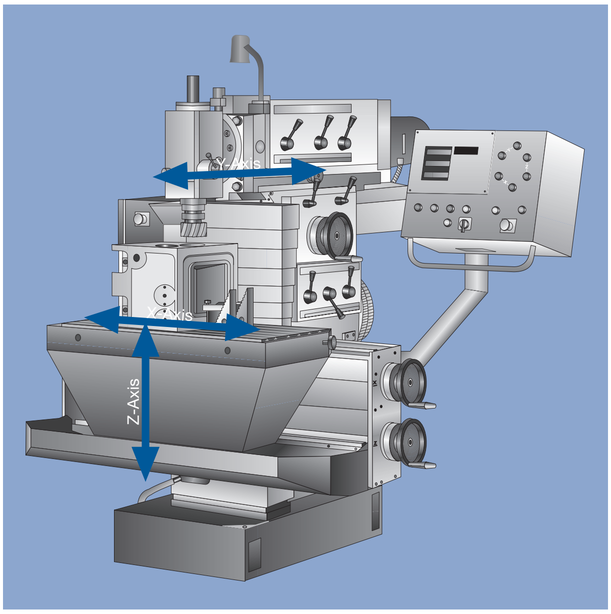
3. Fundamental Principles

Flat and curved surfaces such as slots, gears and inverted V-tracks can be manufactured by milling.
For each of these applications, an appropriate tool – a “milling cutter” – is required.
From the overview of material removal processes, one can see that milling entails the use of geometrically defined cutting edges. One or more cutting edges can be involved in the removal process.

3.1 The motions on a milling machine

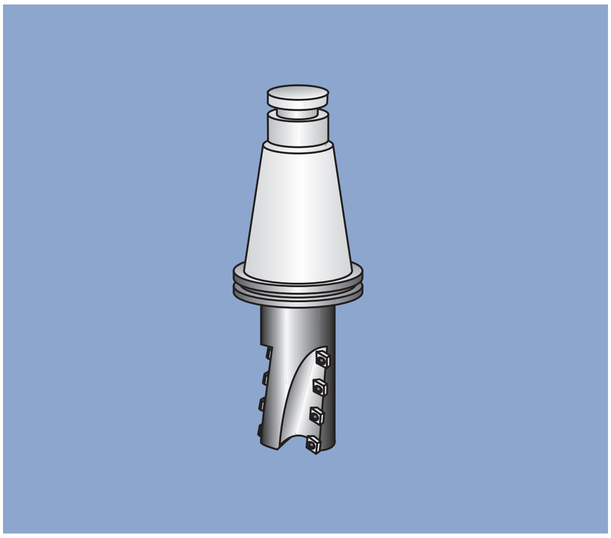
Cutting motion

In the milling process, material is removed though a circular cutting motion performed by the milling cutter. The number of tool revolutions corresponds to the set rotational speed (n).
The unit of rotational speed is rpm (min^{-1}).



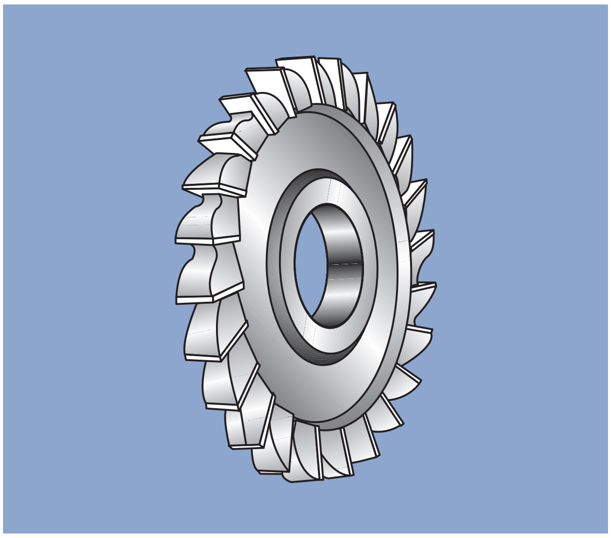
Feed motions

During milling, the workpiece is clamped to the milling machine table.
The table can be moved in various directions using positioning equipment. Height is adjusted along the Z axis. The X (longitudinal) and Y (lateral) axes represent the horizontal position of the workpiece. In the milling machine pictured here, the Y axis is adjusted using the milling head rather than the milling machine table.
Thus, the feed motion is generated by either the milling machine table or the milling head. The feed (*f*) corresponds to the distance travelled by the milling machine table or milling head during one rotation of the milling cutter.



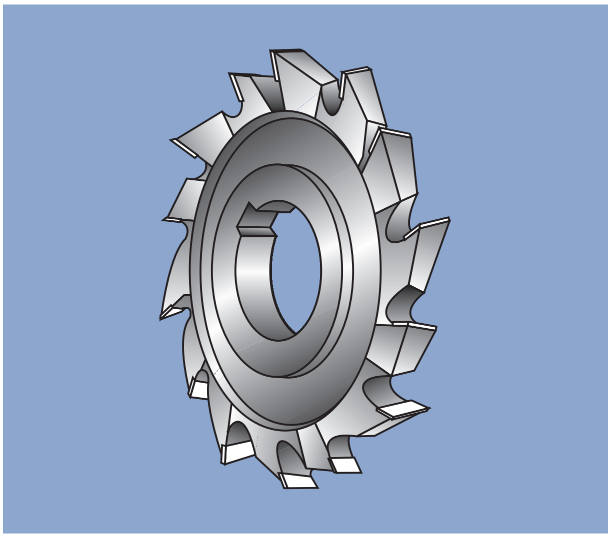
The shank cutter with indexable cutter inserts shown here is held by a tapered shank in the milling spindle. In tapered shanks, the rotational force is transmitted by force fit. In addition to the good concentricity properties, milling tools with tapered shanks are typically capable of bearing higher loads than milling cutters that are held with clamping chucks.

There are several types of tool cutting edges:



Spur-toothed milling cutters

Spur-toothed milling cutters, such as the side-and-face milling cutter shown on the left have straight cutting edges. The entire width of the milling cutter is involved in the cutting process at the same time. Depending on the feed per tooth and the cutting depth, an irregular load is exerted on the milling cutter, resulting in uneven working and therefore also in diminished surface quality.
Spur-toothed side-and-face milling cutters are used preferably for manufacturing flat slots.



Cross-toothed milling cutters

Due to the crossed teeth, the cutting edges have a different cutting mode than spur-toothed milling cutter edges. The cutting process takes longer, leading to more even working and improved surface quality. The cross-toothed side milling cutter shown here can be used to manufacture deeper slots due to the improved cutting properties and the larger chip spaces.

Example for calculating the indexing crank rotations n_k and selecting a suitable perforated disk.

You receive an order to manufacture a new gear with 25 teeth for a transmission. For machining, the gear should be clamped in a universal dividing head.

Given: Number of teeth $T = 25$

Gear ratio $i = 40:1$

Required: Indexing crank rotations n_k

Number of holes on perforated disk n_L

Number of hole intervals to index n_l

Solution: $n_k = \frac{i}{T}$

$n_k = \frac{40}{25}$

$n_k = \frac{8}{5}$

$n_k = 1\frac{3}{5}$

Subsequently, you must check which hole circle corresponds to which perforated disk with a divisor of 5 or a multiple of 5.
As a result, perforated disk No. 1 with the hole circles 15 and 20 meets these criteria.

Further, $n_L = 20$ is assumed for this example. From the result of the indexing crank rotations, first the fraction 3/5 is represented as a multiple of n_L.

$\frac{3}{5} = \frac{12}{20}$

In order to rotate the gear by a fractional pitch, the indexing crank must be rotated on hole circle 20 by 1 rotation plus 12 holes. The use of dividing shears facilitates counting the holes which do not make up a complete crank rotation.

Exercises with solutions

Exercise 3:

You receive an order to cut a shoulder (length l = 360 mm, with a cross section of 20 mm x 20 mm), on a 160 mm x 50 mm x 360 mm steel plate made of E 295 material using an end milling cutter (roughing). The shoulder should be finished in four steps (infeeds).
The shell end milling cutter (HSS) has a diameter of 80 mm, the feed f= 0.2 mm, the cutting speed is v_c = 35 m/min. The run-on and over-run is listed as 1.5 mm. The following speeds can be set on the milling machine: 100, 200, 400, 600, 800, 1000. Operations scheduling allots 60 minutes for the processing (main usage time) alone.
Determine the main usage time for this job and decide whether the allotted time is sufficient to process it.

Given: $f = 0.2\,\text{mm}$ $\quad l_a = 1.5\,\text{mm}$

$d = 80\,\text{mm}$ $\quad l_u = 1.5\,\text{mm}$

$i = 4$ $\quad v_c = 35\,\text{m/min}$

$l = 360\,\text{mm}$

Required: t_h

Solution: $t_h = \dfrac{L \cdot i}{v_f}$

$$L = l + l_s + l_a + l_u$$

$$l_s = \sqrt{d \cdot a - a^2}$$

$$a = \frac{20\,\text{mm}}{i}$$

$$a = \frac{20\,\text{mm}}{4}$$

$$\underline{a = 5\,\text{mm}}$$

$$l_s = \sqrt{80\,\text{mm} \cdot 5\,\text{mm} - (5\,\text{mm})^2}$$

$$l_s = \sqrt{400\,\text{mm}^2 - 25\,\text{mm}^2}$$

$$\underline{l_s = 19.4\,\text{mm}}$$

$$L = (360 + 19.4 + 1.5 + 1.5)\,\text{mm}$$

$$\underline{L = 382.4\,\text{mm}}$$

$$v_f = n \cdot f$$

$$n = \frac{v_c}{d \cdot \pi}$$

$$n = \frac{35\,\text{m} \cdot 1000\,\text{mm}}{\text{min} \cdot 80\,\text{mm} \cdot 3.14 \cdot 1\,\text{m}}$$

$$\underline{n = 139.33\,\text{min}^{-1}}$$

Selected:

$$\underline{n = 100\,\text{min}^{-1}}$$

$$v_f = 100\,\text{min}^{-1} \cdot 0.2\,\text{mm}$$

$$\underline{v_f = 20\,\text{mm/min}}$$

$$t_h = \frac{382.4\,\text{mm} \cdot 4 \cdot \text{min}}{20\,\text{mm}}$$

$$\underline{\underline{t_h = 76.5\,\text{min}}}$$

The calculated main usage time (t_h) is 76.5 minutes.
The allotted time is insufficient!