1.2 MILLING MACHINE:

Milling is a fabrication process during which a work-piece is moved past a rotating tool. In comparison: during a drilling operation the work-piece is stationary, and the rotating drill bit is moved, vertically, into and out of the work-piece.
The process of milling is capable of producing flat, angled or curved surfaces (or a combination thereof), depending on the type(s) of tool(s) being used and the sophistication and type of the milling machine.

Milling machines are referred to as 3-axis machines when the table can move in the x and y directions and the tool in the z-direction. The most sophisticated milling machines are also capable of rotating the table about the x and z axes, producing a so-called 5-axis milling machine. (See http://www.youtube.com/watch?v=QsmiIeAkE-o for a video demonstration of a 5-axis milling machine).

1.2.1 Components of a milling machine:

The upper part of a milling machine is similar to that of a drill press, but built more solidly (due to much higher cutting forces). The main difference between a drill press and a milling machine lies in the table, which is (normally) fixed for a drill press, but can move in the x and y directions for a milling machine.

The workpiece can be mounted either directly to the table, or to a vise which is mounted to the table.

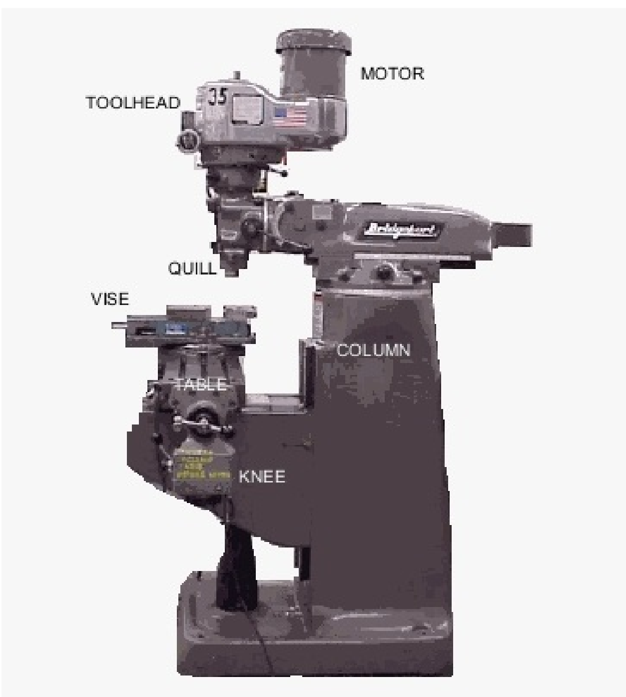


Figure 1.2.1: Vertical Milling Machine

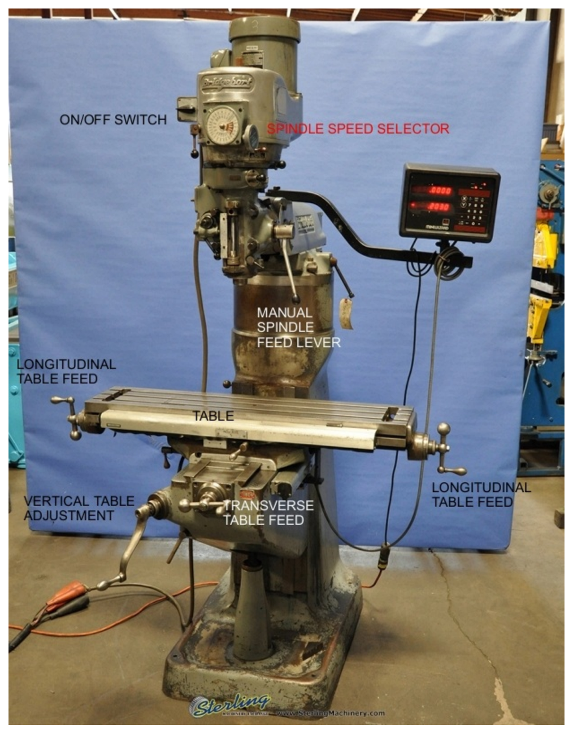


Figure 1.2.2: Vertical Milling Machine

Based on Figures 1.2.1 1 and 1.2.2:

Spindle and quill:	the spindle holds the tool-holding device and rotates inside the quill (which can be moved vertically).
Spindle speed selector:	typically a wheel which allows the proper spindle speed to be selected.
Motor and toolhead:	this part provides the power for the machining operation; it also houses the quill and spindle.
Manual spindle feed lever:	allows for the manual lowering/raising of the spindle; most machines have the option of an automated spindle feed.
Column and knee:	are the vertical and horizontal structural elements of the machine; mounted to them are the toolhead/motor and the table respectively.
Table:	provides a mounting surface for the work-piece or for a vise; it can move longitudinally as well as in the transverse direction (by hand or under power). Knee and table can also be adjusted vertically on some machines.
Draw-in bolt:	sits inside the spindle and extends just beyond the top of the toolhead. It is used to pull (draw) the tool arbour into the spindle and “lock” it in. To change a tool, this bolt has to be “undone”.

1.2.2 Milling tools:

A large variety of tools are available for milling operations; we will only look at the most common ones:

-End mills

Figure 1.2.3: Endmills

End mills have flat, horizontal cutting edges at the bottom and, peripherally, spiral cutting edges as well as grooves (called flutes) for chip removal.
End mills can have 2 to 5 or more flutes. For metal cutting 4 flute cutters are normally used.
End mills produce a cut with a flat bottom; so called “centre-cutting” end mills can be used for plunge cutting (the tool moves vertically into the workpiece to a desired depth). Under “normal” working conditions an end mill is moved in either the x or y direction into the workpiece (peripheral cutting).

-Ball nose end mill:

Figure1. 2.4: Ball Nose Endmill

Ball nose end mills produce a cut with a semi-cylindrical bottom; they can be used successfully when machining advanced, sculpted surfaces.

-Special (form) mills:

Slot cutters are used to produce slots or grooves with special profiles.


Figure1. 2.5: Slot Cutters

-Face mills:

These cutters are used to produce large, flat surfaces or to quickly reduce the thickness of stock material.


Figure 1.2.5: Face Mill

1.2.3 Cutting speeds:

Even more so than with drilling operations, the selection of correct cutting speeds when milling is very important: it can greatly affect the surface finish and the tool life.
As before, cutting speeds depend on the work-piece material (Brinell hardness) and the tool material. Cutting speeds are defined in “surface feet per minute”, the linear velocity of a point on the cutting edge of the tool.

WORK MATERIAL	Bhn	HSS [sfm]	CARBIDE [sfm]
Plain Carbon Steel: AISI 1010 to 1030	up to 150 150 - 200	100 - 140 80 - 120	400 - 900 300 - 700
AISI B1111, AISI B1112, AISI B1113	140 - 180	110 - 200	400 - 1200
Plain Carbon Steel, AISI 1040 to 1095	120 - 180 180 - 220 220 - 300	80 - 120 70 - 110 30 - 80	400 - 800 300 - 500 100 - 300
Alloy Steels with <0.3% Carbon: Aisi 1320, AISI 3120, AISI 4130, AISI 4020, AISI 5020, AISI 4118 etc.	180 - 220 220 - 300 300 - 400	65 - 100 30 - 80 30 - 50	300 - 600 200 - 350 100 - 150
Alloy Steels with >0.3% Carbon: Aisi 1340, AISI 2340, AISI 4140, AISI 4150, AISI 5140, AISI 5150 etc.	180 - 220 220 - 300 300 - 400	65 - 100 30 - 80 20 - 50	275 - 450 180 - 300 80 - 130

Table 1.2.1: Recommended Milling Speeds

Use the same “formula” as before to determine the spindle rpm:

$$\frac{(Cutting\ \ Speed\,[sfm])\,x\,4}{(Tool\ \ Diameter\,[in])} \cong Spindle\ Speed\,[rpm]$$

1.2.4 Feed rates:

This is probably the most critical parameter when milling. It is directly affected by:

-the work piece hardness
-the tool diameter
-the tool material
-the type of tool (end mill, face mill etc.)
-the number of cutting edges (= teeth = flutes)

These feeds are in some publications referred to as chip loads. To find the feed rate in inches per minute the following "formula" has to be used:

$$(Spindle\ RPM)\ x\ (Chip\ Load)\ x\ (\#\ of\ \ Teeth) = Feed\ Rate[in/\min]$$

When working on a mill with manual feed controls, make sure to keep the feed rates on the low side. Note: if feed rates are too low, the tool will dull rapidly. To reduce friction (= heat) and protect the tool (= wear), always use lubricants.

Recommended feeds for HSS tools, in inches per tooth (per revolution of spindle speed):

MATERIAL	Bhn	END MILLS							FACE MILL	FORM MILL
		DEPTH OF CUT = 0.250"			DEPTH OF CUT = 0.050"					
		CUTTER DIAMETER			CUTTER DIAMETER					
		3/8"	3/4"	>1"	1/8"	3/8"	3/4"	>1"		
		FEED PER TOOTH [IN] PER REVOLUTION OF SPINDLE SPEED								
Plain Carbon Steel AISI 1010 to 1030	up to 150 150 - 200	.002 .002	.004 .003	.006 .005	.001 .001	.003 .003	.006 .006	.008 .007	.012 .012	.004 .004
AISI B1111, B1112, B1113	140 - 180	.002	.004	.006	.001	.004	.006	.008	.012	.005
Plain Carbon Steels, AISI 1040 to 1095	120 - 180 180 - 220 220 - 300	.002 .002 .001	.004 .004 .002	.006 .005 .003	.001 .001 .0005	.003 .003 .002	.006 .006 .003	.008 .007 .004	.012 .010 .008	.004 .004 .003
Alloy Steels with <0.3% Carbon	180 - 220 220 - 300 300 - 400	.002 .001 .0005	.004 .002 .002	.005 .003 .002	.001 .0005 .0003	.003 .002 .001	.006 .003 .002	.008 .004 .003	.010 .008 .004	.004 .003 .002
Alloy Steels with >0.3% Carbon	180 - 220 220 - 300 300 - 400	.002 .001 .0005	.004 .002 .001	.005 .003 .002	.001 .0005 .0003	.003 .002 .001	.006 .003 .002	.008 .004 .003	.012 .008 .004	.004 .003 .002
Tool Steel	200 - 250 250 - 300	.002 .001	.004 .003	.005 .004	.001 .0005	.003 .001	.006 .002	.008 .003	.010 .004	.004 .003
Cast Iron	150 - 180 180 - 220 220 - 300	.003 .002 .002	.006 .005 .004	.008 .006 .005	.001 .001 .0005	.004 .003 .003	.007 .006 .005	.009 .007 .006	.014 .012 .006	.005 .004 .003
Zinc Alloys		.004	.008	.012	.002	.005	.008	.012	.020	.005
Brasses, Bronzes	100 - 150 150 - 250	.003 .002	.006 .004	.010 .006	.001 .0005	.004 .003	.008 .005	.010 .008	.014 .010	.004 .003
Cast Aluminum		.003	.008	.010	.002	.003	.010	.012	.020	.005
Wrought Aluminum		.003	.008	.010	.002	.003	.010	.012	.018	.005
Magnesium Alloys		.003	.008	.012	.002	.004	.010	.014	.020	.005
Ferr. Stainl. Steel	135 - 185	.003	.004	.005	.001	.004	.006	.008	.012	.004
Aust. Stainl. Steel	135 - 185 185 - 275	.003 .002	.004 .003	.005 .005	.001 .0005	.004 .003	.006 .004	.008 .006	.012 .010	.004 .004
Mart. Stainl. Steel	135 - 185 185 - 225 225 - 300	.003 .003 .002	.005 .003 .002	.005 .005 .003	.001 .0005 .0005	.004 .004 .003	.006 .005 .003	.008 .006 .004	.012 .010 .008	.004 .004 .003
Plastics		.003	.008	.010	.002	.004	.010	.014	.020	.006

Table 1.2.2: HSS Milling Cutters, Recommended Feed in Inches per Tooth per Revolution of Spindle Speed

Example: *You have decided to use a 4-flute HSS end mill, 0.375" in diameter, to machine a slot 0.200" deep into a piece of plain carbon steel with Bhn = 150. You decide to make the first cut (roughing cut) 0.180" deep and then a finishing cut 0.020" deep. Determine the spindle speed and the feed rate.*

From Table 1.2.1: milling speed for plain carbon steel, Bhn 150

Recommended milling speed is 100 [sfm]

Therefore, with

$$\frac{(Cutting\ \ Speed\,[sfm])\ x\ 4}{(Tool\ \ Diameter\,[in])} \cong Spindle\ Speed\,[rpm]$$

$$\frac{100\,[sfm]\ x\ 4}{0.375''} = 1067\ \ [rpm]$$ *Spindle rpm*

The most likely available spindle speed will be 1000 [rpm]

From Table 1.2.2: feeds for plain carbon steel, Bhn 150

Recommended feed for 0.375" Dia. HSS end mill ,
depth of cut 0.180", is 0.002"

And with

$$(Spindle\ RPM)\ x\ (Chip\ Load)\ x\ (\#\ of\ \ Teeth) = Feed\ Rate\,[in/\min]$$

$$1000\,[rpm]\ x\ 0.002\,[in/tooth/rev]\ x\ 4\ \ [teeth] = 8\,[in/\min]$$

Feed rate for rough cut.

For the finishing cut (depth of cut 0.020") the recommended feed is 0.003", so that the feed rate is

$$1000\ [rpm]\,\mathbf{x}\ \ \mathbf{0.003}\ [in/tooth/rev]\,\mathbf{x\ 4}\ [teeth] = \mathbf{12}\ [\mathbf{in}/\mathbf{min}]$$

Feed rate for finishing cut

1.2.5 Table set-up:

For safety reasons as well as for precise machining performance it is critical that the work-piece is properly fastened to the table.

For smaller work-pieces a machine vise is most commonly used.

Machine vise:

Machine vises consist of one fixed and one moving jaw and a base that is bolted to the mill table. Before being able to use the vise, it must be properly aligned: the jaws must be parallel to the long axis of the table and the plane of the two surfaces on which the moving jaw slides, must be perpendicular to the axis of the quill/spindle. The process is called: tramming the vise.

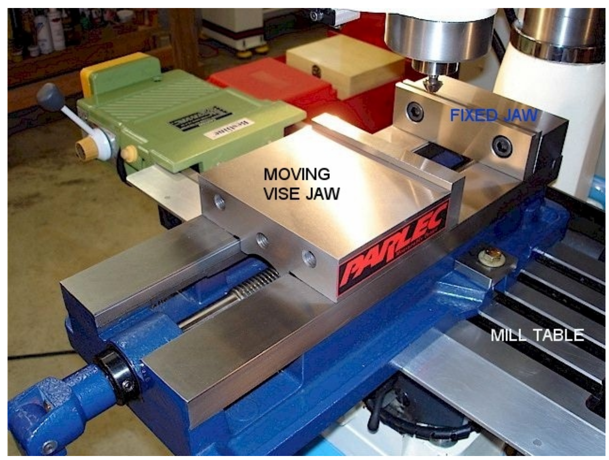
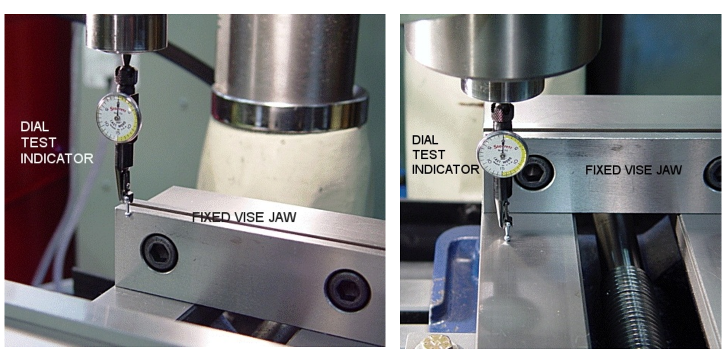


Figure 1.2.6: Machine Vise Mounted on Mill Table

Tramming:



Figures 1.2.7 and 1.2.8: Tramming a Machine Vise

Parallels:

Great care must be taken to not, accidentally, machine into any of the vise surfaces. Whenever a milling operation is required to pierce through the bottom face of the work-piece, the work-piece must be elevated from the vise sliding faces. Parallels (or Parallel Bars) are used for this purpose.

Figure 1.2.9: Parallels

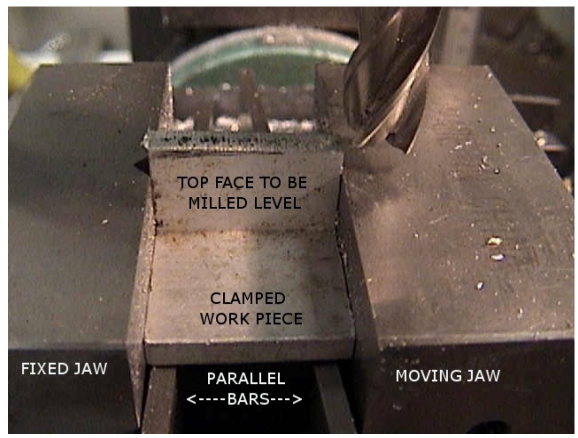


Figure 1.2.10: Parallels in a Vise

Parallels are fabricated in pairs and come in varying lengths, widths and heights. They are considered precision tools and must be treated accordingly.
Parallels are used to elevate the work-piece above the sliding surfaces of the vise.

Shown in Figures 1.2.11 and 1.2.12 are an angle vise and a rotating base for any type of vise.

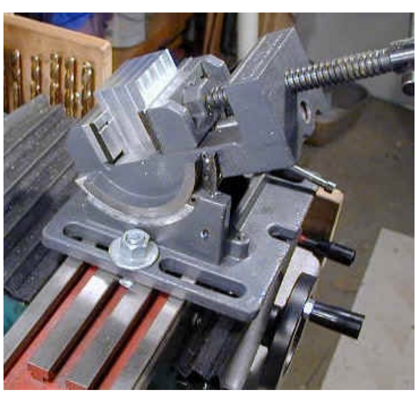


Figure 1.2.11: Angle Vise

Figure 1.2.12: Angle Vise on Rotating Base

Step blocks:

They are used to clamp work-pieces which are too big for a vise or have awkward shapes for clamping in a vise. They make use of the T-slots in the table of the milling machine (and are therefore also referred to as T-slot clamps). As Figure 1.2.13 shows, they consists of a step block, a T-slot nut, a machine screw with washer and a clamping bar.

Figure 1.2.13: Step Block Clamping Components

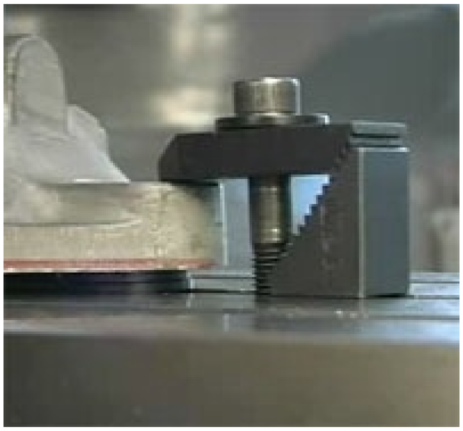


Figure 1.2.14: Step Block Clamp

Figures 1.2.14, 1.2.15 and 1.2.16 show the assembled clamp(s) holding down a work-piece.

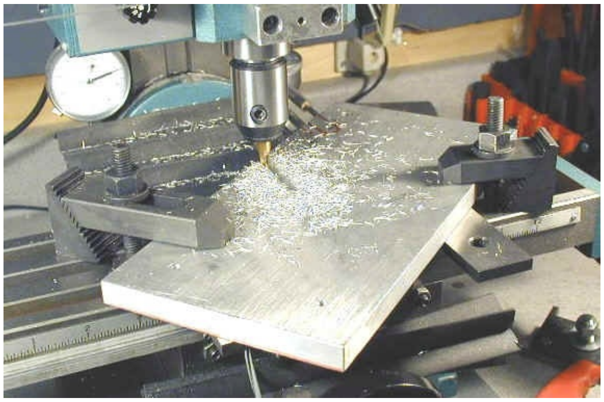


Figure 1.2.15: Step Block Clamps and Parallel Bars

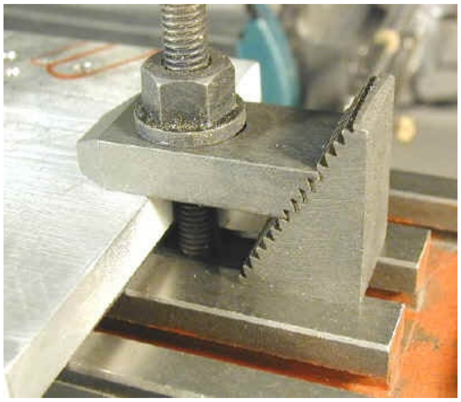


Figure 1.2.16: Step Block Clamp

For proper functioning of the clamps, the screws must be placed close to the work-piece and the clamping bars must be parallel to the surface of the work-piece.

In Figures 1.2.15 and 1.2.16 a T-slot screw and a nut are used instead of the T-slot nut and the machine screw.

V-blocks:

V-blocks are essential when setting up round-bar stock or cylindrical work-pieces.

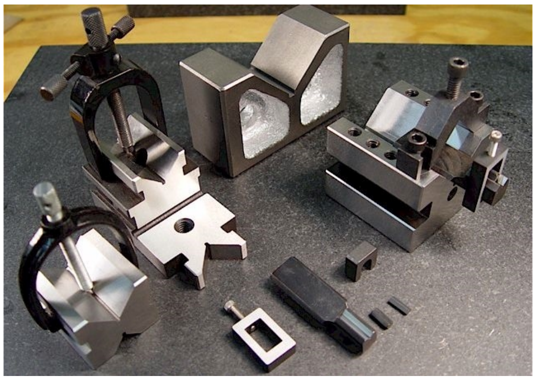


Figure 1.2.17: Various V-Blocks and Clamps


Figure 1.2.18: V-Blocks, Parallels and Vise

Angle plates:

Angle plates are used to provide a vertical reference or mounting surface on the horizontal table.

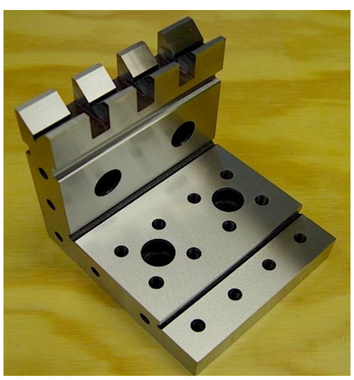


Figure 1.2.19: Angle Plate

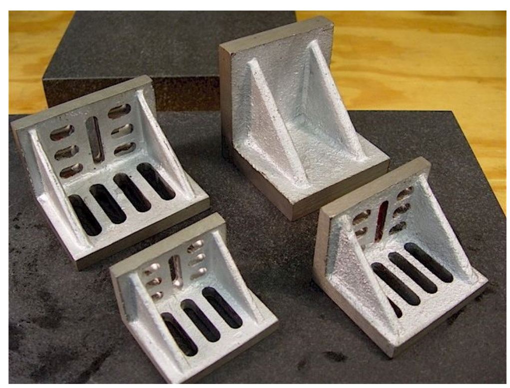


Figure 1.2.20: Angle Plates

For more complex set-ups, other specialty type of tools are available.