18. Climb Milling and Conventional Milling (2h)

(Theory: 2h)

18.1 Peripheral milling

18.1.1 Introduction

Peripheral milling is performed when the rotating axis of the cutter is parallel to the machining surface, whether it is vertical or horizontal. The feed direction can be either **discordant (up or conventional milling)** or **concordant (down or climb milling)** with respect to the cutting speed vector of the mill, as shown in the following figure. The feed direction is chosen by the operator according to the information shown in the following paragraphs. The cross section of the chip has an increasing profile in peripheral conventional milling and a decreasing profile in peripheral climb milling.

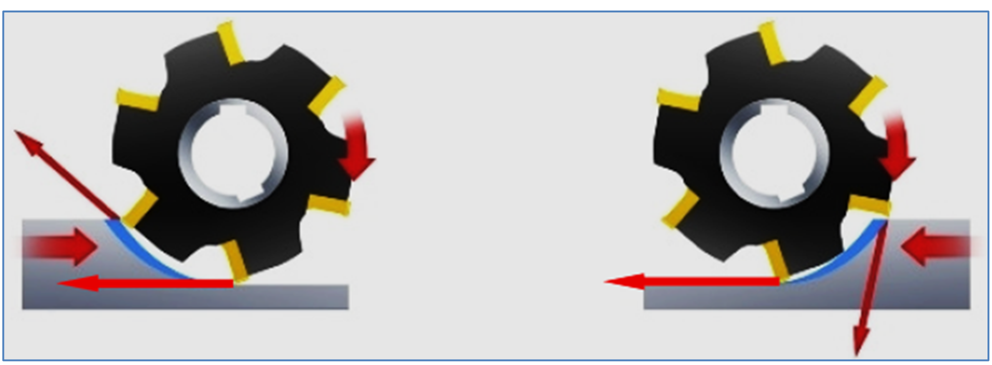

Fig. 153. Discordant cutting direction (left) and concordant cutting direction (right)

18.1.2 Chip section area

The longitudinal section (with respect to the rotating axis) of the chip has the shape of a rectangle both in conventional and in climb milling.

Referring to the following figure, one side of the rectangle is constant and equal to 'b', while the other is variable and equivalent to the thickness 's'. The feed per tooth is indicated with 'a_z'.

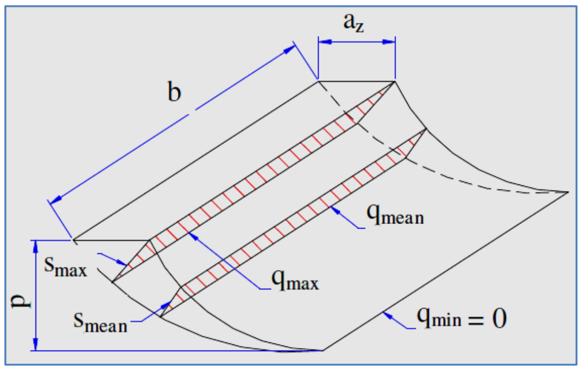

Fig. 154. Chip section area

The maximum thickness 'S_{max} ' is calculated with the formula:

$$s_{MAX} \cong 2 \cdot a_z \cdot \sqrt{\frac{p}{D}} \quad (mm) \quad \text{con} \begin{cases} p = & \text{cutting depth} \\ D = & \text{cutter diameter} \end{cases}$$

The maximum area 'q_{max}' is equivalent to:

$$q_{MAX} = b \cdot s_{MAX} \cong b \cdot 2 \cdot a_z \cdot \sqrt{\frac{p}{D}} \quad (mm^2)$$

18.1.3 Conventional milling: cutter and workpiece movement

The feed direction is discordant with respect to the cutting speed vector of the mill.

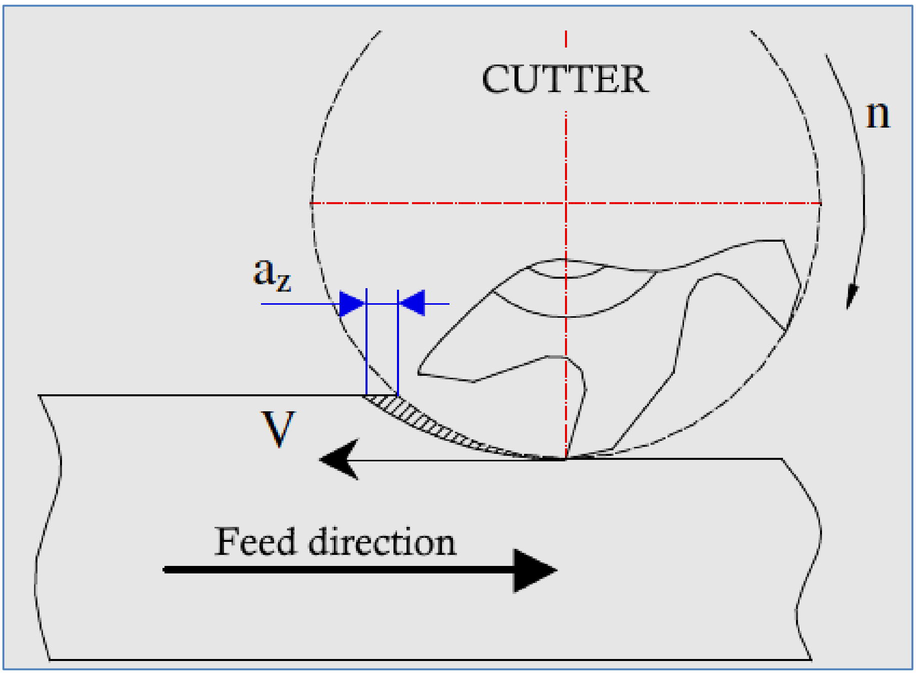

Fig. 155. Relative movement between cutter and workpiece with discordant feed direction

The cross-section (with respect to the rotating axis) of the chip has an increasing profile, varies from zero at the start point of stock removal and ends with a width equal to the feed per tooth 'a_z' at the end point of stock removal. During machining, the cutting edge scrapes against the material; the friction absorbs power and heats up the material causing it to harden. Conventional milling usually results in a poor finish and accelerates the wear of the cutting edges.

18.1.4 Conventional milling: cutting force distribution

The cutting force 'F_t' is tangent to the trajectory performed by the cutting edge of the tooth moving over a cycloid arc. By dividing this force at the point of maximum stress into two vectors, it can be seen that the component of the cutting force parallel to the 'F_o' table goes in the opposite direction with respect to the feed direction; this allows to maintain the contact between the thread flanks in the kinematic mechanism of screw and nut of the axis that makes the table move, neutralizing possible backlashes in the coupling. The component of the cutting force orthogonal to the 'F_v' table tends to lift the workpiece, which must therefore be firmly fixed to the table.

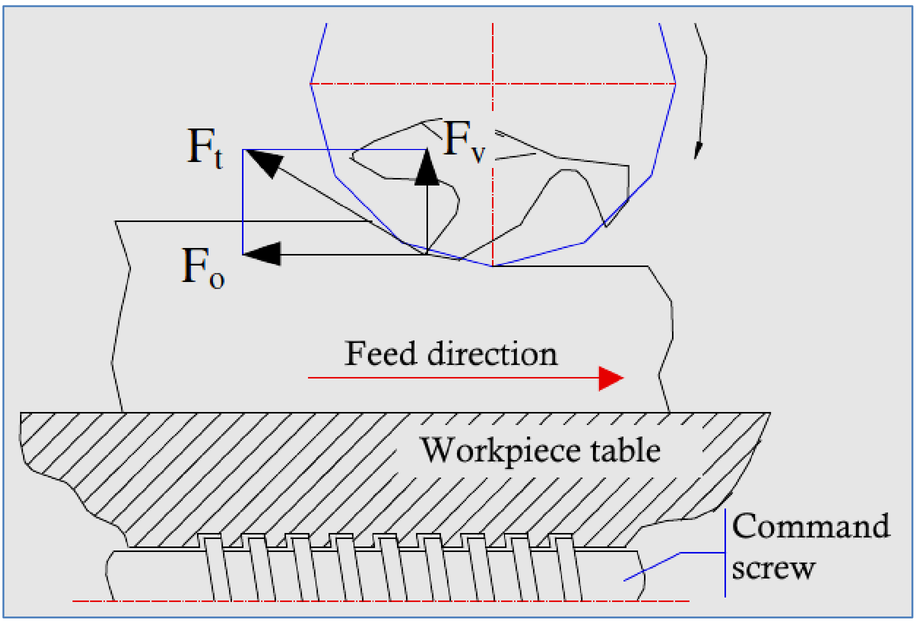

Fig. 156. Cutting forces with discordant feed direction

18.1.5 Climb milling: cutter and workpiece movement

The feed direction is concordant with respect to the cutting speed vector of the mill.

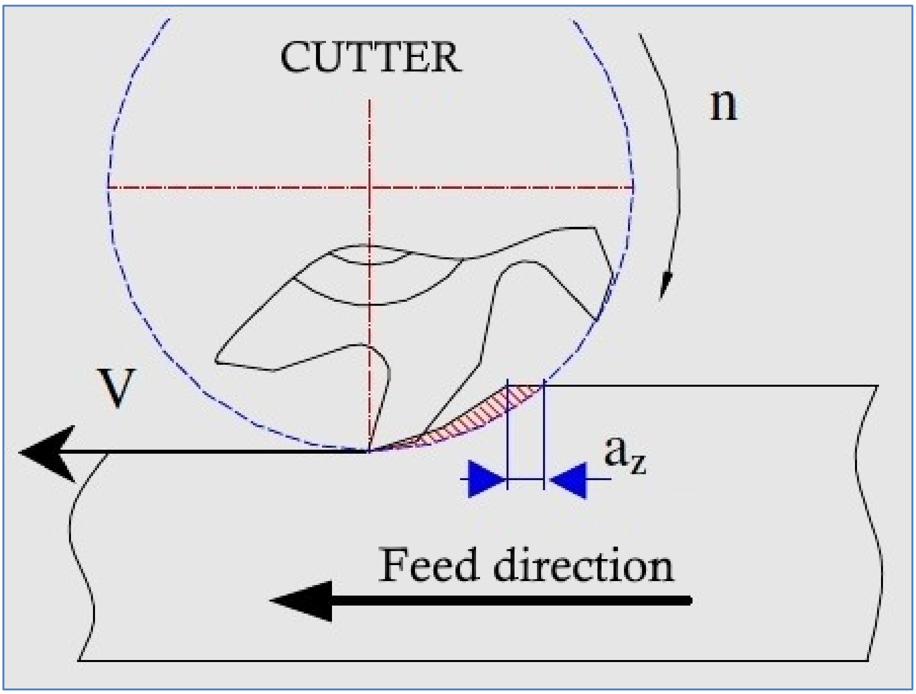

Fig. 157. Relative movement between cutter and workpiece with concordant feed direction

The cross-section (with respect to the rotating axis) of the chip has a decreasing profile, its width at the start point of stock removal is equal to the feed per tooth 'a_z' and it finishes with zero thickness at the end point of stock removal. The produced heat is absorbed mostly by the chip, preventing the material from heating up. Climb milling also facilitates the chip removal.

18.1.6 Climb milling: cutting force distribution

As in the previous case, the cutting force 'Ft' is tangent to the trajectory performed by the cutting edge of the tooth. By dividing this force at the point of maximum stress into two vectors, it can be seen that the component of the cutting force parallel to the table 'F_o' table goes in the same direction with respect to the feed direction; this can cause the screw thread flanks to detach from the nut if the coupling has play. The component of the cutting force orthogonal to the table 'F_v' table tends to compress the workpiece thereby facilitating the fastening system.

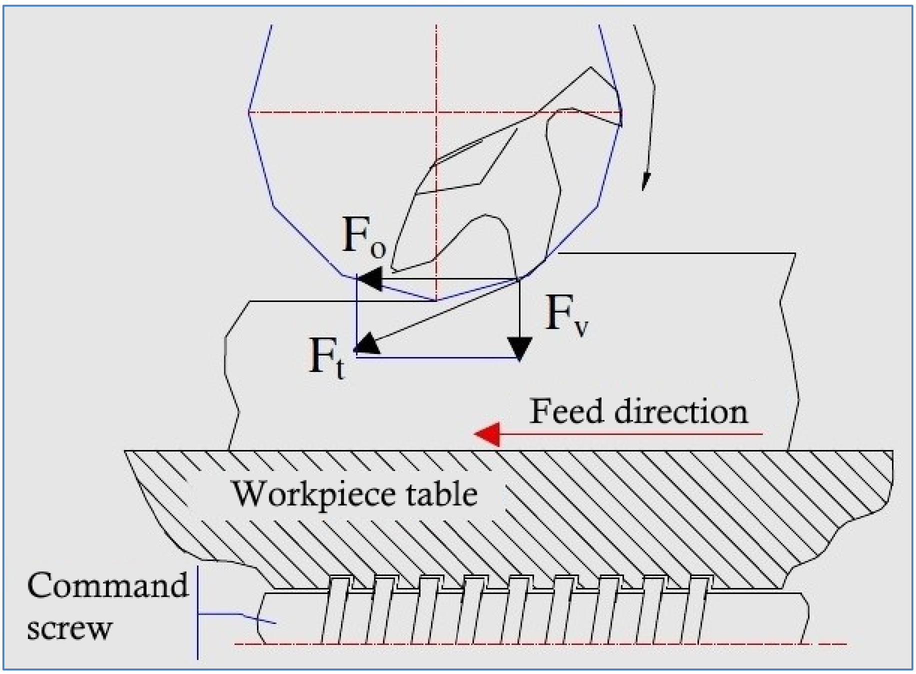

Fig. 158. Cutting forces with concordant feed direction

18.1.7 Conclusions

It can therefore be said that climb milling, as long as it is performed on milling machines with transmission systems with automatic backlash recovery, is preferable to conventional milling because of the lower wear of the cutting edges, the greater stability of the workpiece and the absence of tooth flank sliding on the machined surface. Milling with peripheral cutting, both conventional and climb milling, is characterized by a periodic variation of the chip thickness and consequently of the cutting force; this always causes vibrations that must be taken into account when choosing the cutting parameters.

18.2 Face milling

18.2.1 Introduction

Face milling is performed when the rotating axis of the cutter is perpendicular to the surface to be machined. Several teeth are engaged simultaneously during machining. The chip section between the entry point 'A' and the exit point 'C' has small variations in thickness.

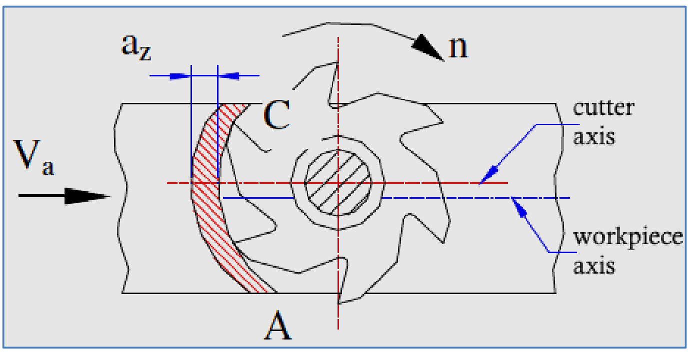

Fig. 159. Cutting forces with concordant feed direction

18.2.2 Chip section area

The chip section is rectangular in shape with sides equal to the pass depth 'p' and the feed per tooth 'a_z'. The section area, which remains almost constant, is calculated using the following formula.

$$q = a_z \text{ x } p$$

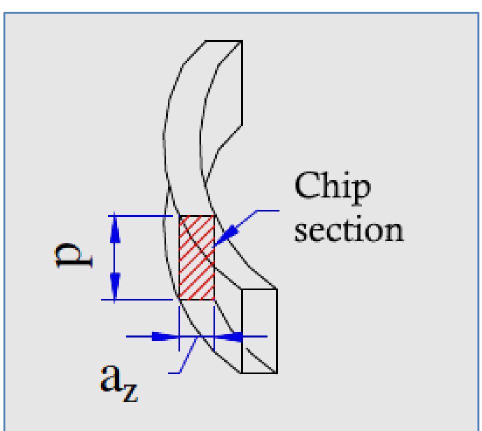

Fig. 160. Cutting forces with concordant feed direction

18.2.3 Climb and conventional face milling

The cutting edge, when working in the arc between points 'A' and 'B', works in concordance; at the same time the cutting edge working in the arc between points 'B' and 'C' works in discordance. When there is play in the coupling between the screw and the nut of the axis, it is possible to avoid the detachment of the thread flanks by decentralizing the position of the cutter by a quantity 's' with respect to the symmetry axis of the pass so that the entry arc 'AB' is greater than the exit arc 'BC'. The value can be calculated according to the following formula.

$$s = (0,05\ /\ 0,1)\ {*}D$$

Tool manufacturers also recommend that a face cutter should not be used for more than 2/3 of its diameter.

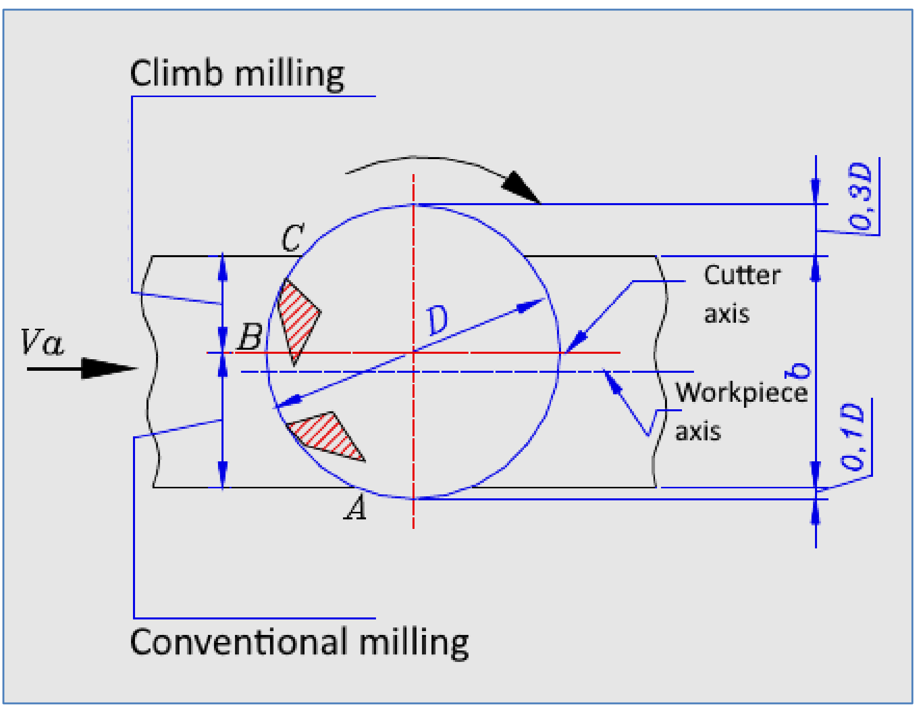

Fig. 161. Conventional and climb face milling

18.3 Comparison of different types of milling

18.3.1 Peripheral conventional milling

In peripheral conventional milling, the cutting edge slides over the material for a short distance before the chip creation begins. The friction generated causes the cutting edge to heat up and its service life is thereby reduced.
The increasing variation in chip thickness ends with an abrupt detachment of the cutting edge from the material causing vibrations that negatively affect the quality of the surface finish.
The direction of the cutting force tends to lift the workpiece from the fastening system.
It should be considered, however, that conventional milling is the only method that can be used in machines with clearance between the screw and nut of the axis on which the machining is performed.

18.3.2 Peripheral climb milling

In peripheral climb milling, the cutting edge begins to cut decisively, immediately encountering a quantity of material to be removed equivalent to the set feed rate.
It generates less vibration, allowing a good surface finish to be achieved.
Most of the heat developed during machining is transmitted to the chip, thereby increasing the service life of the cutting edge.
Under the same cutting conditions, the power required to perform the machining is lower than for conventional milling.
The direction of the cutting force tends to fasten the workpiece to the table.
The only negative aspect of climb milling is that it cannot be used on machines that have clearance in the coupling between the screw and the nut, as this would cause the screw to decouple, increasing the chip thickness by the same amount as the clearance.

18.3.3 Face milling

In this type of milling operation, there are no problems with the selection of the feed direction as long as the cutter works in a way that its axis is properly positioned with respect to the symmetry axis of the pass.
The chip thickness is more constant compared to peripheral milling and the greater number of teeth significantly reduces vibrations, which makes

the machining more uniform and increases the quality of the surface finish.
It is possible to work with higher chip thicknesses because the cutter is usually mounted on a short shaft which reduces tool deflection and allows carbide inserts to be mounted to increase cutting speed.