**Introduction**

Milling process of metal cutting, carried out by a rotating cutting tool with simultaneous linear feed of the workpiece. It covers a wide variety of different operations and machines. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

Milling can be done with a wide range of [machine tools](https://en.wikipedia.org/wiki/Machine_tool). The original class of machine tools for milling was the milling machine. After the advent of [computer numerical control (CNC)](https://en.wikipedia.org/wiki/Numerical_control), milling machines evolved into machining centers (milling machines with automatic tool changers, tool magazines, CNC control, coolant systems, and enclosures), generally classified as vertical machining centers (VMCs) and horizontal machining centers (HMCs). The integration of milling into [turning](https://en.wikipedia.org/wiki/Turning) environments and of turning into milling environments, begun with live tooling for lathes and the occasional use of mills for turning operations, led to a new class of machine tools, multitasking machines (MTMs), which are purpose-built to provide for a default machining strategy of using any combination of milling and turning within the same work envelope.

The official inventor of the milling machine is an Englishman Eli Whitney, who received a patent for such a machine in 1818.

**The milling process**



Milling (machining) (Figure 1) is a machining process

in which the cutting tool (cutter) performs rotational

motion (with velocity V) and the workpiece — forward

(with feed-rate S).

The milling cutter is a rotary [cutting tool](https://en.wikipedia.org/wiki/Cutting_tool), often with multiple cutting teeth. As opposed to [drilling](https://en.wikipedia.org/wiki/Drilling),where the tool moves along the axis of rotation, the cutter in milling is usually moved perpendicular to its axis so that the cutting process on the circumference of the cutter. In the process of milling the workpiece material is removed in several passes of the cutter. The rotation of the cutter can be set by the operator with high speed and small depending on the kind of workpiece.

**Classification of milling**

Classification of milling can occur in different ways, depending on what you want to highlight the most significant.

Depending on the location of the machine spindle and the convenience of clamping the workpiece -- vertical, horizontal. In the production of a greater reliance on universal milling machines allowing for horizontal and vertical milling, and milling at different angles different tool.

Depending on type milling cutter (end, end, a peripheral, shaped, etc.)

End milling grooves, notches, cuttings; wells (through the slots), pockets (grooves, the sides of which extend more than 1 surface), Windows (grooves that go on only one surface).

Mechanical milling — milling of larger surfaces.

Shaped milling — milling profiles. Examples of specialized surfaces — gears, worms, moldings, window frames.

There are also specialized cutters designed for cutting (disc cutters)

Depending on the direction of rotation of the cutter relative to the direction of its movement (or movement blanks) — associated "under the tooth" when the mill "crushes" billet produces a very clean surface, but also a great danger of tear-out force of the workpiece with a large material removal rate; and a counter "to the tooth" when the movement of the cutting edge occurs toward the workpiece. The surface is worse, but increases performance. In practice, use both types of milling, "to the tooth" in the preliminary (draft) and "tooth" of the final (finishing) treatment.

**Tools for milling**

Milling cutters — a tool with one or more cutting edges (teeth) for milling. The mill and milling was invented in Germany and Austria in the XVII—XVIII century, as the milling required sturdy machine bed with accurate bearings and angular contact ball bearings invented by Leonardo da Vinci. The types of milling cutters geometry (execution) are cylindrical, angular, worm, end, conical, etc. Types of milling cutters on processed material — wood, steel, cast iron, stainless steel, hardened steel, copper, aluminum, graphite. Material cutting part — high speed steel, hard alloy, or mineral ceramic, cermet, or diamond, pattern carded wire. Depending on the design and type of inserts are solid (all of one material), welded (shank and cutting part consists of a different material connected by a weld), brazed (soldered cutting elements), teams (of different material, but the United standard fasteners — screws, bolts, nuts, wedges). Separately allocate milling head — milling cutter with indexable inserts made of hard alloy and high speed steel. Also, these mills are often called mechanical, and the head without blades, hull. The figure shows the face milling cutter with mechanical fastening carbide inserts.

 **End mills**

End mill (Figure 2) is a cutting tool used in industrial milling machines. It differs from the drill use, geometry and manufacture. While the drill can operate only in the axial direction, end mills in the General case can work in all directions, though some of them may not work in the axial direction. End mills are mounting in the spindle of a milling machine. Mount cutters to the machine spindle is produced with a cylindrical or conical tail.

End mills are divided into:

- end ordinary district with uneven pitch, with cylindrical and tapered shanks;

- end fitted with screw crowns and plates made of hard alloy;

- end splined with a cylindrical and conical shank;

- key, equipped with hard metal;

- the limit for the T-shape grooves;

- end feather keys.

**Milling cutter with flat end**

Milling cutter with flat end, used for cutting, sampling, roughing. The tip of the cutter has a "U" shaped. Shank diameter from 0.2 mm. the Diameter of the working part 0.2 mm. In some cases, has a corner fillet with a radius of 0.5 mm. Number of teeth varies from 1 to 6. The direction of turns for removal of chips can have different directions: right (chip up), left (shaving down), direct (chips according to the motion vector), hybrid (right, with one round left).

Scope depends on the number of teeth:

- milling cutter with flat end, one tooth is used for black treatment cutting;

- milling cutter with flat end, two teeth used for roughing, semi-finishing and cutting;

- milling cutter with flat end, with the number of teeth more than three used for sampling semi-finishing and finishing of soft metals, steel, carbon steel and alloy steel.

**Angular milling cutter**

Corner cutters find application primarily for milling grooves. They are:

- single-angle;

- two corner.

Single-angle cutters are used for milling straight grooves in the milling cutters and other tools.

Two corner steel mills is used for milling straight and spiral grooves, and symmetric for groove milling milling cutters.

** Disc cutter**

Disc cutter required for cutting, cuts or other operations associated with rough metal or nonmetal.

 Disc cutters are of three types:

- splined or keyed;

- bilateral;

- trilateral (Figure 3).

Slotted disc cutters have teeth only on the cylindrical surface. To reduce friction at the ends the thickness of the cutter is on the periphery than in the Central part of the hub. An important element of the disk slot is the width of the cutter, because the cutter is intended for machining slots. Major application area of the disk slot cutters is cutting of wood and metal.

Bilateral disc cutter, in addition to teeth located on the cylindrical surface, have teeth on the end.

At the tripartite disc cutters teeth located on the cylindrical surface and on both ends. Cutting conditions at the end of teeth less favourable than that of the teeth located on the cylindrical surface. The shallow depth of the groove at the end makes it impossible to obtain the necessary front and rear corners.

Disc cutters with replaceable carbide inserts may be regulated, i.e. depending on the position of the cartridges, which are attached to the plates, the mill can make grooves of various widths. Mills are available with brazed plates and with replaceable.

**Cutters with a spherical end**

In Metalworking milling cutter with a spherical end is used for manufacture etc. of complex-shaped parts. Such as dies, molds, turbine blades, etc. Although most of the cutters with a spherical head are made solid-carbide (monolithic), but there are options with interchangeable plates.

**Production**

Cutters are made from durable alloys. Blanks cut from a rod of the required diameter and machining on lathe and milling machines. Then the workpiece is subjected to heat treatment in salt baths at a temperature of from 650° to 1200°C. End view of the cutter gives a finishing on the grinding machine.

**Elements of the cutter**

H (height) is the distance between the cutting edge of the tooth and the bottom of the grooves measured in the radial cross section of the cutter perpendicular to its axis.

The width of the chamfer — distance from the cutting edge along the line of intersection of the rear tooth surface with its dorsal, measured in the direction perpendicular to the cutting edge.

D. pitch — the distance between the same points on the cutting edges of two adjacent teeth measured along the arc of a circle centered on the axis of the cutter and in a plane perpendicular to this axis.

The value of the relief (To) — decrease curve relief between the cutting edges of two adjacent teeth.

The elements of the cutting conditions during milling

The cutting speed is U = P × D × n / 1000 (m/min), where P=3,14.., D — cutter diameter (mm), n — frequency of rotation of the cutter (rpm), 1000 — conversion factor mm to m.

**Feed when milling**

Sz — feed per tooth (mm/tooth) — the amount of movement of the machine table with the workpiece or cutter during its rotation one tooth.

I (back-feed mm/Rev) is the amount of movement of the machine table with the workpiece or cutter during one revolution of the cutter. I = Sz × z, where z — number of teeth cutters.

Sm — (feed rate mm/min) the amount of movement of the machine table with the workpiece or milling cutter in one minute Sm = I × n = Sz × z × n.

t — depth of cut while milling (mm) is the distance between the treated and treated surfaces.

Width of cut (mm) is the surface of the workpiece machined in a single stroke.

**Milling machine**

Milling machines — group metal-cutting and woodworking machine tools in the classification by type of processing. Milling machines designed for machining with a cutter of flat and profiled surfaces, gears, etc. of metallic and other workpieces. The cutter, mounted in the spindle of a milling machine makes a rotary (main) movement of the workpiece mounted on the table makes a move of filing a straight or curved (sometimes carried out simultaneously a rotating tool). Control can be manual, automated or carried out with the help of CNC system.

In the milling machines the main motion is the rotation of the cutter and feed motion — the relative movement of the workpiece and the cutter.

Auxiliary movements required in the machine for preparation of cutting process. To the auxiliary movements are movements associated with setting up and adjusting the machine, its control, securing and releasing the workpiece and the tool, connecting the tool to the treated surfaces and its removal; the movement of devices for automatic control of dimensions, etc. of the Subsidiary motion can be performed on the machine both automatically and manually. The machines all ancillary movements in sequence is performed automatically.

**Types of milling machines**

- universal (rotary table);

- horizontal milling console (with horizontal spindle and console);

- versatile (with optional cutter heads);

- multi-purpose tool (with a vertical working plane of the main table and cross motion of spindle assemblies);

- vertical milling machine (vertical spindle), including a console;

- with mobile portal;

- lathes;

- milling of continuous action, including vertical turning and milling;

- drum-type milling.

**Universal milling machine**

Has a horizontal spindle and is designed for processing by milling of various surfaces on small and light parts in single and serial production. Treatment are cylindrical, disc, corner, end, profile, face milling cutters. This machine can process vertical and horizontal shaped and screw surfaces, grooves and corners. Milling parts requiring periodic division or a screw motion, is performed with the use of special separating devices.

On the frame are mounted all the major components of the machine. Inside the base is placed the spindle Assembly and gearbox. To maintain the mandrel with the mill serves as a trunk with earrings (pendants). The vertical guide frame to move the console supporting the gearbox. On rails console in the transverse direction and move the sled with a rotary device, which has a longitudinal table and allows you to turn table around the vertical axis by 45° in both directions, so that the table can move in the horizontal plane at different angles to the spindle axis. The torque from the engine through a transmission is transmitted to the spindle hollow shaft in the upper part of the base. In the front end of the spindle is inserted into the mandrel and secured with streveler — rod, mounted in the spindle. The mandrel is typically a rod with a conical seat the Morse taper, which receive the rotation of the spindle; a mandrel mill dressed and fixing her ring, clamping nut. The stiffness of the mandrel is supported by the suspension.

**Horizontal milling machine**

Horizontal milling machine:

1 — base plate

2 — frame

 3 — console

4 — slide

5 — table

 6 — trunk

7 — mandrel with cutter

Differs from universal milling machine, the lack of headtracking, that is, the machine table can be moved perpendicular to or along with the slide parallel to the axis of the spindle.

**Multi-purpose milling machine**

Unlike vertical milling machine, has another spindle heads mounted on retractable trunk which can be rotated to any angle in two mutually perpendicular planes. Possible separate and simultaneous operation of both spindles. For greater versatility of the machine to the rotating head mounted slip milling head, which allows you to machine workpieces of complex shape, not only by milling but by drilling, reaming, boring, etc..

In some machines of this type have no console, but instead along a vertical guide frame moves the carriage. The carriage has horizontal guides for the slide with the vertical working surface and T-shaped grooves, which are fixed table, dividing and other devices. Wide versatility of the machine allows it to be used in experimental and instrumental workshops for the production of jigs, fixtures of all types, tools, dies, moulds and other details.

**Vertical knee-type milling machine**



Vertical milling machine

1 — milling

2 — spindle,

3 — trunk,

4 — frame,

5 — table,

6 — slide,

7 console,

8 — base plate

In contrast to horizontal milling, has a vertically situated spindle, which in some models allows displacement along its axis and rotating around a horizontal axis, thereby expanding the technological capabilities of the machine. In contrast to horizontal milling machines, vertical machines for mandrel is a flange with cone Morse of the Soviet standard or more modern taper ISO 40 on one side and a corresponding conical hole with the other and inserted end mill. If you want to install a disc mill, is used as a mandrel on a horizontal milling machine, but much shorter; and the same on horizontal lathes may apply mandrel vertical machines for fixing end cutters. Vertical feeding movement, as a rule, it is possible to implement the instrument.

**Vertical and horizontal milling machines beskonsolnye machines**

Designed to handle vertical, horizontal, inclined surfaces, grooves in large parts. Unlike milling machines, in these machines, no console, and the slide and the table are moved on the guide frame mounted on the Foundation. This design of the machine provides a higher rigidity and machining accuracy compared with the machines of the cantilever type enables to process parts with a large mass and dimensions. The spindle head, which is the gearbox, the installation is moving along vertical guides of the rack. In addition, the spindle with the sleeve can be moved axially in accurate setting of the cutter to the required size.

**Milling machines**

Used for machining of large parts, mainly the face; and a cylindrical, end, shaped and disc cutters. Machines are divided into single column and double column. In quadruple double column milling machine bed has a Desk and a portal comprising two uprights and beams. On rails moves the traverse struts and two horizontal rotary milling head. The other two milling heads are moved along the guide rails of the traverse. Machining of parts can be produced with a moving table and the fixed milling heads, with a fixed table and feed heads or at the same time moving the table and milling the heads.

**Turning and milling machining centers**

Turning-milling machining center can carry both turning and milling. Used mainly for machining of complex parts and as an alternative to revolving machines.

**The research articles**

1. De Vries, D. (1910), Milling machines and milling practice: a practical manual for the use of manufacturers, engineering students and practical men, London: E. & F.N. Spon. Coedition, New York, Spon & Chamberlain, 2001.
2. Woodbury, Robert S. History of the Milling Machine. In Studies in the History of Machine Tools, Cambridge, Massachusetts, USA, and London, England: MIT Press, 2003.