The Selection of Manufacturing Engineering Processes

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CHAPTER SIX

MILLING OPERATIONS

CONTENTS

6.1 Milling operation

- Milling is a machining operation in which a workpiece is fed past a rotating cylindrical tool with multiple cutting edges.
- This cutting tool in milling is known as the milling cutter and the machine tool that traditionally performs the operation is called a milling machine.
- Milling is an *interrupted cutting operation*, the teeth of the milling cutter enter and exit the work during each revolution.

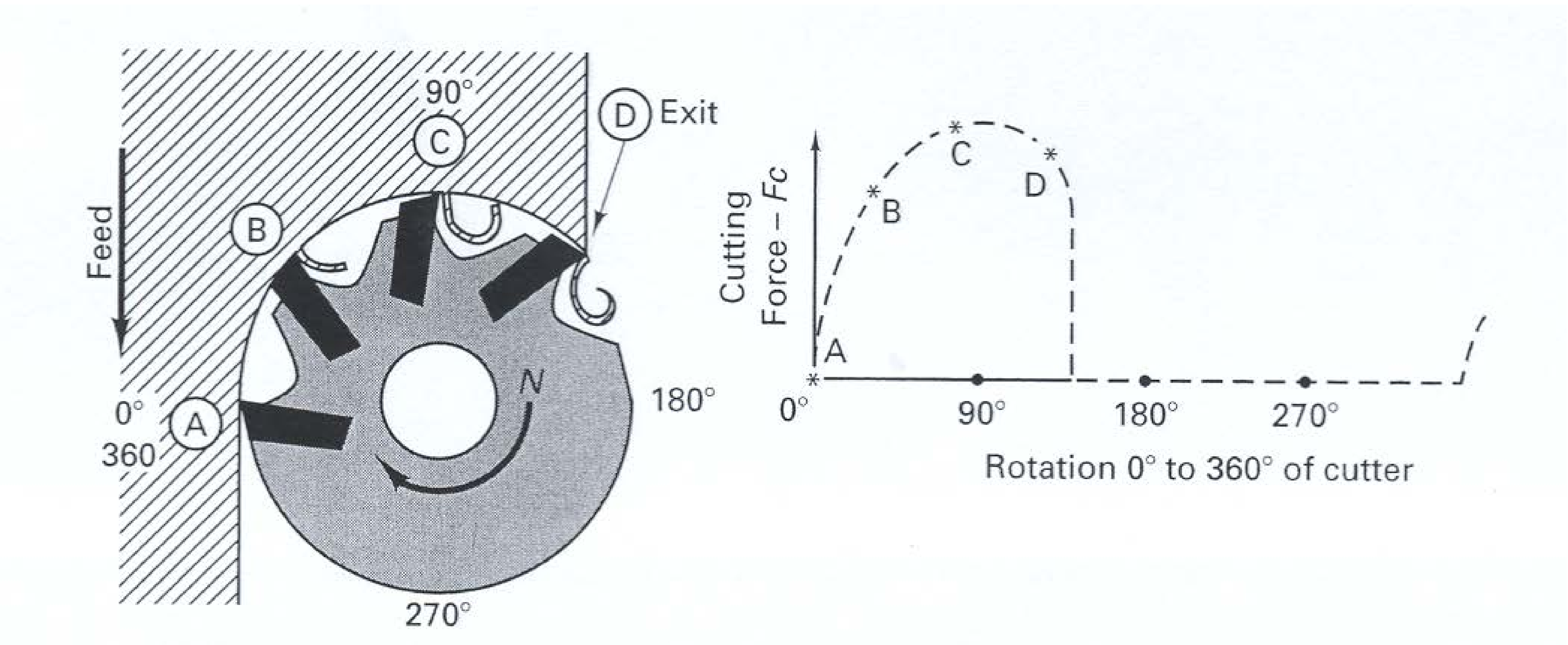


Figure 6.1: Conventional face milling with cutting force diagram for Fc, showing the interrupted nature of the milling process.

6.2 Types of milling operations

There are two basic types of milling operations: slab/peripheral milling and face milling.

6.2.1 Peripheral or slab milling:

In this milling operation the axis of tool is parallel to the surface being machined. In this operation there are two opposite directions of rotation that the cutter can have with respect to the work.

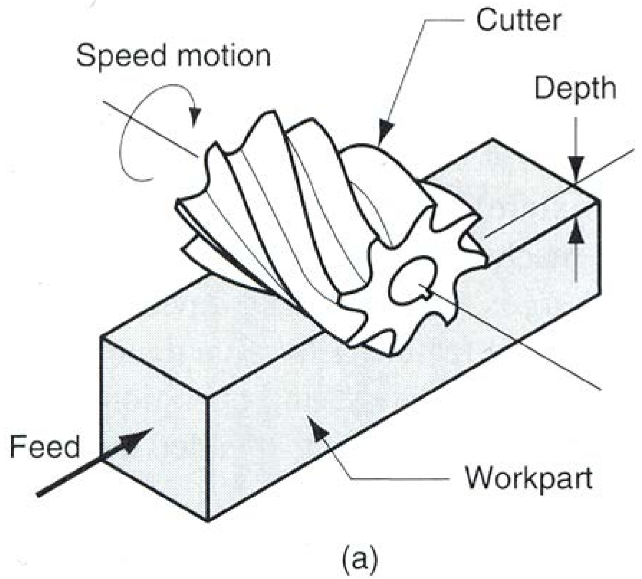


Figure 6.2: Peripheral milling operation.

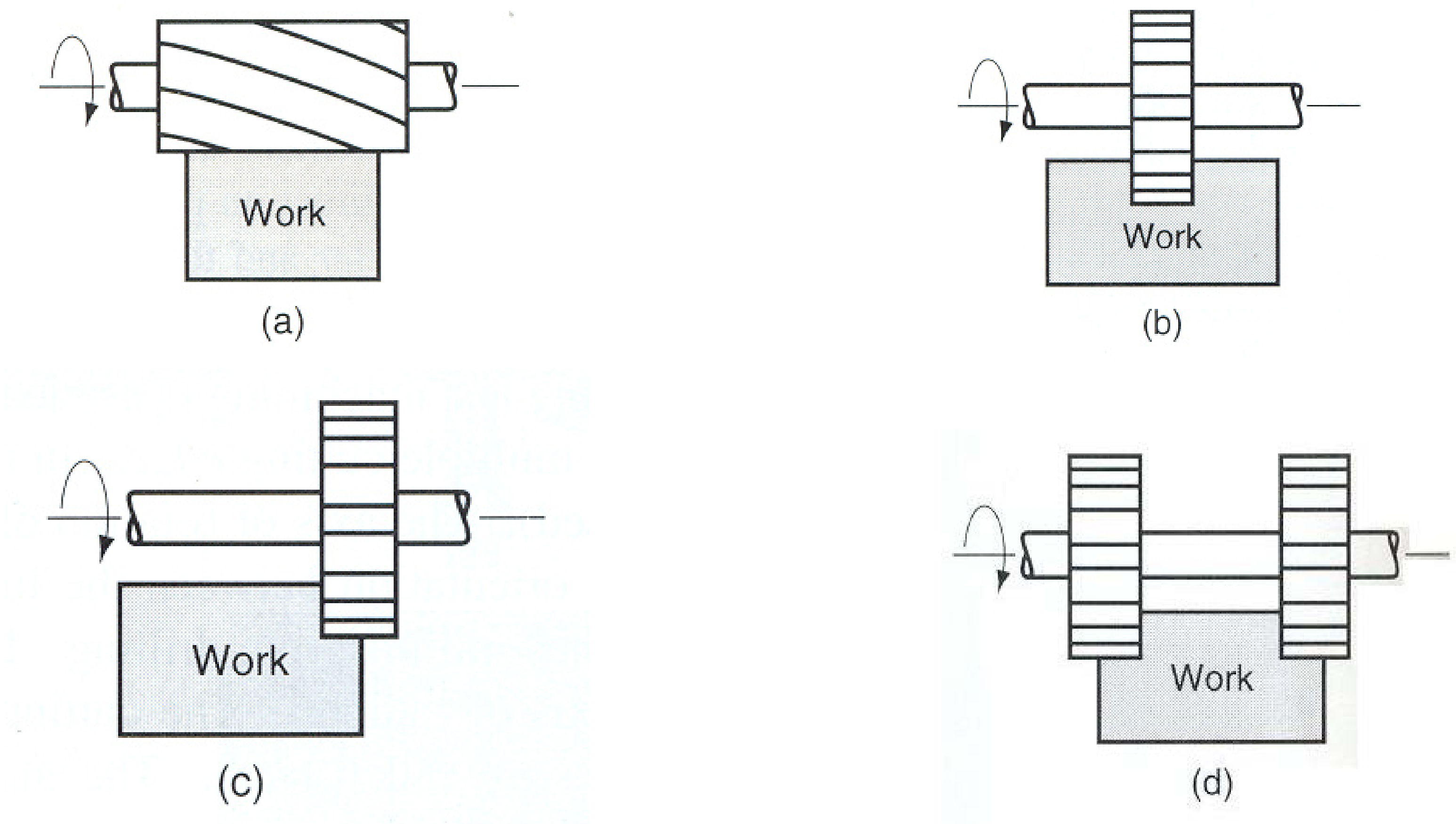


Figure 6.3: Peripheral milling operations: (a) slab milling, (b) slotting, (c) side milling, and (d) straddle milling.

6.2.1.1 Up milling: In up milling the direction of motion of the cutter teeth is opposite to the feed direction. In this type of milling operation, the chip formed by each cutter tooth starts out very thin and increases in thickness during the sweep of the cutter. The chip length is longer than in down milling.

The cutter tends to push the work along and lift it upward from the table, therefore greater clamping force must be employed. In up milling, chips can be carried into the newly machined surface, causing the surface finish to be poorer..

6.2.1.2 Down milling: In down milling, the direction of motion of the cutter teeth is same as the feed direction. In this operation each chip starts out thick and reduces in thickness throughout the cut.

The length of the chip in down milling is less than in up milling. This tends to increase tool life. The cutter force direction is downwards, tending to hold the work against the work table.

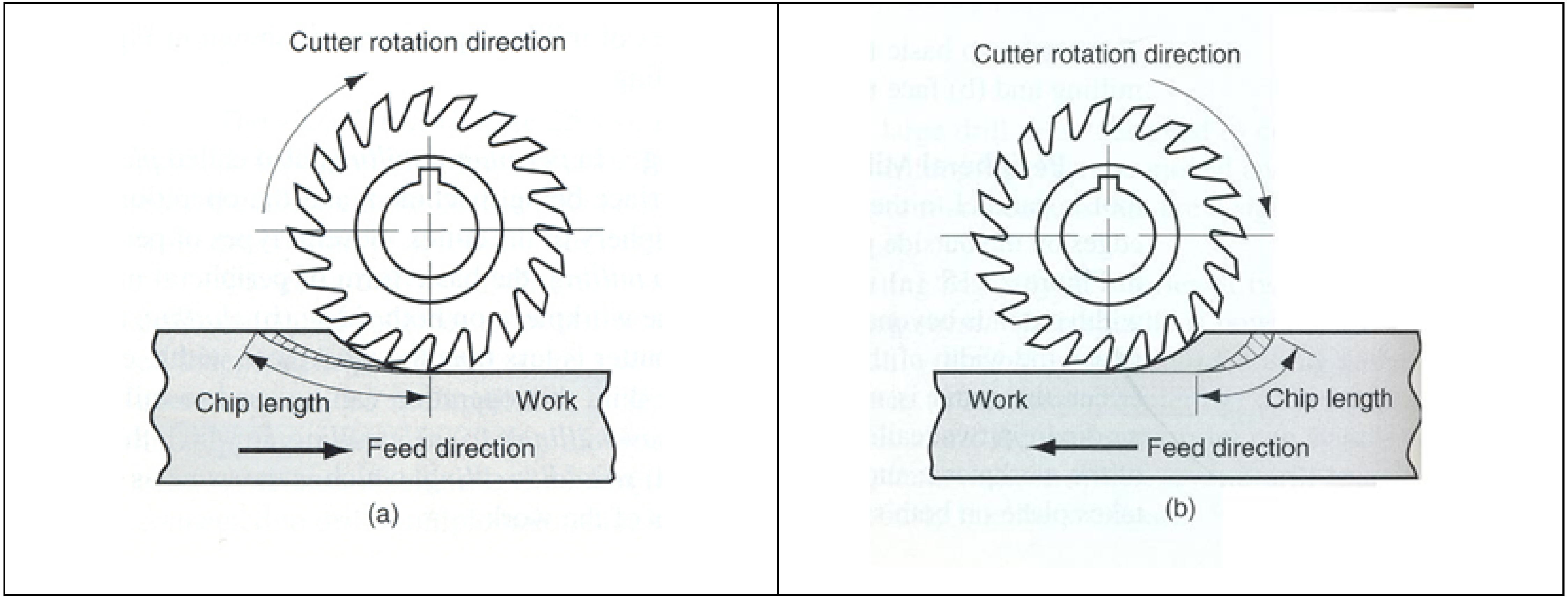


Figure 6.4: Two forms of milling with a 20-tooth cutter: (a) up milling and (b) down milling.

6.3 Face milling

In face milling the axis of the cutter is perpendicular to the surface being milled, as shown in the figure 6.5.

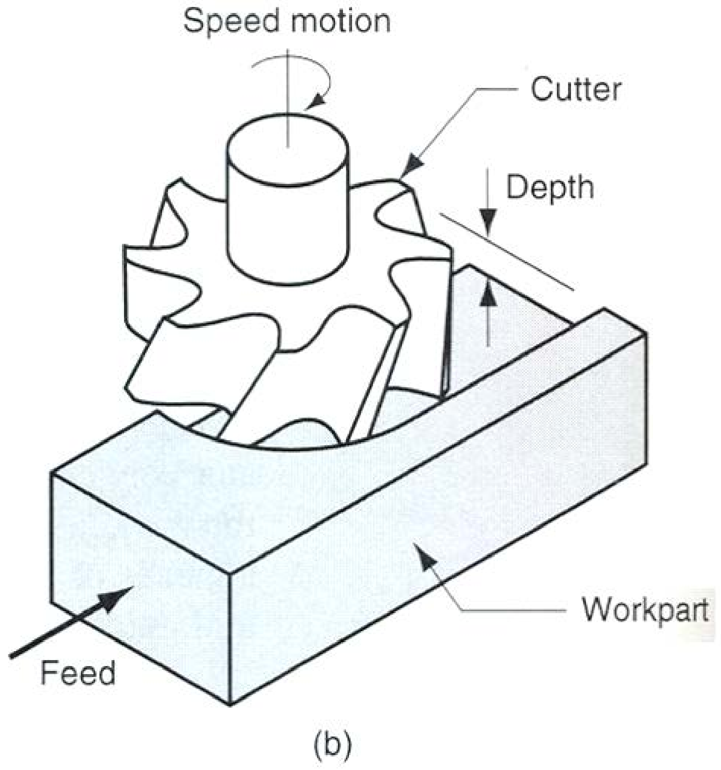


Figure 6.5: Face milling.

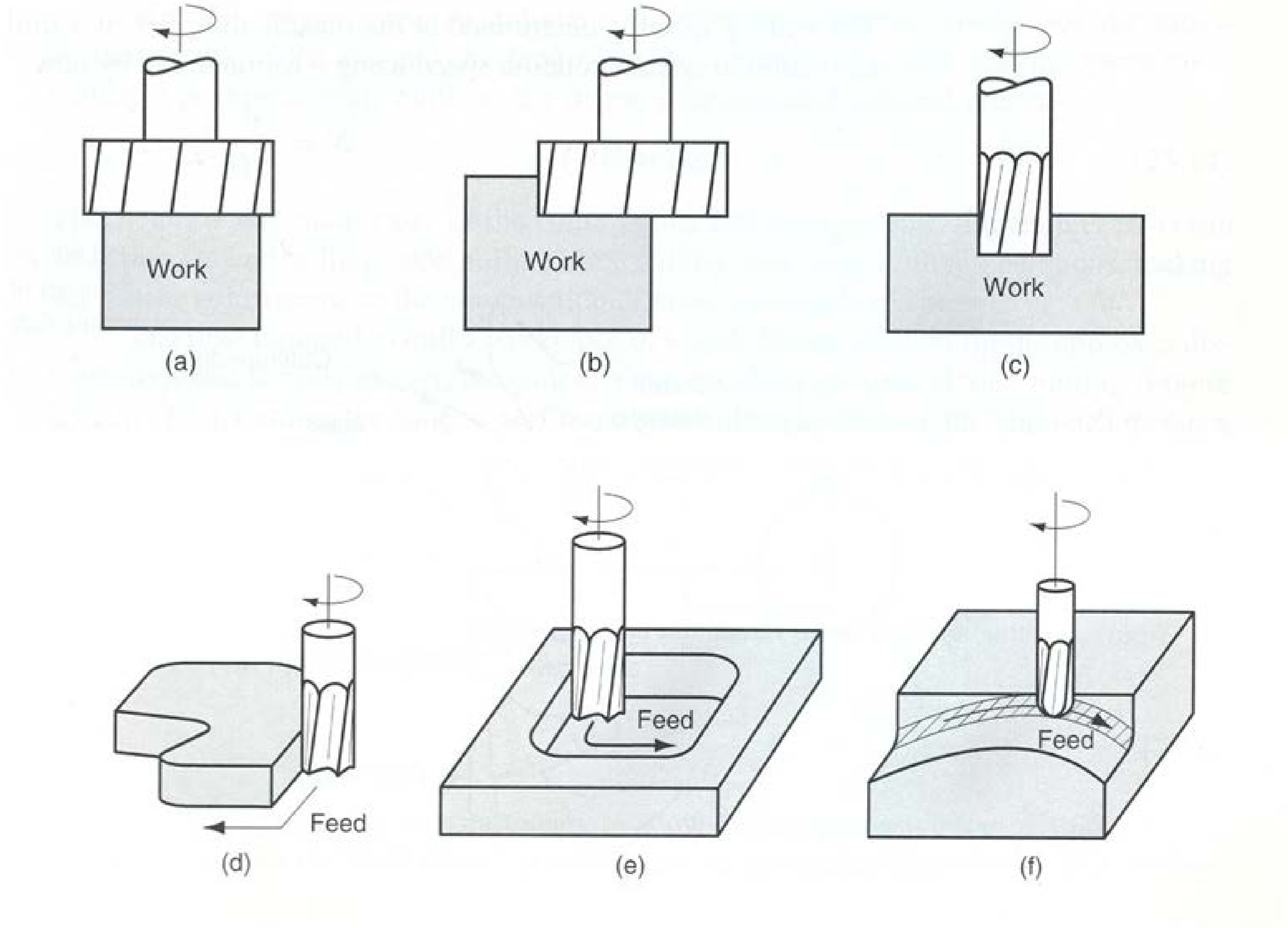


Figure 6.6: Face milling operations: (a) conventional face milling, (b) partial face milling, (c) end milling, (d) profile milling, (e) pocket milling, and (f) surface contouring.

6.4 Cutting conditions in milling

The cutting speed is determined at the outside diameter of a milling cutter. This can be converted to spindle rotation speed.

$$N = \frac{V}{\pi D}$$

Where

N = spindle speed in rpm

V = cutting speed

D = diameter of milling cutter

6.5 Chip thickness in milling

In face milling the axis of the cutter is perpendicular to the surface being milled, as shown in the figure 6.5.

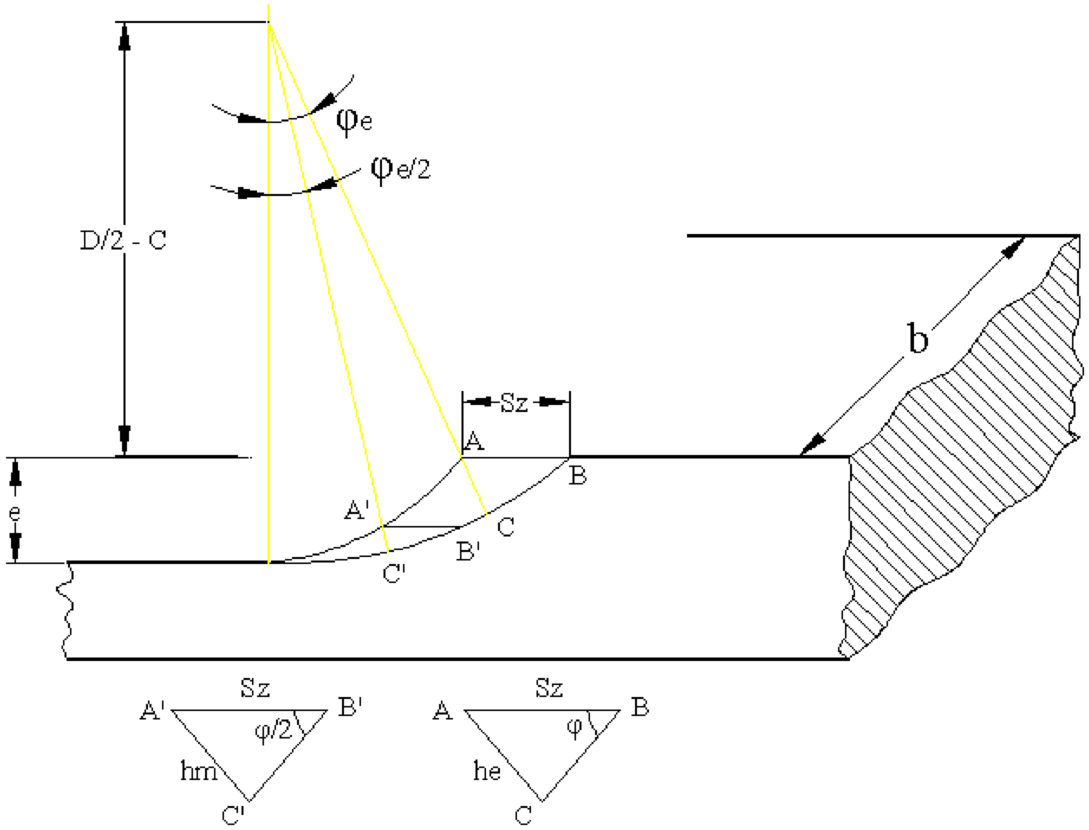


Figure 6.7: Chip thickness detail in milling operation.

The milling operation is characterized by the changing of chip thickness as the cutting proceeds. Therefore the maximum and mean values of chip thickness are to be calculated. Since the chip thickness is an important factor for calculating the cutter forces and power, therefore the maximum and mean values of chip thickness will be calculated.

$$h_e = S_z \sin \varphi_e = \frac{U}{n - z} * \sin \varphi_e$$

$$h_m = 1/2 h_e$$

Where

Sz = feed of workpiece/tooth = *U/(n-z)*

φ_e = angle of rotation of milling cutter during which each tooth remains engaged in workpiece material

U = feed of workpiece/min.

n = rotational speed of cutter in rpm

z = number of teeth on cutter

since φ_e is small such that $\sin \varphi_e = \varphi_e$

e = depth of cut, D = outside diameter of milling cutter

$$\sin \varphi_e = \frac{\sqrt{(D/2)^2 - (D/2 - e)^2}}{D/2} = \sqrt[2]{e/D}$$

6.6 Cutting forces and power in milling

the resultant force R acting on a single tooth in peripheral milling operation can be resolved into tangential and radial components (P_s, P_r) or horizontal and vertical components (P_h, P_v).

Therefore

$$R = \sqrt{P_s^{\,2} + P_r^{\,2}}$$

$$R = \sqrt{P_h^{\,2} + P_V^{\,2}}$$

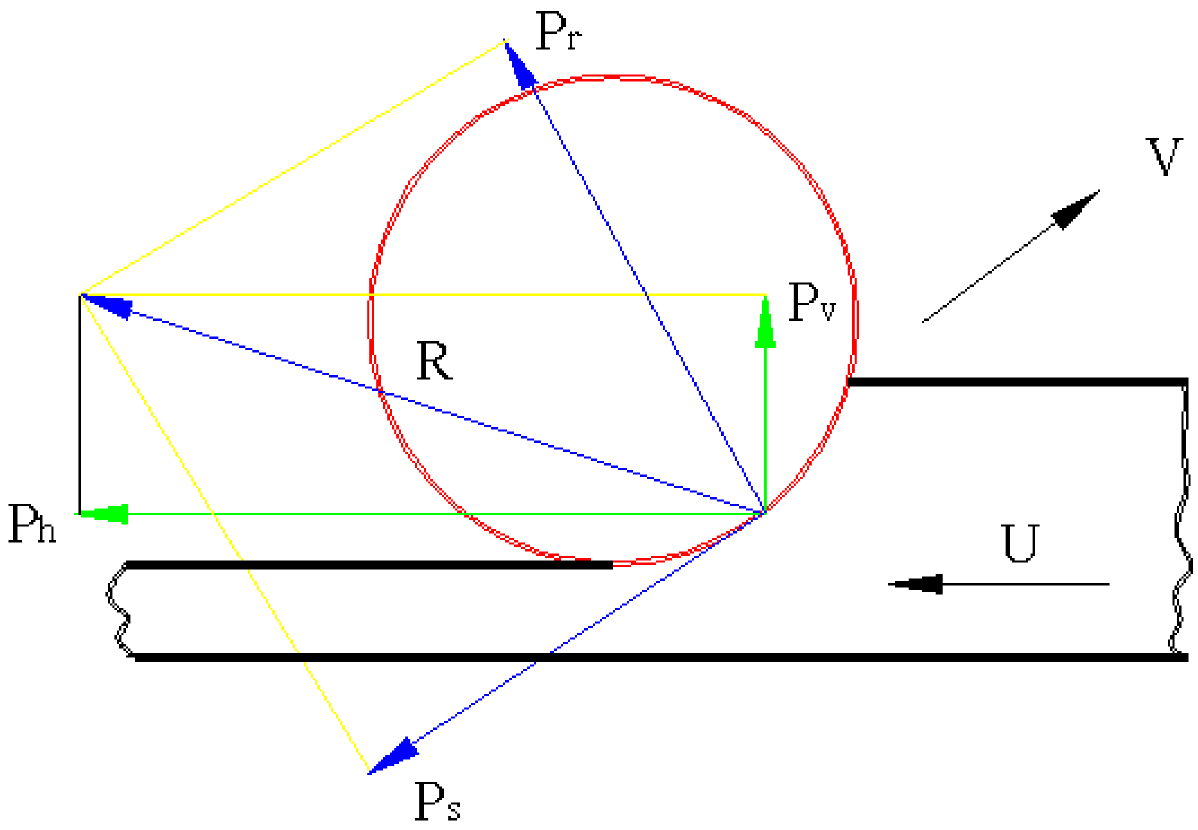


Figure 6.8: Cutting force components in milling operation.

$$R = \sqrt{P_s^{\ 2} + P_r^{\ 2} + P_a^{\ 2}}$$

6.7 The main cutting force “P_s” in peripheral milling

$$P_s = K_s \times b \times h$$

h = momentary chip thickness changing from zero to “h_e” in up milling

or from “h_e” to zero in down milling

$$P_{s\max} = K_s \times b \times h_e$$

$$P_{s\max} = Kz \times b \frac{zu}{n * z} \times \sqrt{e / D}$$

$$P_{s\,mean} = Ks \times b \frac{u}{n * z} \times \sqrt{e / D}$$

The total mean tangential force is:

$$P_{s\,mean(total)} = Z_e \times K_s \times b \frac{u}{n * z} \times \sqrt{e / D}$$

Where

Z_e = number of cutting teeth in the same moment

$$Z_e = Z \times \frac{\theta_e}{2\pi}$$

6.8 The cutting power in peripheral milling

The main chipping power "N_s" can be calculated as follows:

$$N_s = P_{s(total)mean} \times V$$

$$N_s = \frac{U \times e \times b}{\pi \times n \times D} \times K_s \times \frac{\pi \times D \times n}{1000} \times \frac{1}{60 \times 102} \qquad \text{(kW)}$$

$$N_s = \frac{U \times e \times b}{60 \times 102 \times 1000} \times K_s \qquad \text{(kW)}$$

The feed power “N_f” is given by:

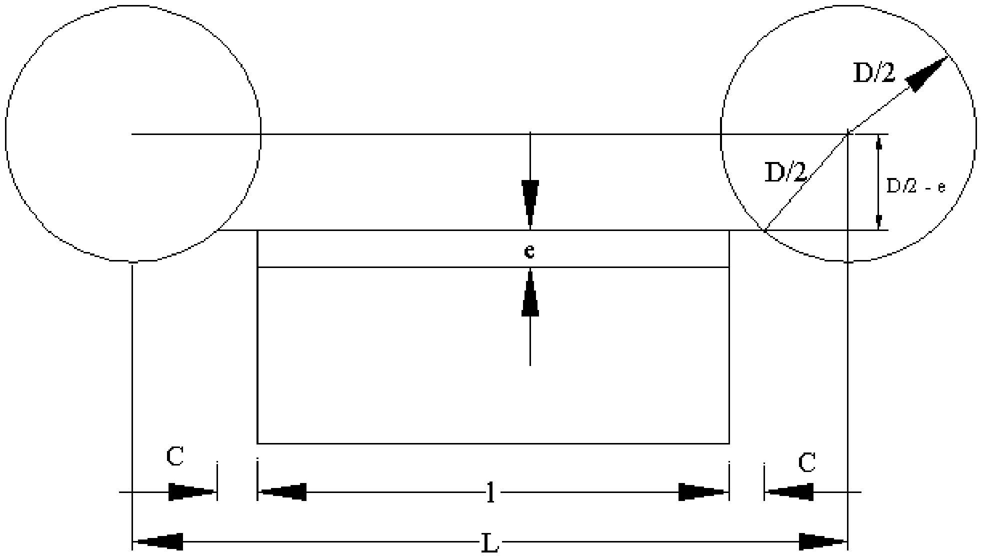
$$N_f = \frac{P_f \times U}{60 \times 102 \times 1000} \qquad \text{(kW)}$$

The total power is:

$$N_e = N_s + N_f = N_s \qquad \text{(approximately)}$$

$$N_{mot} = \frac{U \times e \times b \times K_s}{60 \times 102 \times 1000} \times \frac{1}{\eta_{mech}} \qquad \text{(kW)}$$

6.9 Machining time in peripheral milling



From figure, it can be noted,

$$L = 2\sqrt{e(D-e)} + 2C + l$$

$$t = \frac{L}{U}$$

Where

U = feed of the workpiece per minute

6.10 Material removal rate

Material removal rate can be calculated as following:

$$MRR = \frac{L \times W \times e}{t}$$

Where

L = length of the cut

W= width of the cut

e = depth of the cut

t = machining time

Problems

Problem 1

A slab milling operation is performed to finish the top surface of a steel rectangular workpiece 250 mm long by 75 mm wide. The helical milling cutter, which is 65 mm in diameter and has eight teeth, is set up to overhang the width of the part on both sides. Cutting conditions are v=35 m/min, f = 0.225 mm/tooth, and d = 0.250 in.

Determine:

(a) the time to make one pass across the surface

(b) the metal removal rate during the cut.

Problems

Problem 2

A peripheral milling operation is performed on the top surface of a rectangular workpart that is 300 mm long by 100 mm wide. The milling cutter, which is 75 mm in diameter and has four teeth, overhangs the width of the part on both sides. Cutting conditions are V = 80 m/min, f = 0.2 mm/tooth, and d = 7.0 mm.

Determine:

(a) the time to make one pass across the surface

(b) the material removal rate during the cut.

Problems

Problem 3

In horizontal milling, the following conditions exist:
Work (mild steel with specific cutting energy 3200 N/mm^2); Cutter (No. of teeth 12, tool diameter 120 mm, tool width 30 mm); Machining parameters (cutting velocity 45 m/min, feed velocity 360 mm/min, depth of cut 2.5 mm).

Calculate:

(a) Maximum chip thickness.
(b) Maximum tangential force/tooth.
(c) Machining time for one travel, if work length is 450 mm.
(d) Machining power