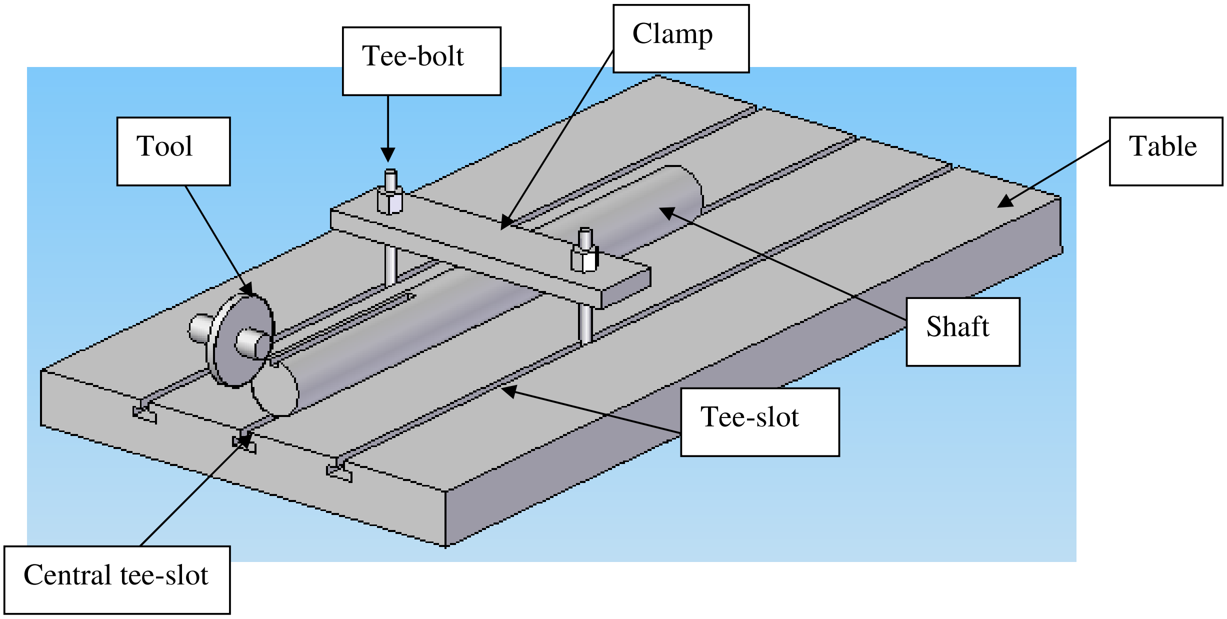
Below is a method of clamping a work piece that has no hole.



Below is a method of clamping a work piece that has a hole.



Below is a method of clamping a shaft along the central T-slot for cutting a keyway.

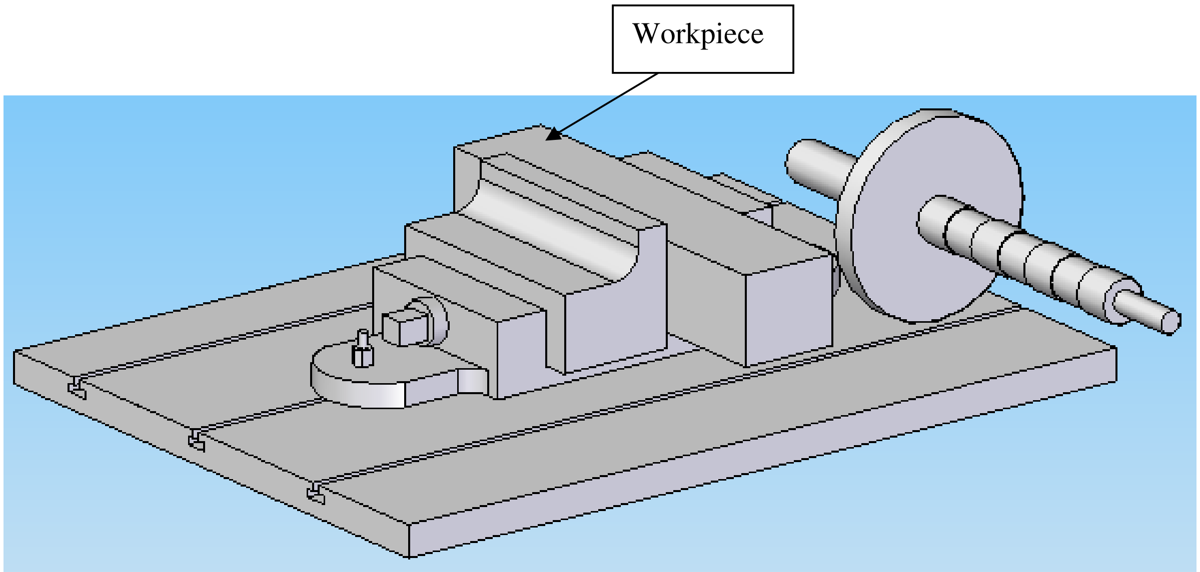


Machine vice.

The vice has holes, which are used for bolting it onto the table, and then the work piece can be conveniently held in it.

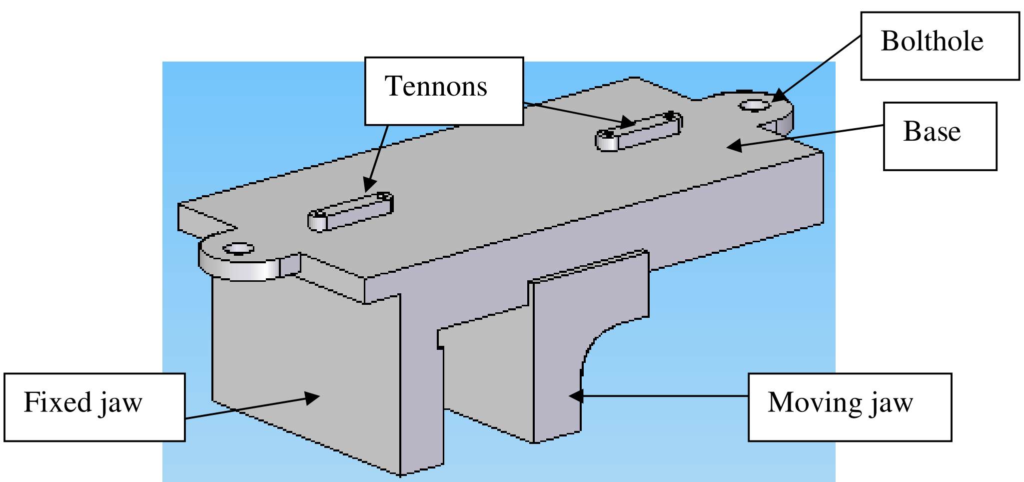
The base of the vice is machined very flat and accurate. The surface held in the fixed jaw is always perpendicular to the base of the vice. There are two tenons at the base of the vice, placed accurately along a line perpendicular to the fixed jaw. The tenons also fit exactly, without clearance in the central tee-slot, such that when the vice is on the table, with the tenons in the central tee-slot, the fixed jaw is automatically aligned perpendicular to motion 2 and parallel to motion 3. The vice therefore becomes part of the table and automatically blends in the machine alignments. This gives correct geometry to any surface machined on a work piece held in a machine vice.

Below is a method of clamping a work piece using a vice bolted on machine table.



Below are the features of the vice that automatically align the fixed jaw parallel to motion 2 and perpendicular to motion 3.

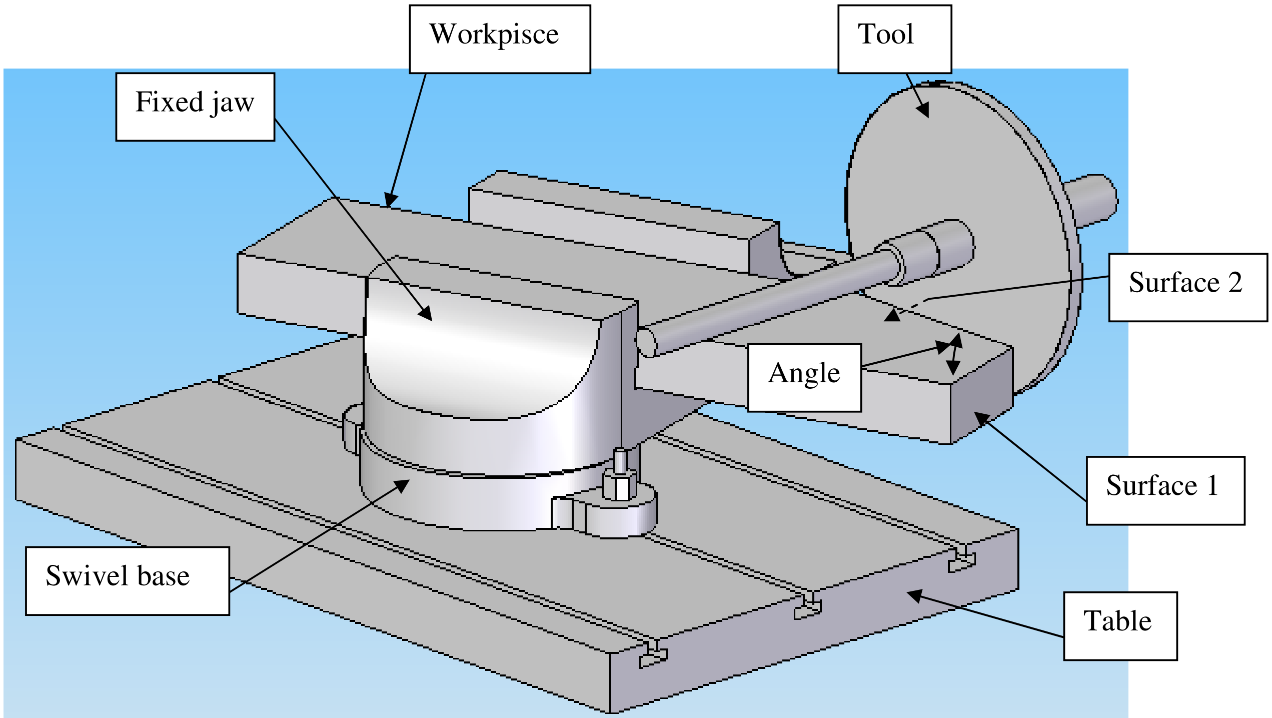
The tennons are fitted in a line perpendicular to the fixed jaw and when placed on the table, they fit without play into the central T-slot, and therefore locates the fixed jaw perpendicular to motion 2 since the T-slot is cut very accurately and is parallel to motion 2.



Vice features

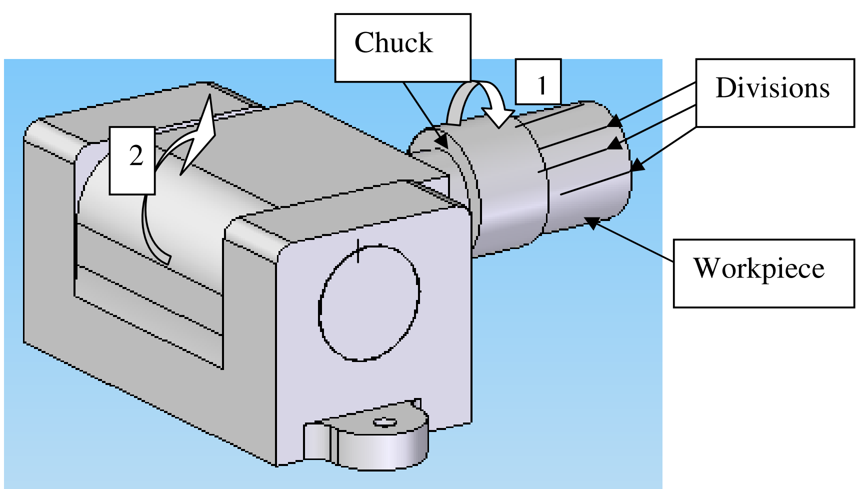
Swivel base vice.

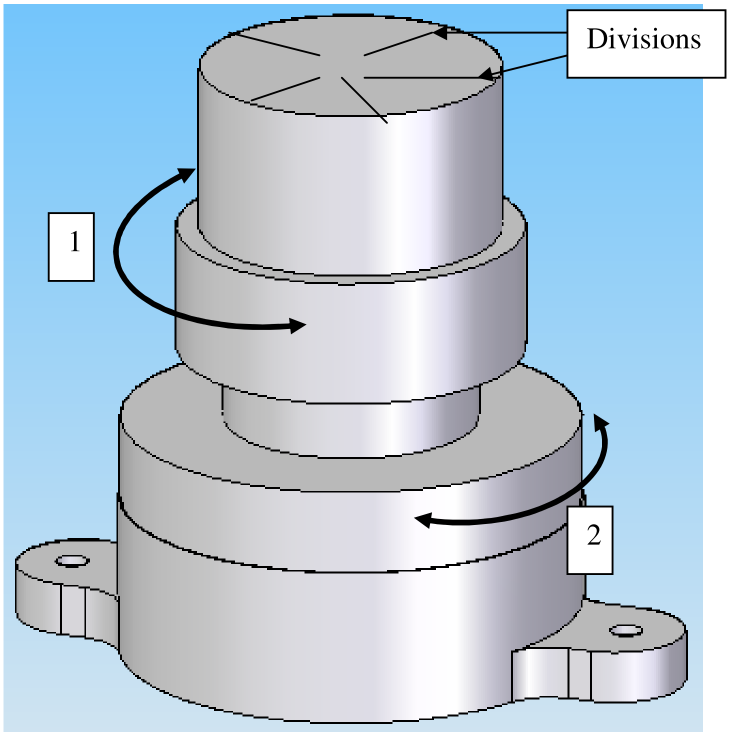
In addition to all the features on the machine vice this vice has a base, which can be swiveled accurately at angles up to 180 degrees. This makes it possible to machine two or more surfaces at some angle to each other after the vice is bolted onto the table.



Dividing Head.

All the features at the base of the vice are also on this device. Ones bolted on the table and the work clamped in its jaws it is possible to rotate the work about its axis and locked it in any position with considerable degree of precision in degree or number of turns or fractions of a turn. The work axis can also be turned and clamped in any position between horizontal and vertical. This increases the number of possibilities of producing surfaces at some angle to each other.

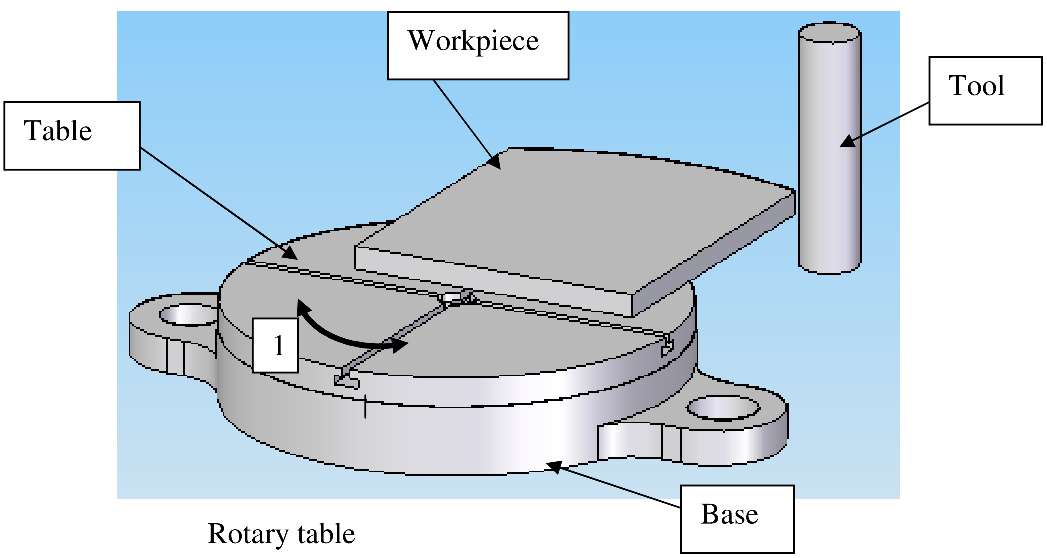




Rotary Table.

The base is also provided with the same features as on the dividing head. It is however a table which can be rotated about an axis perpendicular to the table base and locked in any position between zero and 360 degrees, very accurately.

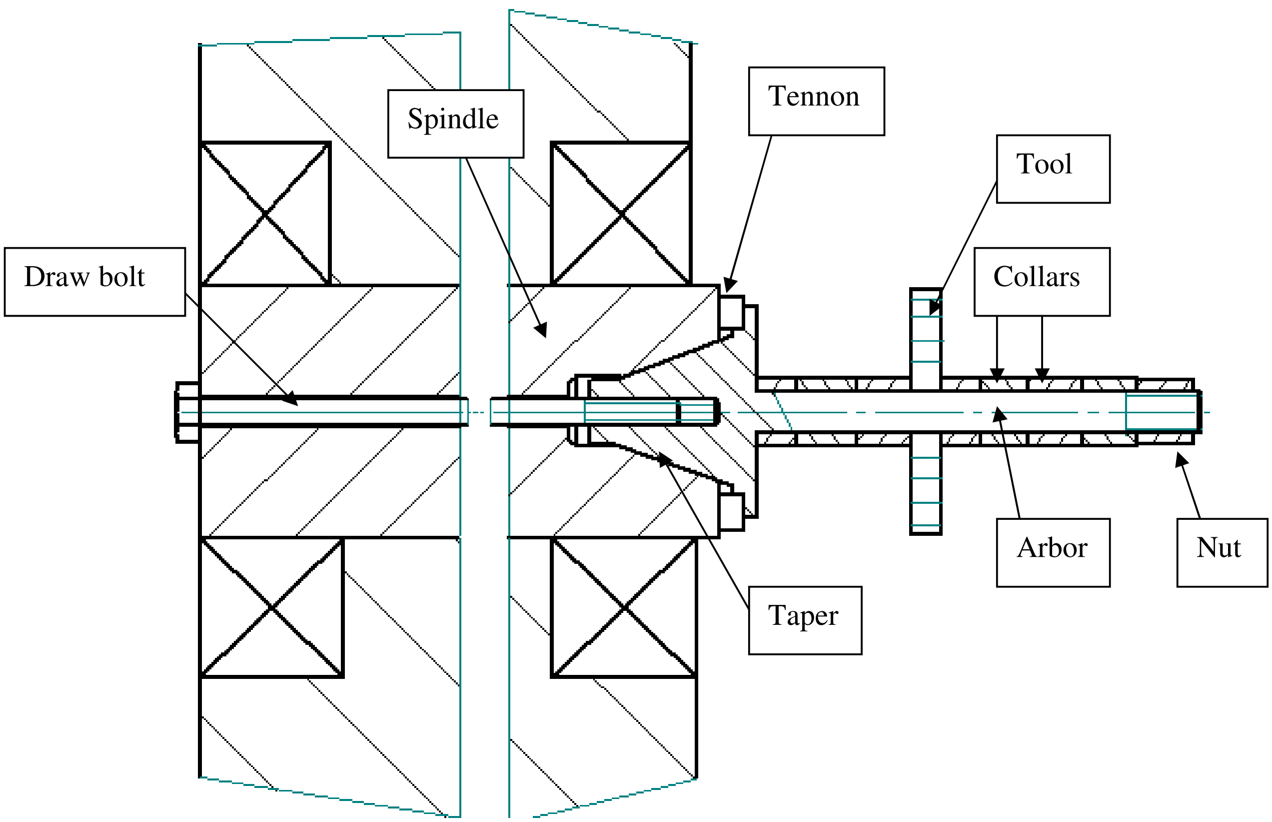
The table has tee-slots on it for bolting or clamping the work piece onto it.



Rotary table

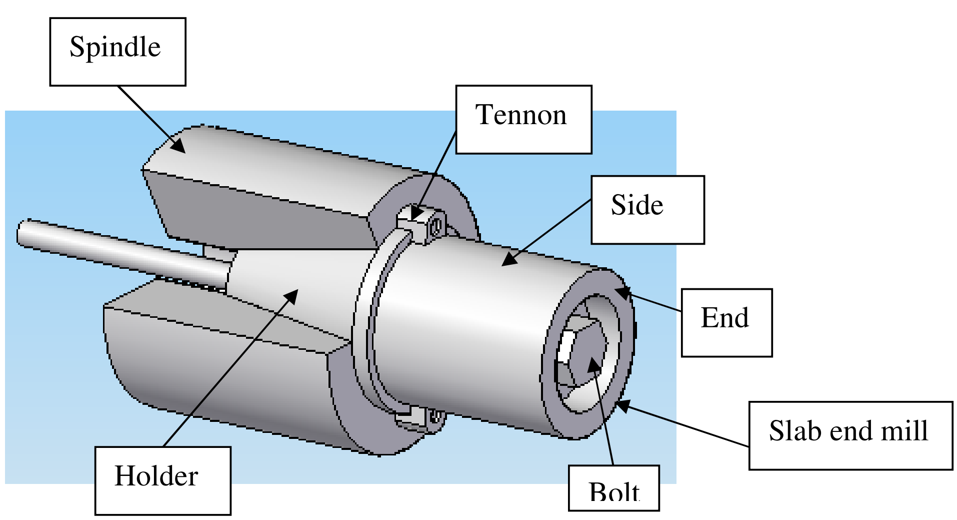
4) Tool Holding.

Most of the tools used on this machine are held on the arbor. The arbor itself is held in the spindle nose where there is a matching taper. A draw bolt is passed through the back of the spindle to hold the arbor in the taper. The taper serves to automatically align the axis of arbor to that of the spindle. The drive from the spindle is given positive drive through tenons at the spindle nose and from the arbor to the tool through the key, which runs the whole length of the arbor. The tool is finally held in position between collars by a nut at the end of the arbor.



The shell end mill.

The slab end mill can also be held using a special tool holder just in the same way as the arbor, improving tool rigidity and speed of metal removal.



Operations.

The result of all operations is always a surface of some form produced. This comes about as a generated surface using single point tool or copying the form from the tool onto the work piece.

In both cases it is possible to produce a surface only if at least two motions of the machine are present at the same time. These are active motions, one of which must be spindle rotation, which is the main motion. Another motion, which is very important but does not exist during actual cutting process is the one used to set the cutting depth. This is passive motion. It is the motion used to give the work piece its size.

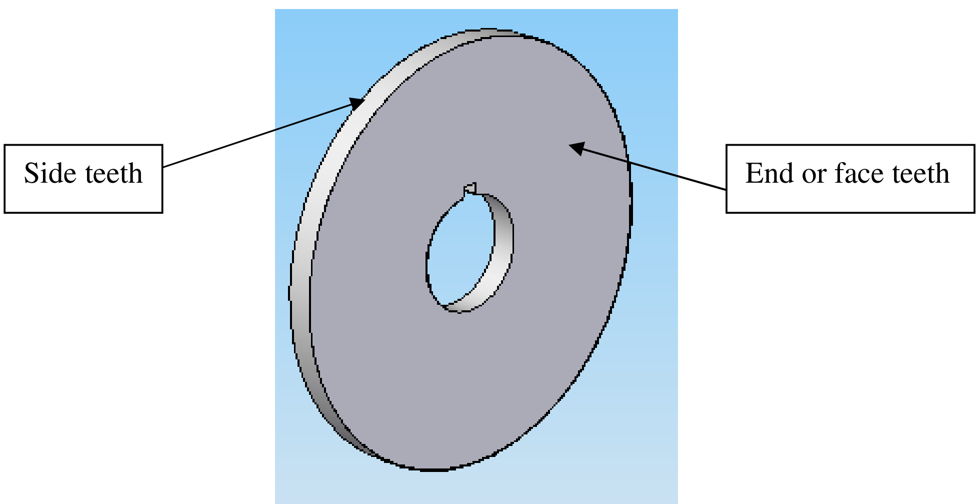
Milling.

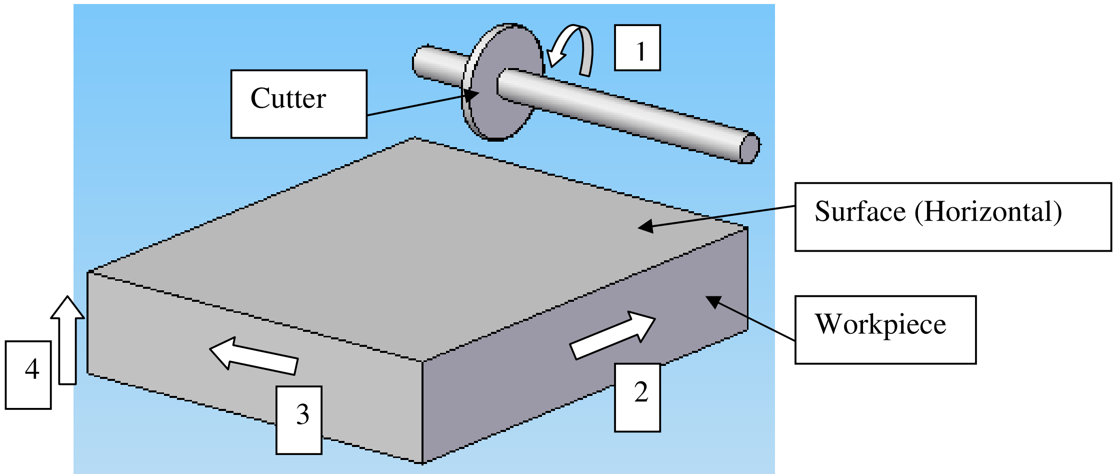
This machine is designed to produce mainly flat surfaces which are parallel, perpendicular or at some angle to each other. Surface orientation can be horizontal, vertical or at some other angle. The tools used to produce the surfaces have their cutting edges parallel to either the horizontal plane or the vertical plane or some other standard angle, usually 30, 45 or 60 degrees. The operation for producing all these surfaces is called milling, and the same operation can be done using different types of tools combined with different types of work holding methods.

The most types of tools used for these are:-

1) Side and face cutter.

This tool is able to cut on both its side and its face. It is held on the arbor.



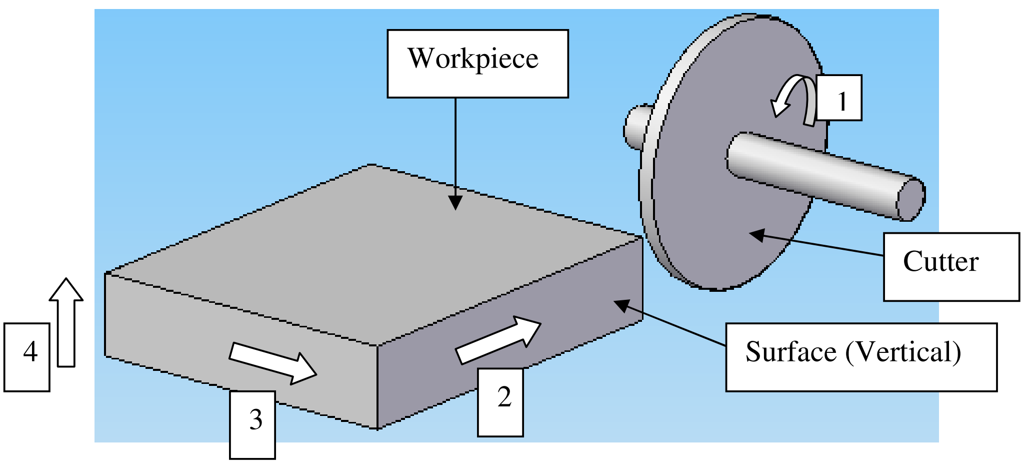


-Motion 1- Active (main motion)

-Motion 2- Active cutting feed

-Motion 3- Passive feed motion for covering full surface.

-Motion 4- Passive feed motion for cutting depth.



-Motion 1- Active (main motion)

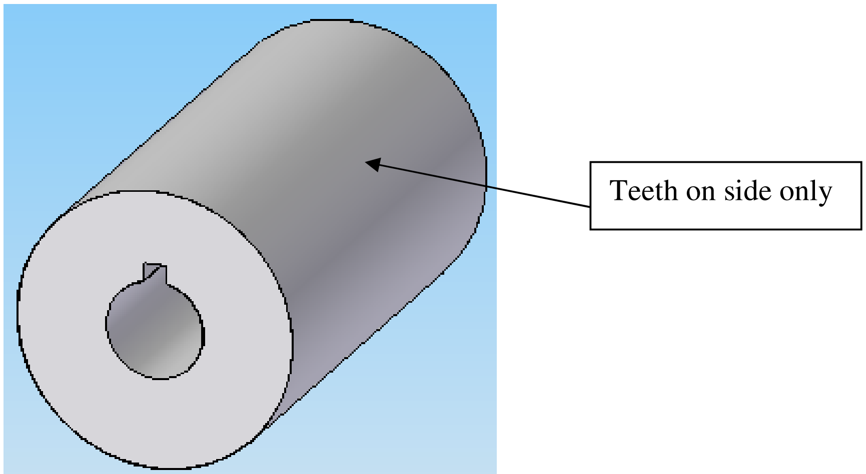
-Motion 2- Active cutting feed

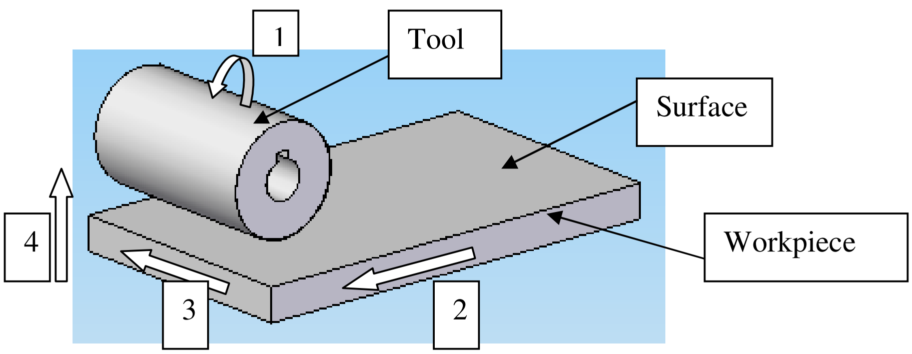
-Motion 3- Passive feed motion for cutting depth

-Motion 4- Passive feed motion for covering full surface.

2) Slab cutter.

This tool has cutting edges only on its side. It is held on the arbor and therefore can mill only horizontal surface since the cutting edges are parallel to the horizontal surface.





-Motion 1- Active (main motion)

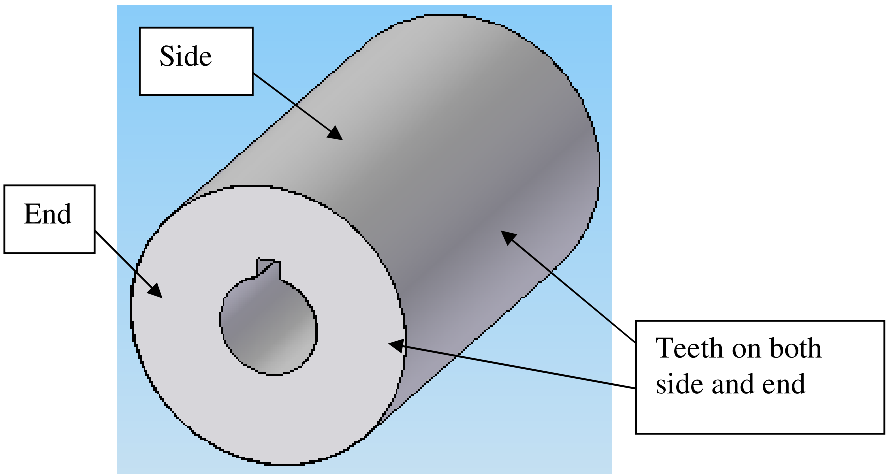
-Motion 2- Active cutting feed

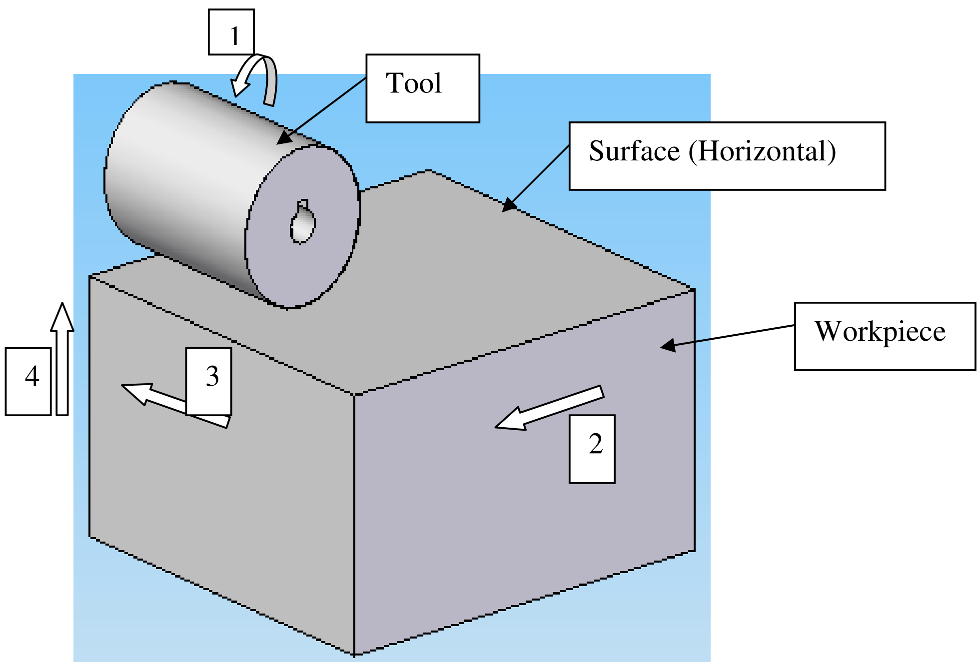
-Motion 3- Passive feed motion for covering full surface.

-Motion 4- Passive feed motion for cutting depth.

3) Shell End Mill

This tool is held using special tool holder, and on the machine, the cutting edges on the side cut horizontal surface and those on the end produce vertical surface.





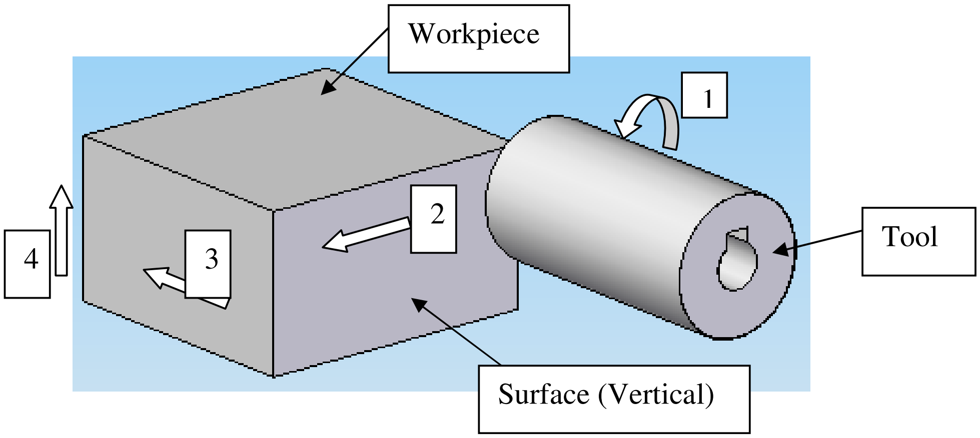
-Motion 1- Active (main motion)

-Motion 2- Active cutting feed

-Motion 3- Passive feed motion for covering full surface.

-Motion 4- Passive feed motion for cutting depth.

Both motions 3 and 4 can be used for sizing depending on the geometry of the work piece.



-Motion 1- Active (main motion)

-Motion 2- Active cutting feed

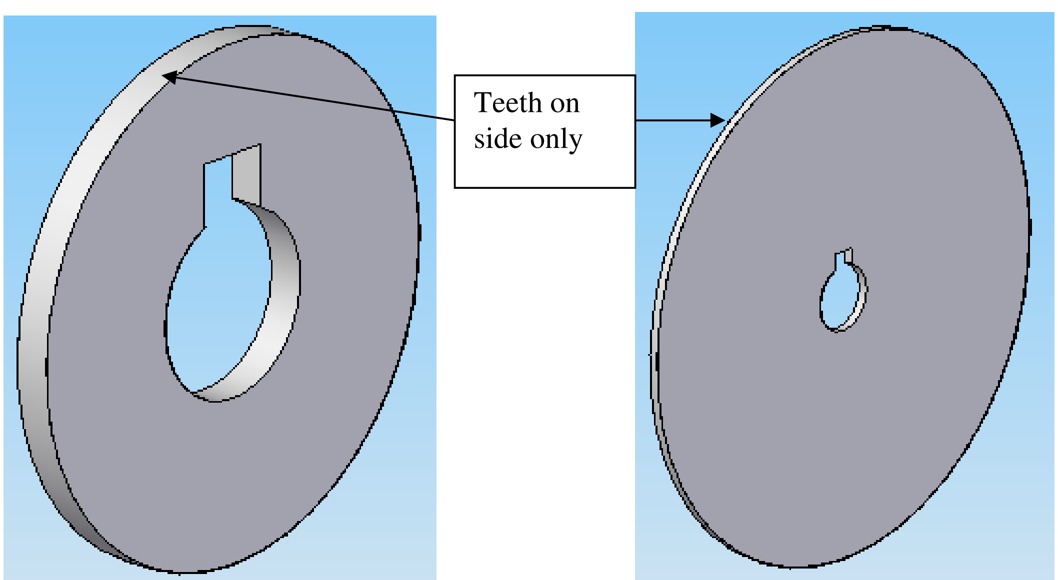
-Motion 3- Passive feed motion for covering full surface.

-Motion 4- Passive feed motion for cutting depth.

Both motions 3 and 4 can be used for sizing depending on the geometry of the work piece.

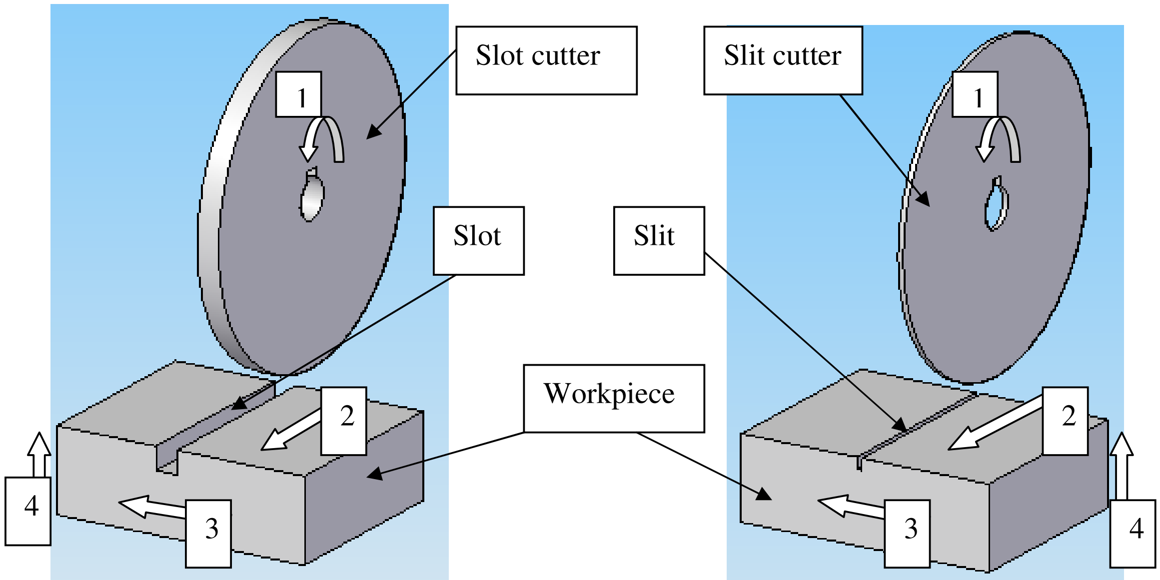
Slotting and Slitting.

This operation produces a groove on a flat surface, using a slotting tool.



Slot cutter

Slit cutter



-Motion 1- Active (main motion).

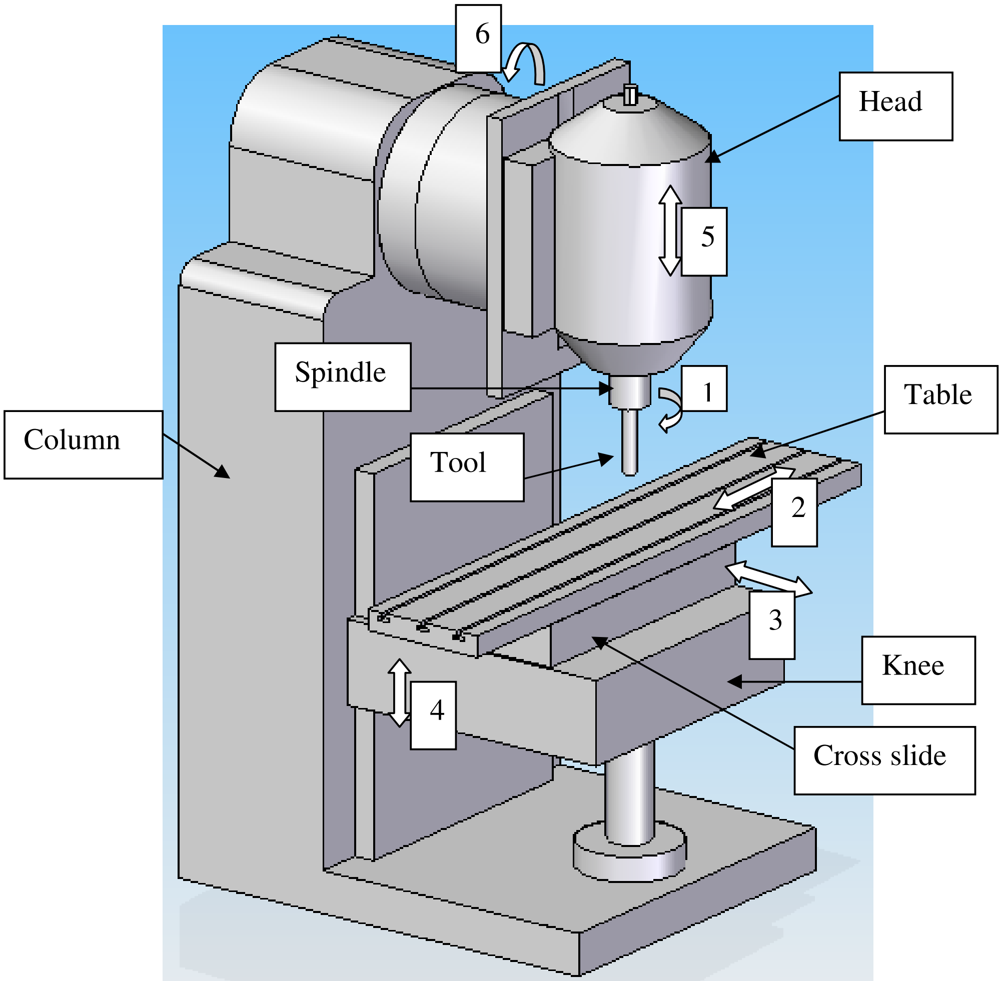
-Motion 2- Active cutting feed.

-Motion 3- Passive sizing motion for slot width.

-Motion 4- Passive sizing motion for slot depth.

Vertical Milling Machine.

General features.



Motions.

Motion 1- Rotary motion of spindle. This is the main motion.

Motion 2- Linear longitudinal motion, parallel to table surface and perpendicular to spindle axis. This motion is horizontal.

Motion 3- linear transverse motion, parallel to table surface and perpendicular to motion 2 and spindle axis. This motion is also horizontal.

Motion 4- Linear vertical motion of knee, parallel to spindle axis and perpendicular to table surface, motions 2 and 3.

Motion 5- Linear motion of sleeve, parallel to spindle axis and motion 4 and perpendicular to table surface, motions 2 and 3.

Motion 6- Angular motion of milling head for setting angle of sleeve motion 5 at some angle to table surface and motion 2.

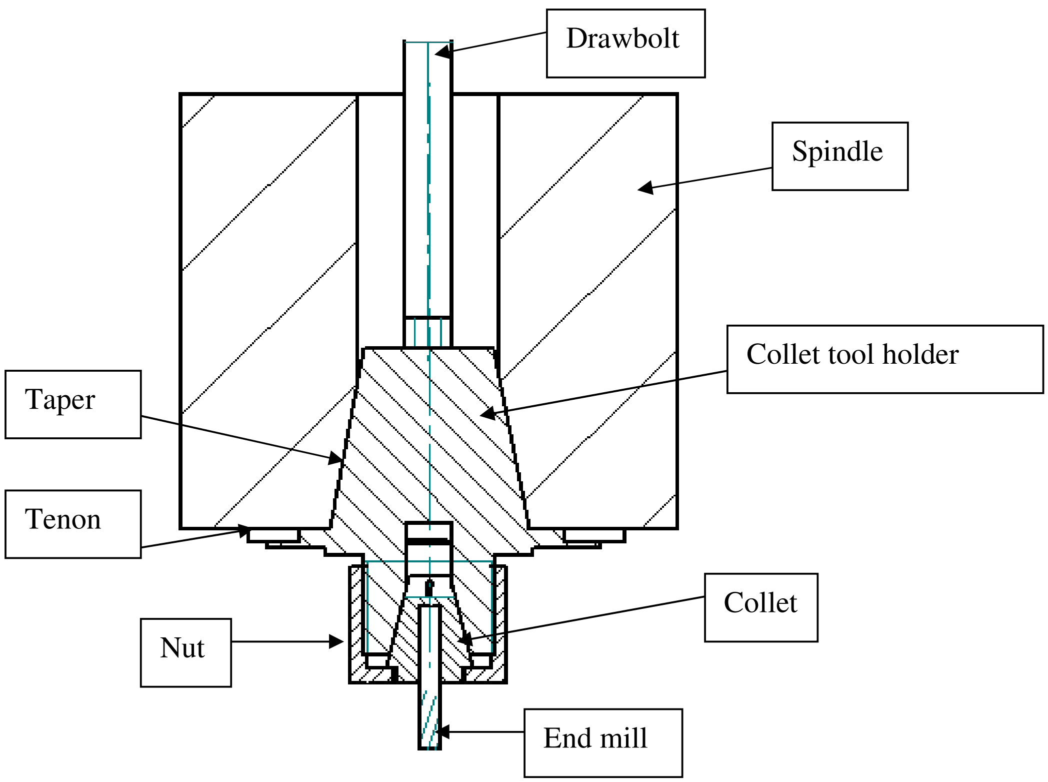
Work holding.

Work holding on this machine is the same as those used on the horizontal milling machine.

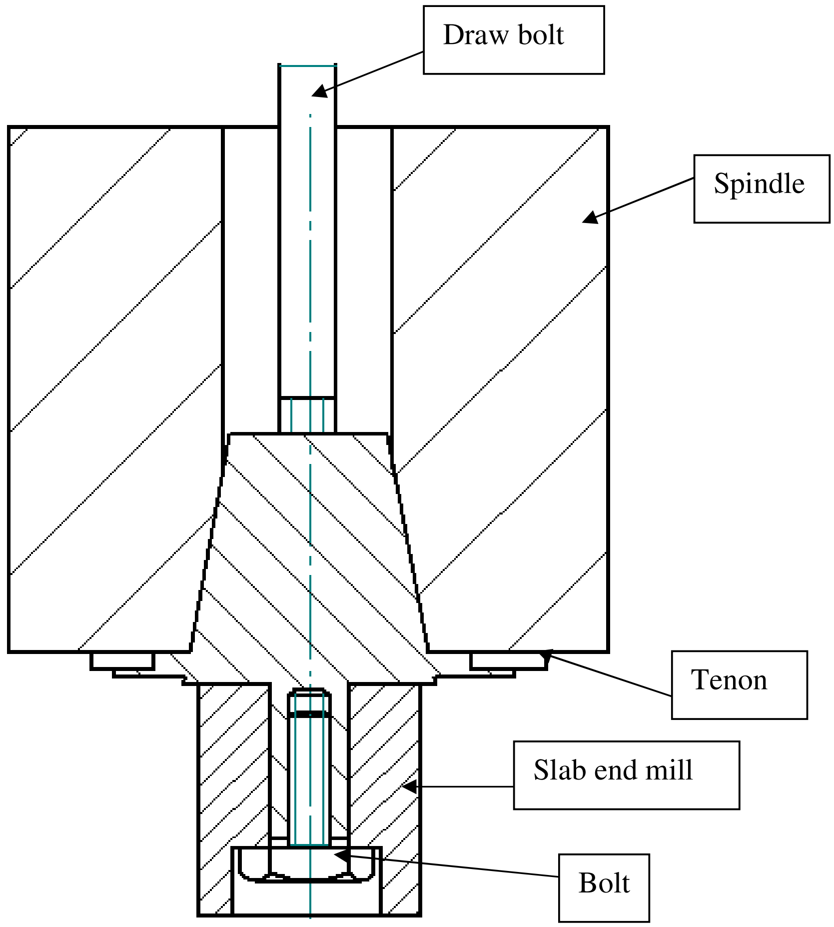
Tool holding.

The spindle nose has the same taper as that found on the horizontal milling machine. This taper takes a tool holder in which the tool can be properly secured. There are three types of tool holder and in all three cases a draw bolt is used to hold the holder in the taper, which aligns the axis of the holder with that of the spindle automatically.

1) Collet holder.

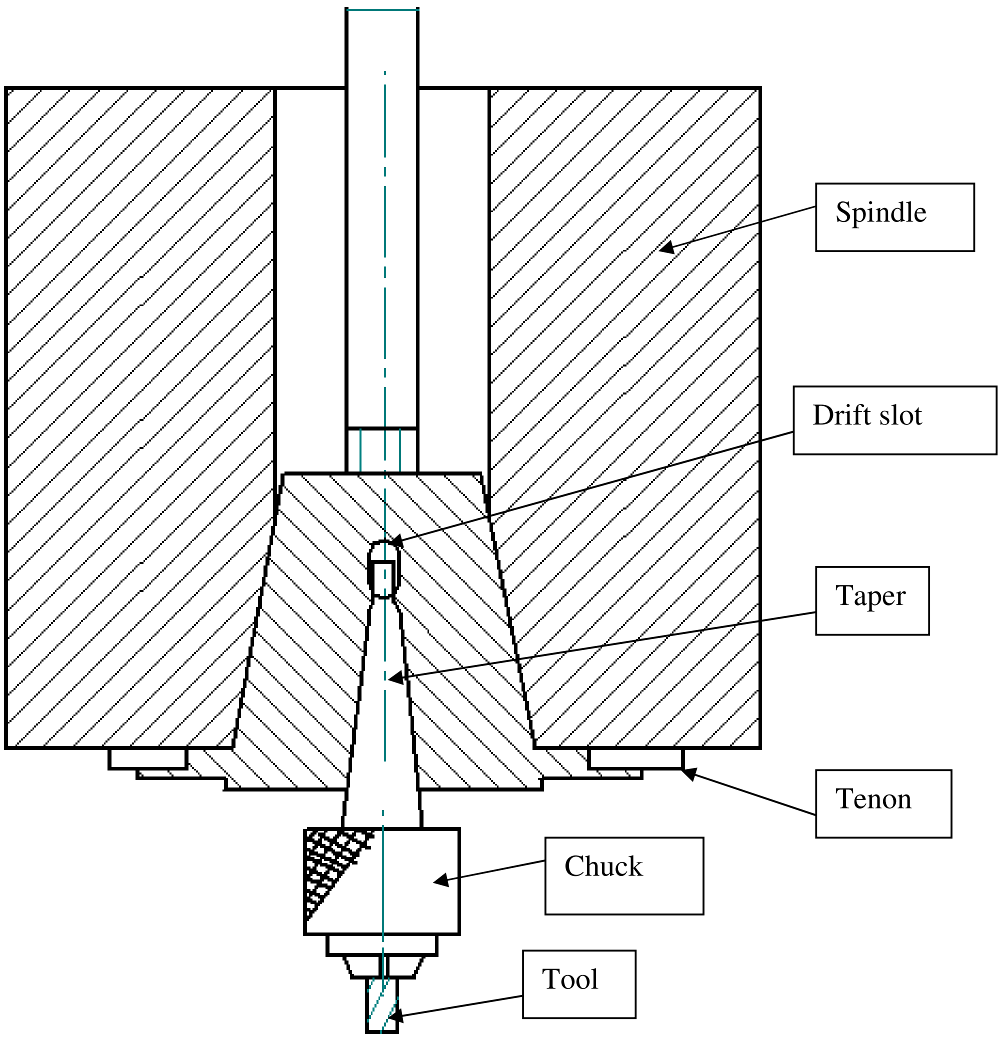


2) Shell End Mill holder.



In both cases, the tool is positively held in the holder and therefore can take both axial and radial loads without coming loose due to vibrations from the cutting forces.

3) Adapter sleeve.



This is a holder, which introduces a standard taper at the spindle nose. The spindle is therefore able to take either a drill directly, or a drill chuck in which a tool is held.

Much as the adapter is positively held in the spindle nose, its taper does not take radial load; therefore, only operations with axial tool load can be carried out using this adapter. Any radial load tends to loosen the tool, affecting the accuracy of surface production.

Operations.

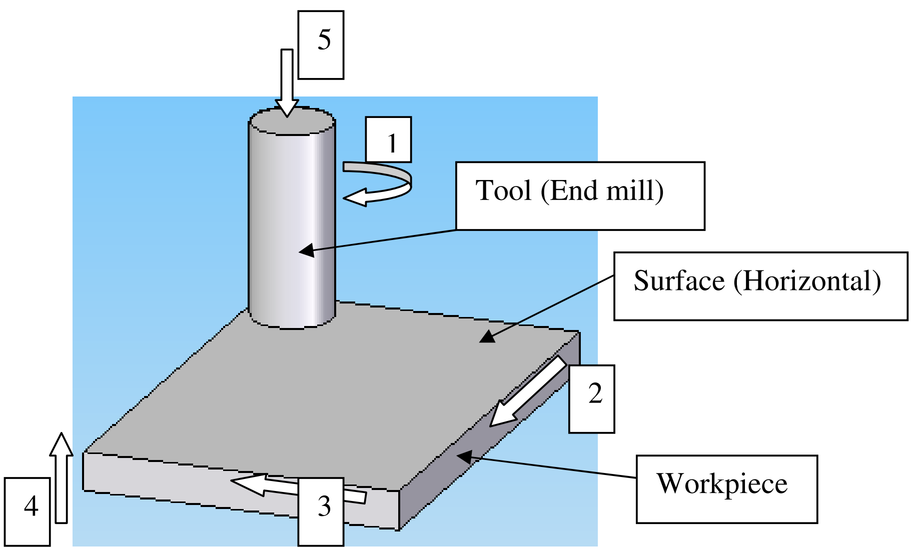
The result of all operations is always a surface of some form produced. This comes about as a generated surface using single point tool or copying the form from the tool onto the work piece.

In both cases it is possible to produce a surface only if at least two motions of the machine are present at the same time. These are active motions, one of which must be spindle rotation, which is the main motion. Another motion, which is very important but does not exist during actual cutting process is the one used to set the cutting depth. This is passive motion. It is the motion used to give the work piece its size.

Milling

The same types of surfaces produced on the horizontal milling machine can also be produced on this machine, either using the end mill or shell end mill.

Flat Horizontal Surface.



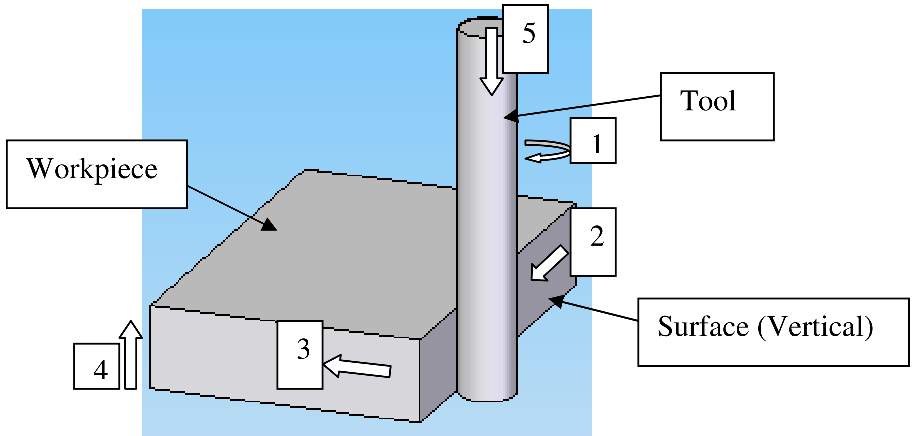
-Motion 1- Active rotary spindle motion. This is the main motion.

-Motion 2- Active cutting feed.

-Motion 3- Passive cutting feed for surface coverage or sizing.

-Motion 4 or 5- Passive cutting feed for setting depth of cut or sizing.

Flat Vertical Surface.



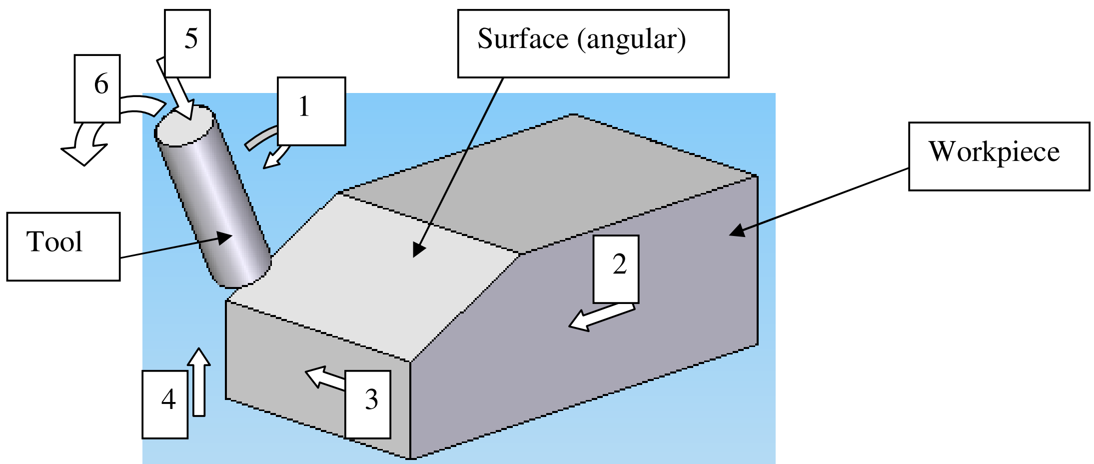
-Motion 1- Active rotary spindle motion. This is the main motion.

-Motion 2- Active cutting feed.

-Motion 3- Passive cutting feed for setting depth of cut or sizing.

-Motion 4 or 5- Passive cutting feed for surface coverage or sizing.

Flat Angular Surface.



-Motion 1- Active rotary spindle motion. This is the main motion.

-Motion 3- Active cutting feed.

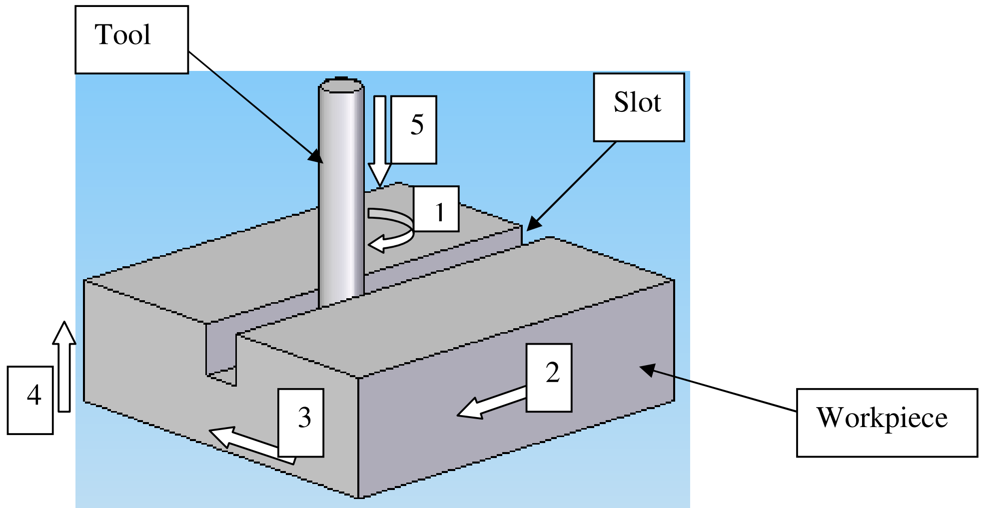
-Motion 4 or 5- Passive cutting feed for setting depth of cut or sizing.

-Motion 2- Passive cutting feed for surface coverage and/or sizing.

-Motion 6- Passive motion for setting the required angle.

This operation is possible only when using the face of the end mill, if the work piece is held in a machine vice. If however other work holding methods are used, then the active and passive motions are decided by the operator, depending on the position and the orientation of the surface on the device used for holding the work piece.

Slotting.



-Motion 1- Active rotary spindle motion. This is the main motion.

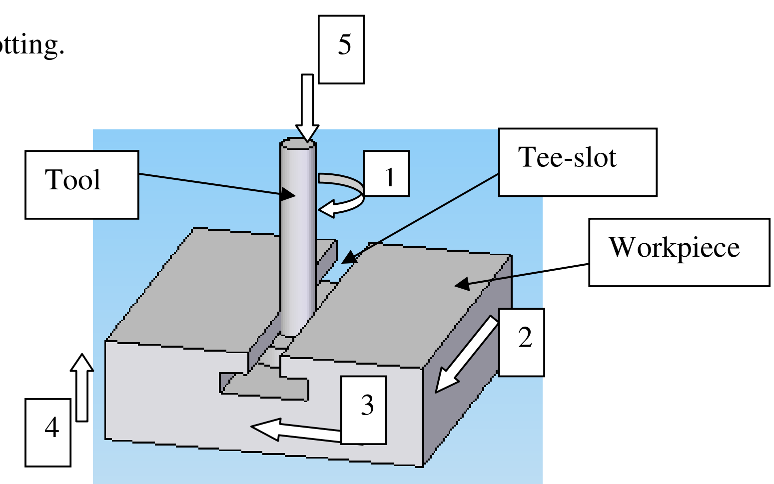
-Motion 2- Active cutting feed.

-Motion 3- Passive cutting feed for slot width or sizing.

-Motion 4 or 5- Passive cutting feed for setting depth of cut or sizing.

This slot is a straight slot. A circular one can be produced using a rotary table. It can also be done round a cylindrical surface using a dividing head.

Tee-slotting.



-Motion 1- Active rotary spindle motion. This is the main motion.

-Motion 2- Active cutting feed.

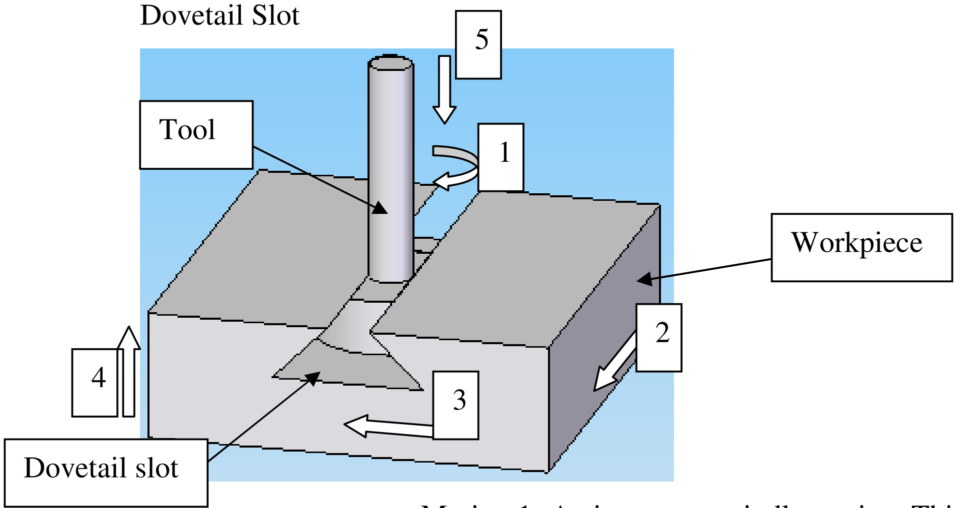
-Motion 3- Passive cutting feed for slot width or sizing.

-Motion 4 or 5- Passive cutting feed for setting depth of cut or sizing.

A slot is first made to accommodate the shank of the tool. The tee is then easily slotted.

This operation produces a tee-slot to accommodate tee-bolts.

Dovetail Slot



-Motion 1- Active rotary spindle motion. This is the main motion.

-Motion 2- Active cutting feed.

-Motion 3- Passive cutting feed for slot width or sizing.

-Motion 4 or 5- Passive cutting feed for setting depth of cut or sizing.

A slot is first made to accommodate the shank of the tool. The dovetail is then easily slotted.

This operation produces dovetail slot for machine slide ways.