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ROLLING

Study Support

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ROLLING

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1. Assortment of rolled products, basic technologies and rolling modes



Time for study: 1 hour



Target After studying this paragraph you will be able to

- describe assortment of rolled products, their basic dividing into two groups, describe differences between particular products
- define basic technologies and modes of rolling



Presentation

1.1. Rolled products assortment

It creates a complex of all sorts of products of rolling mills, divided into groups based on characteristics and production modes. By the characteristics we understand the profile, which means the cross section geometry, and/or a main decisive dimension that serves for defining dimensional assortment of the product mix.

As per processing technology the product mix of rolling mills is divided into two main groups, namely the semi-finished and finished rolled products.

❑ Semi-finished products

Semi-finished products are products of roughing (breakdown) mills. They are determined mainly for further processing to final products of rolling mills. All final rolled products are characterized by a simple geometric shape of the cross section (Figure 1.1). Permissible are wide shape and dimensional tolerances, coarse and uneven surface. When the rolling process technology from the ingot is applied, semi-finished products are divided into blooms, slabs, billets and sheet bars. We can replace rolling of semi-finished products for continuous casting and produce the semi-product, determined for finish rolling, directly from the liquid metal.

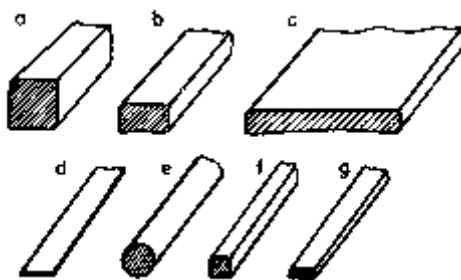


Fig. 1.1 Basic shapes of semi-finished products – a) square bloom, b) rectangular bloom, c) slab, d) sheet bar, e) round billet, f) square billet, g) flat billet

- **blooms** - approximately of square section, the ratio of one side to the other up to 1 : 1.4, range $\square > 140$ mm
- **slabs** - rectangular section, the ratio of one side to the other higher than 1 : 1.4, thicknesses > 80 mm, widths < 2000 mm
- **billets** - up to 1 : 2, range $\square > 40$ mm, $\varnothing 90 \div 210$ mm,
- **sheet bars** - thicknesses $6 \div 36$ mm, widths < 300 mm

□ Finished rolled products

Finished rolled products are final products of rolling. The initial material for the production of finished rolled products is semi-finished products, continuously cast semi-products and/or ingots. In comparison to semi-finished products, the continuously cast semi-products are characterized by a smaller section area, more accurate shapes and dimensions, closer tolerances, improved surface quality and better useful (service) properties. Based on their shape the finished rolled products are divided into bars, sections, flats, special products and tubes (Fig. 1.2).

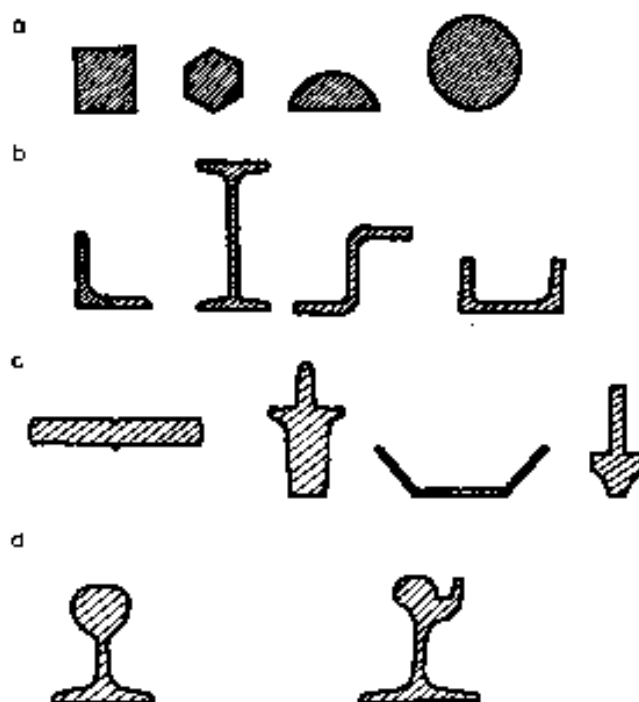


Fig. 1.2 Basic types of finished rolled products – a) bars, b) sections, c) sections for special purposes, d) rails

Rolled bars are characterized by a simple geometric shape of their cross section. Round bars are rolled in a wide range of diameters – from 5.5 up to 210 mm. Reinforcing bars (in short rebars) with longitudinal projections or reinforcing ribs create a special group. Besides, bars with square, hexagon, octagon, half-round, triangular section, and others are produced. A separate group is created by **wire rod** with a small section and simple shape. A most miscellaneous group, as far as shapes, dimensions and weights per running meter is concerned, is created by **rolled sections**.

Flat rolled products represent in our economy a very significant group of rolled products. They are characterized by their thickness and width. They are divided into plates and sheets, thick and thin hot rolled strips, cold rolled strips and foils. The wheel set (a pair of wheels and axle), grinding balls, and periodic profiles belong to a group of **special rolled products**. **Tubes** are divided, based on their processing technology, into seamless and welded tubes.

1.2. Basic technologies and rolling modes

By **rolling** we understand a continuous process, during which the formed material is deformed between the rotating work rolls. The roll gap (a gap between the work rolls) is smaller than the material entry height. As per the direction of passing the rolled material between the work rolls, the position of rolls axes in relation to the rolled material and the course of rolling we divide rolling into **longitudinal, cross and diagonal**.

Longitudinal rolling

The functional scheme of the longitudinal rolling is shown in Fig. 1.3. Rolls are driven in accordance with the sense of rotation (shown by arrows), they draw the metal in-between and press it through the height; at the same time the rolled material is considerably extended (elongated) and spread to a lesser

extent. The longitudinal rolling is one of widespread way of metal forming. It is estimated that up to 95 % of all produced steel is subjected to further rolling in the course of its production. As per the type of rolled products we can differentiate:

Longitudinal rolling in **plain rolls** – flat rolled products (sheets, plates, strips)

Longitudinal rolling in **grooved rolls** – shaped rolled products (rails, sheet piles, bars, sections, wire rod)

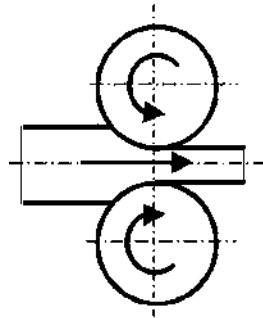


Fig. 1.3 Functional scheme of longitudinal rolling

Cross rolling

The functional scheme of the cross rolling is in Fig. 1.4. This rolling mode is characterized by the fact that the axis of the rolled product is parallel with the rolls axes. The rolls are rotating in the same direction. The rolled material is rotating in the direction of acting the resulting friction forces, i.e. in the opposite direction than is the direction of work rolls. This mode of rolling is used e.g. for the production of shafts or for rolling of grinding balls (Fig. 1.5).

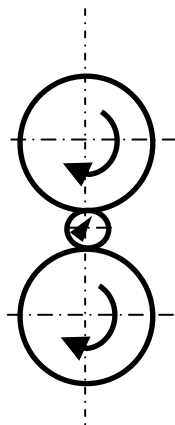


Fig. 1.4 Functional scheme of cross rolling

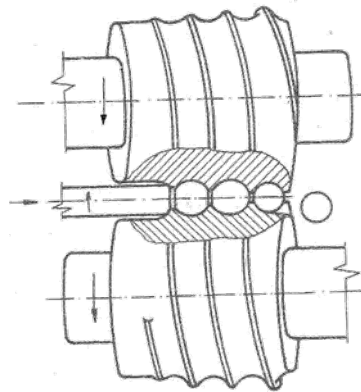


Fig. 1.5 Rolling of grinding balls

Diagonal rolling

Diagonal rolling is a special case of cross rolling. The mechanism of plastic deformation is here a similar one. However, work rolls axes are not parallel, but skew. So, the rolled stock not only rotates, but also feeds forward in the direction of its longitudinal axis, thanks to skew axes of rolls. This mode of rolling is used at rolling of seamless tubes (Fig. 1.6). It is one of widespread ways of the production of hollow semifinished products.

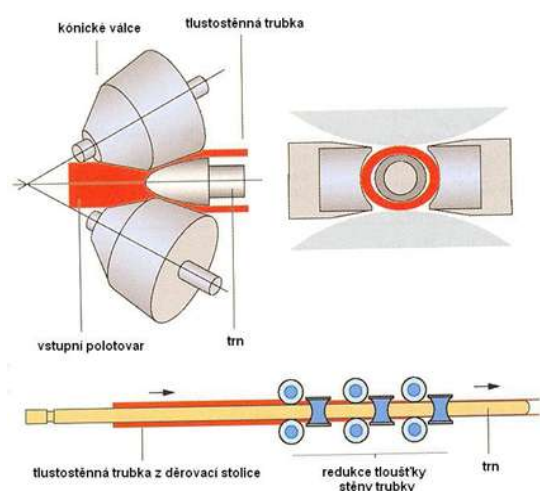


Fig. 1.6 Rolling in piercing mill (seamless tubes)

(kónické válce - conical rolls, tlustostěnná trubka - thick-walled tube, vstupní polotovár - input semifinished product, trn - mandrel, tlustostěnná trubka z děrovací stolice - thick-walled tube from piercing mill, redukce tloušťky stěny trubky - tube wall thickness reduction)



Summary of terms of this chapter

Semi-finished products – finished rolled products – rolled bars – rolled flats – rolled sections – wire rod – longitudinal rolling – cross rolling – diagonal rolling.



Questions to discussed curriculum

- 1.1. What is the difference between the semi-finished product and the finished rolled product?
- 1.2. Are you able to enumerate at least 3 types of semi-finished products and finished rolled products?
- 1.3. What is rolling?
- 1.4. What types of rolling do you know?
- 1.5. What is the difference between longitudinal and cross rolling?
- 1.6. Is it possible to produce grinding balls by rolling? If your answer is positive, what way you will use?
- 1.7. What does diagonal rolling serve for?



References that may be used for further study

GINZBURG, V. B.: Steel-Rolling Technology : Theory and Practice. New York : Marcel Dekker, 1989.

2. Types of rolling mill stands, layout and technological equipment of rolling mills



Time for study: 8 hours



Target After studying this paragraph you will be able to

- split up rolling mills according to particular criteria
- describe the rolling mill and its accessories/auxiliary devices (roll housings, work rolls, bearings, adjustment of rolls, roll counter-balance equipment, fittings for rolling - e.g. guides, roll changing equipment)



Presentation

2.1. Types of rolling mills

Rolling mills may be divided as per:

- construction of rolling mill stands and number of rolls
- sort of rolled products and work roll diameter
- way of rolls rotation
- layout of mill stands

□ Construction of rolling mill stands and number of rolls

Two-high rolling mills

Rolling mills of this type belong to mostly used. They have two horizontally mounted rolls (Fig. 2.1). The rolling mill motor drives either both rolls (top and bottom) or only one roll (normally the bottom roll; the top roll rotates due to friction between the roll and the rolled stock). As per the rolls rotation direction we distinguish the non-reversing (unidirectional) and reversing mills.

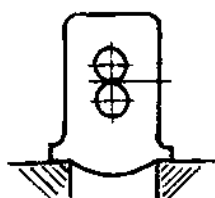


Fig. 2.1 Two-high rolling mill

Three-high rolling mills

That is the question of rolling mills with three horizontally mounted rolls. Rolls in these mills rotate **permanently in one direction**. They are widespread used as they make it possible rolling with increased number of grooves than in case of two-high mill stands. The rolled stock is rolled in one direction between the bottom and intermediate roll and in the opposite direction between the intermediate and top roll. The fix-fitted intermediate roll is directly driven. The bottom and top roll are

driven via the gearbox and they are usually adjustable. They serve for rolling of shaped rolled products (sections) and billets in grooved rolls.

Lauth three-high plate mill (Fig. 2.2) is used for rolling of plates. This rolling mill differs from normal three-high rolling mills by the fact that its intermediate roll has smaller diameter than the top and bottom roll. The intermediate roll is dragged and rotates only by friction effect between the rolled stock and alternately the top and bottom roll. The advantage of smaller diameter of the intermediate roll consists in supporting the rolled stock elongation; nevertheless, the disadvantage is more rapid wear and tear of the intermediate roll.

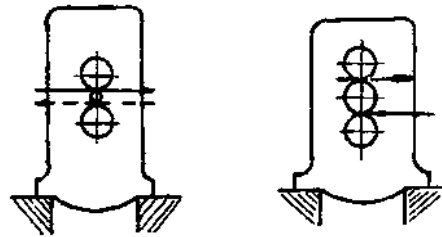


Fig. 2.2 Lauth mill and a common three-high rolling mill

Four-high rolling mills

This mill has four horizontal rolls, mounted in a single vertical plane (Fig. 2.3). Two rolls (inner) are work rolls and two rolls (outer) are back-up rolls. Significance of the back-up rolls consists in a chance of use higher roll forces and decrease in bending (deflection) of work rolls. Small diameters of work rolls permit - except for greater extension (elongation) of the rolled stock - also a possibility of achievement more favourable dimensional thickness deviations. The work rolls of the four-high mill are driven, the back-up rolls dragged. The four-high mill is used for rolling of plates and for hot and cold rolling of steel strip. It is used as non-reversing or reversing rolling mill.

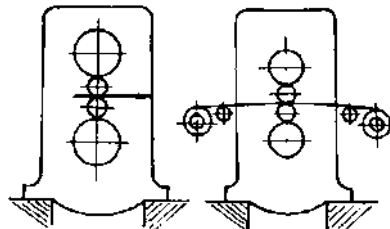


Fig. 2.3 Four-high rolling mills

Multi-roll mills

These rolling mills consist of six, seven, twelve or twenty horizontally mounted rolls (Fig. 2.4). In case of all mentioned mills always only two rolls are work rolls, the other are back-up rolls. Usually work rolls are driven and back-up rolls dragged. The multi-roll mills are used for rolling of very thin sheets, strips and foils.

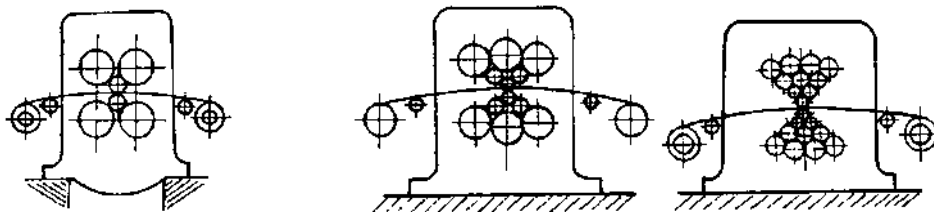


Fig. 2.4 Multi-roll mills

Universal plate mills

These mills have except for horizontally mounted rolls also vertically mounted rolls that are driven via transmission of bevel gear wheels (Fig. 2.5). The vertical rolls act by edging effect on lateral sides of the rolled stock, which leads to creating its lateral “walls”, precision angles and sharp edges. The edging rolls used to be mounted from the front of the mill stand, less frequently from the rear side, but sometimes also from both sides of the mill. Universal mills are used for rolling of slabs, universal plates and steel shapes. To enable rolling of wide-flange beams, the vertical rolls are mounted in the same plane with axes of rolls placed horizontally. Only the horizontal rolls are driven (Fig. 2.6).

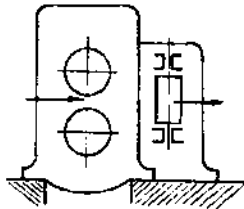


Fig. 2.5 Universal plate mill

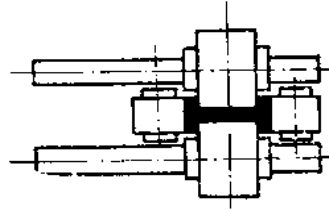


Fig. 2.6 Universal mill for rolling of wide-flange beams

Special structure

They have skew axes of rolls and are used for the production of seamless tubes (Fig. 2.7).

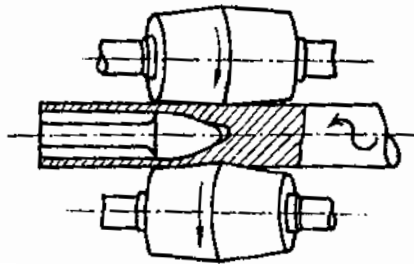


Fig. 2.7 Special structure

Specialities (wheel rolling mills, tyre rolling, thread rolling, rolling of grinding balls...)

□ Sorts of rolled products and work roll diameters

Roughing mills (breakdown mills)

- **blooming mill**
heavy breakdown mills (rolling blooms from ingots)
- **slabbing**
rolling slabs
- **billet mills**
mills for rolling of billets and sheet bars

Rolling mills for hot and cold rolling of finished rolled products

- a) Section mills for production of rolled bars and sections
 - heavy section mills for rolling of rails, heavy beams and sheet piles (rolls Ø 700 to 950 mm)
 - heavy section mills (rolls Ø 500 to 650 mm)
 - medium section mills (rolls Ø to 500 mm)

- small (fine) section mills (rolls $\varnothing$ to 350 mm)
- wire rod mills
- b) Rolling mills for rolling of flat rolled products
 - mills for rolling of plates and armours
 - mills for rolling of sheets
 - mills for rolling of strips
 - universal mills for rolling of universal plates with vertical side walls and accurate angles (equipped with horizontal and vertical rolls)
- c) Mills for rolling of tubes (piercing mills, pilger mills/reciprocating rolling process, Stiefel mills/Stiefel tube-rolling process)
- d) Rolling mills of special constructions (producing tyres, grinding balls etc.)

□ Rolling mills according to way of rolls rotation

- **non-reversing (unidirectional) rolling mills** (e.g. rolling of medium and light sections, strips)
- **reversing (reversible) rolling mills** (e.g. rolling of semi-products, heavy girders, plates)

□ Layout of mill stands

- rolling mills with a single operating stand (Fig. 2.8)
- multi-stand rolling mills with stands operating in one axis (Fig. 2.9)
- rolling mills with the open arrangement of operating stands in three trains (Fig. 2.10)
- rolling mill in the cross-country arrangement (Fig. 2.11)
- semi-continuous rolling mill
- continuous rolling mill (Fig. 2.12)

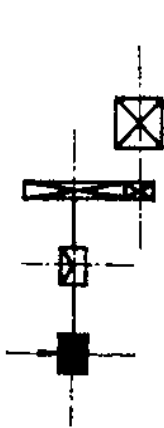


Fig. 2.8 Rolling mills with a single operating stand

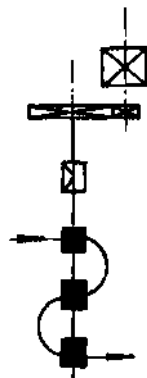


Fig. 2.9 Multi-stand rolling mills with arrangement of operating stands in one axis

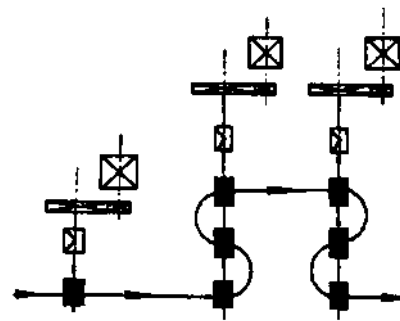


Fig. 2.10 Rolling mills with open arrangement of operating stands in three trains

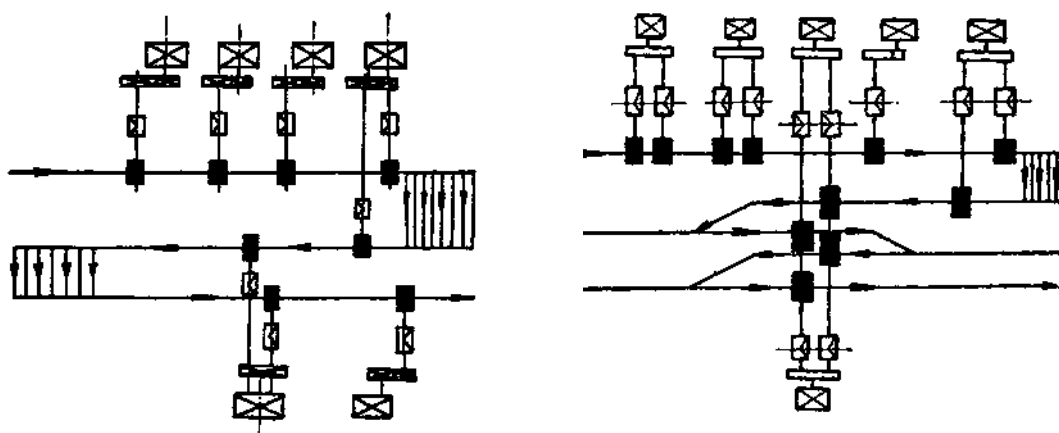


Fig. 2.11
Cross-country mill ("Zick-Zack Strasse")

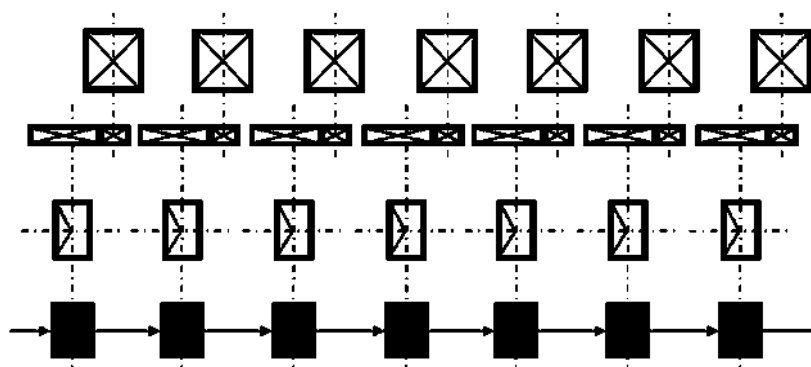


Fig. 2.12 Continuous rolling mill

2.2. Layout and technological equipment of rolling mills

- Rolling mill and its accessories (housings, work rolls, bearings, adjusting equipment, roll counter-balance equipment, fittings for rolling, roll changing equipment)
- Handling equipment, transportation means
- Reheating aggregates

□ Basic equipment of rolling mill stand (roll stand)

The basic equipment of the rolling mill, which directly ensures the origin of plastic deformation, is the roll stand (Fig. 2.13)

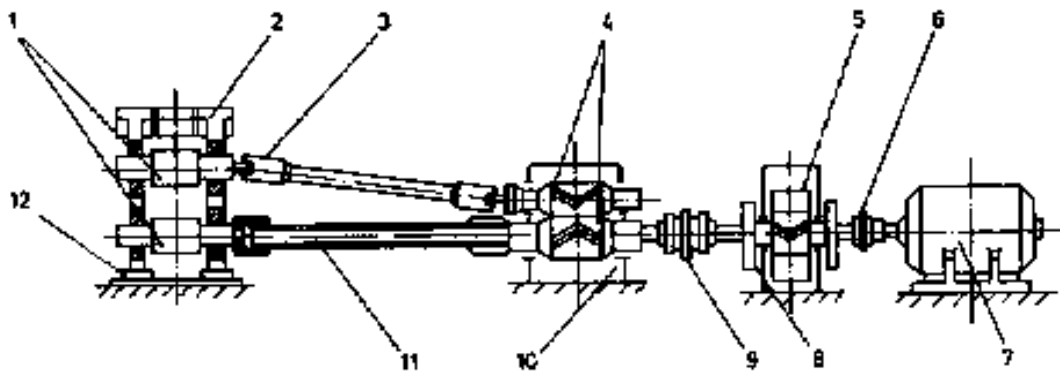


Fig. 2.13 Functional scheme of roll stand main devices

1 – rolls, 2 – housings, 3 – coupling boxes, 4 – pinions, 5 – reduction gear unit, 6 – flexible coupling, 7 – motor, 8 – flywheel, 9 – main coupling, 10 – pinion stand, 11 – spindles, 12 – base plates

Housing

The housing creates a framework of the rolling mill stand and absorbs total metal pressure on rolls in the course of rolling. The housing must be solid and its structure has to enable easy and fast roll changing and easy access to all parts of the housing and other details of the roll stand. Every roll stand has two housings, in which rolls are placed in bearings. In the housing upper part there are adjusting screws and the roll counterbalancing device and their drives.

From the structural viewpoint we distinguish housings as follows:

- enclosed housing – the whole housing is made of one piece (more beneficial from the strength point of view) – Fig. 2.14,
- open housing – with the separated cap, connected to the housing by screws (easier rolls changing) – Fig. 2.15,
- housingless roll stand – rigid chocks connected by solid joints, prestressed – limited stress relaxation (“spring-back”) of rolls, smaller and lighter structure.

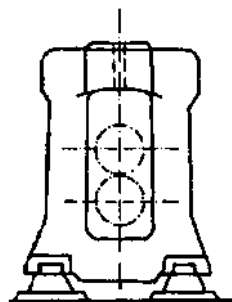


Fig. 2.14 Closed housing

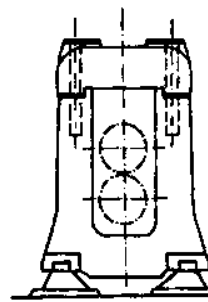


Fig. 2.15 Open housing

Rolls

The roll is a basic part of the roll stand, the metal between the rolls is plastically deformed. They ensure the required shape, dimension and surface quality of the rolled metal. They transfer the force and torque load. They are divided into:

- as per function – **work rolls** and **back-up rolls**,
- as per material and process technology – **cast iron**, **steel cast**, **steel forged**, **compound**,
- as per forming technology – for **rolling of flat products** (**plain** – Fig. 2.16), **grooved** (Fig. 2.17) and **special**,
- as per placing in the roll stand - **horizontal** and **vertical**

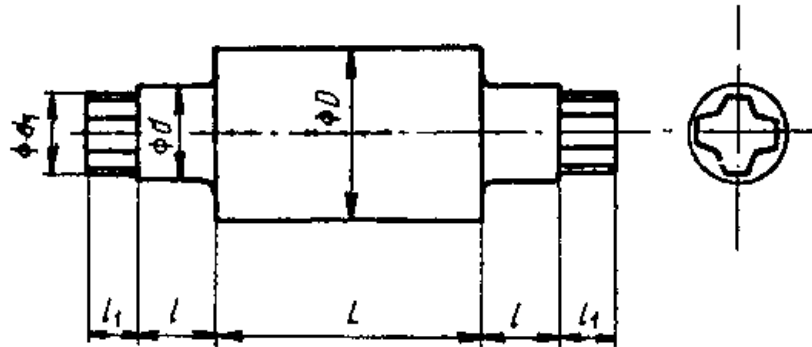


Fig. 2.16 Plain work roll

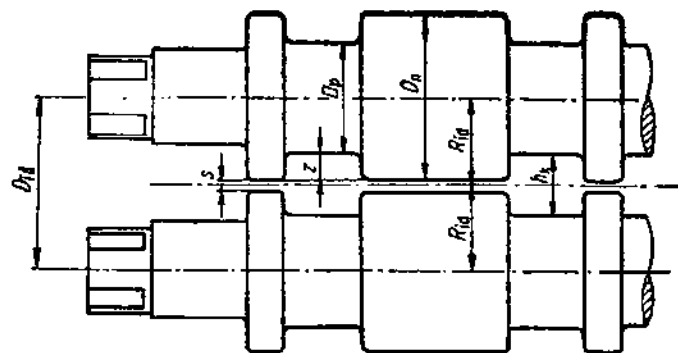


Fig. 2.17 Grooved rolls

The work roll consists of three parts:

- 1) working part - roll body, called roll barrel, characterized by diameter D and length L , which serves for forming the rolled metal
- 2) supporting part, i.e. roll neck (journal), which holds the roll in the housing of the roll stand
- 3) connecting part - wobbler, which connects the roll via further equipment with the main shaft of the electric motor

The roll body is the most important part of the work roll, because it works on the most difficult conditions (high temperatures and pressures, it is subjected to shocks, etc.). It must have high strength, hard surface to resist considerable impacts and pressures from the rolled metal, resistance to wear and tear and high temperatures of the rolled metal. The roll neck has to be resistant to wear and tear, high temperature and torsional and bending strain, the wobbler has to be resistant to torsion and impacts.

Bearings

The bearings serve for accurate mounting of roll necks, in both horizontal and vertical plane. They are placed in chocks. In rolling mills they are used:

- *sliding bearings* (Fig. 2.18)
(shells are of plastics/organic fabric and achieve friction coefficient from 0.02 to 0.1)

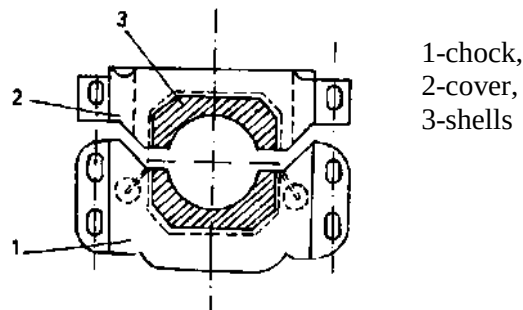


Fig. 2.18 Sliding bearing

- *bearings with rolling friction* (Obr. 2.19)
(low friction coefficient - from 0.001 to 0.003)

They are characterized by small wear and tear and hence high accuracy of the rolled material

- *bush bearings with fluid friction*
similar friction coefficient like antifriction bearings, their dimensions are smaller, wear and tear only slight and elastic deformations negligible

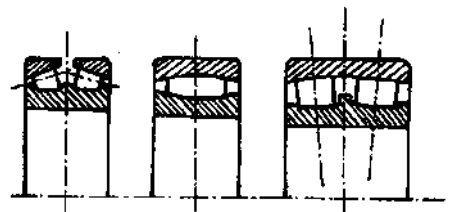


Fig. 2.19 Antifriction bearing

Adjusting and balancing equipment

The production process of various rolled products requires changes of mutual position of rolls, either during rolling mills adjustment or in the course of actual adjusting the rolls before individual passes. The mutual rolls position changing can be reached by means of adjusting and balancing equipment. Various kinds of adjusting the rolls you can see in Figs 2.20 and 2.21.

Adjustment of rolls in the vertical direction determines the gap between rolls and hence also the draft (thickness reduction in the pass).

- Axial adjustment of rolls – take up the lateral clearance.
- The adjustment has to be accurate, with as small as possible time loss.
- The top roll must not drop after passing the metal between the rolls – that is why it has to be counterbalanced together with chocks. The **balancing** is a prerequisite to prevent impacts and wear and tear of the adjusting screw with the nut.

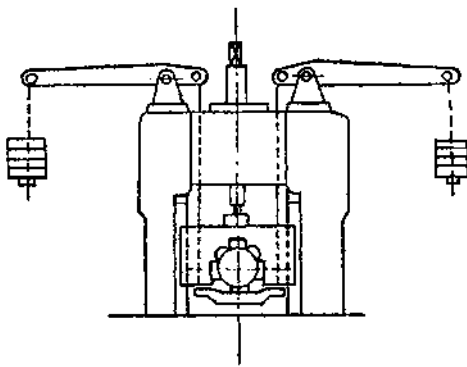


Fig. 2.20 Adjustment by counterbalance

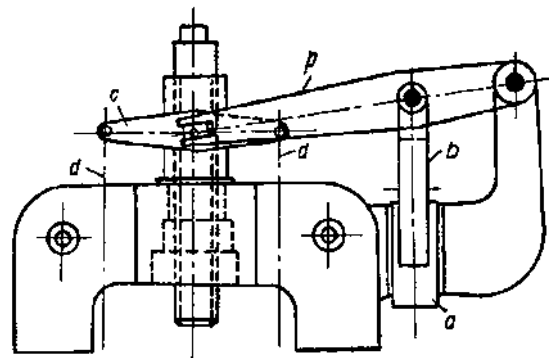


Fig. 2.21 Hydraulic adjustment

Pinion stand and reducers

Pinion stands transfer torque of the driving shaft to the work roll. Pinions of various kinds of roll stands differ only in dimensions and sort of teeth. By their shape they remind work rolls. However, they are not common gears (toothed wheels), they have the journal and the wobbler, like the work rolls (Fig. 2.22).

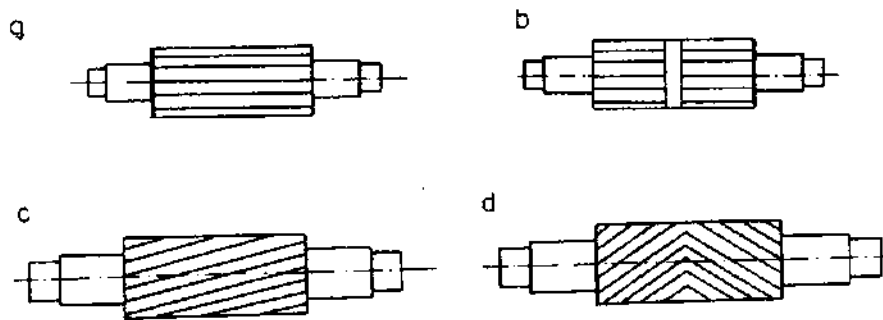


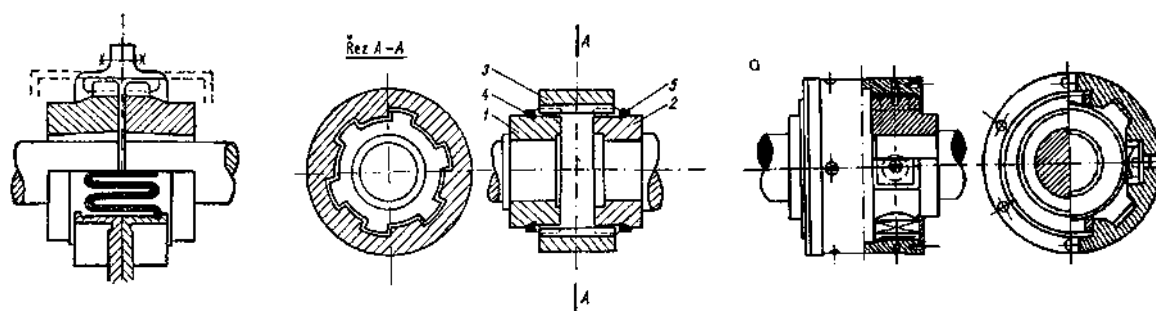
Fig. 2.22 Pinions (a – spur teeth, b – spur offset, c – helical, d – herringbone)

Reducers

The reducers change the number of revolutions of the main motor to the required revolutions of rolls (increase in torque). They may be one-stage, two-stage and three-stage. The gear ratio of each stage may be from 4 to 6.

Couplings

The couplings serve for transfer of torque of the driving engine to the work rolls. Their function consists in absorbing roll force impacts (shocks) and prevention of their transfer to the electric motor. Some kinds of couplings can be seen in Fig. 2.23.



Coupling Bibbi

Main Ortman coupling

Main Schloemann coupling

Fig. 2.23 Some kinds of couplings

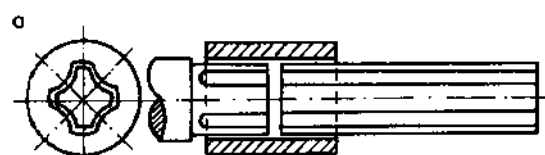
Drives

The roll stand drive system consists of the main (master) drive with the control system, reduction gears and connecting elements. Except for this, continuous work of the roll stand is secured by auxiliary mechanisms, equipped by separate electric motors with appropriate control equipment. With respect to increase in weight of rolled stocks, rolling speed, demands on accuracy and decrease in power consumption, it is necessary to choose the electric drives in such manner so that during operation the automatic control systems with computer control could be utilized.

Spindles and wobblers

The spindles are steel forged shafts which connect work roll necks with journals of pinions, thus making it possible the transfer of torque (Fig. 2.24). In addition to, they enable the axial misalignment as per the position of the live roll.

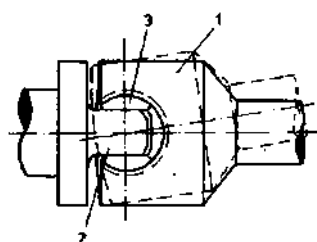
The wobblers can be either plain or stepped (with shoulders). The wobbler – except for connecting spindles – functions as a breaking piece in case of extremely high load of the roll stand.



- spindle with a plain wobbler



- spindle with a rounded-off wobbler



- fork joint of universal spindle

Fig. 2.24 Some kinds of spindles

□ Fittings for rolling

By fittings of the roll stand we understand the auxiliary equipment placed directly at the roll stand, serving for correct entry the rolled material into the rolls and its exit the rolls, or for automatic rolled stock guidance in its transfer from one groove to another groove of the same or adjacent roll stand.

- threading fittings for rolling
(guides, guide benches, guide bushing, guide borders, open and closed guide boxes, twisting guides)
- exit fittings for rolling
(simple and shaped guards)
- repeaters, looping channels

The aim of rolling mill fittings is to ensure guidance and thus make the correct rolled stock entry into the groove and exit out of the groove easier, and to make it possible using higher rolling speeds.

Guides

The guides serve for correct rolled stock directing into the groove of work rolls at the entry side of the roll stand and its safe exit to the runout table of the roll stand (Figs 2.25 and 2.26).

To prevent from bending the rolled stock upwards and downwards during its runnig out of the rolls and/or collaring on the roll, the **guards** are used. For the guards placement it is decisive, if the mill stand works with top or bottom pressure, i.e. whether the rolled metal shows a tendency towards collaring on the bottom or top roll (Fig. 2.27).

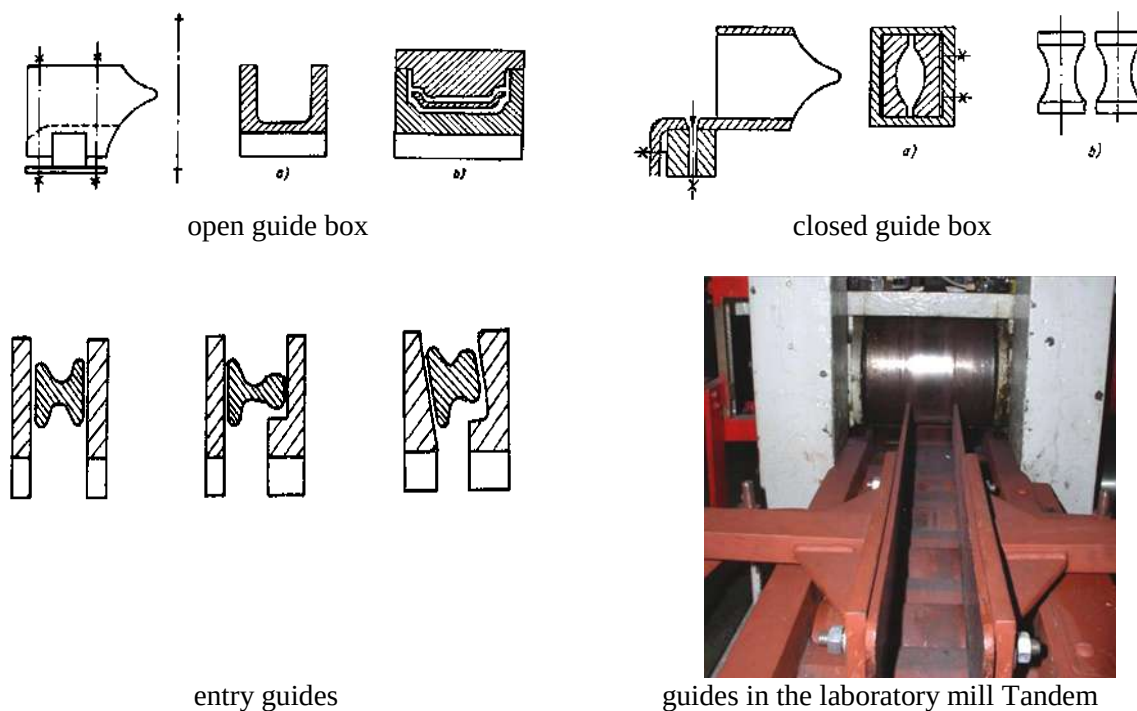


Fig. 2.25 Guides

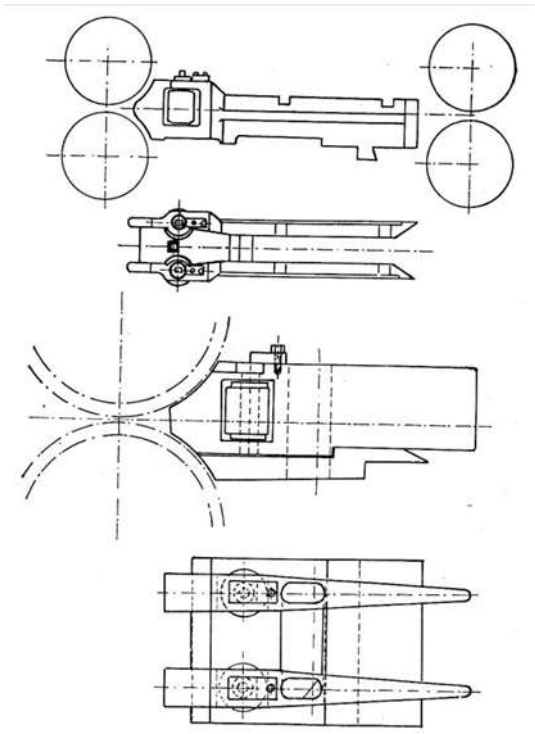


Fig. 2.26 Roller entry guides

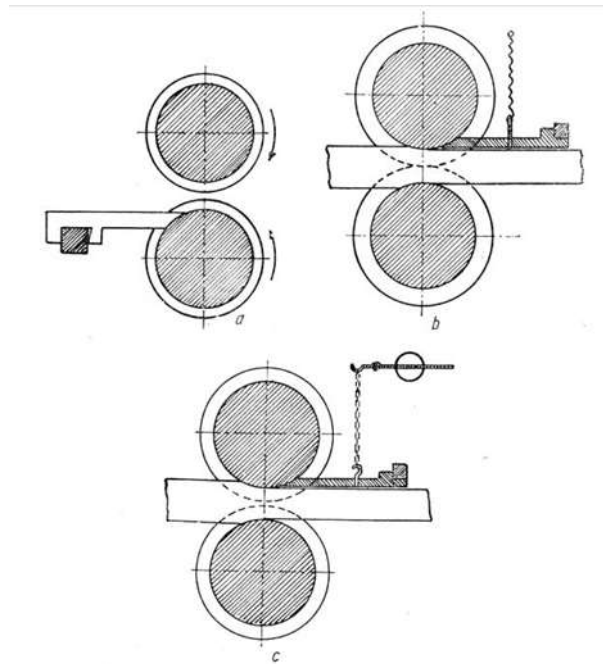


Fig. 2.27 Ways of fixing the guard

Repeaters, looping channels

The aim of the repeater is to swivel the end of the rolled stock through 180° after leaving the rolls and thread it into the groove of the adjacent roll stand. Sometimes the repeaters function as twist guides as well.

□ Auxiliary equipment of rolling mills

Handling equipment and tilting devices (manipulators)

- **Devices for longitudinal transport/handling** (roller tables, feeding rolls, bumpers, stops, pushers, extractors)
- **Devices for cross transport** (manipulators, transfer tables (Fig. 2.28), transfers, displacement and shifting devices, running troughs with stops)

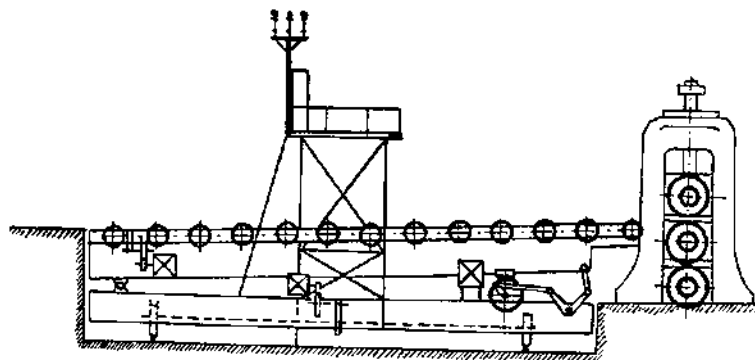


Fig. 2.28 Transfer table

- **Devices for lifting and lowering** - lifting (Fig. 2.29) and tilting tables (Fig. 2.30)

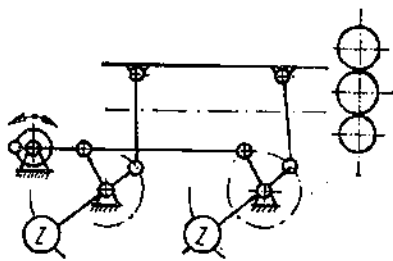


Fig. 2.29 Flowing scheme of lifting table

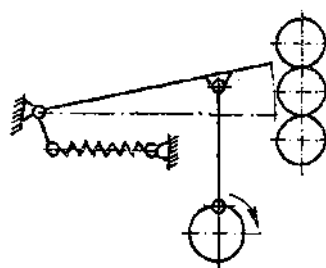


Fig. 2.30 Flowing scheme of tilting table

- **Manipulators** – serve for rotating the rolled stock at a specific angle around its longitudinal axis (Figs 2.31 and 2.32)

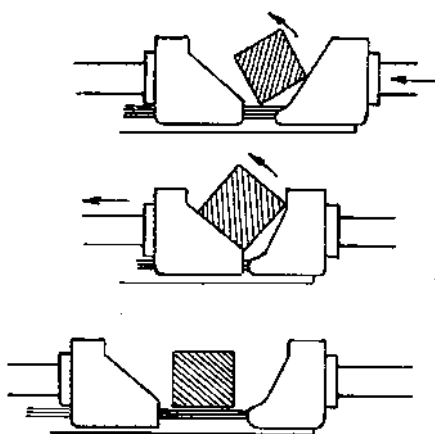


Fig. 2.31 Grey's manipulator



Fig. 2.32 Roller table + tilting

- **Cooling bed** – equipment where rolled products are cooled and at the same time item-by-item transferred to the roller table, on which they are sent to the finishing plant (Fig. 2.33).



Fig. 2.33 Cooling beds

- **Device for transport of bundles/packs and coils and cut-offs removal** – bundles/packs and coils are mostly transported by cranes using special suspensions/slings (Fig. 2.34).

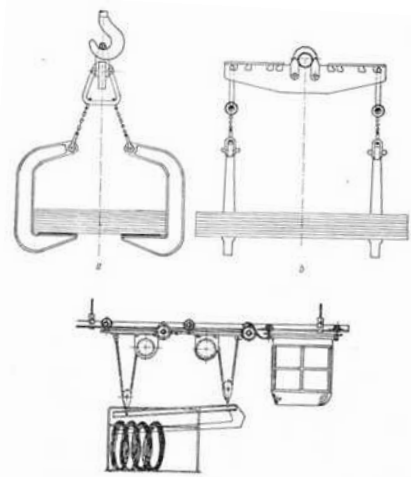


Fig. 2.34 Suspensions/slugs for transport of bundles/packs and coils

Finishing banks

- Shears and saws (Fig. 2.35 - 2.39)



Fig. 2.35 Slitting line

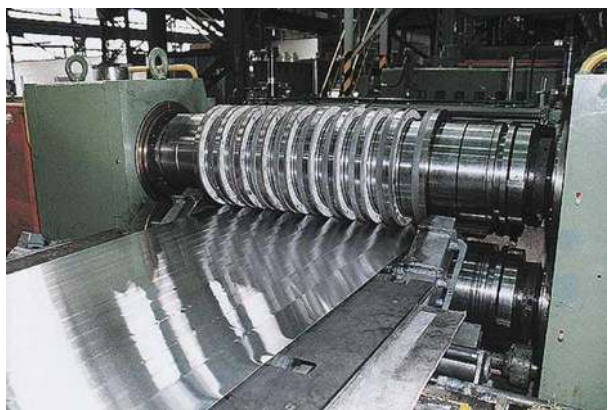


Fig. 2.36 Slitter with circular knives



Fig. 2.37 Circular saw

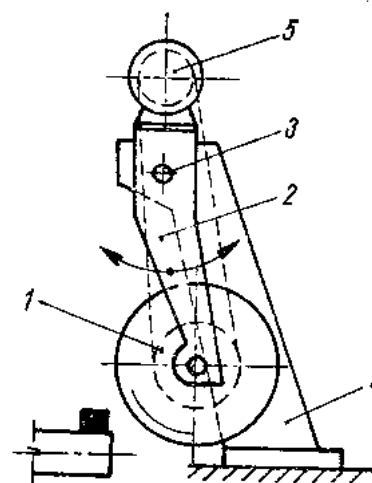


Fig. 2.38 Pendulum saw



Fig. 2.39 Flying shears

- **Levellers** (Fig. 2.40 - 2.42)

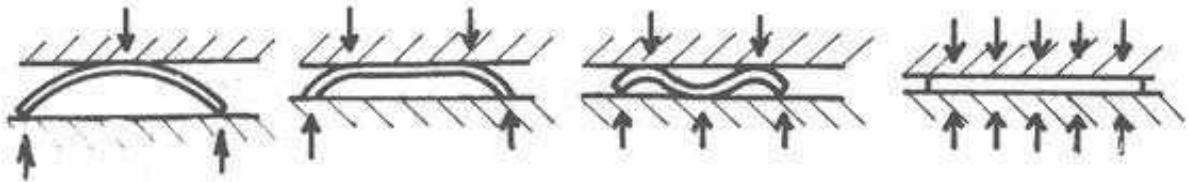


Fig. 2.40 Pressure levelling between even plates

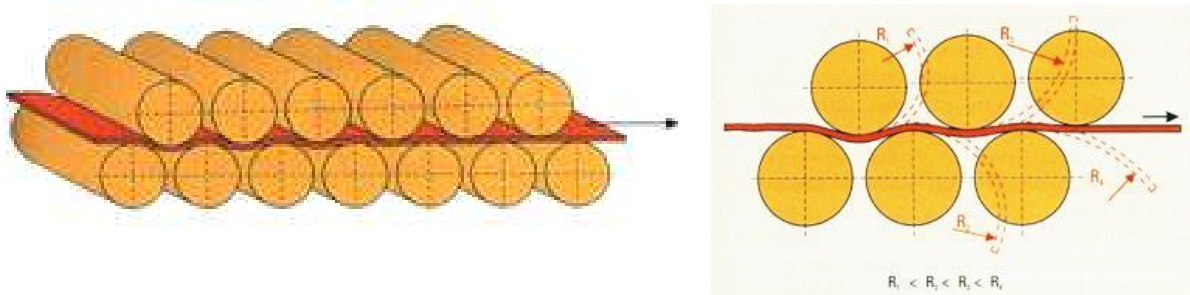


Fig. 2.41 Levelling of sheets by rolling



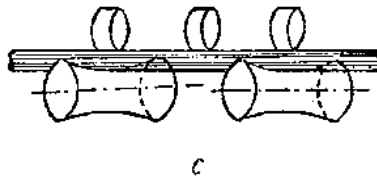
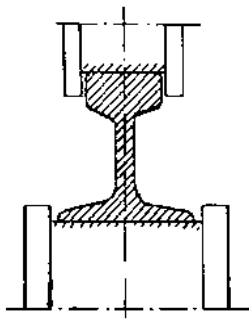


Fig. 2.42 Roller straightening machines

- **Coiling machines** (Fig. 2.43 - 2.46)

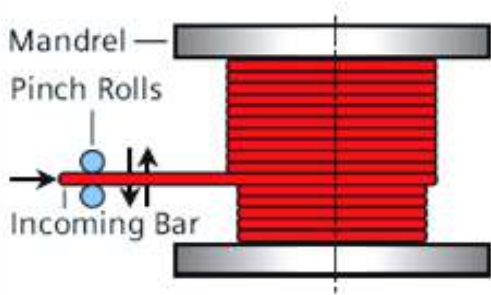


Fig. 2.43 Wire rod coiler (upcoiler)

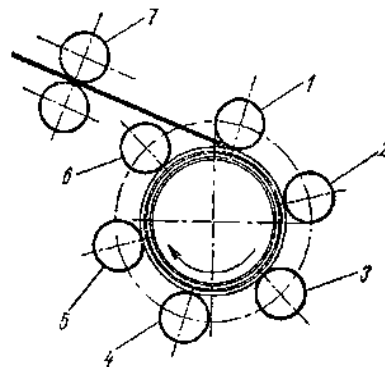


Fig. 2.44 Functional scheme of strip coiler



Fig. 2.45 Bundling press for wire rod coils



Fig. 2.46 Coilers (cold, hot, furnace coiler)

□ Reheating furnaces in rolling mills

- soaking pits – bloomings
- pushing type furnaces (for reheating of slabs, blooms, billets) - Fig. 2.47
- walking beam furnaces (better controlled than pushing-type furnaces)
- rotary-hearth furnaces and roll-over-type furnaces (tube mills – round billets) - Fig. 2.48
- tunnel furnaces (e.g. in front of tube sizing mills)



Fig. 2.47 Pushing-type furnace



Fig. 2.48 Rotary-hearth furnace



Summary of terms of this chapter

Division as per construction of rolling mill stands and number of rolls – sort of rolled products and diameter of work rolls – way of rotation of rolls – arrangement of rolling mill stands, rolling mill – housings, work rolls, bearings, adjusting equipment, balancing equipment, fittings for rolling, roll change devices – transport and handling devices – furnaces.



Questions to discussed curriculum

- 2.1. What are criteria for division of rolling mills?
- 2.2. What types of rolling mill stands do you know, considering their structure and number of rolls?
- 2.3. What is the basic difference between non-reversing and reversing rolling?
- 2.4. What is the difference between continuous rolling mill and rolling mill with cross-country arrangement?

- 2.5. What is the basic equipment of the roll stand?
- 2.6. What types of housings of roll stands do you know?
- 2.7. What is the difference between work rolls and back-up rolls?
- 2.8. What material can work rolls be made of?
- 2.9. What types of work rolls do you know?
- 2.10. What is the function of adjusting and balancing equipment?
- 2.11. What is the reducer as a part of the roll stand complex for?
- 2.12. Why coupling/wobbler is mounted between the spindle and the shaft of the driving motor?
- 2.13. What belongs to fittings of rolling mills?
- 2.14. What is the manipulator determined for?
- 2.15. Are you able to enumerate at least 3 types of furnaces used for reheating of the material in rolling mills?



Used references that are recommended for further study

GINZBURG, V. B.: *Steel-Rolling Technology : Theory and Practice*. New York : Marcel Dekker, 1989.

3. Theoretical aspects of longitudinal rolling



Time for study: 8 hours



Target After studying this paragraph you will be able to

define the deformation zone (contact arc length = contact between the rolled stock and the roll), biting capabilities of rolls, speed relations in the deformation zone, forward slip, strain rate, spreading, roll force, roll torque, forming factor and roll flattening.



Presentation

□ Deformation zone

The longitudinal rolling is a continuous forming process, in the course of which the rotating rolls pull the rolled stock into the roll gap and press it within. These events are not going on at the given moment in the whole volume of the formed material, but only in its limited part – **in deformation zone**. The deformation zone is defined by contact arc length (the projected roll gap length) and mean width (see **Fig. 3.1.**).

Deformation zone

- entry plane AA_1
- exit plane BB_1
- nip angle AB and A_1B_1

Contact arc length

We search for the length of leg AC of right-angle triangle ACO , where:

$$\overline{OA} = R; \quad \overline{OC} = R - \frac{\Delta h}{2} \quad (3.1)$$

$$l_d = \overline{AC} = \sqrt{R^2 - \left(R - \frac{\Delta h}{2}\right)^2} = \sqrt{R^2 - R^2 + 2 \cdot R \cdot \frac{\Delta h}{2} - \frac{\Delta h^2}{4}} = \sqrt{R \cdot \Delta h - \frac{\Delta h^2}{4}} \approx \sqrt{R \cdot \Delta h} \quad (3.2)$$

Mean width of deformation zone

$$b_s = \frac{b_1 + b_0}{2} \quad (3.3)$$

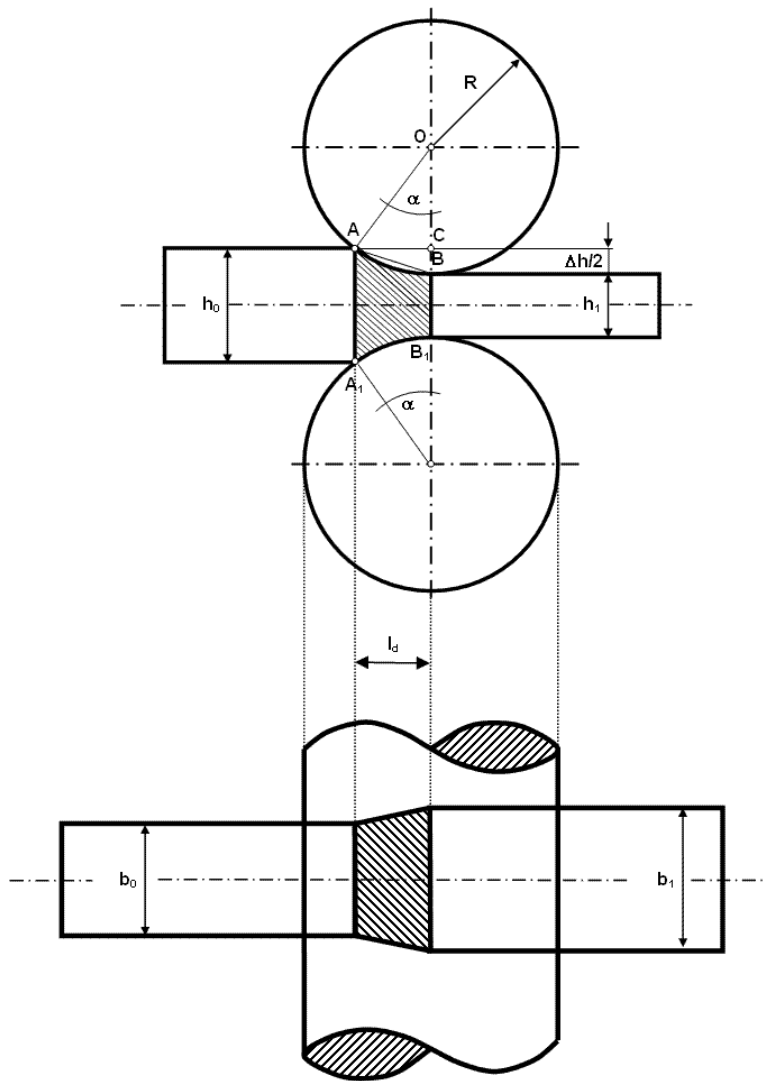
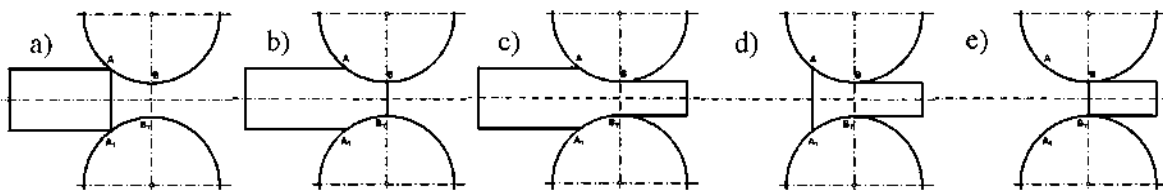


Fig. 3.1 Scheme of longitudinal rolling

□ Biting capability of rolls

The rolling process may be divided into three stages (see Fig. 3.2). In the first stage the rolling starts at the moment of contact between the rolled stock and rolls at points AA_1 and finishes at the entry of the front end into the exit plane BB_1 . In the second stage the parameters of the deformation zone remain without change, we are speaking about steady-state rolling. The third stage starts by the rolled stock rear end entry into the plane AA_1 and finishes by the rolled stock exit from the rolls.

Fig. 3.2 Stages of longitudinal rolling: 1st stage a) to b), 2nd stage c), 3rd stage d) to e)

A prerequisite for realizing the rolling process is the metal bite by rolls. At the contact of the rolled stock with rolls the normal forces N and hence the tangential forces of friction T (Fig. 3.3) will act in contact surfaces.

$$T = N \cdot \mu \quad (3.4)$$

Friction angle β :

$$\operatorname{tg} \beta = \mu \quad (3.5)$$

The x component of normal force N_x :

$$N_x = N \cdot \sin \alpha \quad (3.6)$$

The x component of tangential force T_x :

$$T_x = T \cdot \cos \alpha \quad (3.7)$$

Three cases can occur:

- the bite will not occur $N_x > T_x$; $\alpha > \beta$ (Fig. 3.4 left)
- the bite will not occur $N_x = T_x$; $\alpha = \beta$ (balance)
- the bite will occur $N_x < T_x$; $\alpha < \beta$ (Fig. 3.4 right)

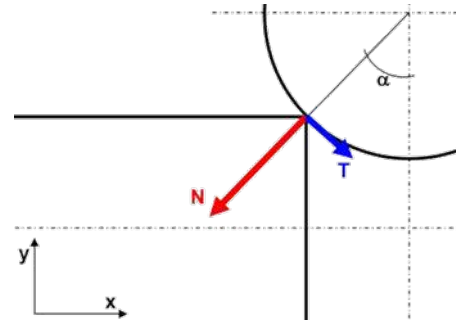


Fig. 3.3 Forces acting on the rolled stock at contact with rolls

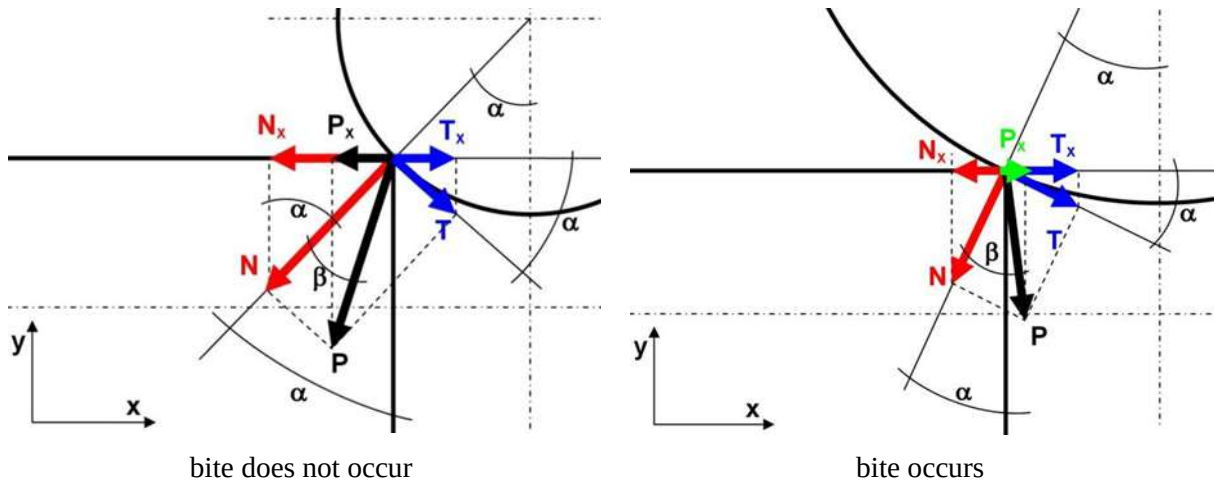


Fig. 3.4 Resolution of forces, rolling on plain rolls

This was valid on the equilibrium conditions. Possibilities of positive influencing – e.g. by additional force or start off moving the rolled stock on the roller table.

After overcoming the initial issues the contact surface between the rolled stock and the rolls will be enlarged and bite conditions will be improved.

□ Speed relations in deformation zone

In the steady-state rolling the continuity law (for continuous rolling) is fully applied. It can be expressed by the following continuity equation:

$$S_0 \cdot v_0 = S_1 \cdot v_1 = S_2 \cdot v_2 = \dots S_n \cdot v_n = \text{const} \quad (3.8)$$

where S_n is cross section area in pass n ,

S_0 and S_1 are cross section areas of the rolled stock in the entry and exit plane of the deformation zone,

v_n – mean exit speed in pass n ,

v_0 and v_1 are mean horizontal speeds of the rolled stock in the entry and exit plane.

With regard to the fact that the rolled product cross section is diminishing in the course of rolling, the rolled product speed has to be increased, which has the following consequences: even at the constant speed of rolls v_v the relation between the speed of the rolled stock and the rolls will be changed. It is necessary to single out from the circumferential speed of rolls its horizontal component in any place of the nip angle:

$$v_{v,x} = v_v \cdot \cos \varphi \quad (3.9)$$

The vertical plane where the relation between speeds v_p and $v_{v,x}$ is changed, as well as the direction of the friction force, is named **neutral plane** (Fig. 3.5).

Neutral plane – its position is determined by neutral angle γ . If we denote the horizontal speed of the rolled stock in the neutral plane $v_{p,\gamma}$, then:

$$v_{p,\gamma} = v_v \cdot \cos \gamma \quad (3.10)$$

During hot rolling the equalizing of speeds in a wider zone around the neutral plane occurs – in **sticking area**.

At the beginning of bite the mean horizontal speed of the rolled stock $v_{p,x}$ is smaller than the horizontal projection of circumferential speed of rolls $v_{v,x}$

$$v_{p,x} < v_v \cdot \cos \varphi \quad (3.11)$$

So, the rolled stock moves relatively against the direction of rolling, whereas the horizontal component of the friction force acts in the rolling direction. This part of deformation zone is called **retardation area**.

For the exit plane will be valid:

$$v_{p,x} > v_v \cdot \cos \varphi \quad (3.12)$$

So, the rolled stock moves relatively in the direction of rolling, whereas the horizontal component of the friction force acts against the rolling direction. This part of deformation zone is named **forward slip area**.

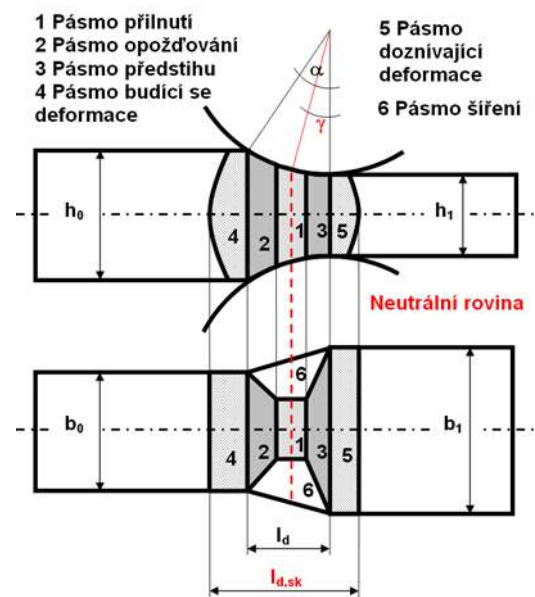


Fig. 3.5 Areas of deformation zone
(1 - adherence (sticking) area,
2 - retardation area, 3 - forward slip area,
4 - exciting area, 5 - fading deformation
area, 6 - spread area, Neutrální rovina -
neutral plane)

The **exciting and fading deformation areas** affect the unquestionable influence of rigid ends on deformation phenomena in the deformation zone, which results in a certain extension beyond its geometric boundaries; then we speak about the real length of deformation zone $l_{d,sk}$.

□ Forward slip in rolling

In the course of rolling the rolled stock exit speed may - on specific conditions - be higher than the speed of rolls. The knowledge of the forward slip is important for continuous rolling.

$$s = \frac{v_1 - v_{obv}}{v_{obv}} \cdot 100 \quad (3.13)$$

where v_1 is exit speed of the rolled stock,
 v_{obv} – speed of rolls.

□ Strain rate

In general, strain rate expresses a change of the relative or actual deformation in time. The instantaneous strain rate

$$\dot{\epsilon} = \frac{d\epsilon}{dt} \quad (3.14)$$

Mean strain rate

$$\bar{\epsilon} = \frac{2}{\sqrt{3}} \cdot \frac{v_v}{l_d} \cdot \ln \frac{h_0}{h_1} \quad (3.15)$$

□ Spread

The lateral flow of the metal in the roll gap causes enlargement (exceptionally even reduction) of the rolled stock width and is called spread. In rolling three sorts of spread occur, namely free, limited and forced.

The spread course and quantity in rolling are influenced in a complex way by mechanical factors (v , e , $\dot{\epsilon}$), geometric factors (h_0 , h_1 , b_0 , l_d , D , α) and physical factors (μ , T , M). The parallel acting of mechanical, geometric and physical factors has influence on the resulting state of stress and the character of changes of longitudinal and lateral deformation.

If the rolled stock leaves the roll gap with a general shape of side surfaces, then we usually determine mean lateral deformation from the relation

$$\ln \frac{b_{1s}}{b_{0s}} = \ln \frac{S_1 \cdot h_{0\max}}{S_0 \cdot h_{1\max}} \quad (3.16)$$

where S_0 , S_1 are entry and exit cross sections of the rolled stock [mm^2],
 $h_{0\max}$, $h_{1\max}$ – entry, exit maximum height of the rolled stock [mm].

If the rolled stock with a variable shape of side surfaces enters and exits the rolls, then values $b_{0\max}$, $b_{1\max}$, or b_{0s} , b_{1s} have to be found out experimentally, always for a specific case of rolling.

So, in dependence on rolling type and mode it is possible to calculate all three increments of width deformations $\Delta b_{\max}$, Δb_s and Δb_{styk} :

$$\Delta b_{\max} = b_{1\max} - b_0 \quad (\text{increment of maximum width}) \quad (3.17)$$

$$\Delta b_s = b_{1s} - b_0 \quad (\text{increment of mean width}) \quad (3.18)$$

$$\Delta b_{\text{styk}} = b_{1\text{styk}} - b_0 \quad (\text{increment of contact surface between roll and rolled stock}) \quad (3.19)$$

In the gap of plain rolls usually a linear width increment of contact surface between roll and rolled stock is presumed for simplification. The mean value of this width b_s is determined from the relation

$$b_s = \frac{b_0 + b_1}{2} \quad (3.20)$$

and hence the horizontal projection of the contact surface

$$S_h = b_s \cdot l_d \quad (3.21)$$

For spread calculations in rolling of thick products with free spread on conditions of roughing mills the following selected formulas are used:

Gubkin's formula

$$\frac{\Delta b}{\Delta h} = \frac{\mu}{\sqrt{2}} \cdot \left(\frac{D}{h_0} \right)^{\frac{1}{2}} \cdot \left(\frac{\Delta h}{h_0} \right)^{\frac{1}{2}} - \frac{1}{2} \frac{\Delta h}{h_0} + \frac{\mu}{\sqrt{2}} \left(\frac{D}{h_0} \right)^{\frac{1}{2}} \cdot \left(\frac{\Delta h}{h_0} \right)^{\frac{3}{2}} - \frac{1}{2} \left(\frac{\Delta h}{h_0} \right)^2 \quad (3.22)$$

Bachtinov's formula

$$\frac{\Delta b}{\Delta h} = 0,407 \cdot \left(\frac{D}{h_0} \right)^{\frac{1}{2}} \cdot \left(\frac{\Delta h}{h_0} \right)^{\frac{1}{2}} - 0,287 \mu \frac{\Delta h}{h_0} \quad (3.23)$$

Smirnov's formula

$$\frac{\Delta b}{\Delta h} = \mu \cdot \left(\frac{D}{h_0} \right)^{\frac{1}{2}} \cdot \left(\frac{\Delta h}{h_0} \right)^{\frac{1}{2}} - \frac{1}{2} \frac{\Delta h}{h_0} + \mu \cdot \left(\frac{D}{h_0} \right)^{\frac{1}{2}} \cdot \left(\frac{\Delta h}{h_0} \right)^{\frac{3}{2}} - \frac{1}{2} \left(\frac{\Delta h}{h_0} \right)^2 \quad (3.24)$$

Tarnovsky's formula

$$\frac{\Delta b}{\Delta h} = \frac{0,61}{\sqrt{2}} \cdot \left(\frac{D}{h_0} \right)^{\frac{1}{2}} \cdot \left(\frac{\Delta h}{h_0} \right)^{\frac{1}{2}} - 0,05 \quad (3.25)$$

where D is diameter of rolls [mm],

μ - friction coefficient (calculation is carried out as per EKELUND's relation (5)),

Δb – absolute spread, $\Delta b = b_1 - b_0$ [mm],

Δh – absolute height reduction [mm].

The spread rate in dependence on chemical composition of the material may be determined for a specific forming temperature e.g. according to the following formula, which was derived in The Institute of Modelling and Control of Forming Processes in the Department of Metal Forming:

$$\begin{aligned} \frac{\Delta b}{\Delta h} (950^\circ\text{C}) = & 0.5143 + 0.0561 \cdot C - 0.0120 \cdot Mn + 0.0312 \cdot Si + 0.0192 \cdot Cr - 0.6931 \cdot N - 3.4313 \cdot P + \\ & + 0.5912 \cdot S - 0.1400 \cdot Cu + 0.0399 \cdot Ni - 0.2552 \cdot Al - 0.1234 \cdot Mo + 17.0206 \cdot W - \\ & - 0.0579 \cdot V - 0.7188 \cdot Ti - 4.4571 \cdot B + 17.8213 \cdot Ca - 11.3084 \cdot Nb \end{aligned} \quad (3.26)$$

The content of particular elements in this equation is given in wt%. Equation (3.26) was obtained by rolling of ca 30 types of steels on plain steel rolls of the laboratory rolling mill K350 in the four-high arrangement.

Characteristic cases of penetration the plastic deformation through height of the cross section and the influence of plain work rolls diameter on spread may be seen in Figs 3.6 and 3.7.

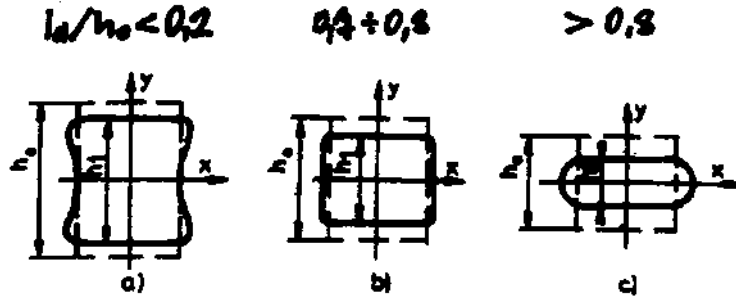


Fig. 3.6 Characteristic cases of penetration the plastic deformation through height of cross section:

- a) height deformation does not penetrate into the middle of the rolled stock height
- b) height deformation strikes central layers of metal
- c) in medium layers of the metal the maximum height deformation is achieved

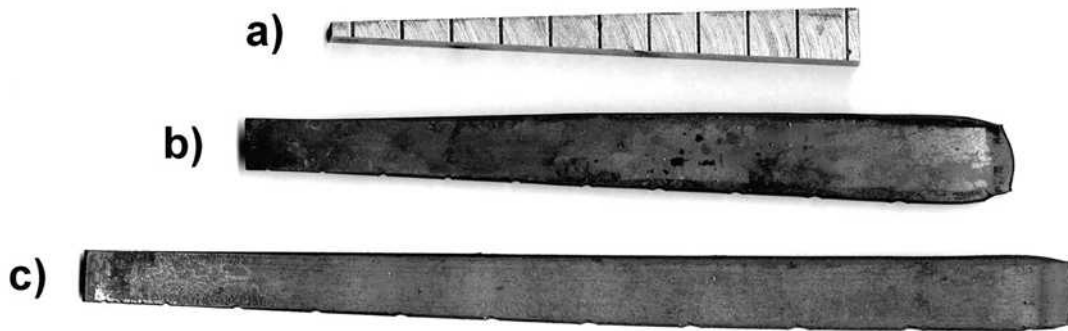


Fig. 3.7 Influence of plain work rolls diameter on spread

- a) initial wedge sample of length 150 mm with milled notches (side-view)
- b) wedge sample after rolling (roll diameter 140 mm – top-view)
- c) wedge sample after rolling (roll diameter 64 mm – top-view)

□ Roll force

Roll force is defined as a vertical component of the resulting compression force of the rolled metal on the work rolls. It is determined as a sum of elementary vertical forces caused by radial and tangential stress components.

The roll force may be calculated as the product of mean flow stress (SPDO) σ_{ps} , mean forming factor Q_{Fv} and contact surface of the rolled stock with the working part of roll S_h .

$$F_V = \sigma_{ps} \cdot Q_{Fv} \cdot S_h \quad (3.27)$$

where F_V is roll force [kN],

σ_{ps} - mean flow stress [MPa],

S_h - horizontal projection of rolled stock contact surface with working part of roll [mm²],

Q_{Fv} - mean forming factor

In rolling of flat products with a small final thickness it is necessary to consider rolls flattening, and hence increase of l_d value, and spread of the material in roll gap. In rolling on grooved rolls the value of the contact surface is determined with respect to the used pass sequence, spread value and groove geometry.

Among main factors influencing the value of roll force rank:

- power-force parameters (except for roll force also roll torque and drive output),
- maximum biting capabilities of rolls – for the reliable bite the following condition has to be fulfilled:

$$\Delta h_{\max} \leq R_{\min} \alpha_{0,\max}^2 \quad (3.28)$$

where $R_{\min}$ is minimum radius of rolls with consideration of re-turning the rolls [mm],
 $\alpha_{0,\max}$ – maximum nip angle [°],

- hot forming limit,
- achievement of required structural state and properties,
- achievement of minimum thickness differences in the cross and longitudinal section of the sheet/plate and maximum flatness

On current conditions the check of power-force parameters is decisive and a stress is also laid on dimensional accuracy of rolled products.

During the calculation and check of power-force parameters the following variables are successively determined:

- mean flow stress σ_{ps} ,
- roll force F_v ,
- roll torque M_k ,
- drive output P

□ Forming factor

The forming factor Q_{Fv} features influence of mean stress acting at the roll/stock interface in the deformation zone on the roll force value. The value Q_{Fv} depends on shape and geometry of the rolled stock in the roll gap, deformation conditions and conditions of friction between the rolled stock and work rolls. For conditions of flat products rolling the forming factor is expressed as a function

$$Q_{Fv} = f_1 \left(\frac{l_d}{h_s}; \frac{b_0}{h_0}; \frac{\Delta h}{h_0}; \mu \right) \quad (3.29)$$

where l_d/h_s is geometric factor,
 l_d - deformation zone length [mm],
 h_s - rolled stock mean height $h_s = (h_0 + h_1)/2$ [mm],
 $h_0; b_0$ - initial height and width of the material [mm],
 $h_1; b_1$ - height and width after rolling [mm],
 μ - friction coefficient in rolling,
 $\Delta h = h_0 - h_1$ [mm]

The geometric factor (in Anglo-Saxon references the term “aspect ratio” is used) implies the roll geometry and the roll gap set up and is expressed as follows:

$$\frac{l_d}{h_s} = \frac{2 \cdot \sqrt{R \cdot (h_0 - h_1)}}{h_0 + h_1} \quad (3.30)$$

where R - roll radius [mm].

For conditions of rolling in symmetrical grooves the opinions of functional expression of forming factor Q_{Fv} are not unified. Differences are above all in the expression of geometric factors.

$$Q_{Fv} = f_2 \left(\frac{l_s}{h_{ss}}; \frac{b_{0\max}}{h_{0s}}; \frac{\Delta h_s}{h_{0s}}; \mu \right) \quad (3.31)$$

The geometric factor l_s/h_{ss} may be expressed by relation

$$\frac{l_s}{h_{ss}} = \frac{2 \cdot \sqrt{R_{sp} \cdot (h_{0s} - h_{1s})}}{h_{0s} + h_{1s}} \quad (3.32)$$

Friction conditions in the roll gap are influenced by the work rolls roughness and hardness, the scaled rolled stock surface and temperature, rolling speed and other factors. In case of the evaluation for a specific rolling mill stand we suppose that the value of friction coefficient μ is in the course of rolling constant and may be included directly in the value of forming factor Q_{Fv} . The aim is to find an optimum function representing an appropriate dependence of forming factor Q_{Fv} on forming conditions.

□ Roll torque

Roll torque is a main part of the basic moment M_z and assures the deformation process of the material in the roll gap. The roll torque is transferred from the twisting moment of the drive via the spindle to the work rolls. In general, the value of roll torque depends on the deformation resistance value which the rolled stock puts up during rolling (in the course of its moving in the rolling direction) to the work rolls. In practice two empirical relations for determination of the value of roll torque M_V [kN·m] exist. The first one is in the form as follows:

$$M_V = F_t \cdot R = \tau_s \cdot S_h \cdot R = \sigma_{ps} \cdot Q_M \cdot S_h \cdot R \quad (3.33)$$

where R is mean working radius [mm],

F_t - friction force [kN],

τ_s - mean deformation resistance of the formed metal in direction of the tangent to the work roll [MPa],

Q_M - mean forming factor for determination of roll torque.

The second relation may be expressed as follows:

$$M_V = F \cdot a = F \cdot \psi_1 \cdot l_d = F \cdot \psi_1 \cdot \sqrt{R \cdot \Delta h} \quad (3.34)$$

where F is the compression force [kN],

a - arm of the resulting compression force [m],

ψ_1 - coefficient featuring the ratio of the arm of the compression force to the projected roll gap length $\psi_1 = a/l_d$.

□ Flattening of rolls

As all rolls are elastic, they are also deformed during forming. A main substance of this deformation is shown in Fig. 3.8, where the shape of the rigid roll with radius R is compared to the flattened roll with radius R' .

Main impacts of the roll flattening are:

- contact arc length is extended as compared with the rigid roll
- the entry and exit surfaces are shifted from the rolls centerline

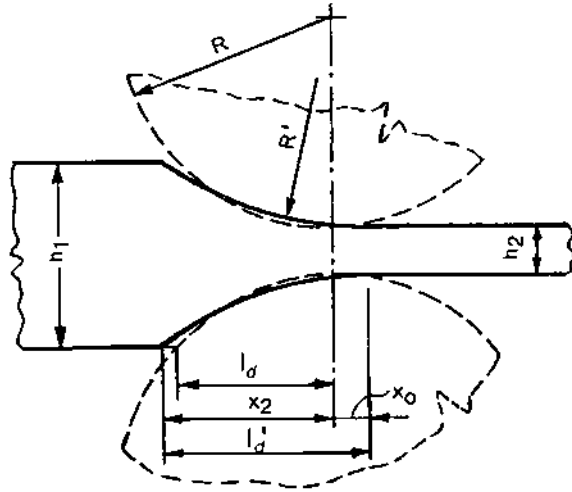


Fig. 3.8 Geometric relations at elastic flattening of rolls

For radius of flattened roll R' the following relation is valid:

$$R' = R \cdot \left(1 + e \frac{F_v}{b \cdot \Delta h} \right) \quad (3.35)$$

$$R' = R \cdot \left(1 + \frac{16 \cdot (1 - \nu^2)}{\pi E} \cdot \frac{F_v}{b \cdot \Delta h} \right) \quad (3.36)$$

where R is roll radius [mm],
 F_v - roll force [N]
 e - elastic constant [MPa^{-1}]
 E - modulus of elasticity in compression [MPa]
 b - rolled stock width of [mm]
 ν - 0.3 (Poisson number)



Solved tasks

Example 3.1

During rolling in blooming with roll diameter $D = 1\,100$ mm a pass with absolute thickness reduction $\Delta h = 120$ mm was carried out. Calculate the nip angle and deformation zone length using approximate and accurate formula. Express the percentage difference. Make a decision whether it is possible to use the approximate formula in technological practice.

♦ Solution

For calculation of nip angle we use the following equation:

$$\alpha = \arccos \left(1 - \frac{\Delta h}{D} \right) = \arccos \left(1 - \frac{120}{1100} \right) = 27^\circ 00' 44''$$

The length of the deformation zone we calculate using the approximate and accurate relation:

$$l_d = \sqrt{R \cdot \Delta h} = \sqrt{550 \cdot 120} = 256.9 \text{ mm}$$

$$l_d = \sqrt{R \cdot \Delta h - \frac{\Delta h^2}{4}} = \sqrt{550 \cdot 120 - \frac{120^2}{4}} = 249.8 \text{ mm}$$

The error in per cent we determine simply by means of rule of three:

100%.....249.8 mm

x%256.9 mm

$$x = \frac{256.9}{249.8} \cdot 100 = 102.84\%$$

The mistake in the case of using the approximate formula represents 2.84 % and this approximate formula may be applied in the technological practice.



Summary of terms of this chapter

Deformation zone – biting capabilities of rolls – forward slip – strain rate – spread – roll force – roll torque – forming factor – flattening of rolls.



Questions to discussed curriculum

- 3.1. What are biting capabilities of rolls?
- 3.2. What is forward slip in rolling?
- 3.3. What is strain rate? What is its unit?
- 3.4. What expresses spread in rolling?
- 3.5. What are 3 types of spread?
- 3.6. What factors have essential influence on spread value?
- 3.7. How is defined roll force?
- 3.8. What features the forming factor?
- 3.9. What the forming factor value depends on?
- 3.10. What is roll torque?
- 3.11. What are main consequences of roll flattening?



Used references that are recommended for further study

GINZBURG, V. B.: *Steel-Rolling Technology : Theory and Practice*. New York : Marcel Dekker, 1989.

4. Production of semi-finished rolled products and tie-in of rolling with continuous casting



Time for study: 3 hours



Target After studying this paragraph you will be able to

describe production of semi-finished rolled products, advantages and disadvantages of continuously cast semi-products...



Presentation

□ Initial material in rolling mills

- 1) **cast** – ingots, continuously cast semi-products (CCS), centrifugally cast hollow ingots, die cast slabs, powder materials and others
- 2) **hot rolled semi-finished products**

□ Production of semi-finished rolled products

- **blooming**
blooming mills, they roll blooms of square cross sections or also slabs to $\leftrightarrow$ 1200 mm, reheating in soaking pits, reversing two-high mills (heavy manipulators), plain part + grooves, tilting. The blooming flow diagram at Třinecké železářny (Třinec Iron and Steel works) is given in Fig. 4.1
- **slabbing**
slab rolling, horizontal and vertical rolls, plain rolls, in an upright position to remove bevels, then in horizontal position (flatwise)
(not used any more – replaced for continuous casting)
- **billet mills**
mill stands for rolling of billets and sheet bars, up-to-date – continuous, groove designing (box grooves, diamond – square, oval – square, oval – round)



Fig. 4.1 Blooming at Třinec Iron and Steel Works

(TŽ - ohřívací pece a blokovna I. – soaking pits, reheating furnaces and blooming I
ZPO 1 – CCM No. 1, bramové hospodářství – slab treatment,
vratná trať – reversing rolling mill

1 - transfer car, 2 - finishing line, 3 - protective layer spraying, 4 - transfer set, 5 - walking beam furnace, 6 -hydraulic scalebreaker No. 1, 7 - old soaking pits, 8 - new soaking pits, 9 - ingot bogie, 10 - hydraulic scalebreaker No. 2, 11 - ingot tilter, 12 - blooming drive, 13 - pinion stands, 14 - blooming roll stand (two-high mill), 15 - roller tables, 16 - hydraulic shear, 17 - bloom and slab stamping machine, shromažďovací místo - gathering places, kontrolní bod - checking points, hlavní agregáty - key aggregates, pomocná zařízení - auxiliary equipment)

Roughing mills are with a single roll stand or two roll stands in tandem arrangement – with two-high roll stands or three-high roll stands (older mills). Currently bloomings are equipped with rolls of diameters 1200 and 1300 mm, or up to 1350 mm. Ingots are reheated in soaking pits. One soaking pit has usually 4 chambers for 6 to 8 ingots. The ingot rolling requires using higher reheating temperatures, which ensure better weldability and achievement of higher finish rolling temperatures. The ingot rolling procedure show photographs in Fig 4.2.



Ingot stripping



Soaking pits



Fig. 4.2 Ingot rolling in blooming

The billet rolling mills work usually as single-line mills, located directly behind blooming mills in the open, semi-continuous or continuous arrangement (e.g. Fig. 4.3).

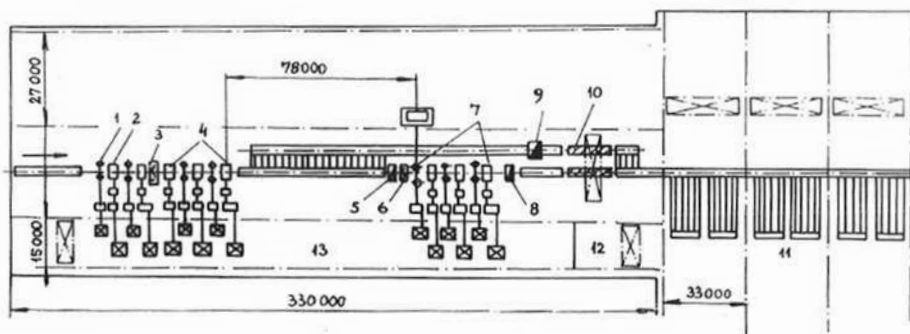


Fig. 4.3 Layout of billet mill with three trains

□ Continuous casting of semi-products (CCS - Continuously Cast Semis)

It is the widespread used mode of production replacement for rolled semi-finished products nowadays.

Benefits of continuous casting in comparison with the ingot technology:

- productivity,
- material savings 10 to 15 %,
- fuel energy savings,
- production and investment costs savings
- labour force savings,
- improvement of surface, internal quality and homogeneity

Disadvantages of continuous casting:

- central segregates and porosity (Figs 4.4 and 4.5), pressure-welding up of which requires an increased reduction ratio,
- limited CCS assortment as far as dimensions and shapes is concerned
- mostly insufficient casting speed with regard to required entry speeds of continuous rolling mills



Fig. 4.4 Macrostructure of continuously cast slab with thickness 150 mm (transformer steel with 3 % Si)



axial shrinkage porosities



axial crack

Fig. 4.5 Round continuously cast semi-product Ø 535 mm

Currently a very large steel assortment is continuously cast. Except for common sorts of carbon and slightly alloyed steels also microalloyed, silicon, corrosion-resistant, creep-resistant, etc. steels are cast.

Continuous casting machines (CCM)

That is the question of direct connection of continuous casting on CCM equipped with stationary moulds with rolling of finished products. This procedure is limited by considerable differences between the CCM exit speed and the minimum entry speed of finishing rolling mills.

As on CCM with stationary moulds the increase in casting speed to 6 to 7 m·min⁻¹ is difficult, the high-reduction forming machines are integrated between CCM and the rolling mill. Some of them, e.g. planetary mill Sendzimir or Platzer, are able to roll out the finishing rolled product (strip) with the rolled stock extension in one pass.

In the near future, dimensions and shapes of CCS could be very close to dimensions and shapes of final products (so-called near-net-shape-casting).

The required smaller dimensions of CCS and at the same time higher casting speeds are ensured by development and commissioning of the new generation of CCM with movable moulds. Photographs of the continuously cast semi-product and examples of conventional and new CCM types are shown in Figs 4.6 - 4.9.



Continuously cast slabs



Continuously cast semis with round cross section



Billet continuous casting



Fig. 4.6 Continuously cast semi-finished products

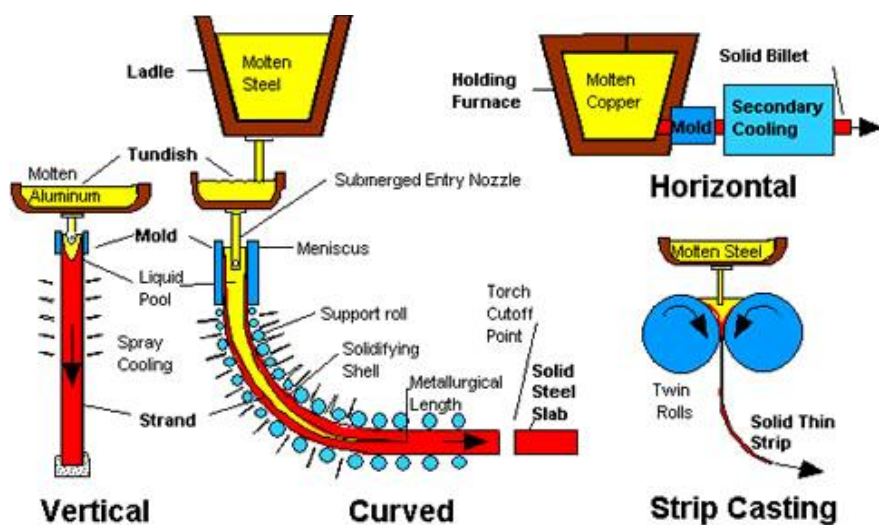


Fig. 4.7 Various technologies of steel and non-ferrous metals continuous casting

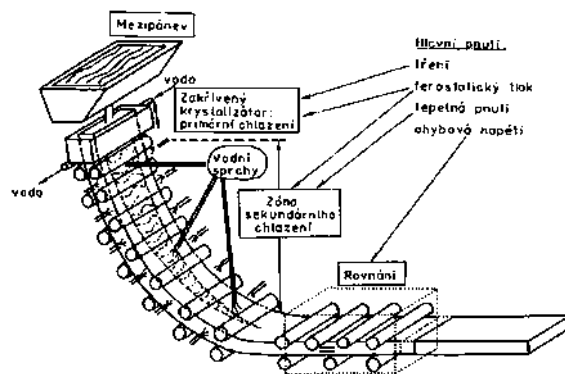


Fig. 4.8 Slab continuous casting with bending of CCS

(mezipánév - tundish, voda - water, zakřivený krystalizátor: primární chlazení - curved mold: primary cooling, vodní sprchy - water sprays, zóna sekundárního chlazení - secondary cooling zone, rovnání—straightening, hlavní pnutí: tření, ferostatický tlak, tepelná pnutí, ohybová napětí - main stresses: friction, ferostatic pressure, thermal stresses, bending stresses)

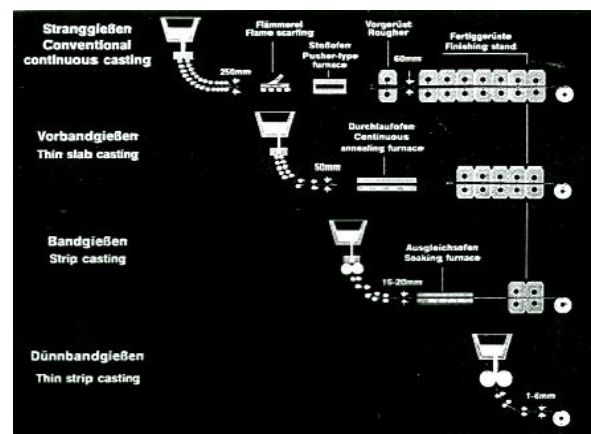
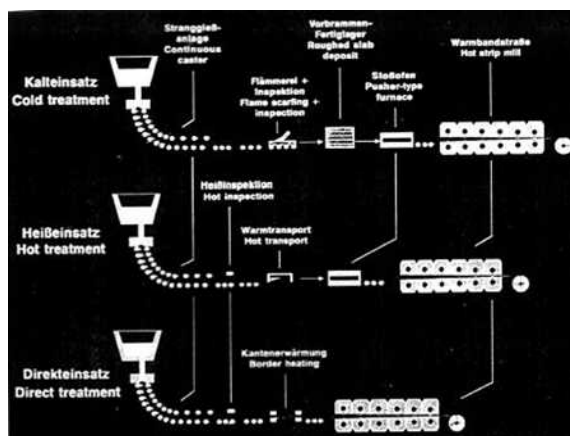


Fig. 4.9 Thin slabs and strips continuous casting

□ Ingots

The ingot dimensions, shape and weight depend on the purpose of its use and chemical composition of steel. The ingot cross section is:

- *square* for rolling of semi-finished products, steel sections, narrow and partly wide strips, universal flats and seamless tubes;
- *rectangular* for rolling of flat products, i.e. plates and thin sheets, wide strips and universal mill plates of larger widths;
- *round* for rolling of seamless tubes
- *polygonal*, mostly for blanks (rough forgings).

A general rule is valid: the higher quality and more demanding steels are cast to ingots with smaller weight and more bevels. Carbon steels with carbon content to 0.3 % are cast to ingots of the biggest weight.



Summary of terms of this chapter

Ingots – continuously cast semi-products (CCS) – semi-finished rolled products – blooming – slabbing – billet mills



Questions to discussed curriculum

- 4.1. What are roughing mills?
- 4.2. What furnaces are used for reheating of ingots before rolling?
- 4.3. What are benefits of continuous casting?
- 4.4. What are disadvantages of continuous casting?
- 4.5. How may ingots be divided as per their cross section?
- 4.6. What do you think - is surface and internal quality of ingot better than of continuously cast semi-product or vice versa?
- 4.7. Are currently ingots still used?



Used references recommended for further study

GINZBURG, V. B.: *Steel-Rolling Technology : Theory and Practice*. New York : Marcel Dekker, 1989.

5. Flat hot and cold rolled products



Time for study: 8 hours



Target After studying this paragraph you will be able to
describe production of hot and cold rolled plates and strips
acquire a survey of manufacturing plants in our region and their product mix



Presentation

5.1. Plates

That is the question of flat products with a full cross section along the whole length. A boundary between plates and sheets is **thickness 3 mm**. Width is to 5 m, maximum thickness up to 100 mm.

Initial semi-products – slab ingots (up to 100 tons), continuously cast slabs, rolled or forged slabs. Reheating is carried out in continuous walking beam or pushing-type furnaces (Fig. 5.1). They are rolled especially in a **single roll stand** (less often with two roll stands and others) – Figs 5.2 and 5.3, and **reversing rolling mills** (with **four-high** or two-high stands). There is a chance to roll the width in advance, turn the rolled-out stock by 90° and finish-roll the length (reduction of anisotropy).



Slab after reheating in walking beam furnace



Rolled-out stock of initial slab in plate four-high mill



Resulting plate



Four-high rolling mill 3.5 (Vítkovice)

Fig. 5.1 Plate production procedures

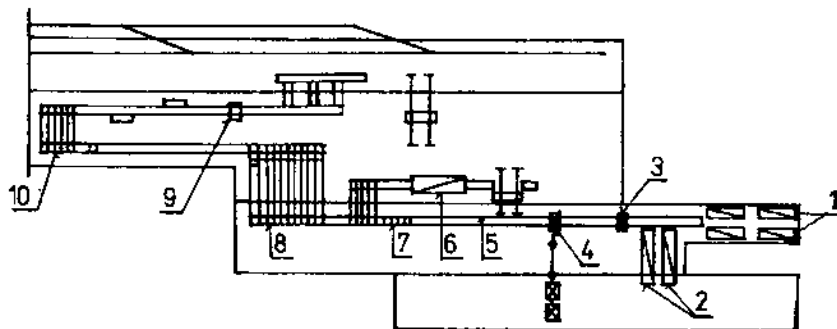


Fig. 5.2 Scheme of a single stand plate rolling mill

1-chamber reheating furnaces, 2-pushing-type reheating furnaces, 3-scalebreaker, 4-four-high stand, 5-roller table, 6-heat treatment furnace, 7-straightening machines, 8-cooling bed, 9-shears, 10-transfer

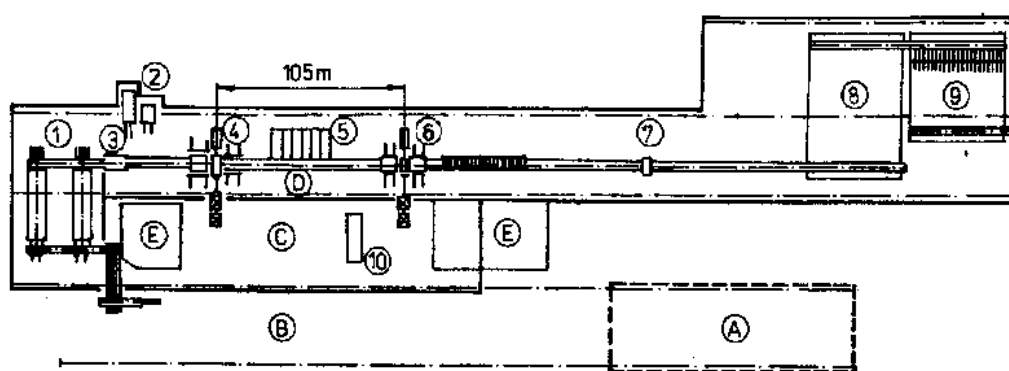


Fig. 5.3 Scheme of two-stand plate rolling mill 5.5 – 4.8

1- pushing-type furnaces, 2- car-hearth furnaces, 3- scalebreaker, 4- 5.5 m four-high mill, 5- transport devices, 6- 4.8 m four-high mill, 7- hot straightener, 8- cooling bed, 9- inspection bed, 10- roll-turning shop

Rolling mill stands are equipped with two independent **adjusting systems**: the rough electro-mechanical adjustment between passes and the fine hydraulic adjustment in the course of the pass. A prerequisite for a long service life is efficient **roll cooling**.

The plate rolling is connected with various finishing banks (for accelerated cooling, cooling beds, dividing devices and heat treatment furnaces). A very suitable is connection with **TMRC (thermomechanical rolling and cooling)** → temperature and deformation control → the aim is control of structural processes → finer grain → better mechanical properties.

□ Four-high mill 3.5 in Vítkovice Steel, a.s.

The initial material for the four-high rolling mill 3.5 is mostly slabs coming from the own continuous casting machine, which are reheated in pushing-type furnaces. Slab dimensions:

- thickness: 100 - 250 mm,
- width: 800 - 1 580 mm,
- length: 1 700 - 3 100 mm

The slab shortest length is limited by the pitch of bearing skid rails and the maximum by the furnace inside width.

Each furnace has two rows, but different construction, control system and different output and technological parameters of reheating.

Charging and reheating slabs in pusher furnaces

There are two chances of slab charging:

- charging from the storage yard of 3.5 Four-high rolling mill (Fig. 5.4) - stored slabs are charged to furnaces as per the charging schedule prepared in advance,
- direct charging – slabs are transported from the CCM runout section only after necessary cooling down and charged to pushing-type furnaces. The temperature of slabs is usually higher, in dependence on cooling time and transport.

Reheating in pusher furnaces is carried out in such a way so that slabs could not be damaged during reheating. Slabs are divided into groups as per steel grades, for each group the different strategy of reheating is chosen. Groups of steels are marked by numerals 1 - 9. Particular steel grades are ranked to the reheating groups in the production management system. The temperature mode of the furnaces is controlled by the control computer in dependence on the pace of rolling in such a way so that reheating to the prescribed temperature and uniform warming-through the slab could be guaranteed. The common steel grades are reheated to the slab average temperature 1 220 °C (for the rolled product thickness up to 6.4 mm 1 250 °C - faster cooling in rolling). The alloy, microalloyed and high carbon steels are reheated to the slab average temperature 1 250 °C (higher resistance characteristics in forming - more pass reductions and hence faster cooling).



Fig. 5.4 Slab storage yard

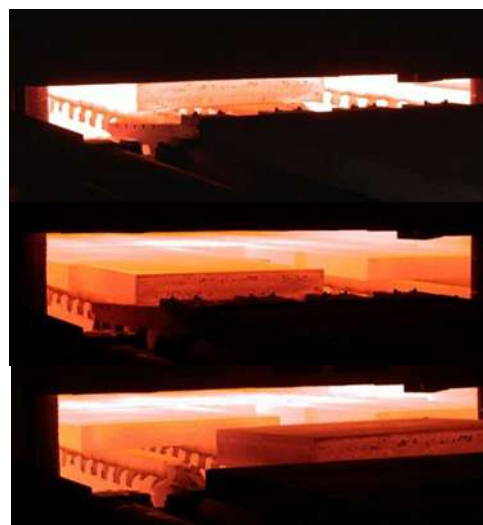


Fig. 5.5 Sequence of slabs extraction out of the furnace

Slab extraction out of pusher furnaces

Based on signal from the process computer of the rolling mill or signal from the operator, the reheated slab is extracted out of a specific row in the furnace by means of the extractor (Fig. 5.5). The slab is put into the centre line of the roller table section behind the furnace. After putting the slab on the roller table the slab is transported to the hydraulic scalebreaker.

In conventional or temperature-controlled rolling where an imperceptible decrease in slab temperature before rolling has no substantial influence, the signal for extraction the slab out of the furnace is sent in such a way that the slab is transported to the roller table behind the scalebreaker slightly ahead of time. From the roller table the slab is transported to the front side of the roll stand, as soon as the roll stand is released.

In controlled rolling (CR, TMR) the signal for extracting the slab out of the furnace is sent in such a way so that a fix pace of rolling the pertinent group of slabs was maintained and the new slab could be transported to the roll stand without delay. The slab oscilation on the roller table behind the

scalebreaker is carried out at speed $\pm 0.15 \text{ m.s}^{-1}$ to prevent the local slab cooling and overheating the rollers.

Hydraulic scalebreaker of slabs

This device serves for removal the primary scale from top and bottom surface of slabs by water with pressure 23 MPa (on nozzles). In relation to slab thickness, the corresponding distance of top nozzles from the slab surface is continuously set up. The bottom nozzles are fixed below the rollers. The slab thickness is set up by the control system of the scalebreaker either from the furnace control system or manually from the operator cabin. After passage the scalebreaker the slab:

- is transported by the feeding roller table to the rolling mill stand, or
- is oscillating on the roller table behind the scalebreaker.

Basic technological parameters of the four-high rolling mill 3.5

The rolling mill has four rolls: two are work rolls and two are back-up rolls.

- Work rolls (Fig. 5.6).
 - max diameter 1 005 mm
 - min diameter 940 mm
 - roll barrel 3 500 mm
- Back-up rolls (Fig. 5.7).
 - max diameter 1 900 mm
 - min diameter 1 750 mm.



Fig. 5.6 A pair of work rolls with chocks prepared for changing

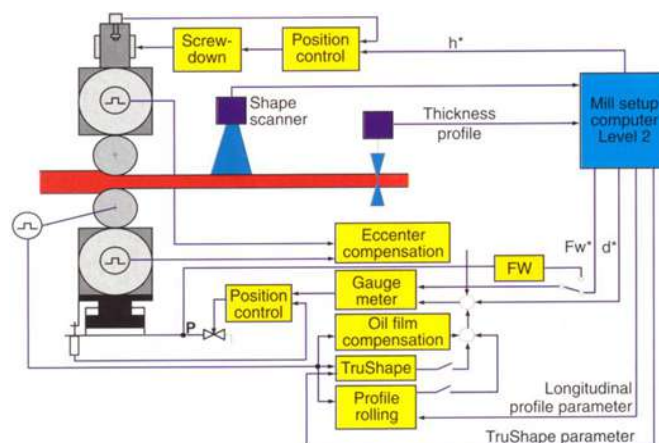


Fig. 5.7 Back-up rolls, front view - “undressed” roll, rear view - roll with chocks and cooling nozzles

The roll stand K3.5 is shown in Fig. 5.8. The pressure capability of the stand (roll force maximum value, including dynamic peaks acting in the roll gap, for which the stand is designed and which must not be exceeded during normal operation) is 62 MN.



Fig. 5.8 Roll stand K3.5 – side view and control cabin view



Work roll cooling: it is a segment system of cooling, which affects the thermal crown of work rolls at the same time. The segment cooling is divided into three zones along the roll barrel (edge - centre - edge). Hydraulic descaling in the roll stand: it is carried out always against the direction of entry the rolled material inbetween rolls. Top nozzles are set up simultaneously with a lift of the top rolls assembly, and so no set up of these nozzles through height is needed. Bottom nozzles are stationary. The counterbending system of work rolls: hydraulic cylinders are used for pushing the work rolls to the back-up rolls.

The real **thickness** of every finish-rolled product is measured after final pass by means of contactless thickness gauge with three heads. Measurements are carried out during movement of the rolled product in the middle of plate and simultaneously in the distance ca 150 mm from its both edges; thus it is ensured that the fluent course of rolling will not be disturbed. During thickness measurements the influence of the steel temperature and chemical composition is automatically compensated.

Temperature measurements of slabs and rolled-out stocks are carried out by pyrometers before and after the rolling mill stand.

Shape of the rolled material is measured in an optical way by means of Shape Scanner (Fig. 5.10). It is located perpendicularly above the turntable at the roll stand rear side above the crane runway. The rolled material shape is shown optically at the scanner surface. The receiver uses the own thermal radiation of the material. The following measurements are carried out:

- 46

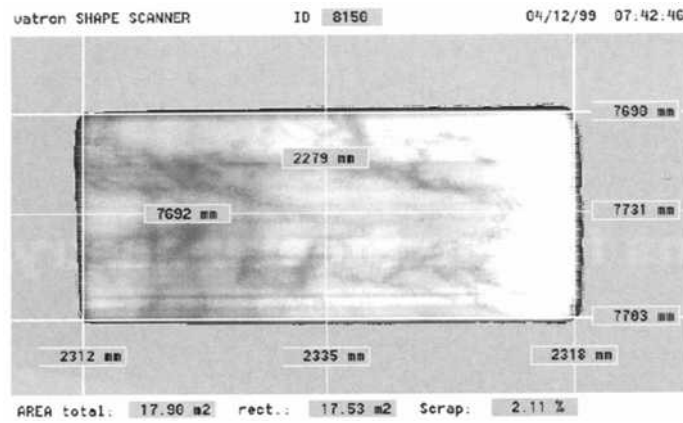


Fig. 5.10 Plate shape measurement

5.2. Hot rolled strips

Hot rolled strips represent a crucial share of the flat products totally produced quantity. They are produced in thicknesses from 0.8 to 35 mm, in widths up to 2.3 m and coil weight up to 45 tons.

For hot rolling of steel strips the following rolling mills are mostly used: **continuous**, **semicontinuous** (Figs 5.11 – 5.13), **Steckel**, reversing compact, planetary.

The issue of so-called **temperature wedge** in case of continuous mills (the rear end of the strip is cooler by up to 90°C) is solved by introduction the rolling technology with speed up. This technology consists in speeding up the finishing train at the moment of gripping the front end of the strip by the coiler, which leads to warming of faster rolled and cooler rear parts of the strip by the deformation heat.

Another possibility is installation of **coilbox**: The rolled-out stock is coiled with the heat preservation and temperature equalization. The temperature wedge along the mill is reduced to ca 20 °C.

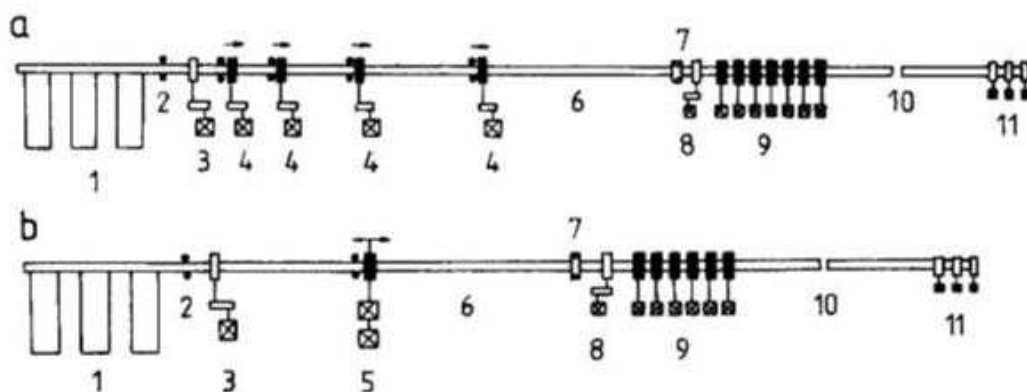


Fig. 5.11 Scheme of continuous (a) and semicontinuous (b) wide strip mill

1-reheating furnaces, 2-vertical scalebreaker, 3-horizontal scalebreaker, 4-continuous universal four-high mill, 5-reversing universal four-high mill, 6-connecting roller table, 7-flying shears, 8-scalebreaker, 9-continuous four-high stands of finishing train, 10-runout and cooling section, 11-coilers

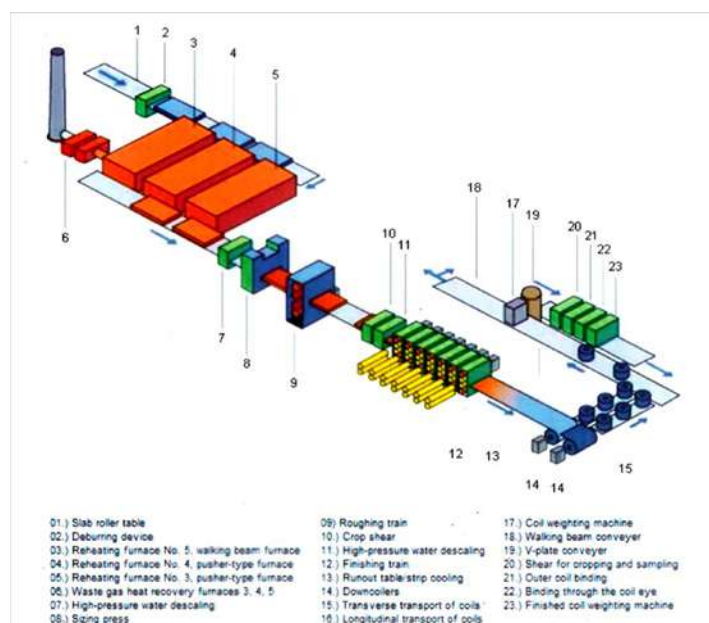


Fig. 5.12 Scheme of up-to-date semicontinuous mill for strip hot rolling



Fig. 5.13 Continuous mill train

Steckel mill

This rolling mill is equipped with a four-high roll stand with two furnace coilers (the rolled-out product is alternately coiled on both coilers located in furnace chambers before and after the roll stand, and it is thus continuously after-heated). This type of rolling mill is used above all for rolling of strip made of steel grades with deteriorated hot formability, e.g. corrosion-resistant steels. The scheme of Steckel rolling mill you can see in Fig. 5.14.

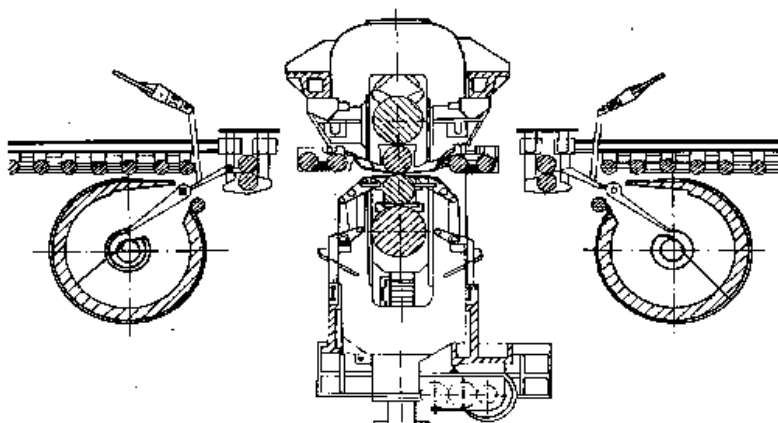


Fig. 5.14 Scheme of Steckel mill

□ Strip rolling mill P1500 Steckel (Minimill – ArcelorMittla Ostrava a.s.)

The scheme of this rolling mill is shown in Fig. 5.15. The liquid steel in casting ladles is transported by transfer cars to the area of the Minimill, where it is further processed by secondary steelmaking (ladle furnace).

In the ladle furnace the following procedures are carried out:

- temperature and chemical homogenization,
- steel deoxidation and its accurate alloying to the required chemical composition,
- steel desulphurization,
- decrease in content of non-metallic inclusions,
- thermal treatment – correction of temperature to the prescribed value for casting

After finishing the steel secondary treatment at the ladle furnace station, the casting ladle with liquid steel is mounted in the ladle turret of the continuous casting machine from where the steel is cast via the tundish into the mould. It is possible to cast CCS in width 740 to 1575 mm and thickness 150 mm. CCS is by flame cutting (cutting torch) divided into particular required lengths (max 18 m).

The hot CCS is on the roller table transported to the walking beam preheating and soaking furnace. After reheating to rolling temperature the CCS is transported to the area of the Steckel rolling mill P1500. After scale removal the CCS enters the two-stand tandem reversing rolling mill with one vertical edger. The rolling mill is equipped with two furnace coilers, which make temperature of the rolled stock in the course of rolling more uniform. After the finishing pass through the mill stand the strip is led on the roller table through 7 sections of laminar cooling to the coiler of final strip. After coiling, finishing (final treatment) and marking, the coils are transported to the storage area (Fig. 5.16).

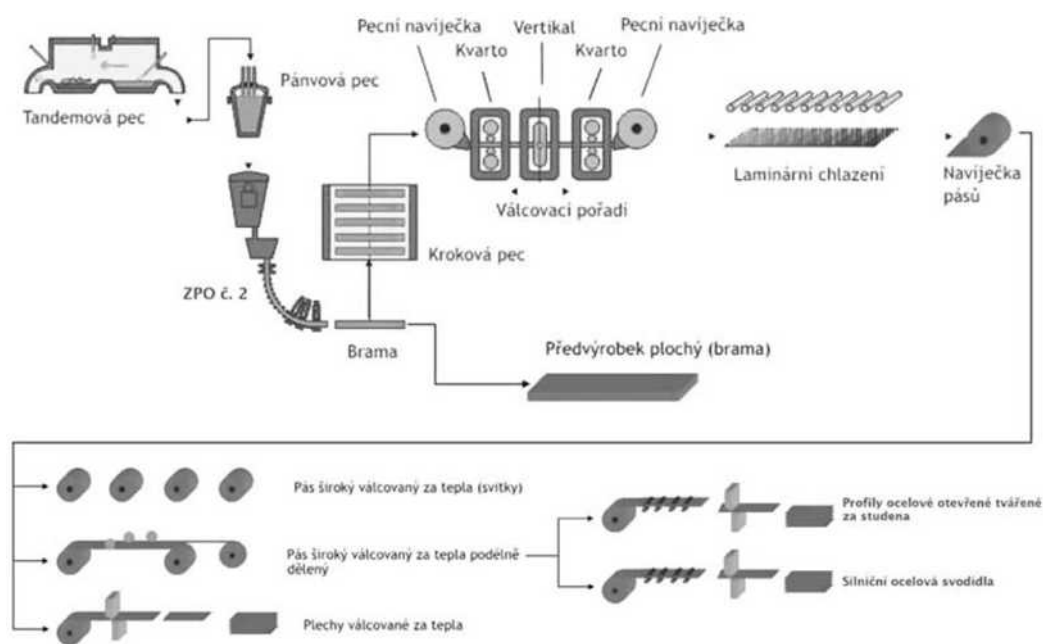


Fig. 5.15 Scheme of mill P1500 Steckel, ArcelorMittal Ostrava, a.s

(Tandemová pec - tandem furnace, Pánvová pec - ladle furnace, ZPO č. 2 - CCM No. 2, Brama - slab, Předvýrobek plochý (brama) - semifinished flat product (slab), Pecní navíječka - furnace coiler, Kvarto - four-high mill, Vertikal - edger, Válcovací pořadí - rolling mill train, Laminární chlazení - laminar cooling, Navíječka pásů - strip coiler;

Pás široký válcovaný za tepla (svitky) - hot rolled wide strip (coils), Pás široký válcovaný za tepla podélně dělený - slit hot rolled wide strip, Plechy válcované za tepla - hot rolled sheets/plates, Profily ocelové otevřené tvářené za studena - steel cold formed opened sections, Silniční ocelová svodidla - steel road barriers)

The production plant of the proper Steckel mill was designed for annual capacity ca 1 000 kt/year. By gradual technological measures the annual capacity was increased to 1 270 kt/year.



Unequally (inhomogeneously) cooled strip



Water cooling - detail



Strip coiler



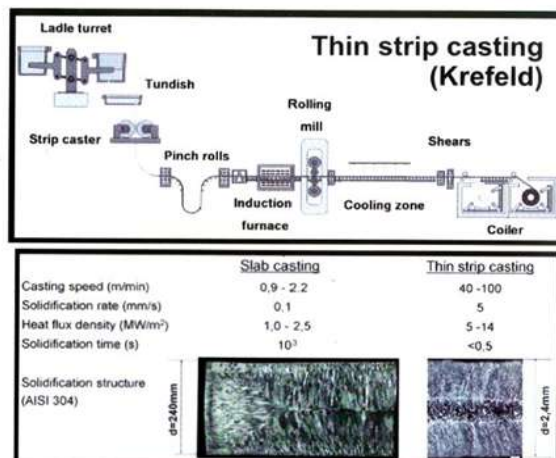
Coil

Fig. 5.16 Two-stand mill P1500

□ Continuous casting of steel strips



Fig. 5.17 Steel strip



	CASTRIP [®] Process	Thin Slab Casting	Thick Slab Casting
Strip Thickness (mm)	1.6	50	220
Casting Speed (m/min)	80	6	2
Average mold heat flux (MW/m ²)	14	2.5	1.0
Total solidification time (s)	0.15	45	1070
Average shell cooling rate (°C/s)	1700	50	12

Fig. 5.18 Continuous casting of strips

□ Strip casting between rolls – non-ferrous metals

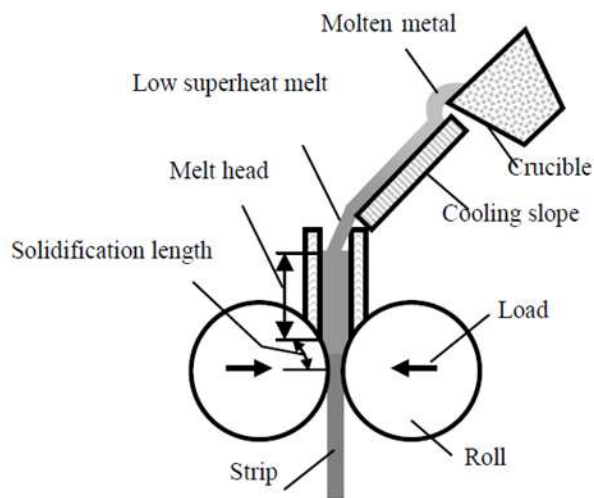


Fig. 5.19 Magnesium alloys



Fig. 5.20 Aluminium

□ “Direct” rolling

That is the question of rolling immediately after the continuous casting machine (it is very advantageous as far as power and the whole economy is concerned).

Questions: To cast various slab thicknesses or to cast directly the strip?

How to harmonize the casting and rolling speed?

CSP : Compact Strip Production (Fig. 5.21)

continuous process, 160 m long tunnel furnace (for up to 3 slabs of length 50 m)

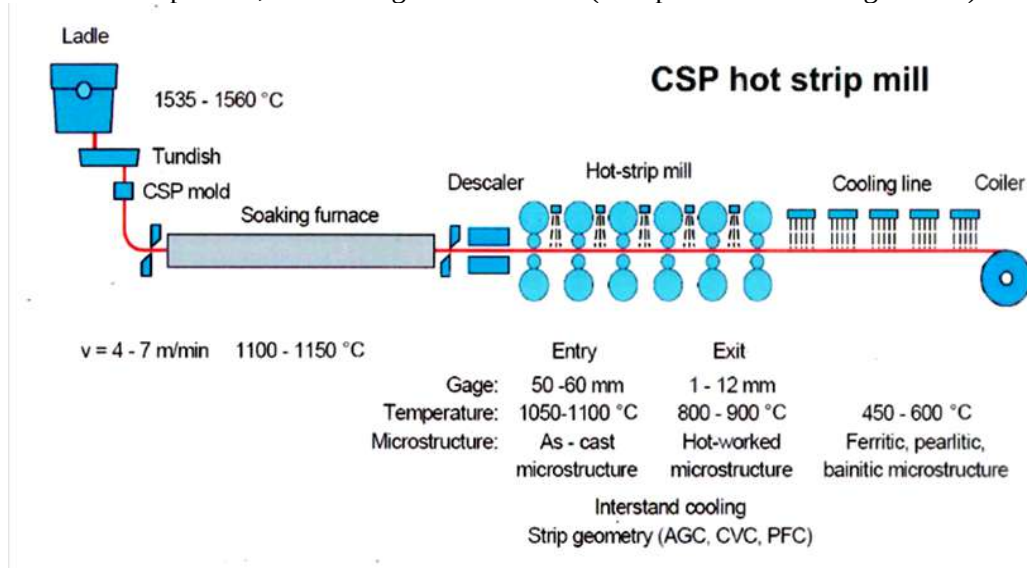


Fig. 5.21 CSP : Compact Strip Production

ISP : Inline Strip Production (Fig. 5.22)

continuous process, forming the slab in the course of its bending, after-heating in the coiler

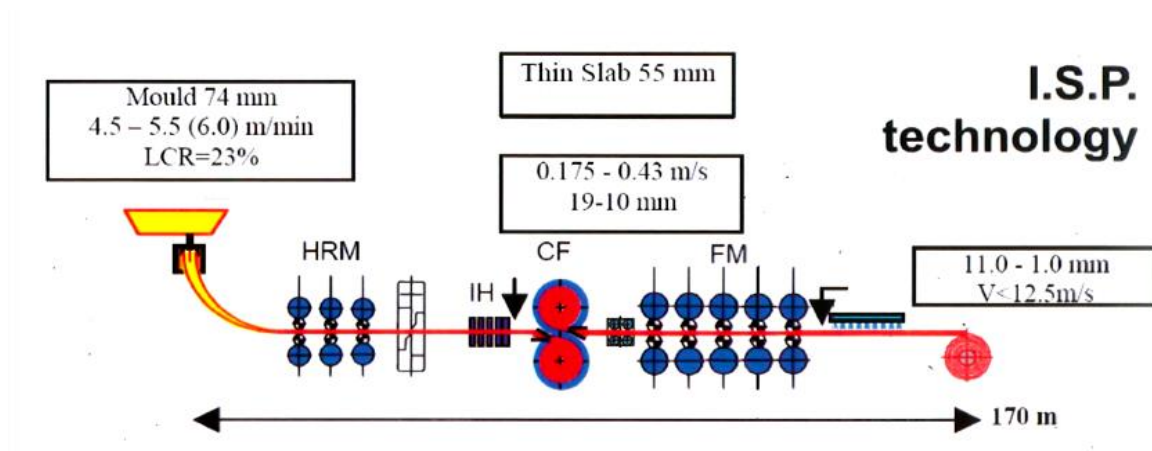


Fig. 5.22 ISP : Inline Strip Production

5.3. Cold rolled strips

A major part of the produced hot rolled strip is determined for further processing in cold rolling mills. In cold rolling **the useful properties of strips are increasing** – increase in surface equality, achievement of required miscellaneous combinations of strength and plastic properties, especially physical and service properties, etc. are evident.

Thin strips are produced of low and high carbon steels, electrical silicon steels, transformer steel, deep-drawing steel, austenitic CrNi steels, widespread are strips of non-ferrous metals.

The strip processing technology in cold rolling mills is usually the following:

- Continuous pickling of strip in solution of HCl or H₂SO₄.
- Cold rolling in the continuous tandem mill with four to six roll stands.
- Continuous annealing or batch (in bell-type furnaces) annealing of strip.
- Sizing/smoothing (planishing) in a continuous single-stand or two-stand rolling mill.
- Finishing of sheets dimensions or surface in slitting/cut-to-length lines, or in galvanizing/coating lines as per requirements of customers.

Used manners of scale removal:

- chemical (pickling in solution of HCl or H₂SO₄)
- electrolytic pickling
- mechanical (cracking, tensile and pressure strain extension of strips, brushing and grinding)

The strip after pickling is susceptible to corrosion – it has to be protected as soon as possible.

Basic types of strip cold rolling mills:

Two-high mill, classic four-high mill, four-high mill MKW (“Mehrwalzen-Kaltwalzwerk” - Fig. 5.23), cluster mill [six roll(er) mill] and Sendzimir mill [20 roll(er) mill] - Fig. 5.24.

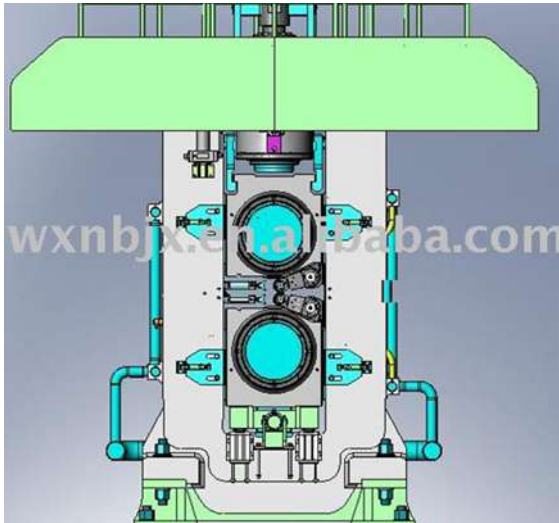


Fig. 5.23 Four-high mill MKW

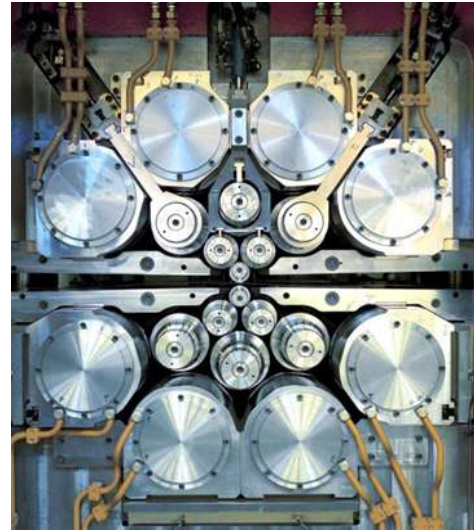


Fig. 5.24 20 roller mill

All these stands can work as reversing or continuous. Examples of the rolling mill and production process of the transformer steel are shown in Figs 5.25 and 5.26. Reversing stands have before and after the roll stand recoiling and decoiling drums.

Tandem mill Ste Agathe : Instrumentation

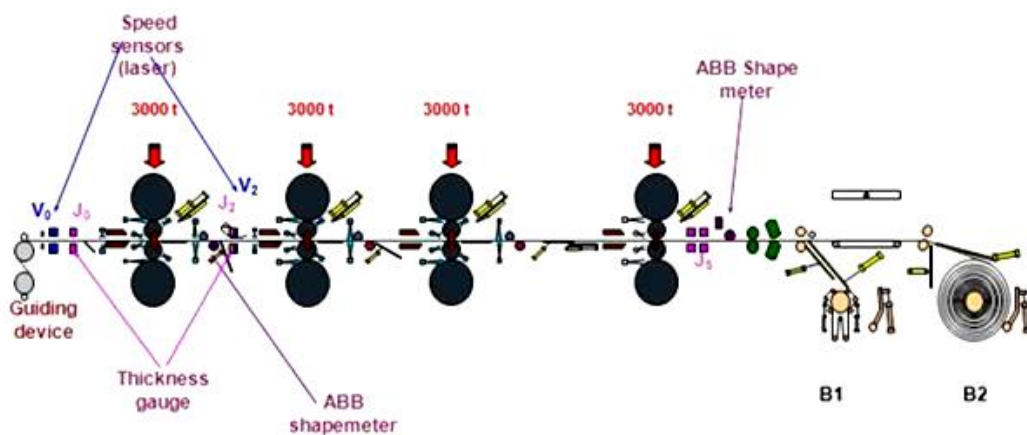


Fig. 5.25 Cold strip rolling mill

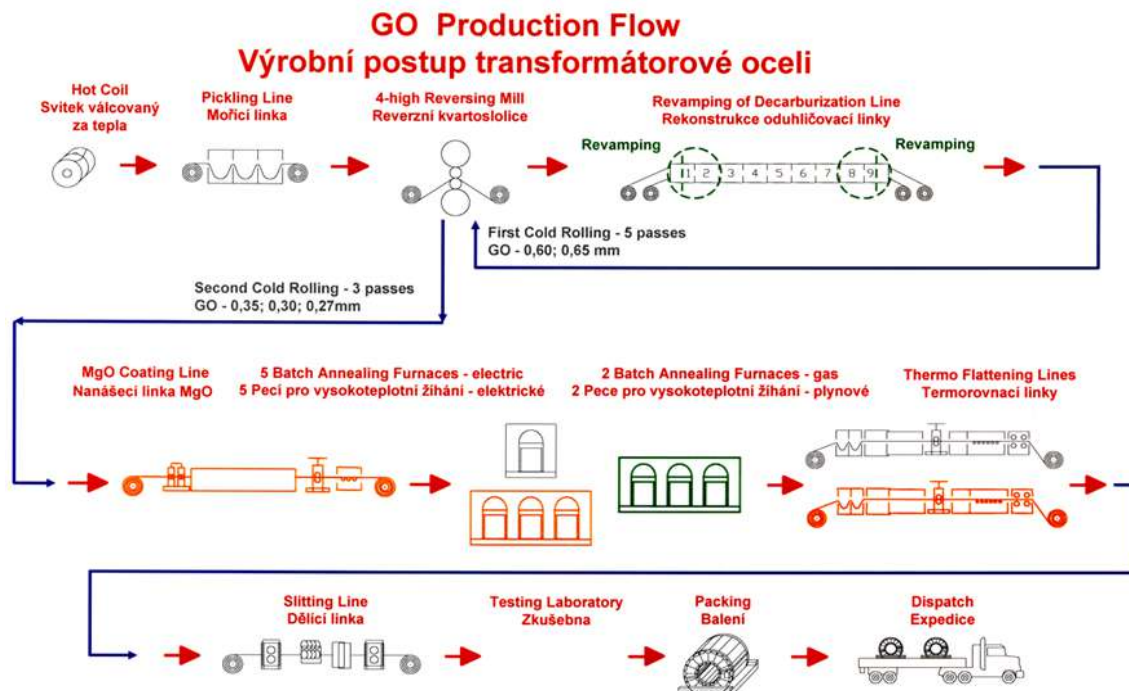


Fig. 5.26 Production flow of transformer steel rolling

Specifics of cold rolling

- deformation texture origin – properties anisotropy
- strain hardening cumulation – annealing (intermediate, final annealing – normalizing, recrystallization, soft annealing, stress relief annealing; heat treatment)
- lubricated hard metal rolls (lowering friction and roll forces, better surface)
- smaller diameter of work rolls – restricted spread (and edge cracking), lower roll forces, lower effectively rolled minimum thickness
- rolling with tension derived by coilers (front, rear) – increased stability of the rolled semi-product, possibility of decrease in deformation resistance

Due to intensive strain hardening in cold forming the steels lose gradually their technological weldability; when the limit of total cold deformation is achieved, their further forming is possible only after prior recrystallization annealing. Intermediate or final **annealing** is carried out in protective atmosphere (hydrogen + nitrogen; lines with bell-type furnaces or continuous lines) – e.g. Fig. 5.27.



Fig. 5.27 Bell-type (batch) annealing furnace

Further finishing procedures in strip rolling mills

Heat treatment, protective coating with metals [Zn (Fig. 5.28), Sn; hot dip coating with molten metal, electrolytic galvanizing/coating], painting/varnishing, coating, plating, enamelling, grinding, polishing, levelling

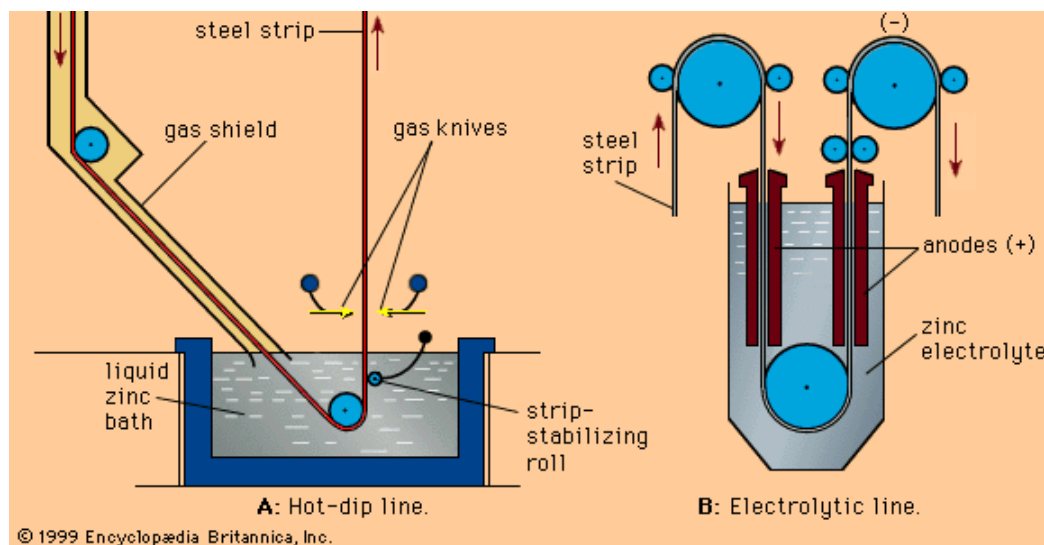


Fig. 5.28 Rolled strips galvanizing



Summary of terms of this chapter

Plates – hot rolled strips – cold rolled strips – Steckel rolling mill – direct rolling



Questions to discussed curriculum

- 5.1. What is the difference between (heavy) plate and thin sheet?
- 5.2. What are initial semi-products for rolling of plates/sheets and strips?
- 5.3. What are specifics of the Steckel rolling mill?
- 5.4. What are reasons for cold rolling of strips?



Used literature recommended for further study

GINZBURG, V. B. *Metallurgical design of flat rolled steels*. New York: Marcel Dekker, 2005.

6. Prediction of power-force parameters of rolling and methods of flatness control of flat rolled product



Time for study: 2 hours



Target After studying this paragraph you will be able to

define basic requirements laid on up-to-date rolling mills and specify what are chances for strip dimensions, crown and flatness control



Presentation

The capability of the accurate roll force and power prediction for perfect control of the forming process is decisive in hot strip rolling.

In the past the prediction models were developed mainly on the basis of OROWAN's theory and its variants. However, a range of the process conditions, in the framework of which the accurate prediction is required, was to a lesser extent limited, above all due to a couple of simplified assumptions included in OROWAN's theory. The exact prediction of power-force parameters carefully formulated by the finite elements method is probably the best choice.

The metal flow is influenced by the heat distribution in strip because yield stress depends strongly on temperature. On the other side, the temperature distribution in rolls is influenced by the heat generation, which is caused by plastic deformation and friction, as well as the speed field in the roll; this results in the relationship between the mechanical and temperature behaviour of the roll. For the prediction of roll forces lots of procedures, which use e.g. the finite element or neuron network methods, are available.

□ Basic requirements laid on up-to-date rolling mills

- high production capacity,
- capability of managing higher power-force load,
- high roll stand rigidity

The high rigidity of the rolling mill stand ensures minimum thickness deviations along and across the sheet, and so required flatness and shape (crown) accuracy. It may be reached by increase in work roll diameter, back-up roll diameter or cross section of the solid web of the housing.

The roll gap shape of is controlled by **roll deflection or roll counterbending**. **Rolls with camber** are such rolls the shape of which is not fully cylindrical. The uniform thickness along the strip is assured by so-called **pressure adjustment** during the pass. We speak about the electro-hydraulic system **AGC** (Automated Gauge Control).

□ Strip dimension, crown and flatness control

The automatic control of important technological variables, mainly dimensions of the rolled stock, has to be carried out in up-to-date strip mills. That is the question of the width and thickness control along and across; this control is connected with flatness of the strip section at the same time. If the rolled stock is less plastic, the bond stresses start to act against non-uniform extension across the width – if

these stresses surpass critical values, the rolled stock loses its longitudinal stability and this gives rise to local waves (Fig. 6.1).

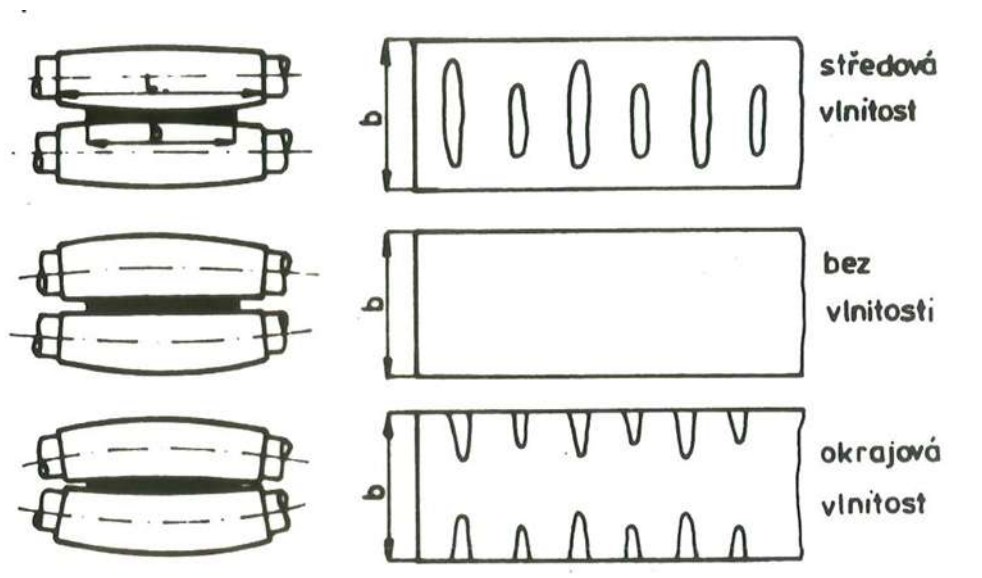


Fig. 6.1 Impact of roll gap shape on rolled strip flatness
(středová vlnitost - central waviness, bez vlnitosti - without waviness,
okrajová vlnitost - edge waviness)

Except for various kinds of waviness, the waviness near the strip edge (wavy edges) can come into existence when the roll gap has the wedge shape. This waviness causes also deviations from straightness - sable-shaped defect of the rolled strip, called camber as well.

The rolled stock cross section contour and flatness control is possible by the rolls shape change, their magnitude set up change and controlled bending the rolls. The controlled roll shape changes are achieved by either the roll crown (roll grinding to the crown shape), which is usual in case of both the work and the back-up roll of mill stands, or controlled sectional cooling of the work roll surface. However, these ways are insufficient.

The most efficient ways of automatic control of the rolled stock cross section contour (crown) and flatness are based on the work roll bending control. The basic mode of this control consists in work rolls counterbending against the induced roll pressure. This mode is implemented by means of hydraulic expanding cylinders that are placed between the work rolls chocks, or between the chocks of work rolls and back-up rolls, or between the work rolls chocks and between the chocks of work rolls and back-up rolls simultaneously.

A progress in the crown and flatness control represented the introduction of mill stands with axially shiftable rolls (Fig. 6.3), which are more efficient for crown and flatness control than the hydraulic "counterbending" of work rolls.

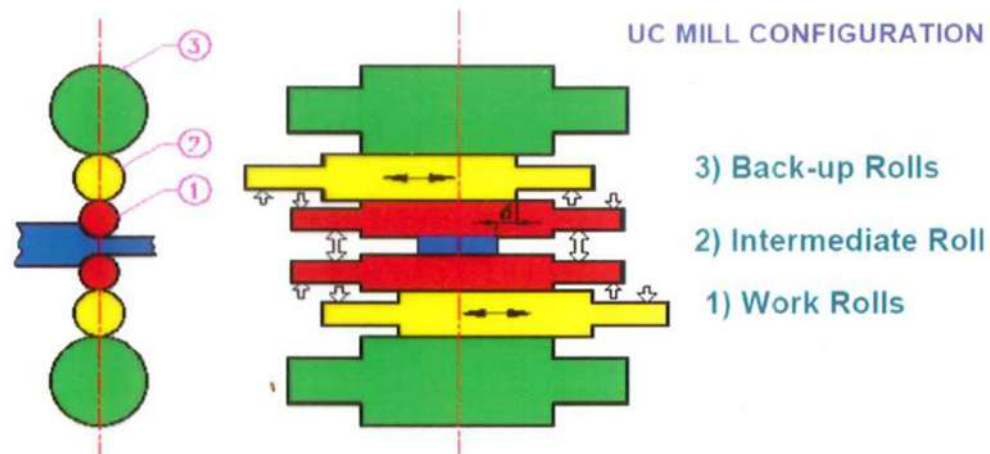


Fig. 6.2 Schematic illustration of up-to-date six roll mill stand enabling efficient crown and flatness control of rolled strips

Further improvement of the crown and flatness control of strips brought the introduction of grinding the work roll surface to a mild shape reminding the S-curve. Differences of roll diameter along its barrel are usually from 0.3 to 0.8 mm. Both work rolls shape is fully identical, nevertheless - the rolls are turned to each other (swivelled through) by 180° and mutually shiftable in opposite directions. Changes of axial shift magnitudes can result in roll gap with neutral, negative and positive crown (Fig. 6.3).

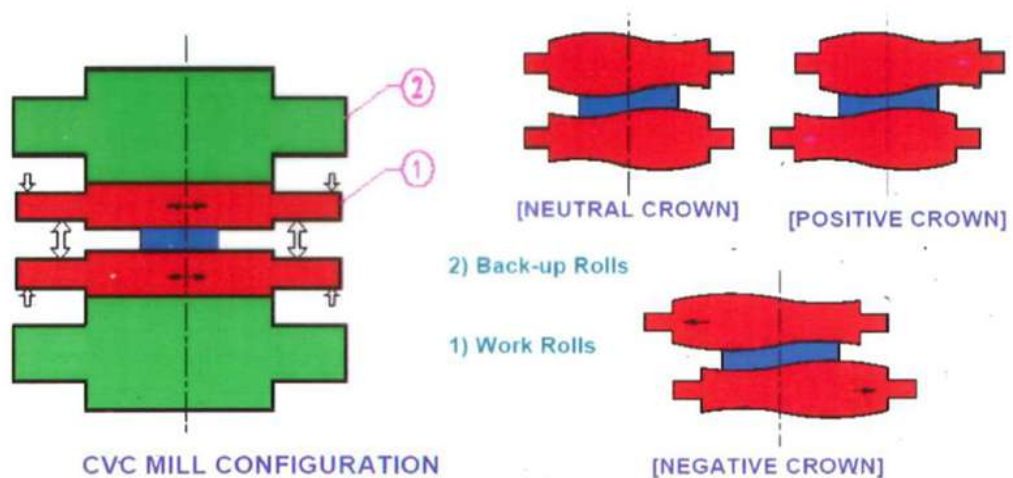


Fig. 6.3 Symbolic scheme of changes the work roll grinding ("S-curve shape")



Summary of terms of this chapter

Counterbending of rolls – crowned rolls – AGC – pressure adjustment



Questions to discussed curriculum

- 6.1. What are requirements for rolling mill stands?
- 6.2. What are chances of the rolled product dimensions control?



Used references recommended for further study

7. Rolling of long products



Time for study: 8 hours



Target After studying this paragraph you will be able to

describe the production of heavy, medium and fine sections, bars and wire rod. You will get a survey of manufacturing plants in our region and their product mix.



Presentation

7.1. Rolling of heavy sections

□ Heavy sections assortments:

To a group of heavy sections we rank rails of weight 30 to 75 kg/m, grooved rails, I sections /beams/ (of height 200 to 600 mm), U sections /channels/ (of height 200 to 450 mm), equal and unequal angles, round bars of diameter up to 300 mm, sheet piles and wide-flange H-beams, designated as WF beams as well.

They are rolled in heavy rolling mills with **two-high or three-high stands** (roll diameter up to 950 mm). They are characterized by the **continuous arrangement or open arrangement** (stands in a centreline). For rolling of wide-flange beams **universal mills** are used.

The **rolling** can be realized

- **in a single heat** (e.g. from ingots after heating in soaking pits);
- **in two heats** – reheating of semi-finishing products rolled in blooming mills

□ Rolling of I-beams

Initial material is blooms and CCS. Beams may be divided as per the web height and flange width. The basic shape of I-beam and WF-beam can be seen in Figs 7.1 and 7.2. Except for classic I-beams also series of light (economical) IE-beams, light IPE-beams with parallel flanges (Fig. 7.3) and WF-beams (*Note: IPB designation corresponds to DIN standard*) were developed. They are rolled in universal rolling mills with specific grooving design. Grooves are created by two pairs of rolls, of which the horizontal rolls are driven and carry out total deformation work.



Fig. 7.1 I-beam

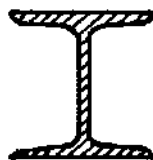


Fig. 7.2 H-beam

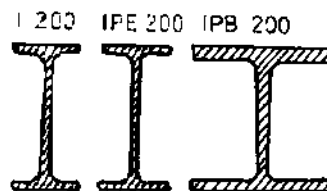


Fig. 7.3 Comparison of cross sections and shape indicators of I 200, IPE 200 a IPB 200

□ Heavy cross-country (HCC) rolling mill (ArcelorMittal Steel Ostrava, a.s)

HCC (Heavy Cross Country) rolling mill covers by its production capacity a major part of the commodity “long products” of the above mentioned company. It produces by hot rolling heavy and medium sections, from simple cross sections, via shaped sections I, IPE, U and others, up to special sections (mine rails and shackle connections). A part of the product mix of HCC mill is also a “portfolio” of semi-products used for further processing (hot, cold) in another technological equipment of the following plants in the ArcelorMittal Steel Ostrava, a.s. That is the question of round bars, sections for steel-arc supports in mines and flats of width 130 to 170 mm.

Layout and arrangement of HCC mill

Currently the material is reheated in the continuous pusher furnaces (Fig. 7.4)



Fig. 7.4 Continuous reheating pusher furnaces of HCC mill

Transport of the charged material and its handling is ensured by feeding roller tables and front pushers cooled by water. Work surface of the furnace hearth in length 18.5 m enables reheating the billets with length 4 – 5 m in several successive rows, which assures reheating of CCS in the entire dimensional range currently produced on CCM. The rolling mill is created by nine stands in cross-country arrangement in three parallel trains (Fig. 7.5): 1st train - 5 stands, 2nd train - 3 stands and 3rd train - 1 stand.

Roll stands No. 1 to 4 of the roughing train are horizontal two-high roll stands, mounted in the cast steel open frame. The stand No. 5 of this train can also work as a reversing two-high stand realizing three passes. Stands No. 6 to 9 are non-reversing (continuous) horizontal two-high roll stands with a chance of conversion to universal stands (stand No. 9 see Fig. 7.6). Between stands in particular trains the rolled-out stocks are transported by roller tables, transfer between trains is ensured by cable transfers. Cutting-to-lengths is carried out by means of circular slide saws. After cutting-off front ends the rolled products are transported on the roller table to the chain cooling bed where cooled out. The whole rolling mill layout is schematically shown in Fig. 7.7.



Fig. 7.5 View of cross-country arrangement of roll stands in rolling mill HCC



Fig. 7.6 Finishing stand No. 9, left - stand No. 8 and transfer to stand No. 9, right - the detail

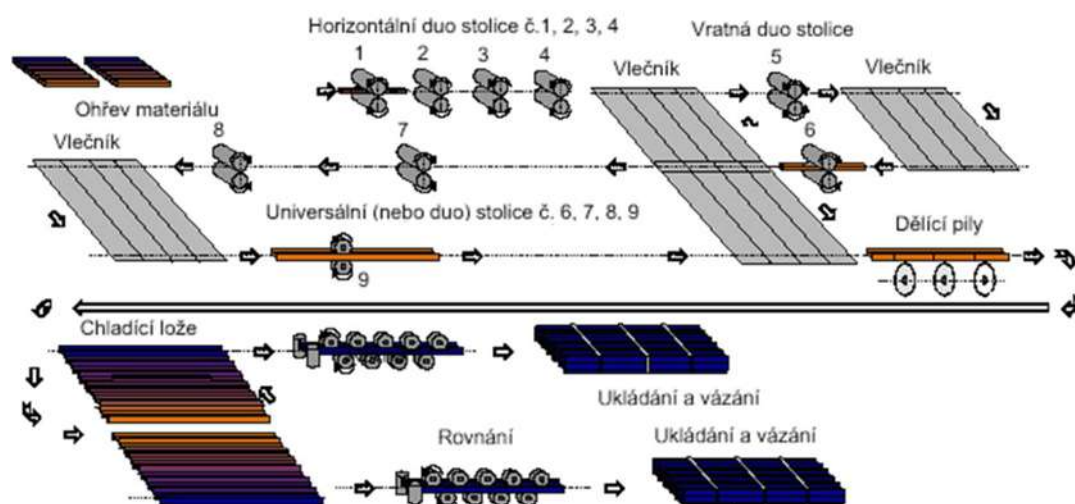


Fig. 7.7 Scheme of the rolling mill HCC and finishing plant layout

(Ohřev materiálu - material reheating, Horizontální duo stolice č. 1, 2, 3, 4 - horizontal two-high roll stands No. 1 to 4, Vratná duo stolice - reversing two-high roll stand, Vlečník - transfer, Universální (nebo duo) stolice č. 6, 7, 8, 9 - universal (or two-high) roll stands No. 6 to 9, Dělící pily - cutting saws, Chladicí lože - cooling beds, Rovnění - straightening, Ukládání a vázání - storage and binding)

The rolling mill is continually followed by the finishing bay. The finishing plant area is oriented perpendicularly to technological flow of the processed material. The rolled material is taken from the cooling bed to final processing (cutting to accurate lengths, straightening, drilling, grinding, bundling)

and weighing) in two identical finishing lines. Each line includes the following technological equipment: straightener SIMAC, collecting pockets, magnetic pilers, punching presses, cut-to-length circular saws, mechanical binders of bundles, scales (weighing machine) Metripond and other equipment. The material handling is carried out by means of overhead travelling cranes. To each finishing line belongs the roll storage yard.

□ Rolling of U sections

The initial semi-product is blooms of square or rectangular cross section. The basic shape of U section is in Fig 7.8.

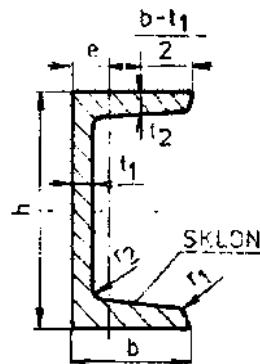


Fig. 7.8 Basic shape of U section
(SKLON – INCLINE)

□ Rolling of rails

Rails belong among the most important and exacting products of heavy rolling mills. We can divide them into **railway**, **mine** and **special** (grooved, crane, turnout, tongue/point, crossing frog). Rails are to be abrasive wear resistant and tough, elastic, but not brittle. The shape of the grooved rail is in Fig. 7.9.

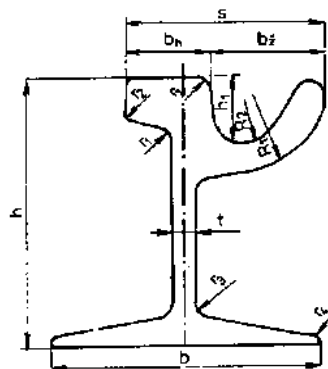


Fig. 7.9 Grooved rail (tramway rail)

Rails are rolled from blooms in heavy rolling mills

- in a single heat (as a rule 4 reversing two-high roll stands, 7 – 9 passes)
- in two heats (assures better quality production, more passes)

In the sequence of preparatory passes the square or rectangular cross section of the rolled stock is adapted to a shape suitable for rolling in leading shaping passes. Some possibilities of the rail groove designing are shown in Fig. 7.10.

Maintaining the correct **finish rolling temperature**, which is lower than in rolling of other shaped sections, is very important. **Heat treatment and straightening of rails:** The rail foot is cooled faster,

the rail head later and with pertinent shrinkage in length – straightening is therefore necessary! There is a chance of hardening with self-tempering.

Inspection of rails – **internal defects** (ultrasound), **external defects**:

- cracks and hair cracks, mostly on the rail head
- shrinkage cavities marks
- slivers - appear mainly on the rail foot
- incorrect shape with deviations outside the tolerance zone
- rail chamfering, curvature into the spiral shape

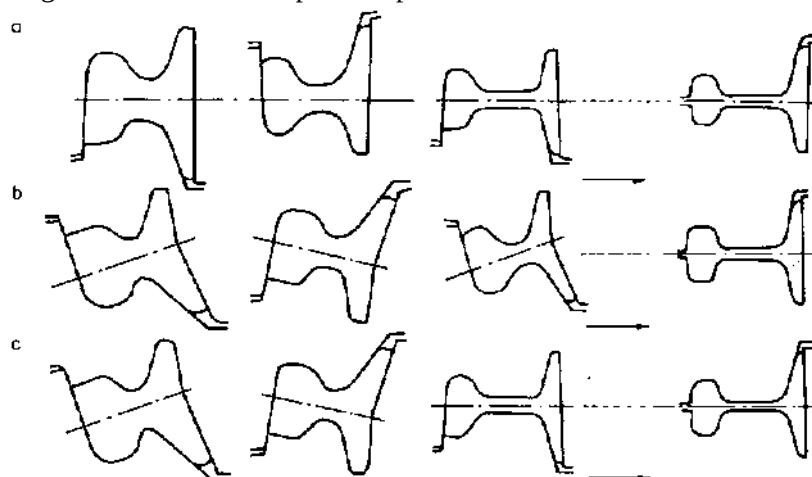


Fig. 7.10 Sequences of grooves in rail rolling

- “beam” mode
- inclined position of grooves
- alternation of inclined and horizontal positions

Grooved rails

They are rolled using a higher number of passes. Rolling is more difficult, the groove is created by means of a special vertical roller in the last two passes (Fig. 7.11).



groove before finish rolling

finishing groove

Fig. 7.11 Rolling of the rail groove

□ Třinecké železářny (TŽ) – Heavy rail rolling mill

The operational scheme of this mill is in Fig. 7.12. Reheating of continuously cast semis (CCS) with dimensions 300 x 350 mm and 300 x 385 mm is carried out in the walking beam furnace. That is the question of the five-zone continuous furnace (the entry zone without reheating), with fully automatic reheating, charging and extraction of CCS. The motion of CCS in the furnace is possible by the system of movable and fixed walking beams. The furnace is lined by refractory concrete and heated by a mixture of blast furnace and natural gas by means of top burners. The heating time of CCS to the rolling temperature is 5 hours. CCS is then transported on the roller table through two hydraulic scalebreakers (pos. 6 and 10), which guarantee the perfect primary scale removal, to Blooming I where

CCS are rolled to dimensions necessary for entrance into the reversing heavy rail rolling mill. These dimensions are determined by the steel grade and shape of particular rails or sections. The blooming mill is a roughing two-high roll stand with roll diameter 960 mm. Rolling speed is $3 - 6 \text{ m} \cdot \text{s}^{-1}$, roll barrel 2 250 mm. These rolls have 5 grooves. The initial semi-product for the reversing mill is rolled in 7 passes with regular tilting. This entry material is different for each rail shape. The reversing rail rolling mill is composed of 4 roll stands with open arrangement. Roll stands No. 1 and 2 are driven by a common motor, as well as roll stands No. 3 and 4. In the course of rolling the scale is removed by high-pressure hydraulic scalebreakers (installed before grooves No. 2, 3, 5, 6, 7, 8, and 9) and grooves are lubricated by the environment friendly oil. The high pressure water assures a very good removal of secondary scale originating during rolling (Fig. 7.13).

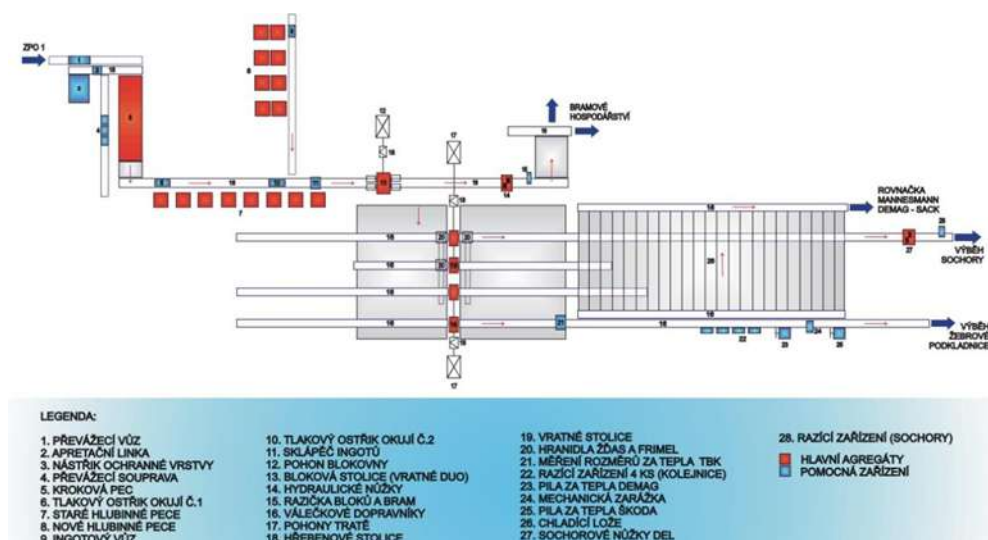


Fig. 7.12 Operational scheme of reversing rail rolling mill

(ZPO 1 - CCM No. 1, **bramové hospodářství - slab treatment, rovnačka MANNESMANN DEMAG SACK - straightener MANNESMANN DEMAG SACK, výběh sochory - billets runout, výběh žebrové podkladnice - ribbed sole-plates runout**

1- transfer car, 2 - finishing line, 3 - protective layer spraying, 4 - transfer set, 5 - walking beam furnace, 6 -hydraulic scalebreaker No. 1, 7 - old soaking pits, 8 - new soaking pits, 9 - ingot bogie, 10 - hydraulic scalebreaker No. 2, 11 - ingot tilter, 12 - blooming drive, 13 - blooming (reversing two-high roll stand), 14 - hydraulic shear, 15 - bloom and slab stamping machine, 16 - roller tables, 17 - rolling mill drives, 18 - pinion stands, 19 - reversing roll stands, 20 - manipulators ŽDAS and PRIMEL, 21 - hot dimension measurement TBK, 22 - stamping machine 4 pcs (rails), 23 - hot saw DEMAG, 24 - mechanical stop, 25 - hot saw ŠKODA, 26 -cooling bed, 27 - billet shear DEL, 28 - stamping machine (billets), Hlavní agregáty - key aggregates, pomocná zařízení - auxiliary equipment)

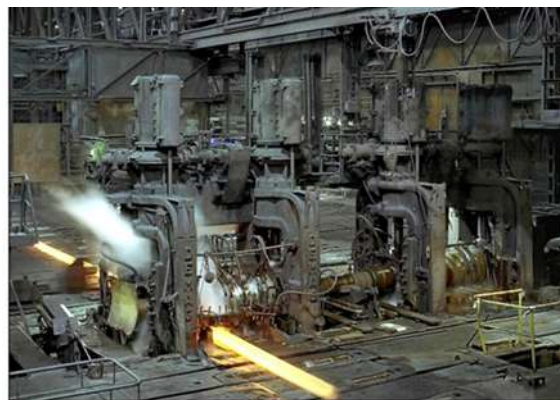


Fig. 7.13 Rails production at TŽ

Immediately after rolling the rails are measured by TBK device. It is the on-line equipment for laser measurements of the rolled material. Two types of TBK device are installed in the rolling mill at TŽ: TBKh for hot measurements of dimensions (Fig. 7.14) and TBKk for cold measurements of dimensions. The finish-rolled rail is transported to the cooling bed, which is divided into 3 sections of cable transfers, electrically interconnected. Rails on the cooling bed are cooled down spontaneously. In the course of this cooling their temperature decreases from 900°C to 50°C and shrinkage accompanied by deformation of the rail occurs. After cooling down the rail is straightened in the Mannesman-Demag-Sack straightening machine (Fig. 7.15). Straightening is carried out in both the horizontal and vertical axis. The straightening effect is reached by several deflections of the straightened material in the plastic deformation area.



Fig. 7.14 Equipment for hot rail dimensions measurements (TBK)



Fig. 7.15 Rail straightening

Every straightened rail goes through the measuring centre, where checking of dimensions, surface defects, straightness and internal homogeneity is carried out. Measurements of the rail straightness and dimensions are carried out by laser. Checking of surface defects ensures the line Eddytron 4.1, checking of internal defects is carried out in the line Sonotron 5.1.

The carefully checked rail is transported by the roller table to the Linsinger and Wagner cutting and drilling machines, which carry out rails cutting to accurate lengths according to customer requirements. Afterwards, the final measurement of rail ends straightness follows. After-straightening, as the case may be, is carried out on the Berner presses.

□ Sheet piles rolling

Another complicated section rolled in heavy mills is sheet piles. They are used for constructions associated with water, like dams, bridges, embankments of watercourses, consolidations of artificial fillings and others. Their rolling by 11 passes starts from the initial semi-product of rectangular cross section. Their interlock shape has gradually been prepared in five grooves, the final shape by curvature in special twisting guides (Fig. 7.16).

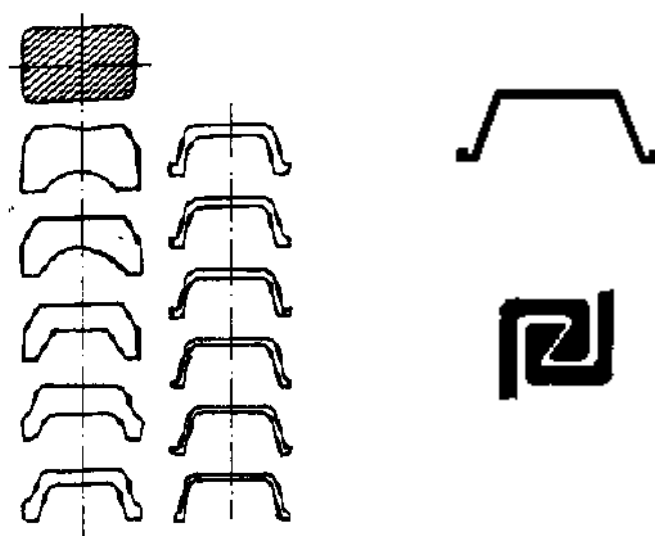


Fig. 7.16 Sequence of passes for Larsen type sheet pile rolling, its shape and detail of interlock

□ Equal and unequal angles

Their rolling is performed in 5 to 9 passes with one or two heatings. The grooving design of angles is distinguished by some specifics. Rolling of thin arms requires higher thickness reductions in particular grooves. They cool down rather fast during rolling, which results in roll force increase, finish rolling temperature decrease, and “spring-back” of rolls increase. It means that the rolls are subjected to more wear and tear.

□ Production of heavy sections and bars at Vítkovice Steel, a.s.

The heavy section rolling mill at Vítkovice, consisting of 4 roll stands, is connected with the billet mill, created by a single-roll stand (No. 5), determined for rolling of billets. The whole complex of two rolling mills (five roll stands in total) uses a common pusher furnace for reheating of semis, as well as a common crew. The total production capacity is 170000 tons/year. The shipping (dispatching) and finishing technologies of both rolling mills are independent ones. The basic technological equipment and product mix are as follows:

Heavy section rolling mill

Product mix: round and square bars, beams, angles, sheet piles, crane rails, sleepers, rims and special shaped sections with weight per metre 18 to 141 kg/m. Maximum shipping length of sections is 21 m. The gas-fired pusher furnace with output 60 t/h is available. The rolling mill is equipped with 4 reversing two-high roll stands (Fig. 7.17), the roll stand No. 4 (Fig. 7.18) may be redesigned/rebuilt to the universal one with non-driven vertical rolls (edgers) and horizontal upsetting stand for rolling the beam sections. Two handling cars serve for transfer of rolled products between roll stands. Maximum roll diameter is 940 mm, roll barrel 2 300 mm.



Fig. 7.17 View of roll stands No. 4, 3, 2, and 1 from left to right



Fig. 7.18 Roll adjustment of roll stand No. 4

Three hot saws are used for cropping ends and cutting to shipping lengths (Fig. 7.19). Two cooling beds of length 21 m serve for rolled products cooling down (Fig. 7.20). Straightening is carried out in the 7-roller straightening machine (Fig. 7.21). In Fig. 7.22 you can see a pair of finishing rolls prepared for building into roll stand No. 4.



Fig. 7.19 Sheet pile cutting to commercial length

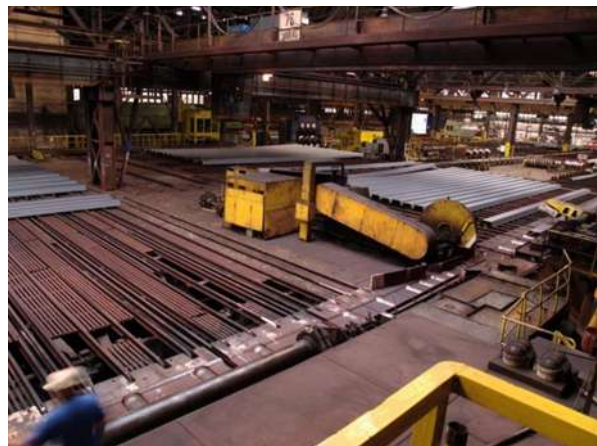


Fig. 7.20 Cooling beds



Fig. 7.21 Sheet pile straightening



Fig. 7.22 Rolls with two finishing grooves

Billet mill (stand No. 5 – a part of the heavy section mill)

Product mix: rectangular and square billets of width from 120 to 300 mm and length to 12 m. Maximum roll diameter is 920 mm, roll barrel 2 200 mm. This roll stand uses the same furnace for reheating as the section mill. For cutting of billets serve two hot saws and hot shear.

The finishing plant of the heavy section mill is equipped by the following machines:

- 7-roller straightener for sections, round and square bars,
- side straightening press for bars,
- hyperbolic straightener for round bars,
- twisting straightener for crane rails and rectangular bars,
- 3 cold saws,
- cooling down walking beam furnace – controlled cooling down, annealing against flakes formation and soft annealing for rolled bars,
- grinding machine for slabs and billets,
- peeling machine for round bar surfaces,
- grinding machine for round bars,
- magnetic surface crack detection line for round bars,
- ultrasonic inspection (purchased service according to customer requirements),
- line for pairing off sheet piles, lock pressing and equipment for tests of bond strength of locks by pressing

7.2. Rolling of heavy, medium and fine sections and bars

In the product mix of heavy and medium rolling mills we can find above all shaped sections, in the product mix of fine mills the rolled products with a cross section of simple shapes, i.e. bars dominate. Heavy section mills are in the open and/or cross country arrangement, medium and fine mills are in the open, cross country, semi-continuous and/or continuous arrangement.

Rolling process technology

The initial material for rolling of steel sections and bars is continuously cast blooms and billets. Cross section dimensions are determined as per the product mix, finish rolling speed and used sort of the charge. Minimum reduction ratio must be for common steels 5 to 8, for high-grade steels 8 to 10, for high-alloy steels 10 to 14.

Bars are rolled in various rolling mills, their cross section range is limited by the type, structure and arrangement of roll stands. In Fig. 7.23 you can see mostly used sequences of grooves (pass sequences).

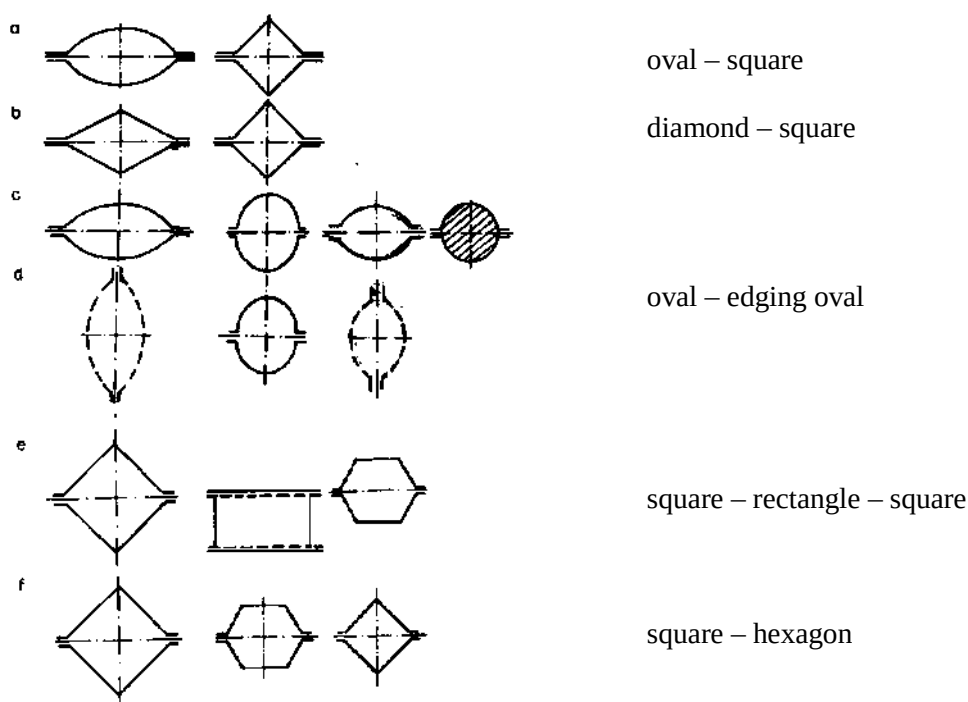


Fig. 7.23 Set of grooves for round bar rolled in the roughing train

□ Třinecké železářny – fine section (bar) rolling mill (so-called rolling mill C)

The continuous bar rolling mill at Třinecké železářny was commissioned in year 1960. In this time the product mix was mainly reinforced concrete bars (so-called rebars), structural and flat rolled product. The initial material is billets (squares 150 mm, lengths in the range 8.5 -12 m). The charge reheating to rolling temperature is ensured by the walking beam furnace with bottom and top heating. The furnace is fired by mixed gas and billets are charged by the side roller table; they are prepared on fixed beams, from where they are taken out by movable beams, ensuring the actual operation of the walking beam mechanism and at the same time heating the charge to the final rolling temperature.

The roughing mill (Fig. 7.24) is created by 4 roll stands S.I.M.A.C. The roll stands are arranged in this mill with the following sequence: horizontal, vertical, horizontal, vertical. The roll diameter is 620/520 mm, roll barrel 850 mm. The grooving of rolls enables rolling of squares 150 mm to round bars with

diameter 100 mm. These rolled stocks are transported by the covered (heat-insulated) roller table to the two-strand rolling train. The heat-insulated roller table ensures temperature homogenization across in the rolled stock cross section.

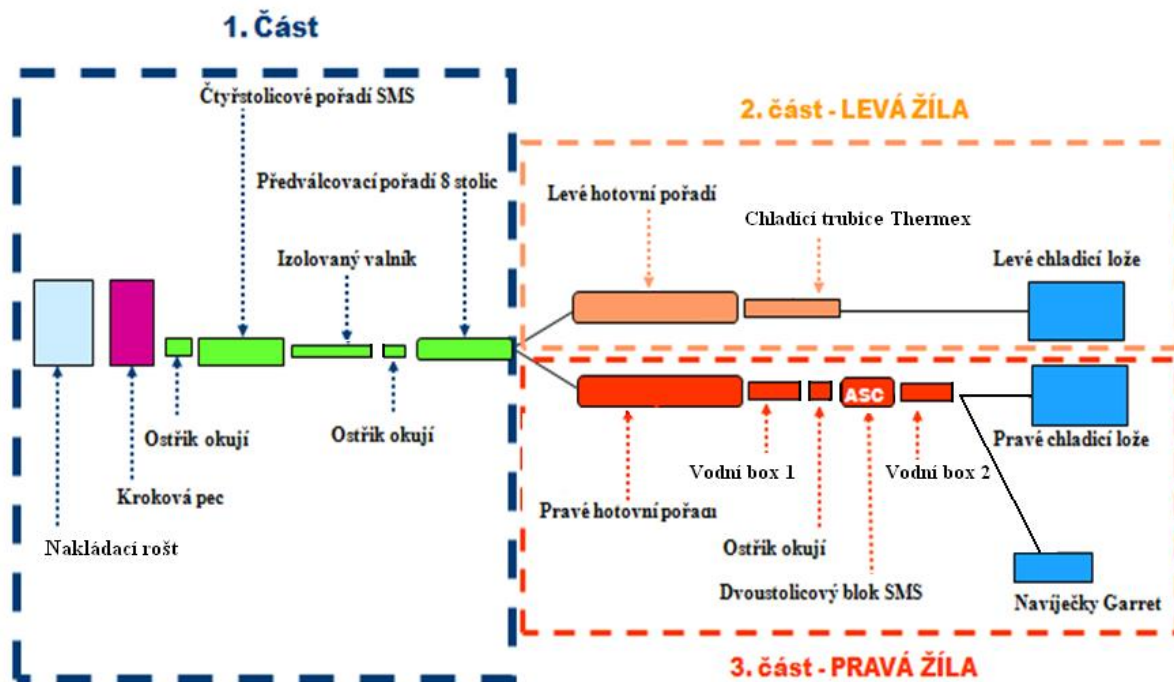


Fig. 7.24 Scheme of continuous fine rolling mill

(1.část - 1st part, 2.část- levá žíla - 2nd part - left strand, 3.část- pravá žíla - 3rd part- right strand
Čtyřstolicové pořadí SMS - 4-roll stand train SMS, Předválcovací pořadí 8 stolic - roughing mill consisting of 8 roll stands, Izolovaný valník - insulated roller table, Ostřík okují - hydraulic scalebreaker, Kroková pec - walking beam furnace, Nakládací rošt – loading bed
Levé hotovni pořadí - left finishing train, Pravé hotovni pořadí - right finishing train, Chladicí trubice Thermex – cooling equipment Thermex, Vodní box - Water box, Ostřík okují - hydraulic scalebreaker, Dvoustolicový blok SMS - 2-roll stand block SMS, Pravé/levé chladicí lože - right/left cooling bed, Navíječky Garret – coilers Garret)

In the roughing mill the roll stands (8 totally) are in the horizontal arrangement only. From the initial material of diameter 100 mm rolled products with dimensions 82 to 31 mm may be rolled. After the roughing mill the right and left finishing train follow.

The right finishing train begins by the looping table and shear N3 for cropping front and rear ends of the rolled product. It includes eight roll stands in the following arrangement: the early two roll stands are horizontal, afterwards vertical and horizontal roll stands alternate. Maximum exit speed is 15 m.s^{-1} . After the last roll stand of this train the material is further processed as per the product mix. Plain rounds, hexagons, flats and angles are processed without cooling. In case of rebars the method called slittrolling including cooling section Thermex is used. The last mode represents controlled cooling of plain rounds in the 6 meters long cooling section SMS Schloemann.

This finishing train is followed by two roll stands in arrangement Vertical – Horizontal, so-called ASC (Automatic System Control). These roll stands ensure precision finish rolling of the rolled product. Rolls diameters are 360/295 mm, roll barrel is 160 mm. The system works fully automatically, using two laser measuring devices, which instantaneously evaluate and control the needed thickness reduction in the roll stand. Exit rolling speed ranges from 1.2 to 15 m.s^{-1} .

ASC roll stands are followed by the controlled cooling section and the switch enabling rolling to coils in coilers of Garret type. In coils may be rolled the rounds, squares, and hexagons in range from 15 to 50 mm. Before actual coiling the rolled product goes through the feeding rolls, shear N6 and water

box WB3 with automatic temperature control. After the water box the material is transported to the switch distributing the material into coiler drums No.1 or 2 – see Fig. 7.25.

In Fig.7.26 you can see that the coil is pushed out of the coiler chamber, seized by the four-arm tongs suspended on the turret and transferred to the loading pallet. The coil on the pallet is then transported by the pallet type conveyor up to the place of tipping on the C-hook conveyor. During transport the material is cooled in the open air or may be subjected to accelerated cooling (6 fans available) or slowed down cooling in insulated tunnels (2 tunnels with capacity 12 coils/tunnel). At the end of the pallet conveyor is located the hydraulic tipping device which places coils on hooks. The material suspended on the hooks passes the station of gauging checks and visual surface inspection, test samples are taken and front and rear ends of coils cut-off. The finished coil is weighed, pressed and bound by the steel binding strip.

The left finishing train begins by the roller table for transfer to the left strand, the looping table and the shear. It includes eight roll stands with the same arrangement as the right finishing train. After the last roll stand two cooling sections Thermex for processing of rebars (reinforcing steel bars with ribs) with diameter 10, 12, 14 and 16 mm, using slittrolling technology, are located. The rotary shear for cutting to “cooling bed lengths” follows. Then the cooling sections Thermex for controlled cooling of rebars with diameters 18 to 32 mm are installed. Subsequently, the rolled product is transported by the roller table to the left cooling bed. The cooled products are prepared for further processing (cutting to commercial lengths, binding).



Fig. 7.25. Coiling drums



Fig. 7.26 Coils transport

❑ Rolling mill of special sections (VÚHŽ Dobrá)

VÚHŽ, a.s. produces special rolled sections of structural, tool and corrosion-resistant steels and non-ferrous metals in small batches 10 - 100 t. The product mix is given in Fig. 7.27. Currently – after modernizations - the rolling mill annual capacity increases every year; in year 1994 when the first section for the automotive industry was finish-rolled the production increased from 252 tons/year, via 4000 tons/year, up to 5000 tons/year in year 2006. Sales of produced special sections represented in year 2006 31% of the VÚHŽ total turnover. A lot of shapes, currently produced by welding, connecting, machining, forging, casting or other technological processes, can economically be replaced by using special rolled sections.

The initial material is supplied mostly by Třinecké železářny, a.s. and stored in the storage yard. As per rolled section the supplied material is cut to required lengths and transported to the gas-fired walking beam furnace for reheating.

After exit the furnace the reheated semi-product is transported by means of the roller table to the rolling mill stand. All semi-products handling carry out the rolling mill operators (rollers) by hand by

means of tongs (Fig. 7.28). Only a single roll stand is available; it has to incorporate the entire sequence of 5 to 6 grooves. From this results that on the whole roll barrel are cut the roughing, preparatory, leading and finishing grooves (Fig. 7.29). As an indicator for comparison of roll service life the total length of the product rolled during the lifetime of one set of rolls (gross production) is used. This indicator quotes how many kilometres of the rolled section passed a single set of rolls during its service life. After finishing the rolling campaign, the rolls are changed and renovated. The total rolled sections length depends not only on the material of rolls, but also on maximum range of the roll diameters usable for renovations. Maximum pitch diameter of rolls is given by the housings structure and equals 525 mm. When the roll diameter is higher, the rolls cannot be put in the roll stand through the housing windows. All the work rolls handling is carried out automatically from the control cabin.

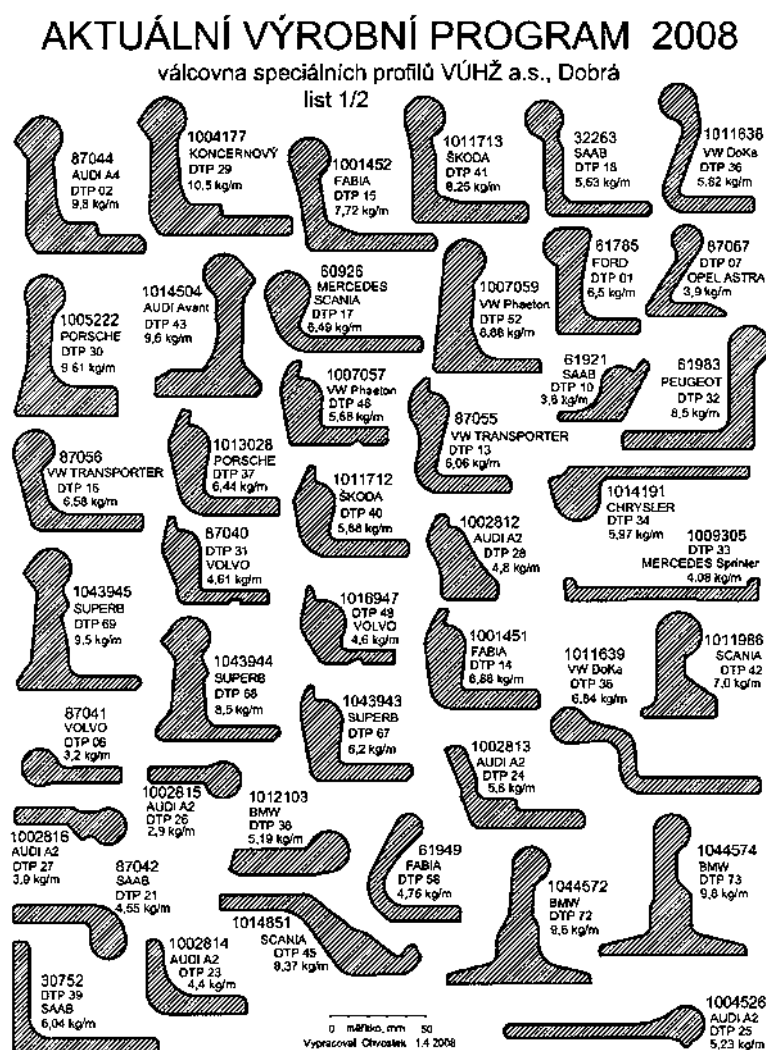


Fig. 7.27 Product mix of special section rolling mill, for each section the car maker, specific model and section weight per meter are given

(AKTUÁLNÍ VÝROBNÍ PROGRAM 2008 - TOPICAL PRODUCT MIX 2008
Válcovna speciálních profilů VÚHŽ a.s., Dobrá - Rolling mill of special sections VÚHŽ a.s., Dobrá)



Fig. 7.28 Manual rolled stock handling

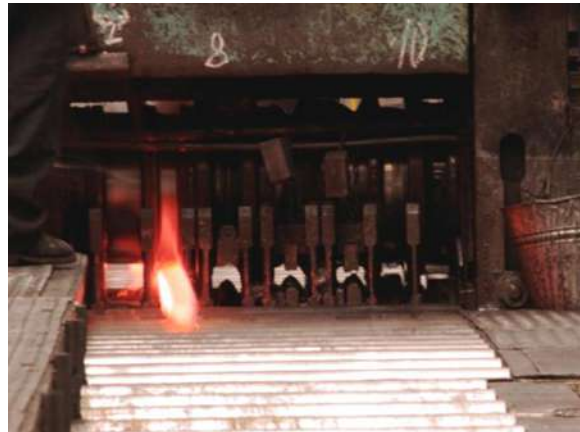


Fig. 7.29 Grooves

After rolling the section is transported by means of roller table to cooling bed. After cooling the section is transported to the straightener. After straightening the workers operating this machine cut both ends and place the section to the packet determined for shipping. In the course of rolling 3 checks for verification of shape, dimensions and possible surface defects are carried out. The first check is carried out by the rollers (continuous surface check of every piece after rolling). The second check is carried out by the foreman and technical supervisor. The sample is cut-off from the rolled section and put on the profilometer scanner; at magnifying 10 times all dimensions are checked by means of the foil, on which the exact profile is plotted. The third check used to be carried out after straightening. Due to wide spectrum of produced sections the grooved rolls inventory has to be large.

□ Medium-fine section rolling mill (ArcelorMittal Ostrava, a.s.)

Product mix

This medium-fine section rolling mill is situated within the area of works 14 - Rolling mills of the company ArcelorMittal Ostrava, a.s.

The rolling mill product mix consists of:

- round bars – dimensions: $d = 10 - 65$ mm,
- hexagonal bars – dimensions: A20 – A34,
- flats – dimensions: width 20 – 120 mm, thickness 4 - 50 mm,
- equal angles – dimensions: arm width 38 x 38- 90 x 90, thickness 4 –13 mm,
- IPE, IPEA beams – dimensions: 80, 100, 120, 140
- I beams – dimensions: 80, 100, 120, 140
- U, UE channels – dimensions: 50, 65, 80, 100, 120, (UE 100),
- tee-beams – dimensions: T40
- rebars – dimensions: $d = 10, 12, 14, 16, 18, 20, 22, 25, 28, 32, 39$

Rolling mill basic description

The basic layout of the rolling mill is given in Fig. 7.30.

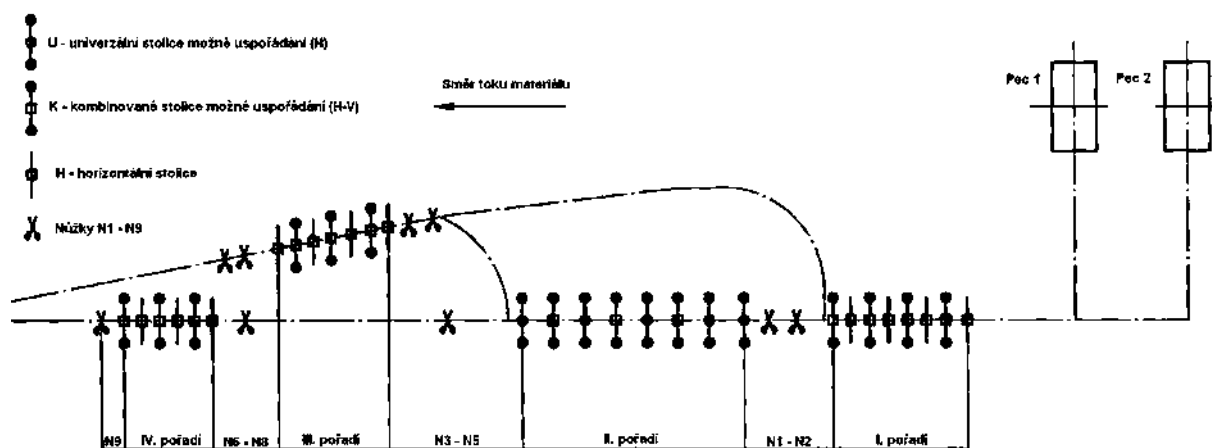


Fig. 7.30 Basic layout of medium-fine section mill, ArcelorMittal Ostrava, a.s.

(Pec 1 a 2 - Furnaces No. 1 and 2, Směr toku materiálu - material flow direction, I. až IV. pořadí - train No. I to IV, U - universal roll stands, K – combined roll stands (with possible H-V arrangement), H - horizontal roll stands, Nůžky – shears)

The rolling mill includes 4 independent continuous trains that may variably be integrated in the rolling process. Trains I and II may roll can be rebuilt from combined roll stands (with changeable vertical and horizontal rolls) to horizontal two-strand roll stands. Rolling starts from initial square 115 mm. Inbetween trains the flying shears are located, which crop front and rear ends or chop the rolled stock in case of the mill failure. Roll stands of all four trains are constructed as housingless, without prestressing. As per type these roll stands can be divided into two-high and universal stands.

Cut to lengths, cooling, temperature measurement and rolled products checking

The shear is used as a main dividing aggregate of the rolling mill. Two types of shears are used: the rotary shear and the crank flying shear. For controlled cooling the pressure water serves; it is a part of the water treatment system (controlled cooling GOLEM). Temperature measurements are carried out on particular measuring spots. In all four trains the pyrometer PYROFAST is used, only on the runout roller table the pyrometer MAUER is used.

Rolled products from trains II and IV are transferred to the walking cooling bed by a system of feeding roller tables and switches. Individual rolled products are - after cutting in shears (considering from which train they run out) - decelerated (braked) on feeding roller tables to the cooling bed. After braking they are stored into slits of steel grids as per the rolling schedule. The cooled down bars may be transferred, if needed, to the straightening operation. Maximum bar length for transfer on the cooling bed is 128 m, minimum 80 m.

□ Works “Rolling mills” – Fine section mill (ŽDB Group, a.s. Bohumín)

The fine section mill was commissioned in years 1947–48 and the assortment produced corresponded to a normal product mix of fine rolling mills (rebars, round, square, angles, tee-beams) with a small portion of special sections. The last reconstruction of this mill was carried out in year 2007. The continuous roughing train Morgan was replaced for a three-high roll stand with tilting tables. This reconstruction enabled to increase the initial pass section from the original square max 80 mm up to square 130 mm. The fine section mill may be characterized as a semi-continuous rolling mill with three trains, consisting of:

- the roughing three-high roll stand with tilting tables,
- roughing trains PP1, PP2 with open arrangement,
- finishing train HP of open layout,

- collecting pockets,
- two straightening machines HRL 40

7.3. Rolling of wire rod

Wire rod is a hot rolled product wound to coils, which has usually in all its length the constant and full cross section. The cross section is most often round-shaped, but it can also be square, half-round, polygonal, etc. Wire rod diameter is most often from 5.5 to 20 mm. Wires of diameter below 5 mm are produced by **cold drawing**.

The goal of production of hot rolled wire rod is achievement of optimum microstructure of the formed material and mechanical properties, both across and along the whole length.

Steels for wire rod production

Among steels for production of wire rod can be found mainly reinforcing steels, high-alloy corrosion-resistant (stainless) and high-speed steels, carbon non-alloy structural steels, carbon alloy steels, with yield point up to 1400 MPa.

Requirements for wire rod quality

Dimensional tolerances have to be maintained. Ovality should not exceed 70 % of the tolerance zone. Minimum surface decarburization, minimum occurrence frequency and depth of surface defects, small quantity of easily removed scale and optimum roughness of wire rod surface should be guaranteed.

Wire rod rolling mills

Wire rod rolling mills can be arranged in the open (looping), semi-continuous, continuous with twisting between horizontal roll stands, continuous with roll stands in H-V arrangement, and continuous with finishing blocks arrangement.

Introduction of finishing blocks in the finish-rolling train and controlled cooling from the finish rolling temperature with the following coil handling equipment had key importance for development of wire rod rolling mills.

Finishing blocks are mechanically firmly interlocked small roll stands, driven by a single drive (costly loop control and tension rolling are eliminated).

Basic types of wire rod mills you can see in Fig. 7.31.

Progressively a series of concepts was developed. Except for original concept of companies Morgan and Kocks, the finishing blocks are manufactured by companies Danieli, Schloemann, Mannesmann-Demag-Sack and others (Fig. 7.32).

Benefits of high-speed blocks

- initial billets up to square 150 mm – coil also more than 2500 kg, capacity also more than 800 kt/year
- overhung rolls (disks) with a chance of fast change
- high capacity given by high exit speed (also more than 100 m/s) – attention: influence of deformation heat!
- space savings, flexibility at change of the product mix
- rolling without twisting
- long service life of roll grooves

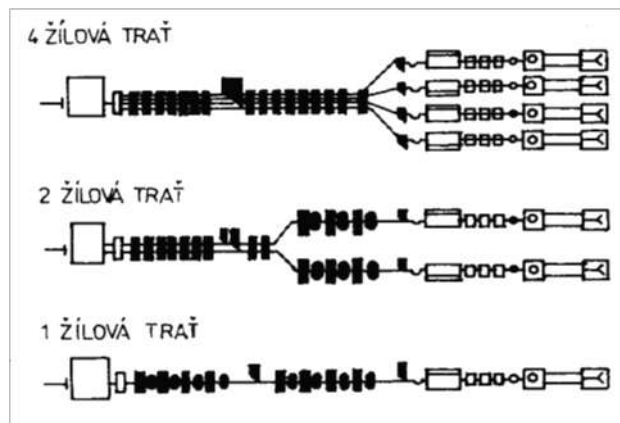
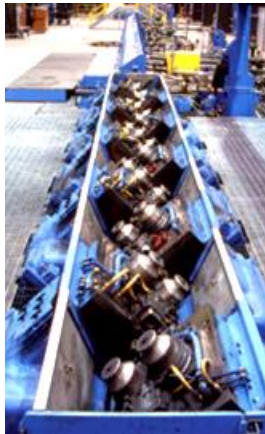
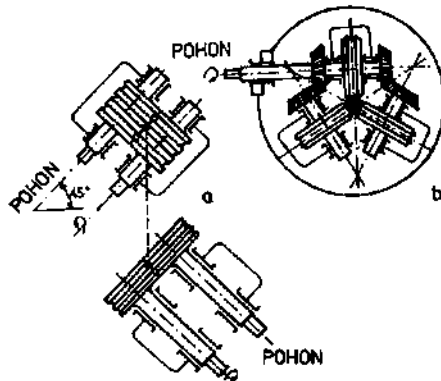


Fig. 7.31 Continuous wire rod mills with finishing blocks (1-, 2-, 4- žilová trat' – 1-, 2-, 4- strand rolling mill)



Morgan



a) Schloemann, b) Kocks



Kocks

Fig. 7.32 Examples of finishing blocks
(POHON – DRIVE)

Technology of wire rod rolling

Reheating of billets in walking beam furnaces to relatively low temperatures (also below 1050°C – because in the medium and finishing rolling train the temperature increases!). **Grooving design** is based especially on sequence oval – square and subsequently oval – round.

Controlled cooling from finish rolling temperatures

- accelerated water cooling from finish rolling temperature (1000 – 1100°C)
- reduces origin of coarse grains and structure heterogeneity
- prevents from scaling and enormous decarburizing
- cooling system Stelmor – the laying head creates wraps, which are laid on the conveyor and subject to air blowing, or insulating plates are used for prevention from thermal loss (accelerated or decelerated cooling) – Figs 7.33 - 7.35
- only then creation of the actual coil

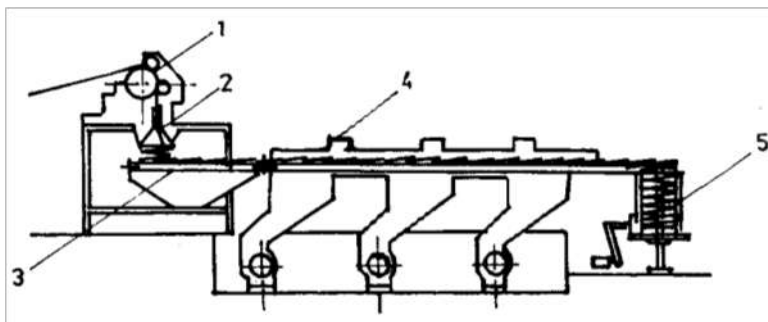


Fig. 7.33 Functional chart of coling equipment Stelmor

1 – entry guide equipment, 2 – laying head, 3 – chain conveyor, 4 – air fans, 5 – cooled coils storing



Fig. 7.34 Insulating plates on conveyor Stelmor

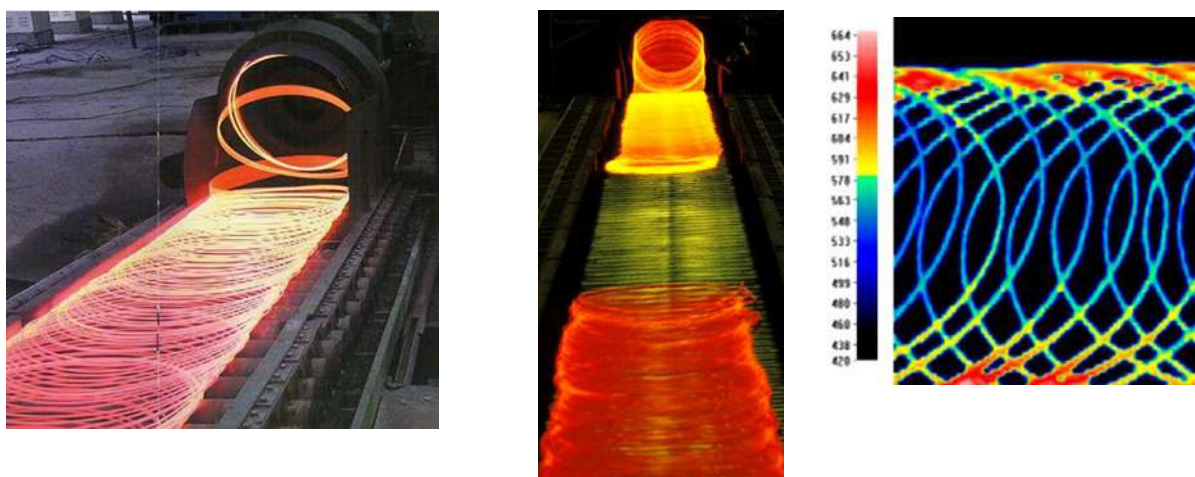


Fig. 7.35 Laying head and cooled wraps of wire rod on Stelmor conveyor (thermal imaging camera)

□ Třinecké železářny – Wire rod mill (rolling mill D)

The continuous wire rod mill (KDT mill) at TŽ a.s. currently ranks to the most up-to-date rolling mills in the world. This high-speed two-strand rolling mill (Fig. 7.36) makes it possible rolling of wire rod with diameter 5.5 mm to 20 mm, with grading 0.5 mm. The KDT mill production capacity is 820 000 t/year. Maximum ovality amounts to 60 % of the tolerance zone. In KDT mill the wire rods made of low, medium and high carbon steels are rolled, further wire rods determined for production of ropes and strands, the steel tyre cord wires, filler welding materials, connecting components and machine parts, as well as for production of wires made of bearing and free-cutting steel.

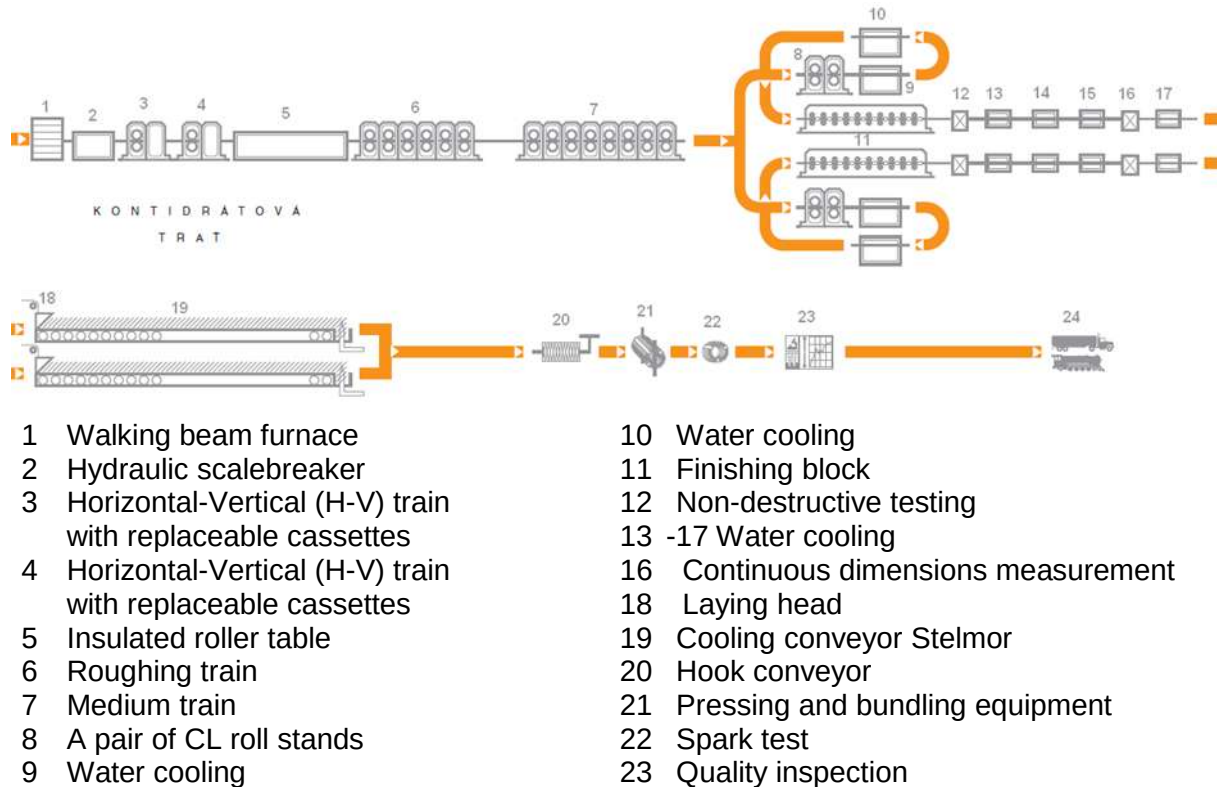


Fig. 7.36 Symbolic diagram of continuous wire rod mill

Preparatory train

The reheated bill is after discharging out of the furnace descaled in the high-pressure water scalebreaker. In front of the first roll stand are located feed rolls that serve for safe entrance the bill into the roll stand groove. This preparatory train is created by four housingless SHS roll stands with roll diameter 650 mm. The rolling is carried out in a single strand with H-V roll stand arrangement, using the pass sequence oval-round and a slight interstand tension. The sliding roll stands enable symmetrical set up of the rolls, including the axial adjustment, which ensures adjusting the groove axis into the centreline of the mill. The advantage is very fast replacement of grooves and hence high utilization of the rolling mill operating time, outstanding rigidity of the roll stand thanks to its optimum construction and the fact that no test pieces of rolled stocks at the groove replacement are needed. The preparatory train exits the round semi-product of diameter 120 mm.

Insulated roller table (tunnel furnace)

The insulated roller table follows directly the preparatory train, and starts the two-stranded part of the rolling mill. Its target is to introduce the rolled stock with a decreased entry speed into the first roll stand of the roughing train. The whole roller table is covered for maintaining the rolled stock temperature. Thus the temperature difference between the front and rear part of the rolled stock is eliminated; thanks to this, thermal losses are diminished in the course of waiting before entrance the rolled stock into the roughing train. Maximum temperature difference between front and rear part of the rolled stock is guaranteed 30 °C. Behind the insulated roller table is the shear located, used for cutting the rolled stock in emergency cases (failures) in the rolling mill. The roller table is designed in such a way so that false air intake into the furnace and hence origin of the secondary scale were minimized. Rollers of individual strands of the roller table are driven independently.

Roughing train

That is the question of the old roughing train, composed of six roll stands with horizontal arrangement and pass sequence oval – round. Diameter of rolls of stands No. 1 to 4 is 540 mm, No. 5 to 7 - 480

mm. Roll stand No. 2 of the previous four-strand mill was abolished, nevertheless – original numbering was preserved. All drives of the roughing and medium train are DC motors with power 800 kW. The last roll stand of the roughing train is followed in each strand by the crop shear for cropping head and tail end of the rolled stock, or these shears can function as the chopping shear for its scrapping in case of emergency.

Medium train

The medium train is created by totally 8 roll stands in horizontal arrangement with the pass sequence oval – round. This train prepares rolled stocks for entry into two independent finishing trains. Roll diameter of stands No. 8 and 9 is 440 mm, No. 10 to 15 - 380 mm. After every odd pass the rolled stock tilting is introduced.

Looping system before finishing block

The medium train is followed by 2 looping devices (Fig. 7.37), each for one rolling strand. Total length of the loop is 86 m. This length guarantees a possibility of elimination temperature differences in the rolled stock section after cooling. To prevent high tension during rolling the looping tables and looping channels are installed. The looping table is followed by the tearing shear. This shear is followed by two CL roll stands in H-V arrangement. These roll stands make a significant contribution to improvement of the rolled stock geometry, mainly in case of low number of passes in the finishing block (rolling of higher wire rod diameters). CL roll stands are equipped with overhung rolls with diameter 208 mm, made of sintered carbides. After CL roll stands the material is introduced into two cooling sections (VS1 and VS2). Each section has 3 optional cooling zones; water is used as a cooling medium. By means of these sections the rolled stock temperature in front of its entrance into finishing block is controlled. After leaving the cooling sections the rolled stock is led through the looping channel to the rotary shear (maximum diameter of cutting is 33 mm), which crops front and rear ends of the rolled stock, or it may be introduced through the switch into the chopping shear equipped by pinch rolls.

Finishing block

The KDT rolling mill at Třinec is equipped by finishing block Morgan. This block is created by 10 roll stands with H-V arrangement. The groove is created with two disks, mounted in such a way that they form an angle 45° with the horizontal plane. They are made of special, very hard and resistant materials on the basis of sintered carbides. Rolls are overhung, which enables their easy replacement. The first three roll stands of the finishing block have diameter of rolls 208/187x72 mm (208 mm – diameter of new rolls, 187 mm – diameter of worn out rolls). The remaining rolls of the finishing block have diameter 159/143x62 mm. Within the finishing block is installed interstand cooling of round rolled stocks with pressure control of the cooling water from 0 to 6 bars. Maximum rolling speed is 120 m.s^{-1} , the guaranteed speed is 105 m.s^{-1} .

Water cooling sections

Immediately after exit from the finishing block the rolled product enters the controlled water cooling system. This water cooling system has total length 36.6 m and consists of 4 cooling boxes (VS3 to VS6). Each of them is 4 m long. The cooling box has three cooling and 3 wiping nozzles (one is air nozzle). Water pressure for the first two boxes may be controlled in the range of 2 to 6 bars. The last two cooling boxes work with constant water pressure 6 bars.

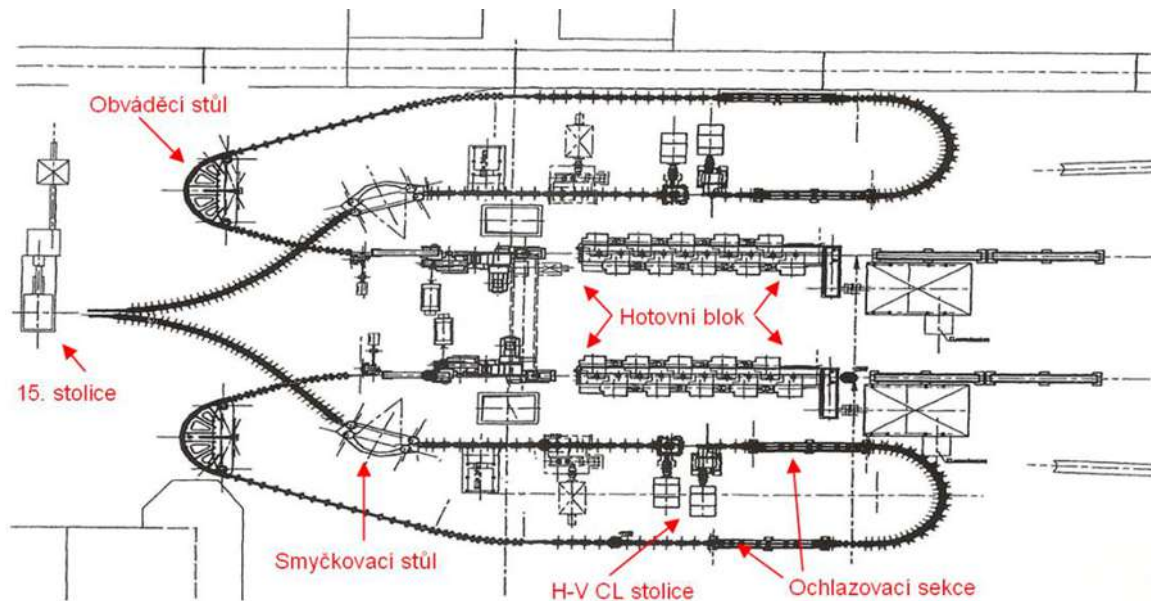


Fig. 7.37 Looping system before finishing block

(H-V CL stolice - H-V CL roll stands, hotovný blok - finishing block, smyčkovací stůl - looping table, obváděcí stůl - looping channel, ochlazovací sekce - cooling section, 15. stolice - roll stand No. 15)

Laying equipment

In front of the laying head are installed the pinch rolls, made of sintered carbides, with rollers diameter 186 mm. They ensure required speeds of the rolled products rear ends for laying wire rod wraps. In case of smaller diameters of rolled products they cause decelerating (braking effect), in case of larger diameters they ensure the acceleration. The laying head is mounted with incline 10° . It forms wire rod wraps with diameter 1080 mm (see Fig. 7.38).

Stelmor conveyor

That is the question of a roller type conveyor with total length 85 m (see Fig. 7.39). It consists of ten separate speed control sections (R1 to R10), graded through height. The first entry section is adjustable in the height direction. The independent speed control of particular sections enables changing of thermal nodes of overlapping wraps with ensuring uniform speed of wire rod cooling. Between sections R9 and R10 there is a height difference 0.1 m, which allows to perform a jump change of feeding speed of the wire rod wraps before entry into the collecting chamber. Speed of the conveyor is between 0.05 and 1.3 m.s^{-1} . The wire rod cooling modes are set up automatically according to the rolling mill schedule. Density of distribution the wire rod wraps is given by rolling speed and speed of the conveyor and depends on the cooling mode.



Fig. 7.38 Laying head



Fig. 7.39 Stelmor conveyors

Collecting chamber

The collecting chamber is designed for maximum coil weight 2 000 kg. Maximum wire rod temperature at entrance into the collecting chamber is 600 °C. Wire rod wraps are gradually laid on the coil plate which is continually lowered in the course of filling the coil, sliding on the mandrel located in the collecting chamber. After the mandrel is filled up, the plate is turned down and the coil is tilted from vertical to horizontal position, from where it is delivered on the transfer car, located behind the collecting chamber. From the car the coil is loaded on the hook conveyor. Each strand has its own independent conveyor, which ensures feeding empty and transfer full hooks to the basic hook conveyor. The equipment works fully automatically and is controlled by hydraulic slave cylinders.

Measuring equipment

The rolled stock temperature is measured continuously by 5 optical double-spectral pyrometers and 1 single-spectral pyrometers of company Raytek. Positions for temperature measurements are: in front of entry into the roughing train (T1), behind the medium train (T2), in front of the finishing block (T3), behind the laying head (T4), on Stelmor conveyor (T5) – double-spectral pyrometer and in front of the collecting chamber (T6) – single-spectral pyrometer.

Both rolling strands are equipped by two independent measuring devices, which continually provide information on the rolled stock quality so that the required dimensional tolerances and required surface defects occurrence might be reached:

“Mesameter”, which works on the basis of shielding the laser sensor. It swivels around the measured wire rod through 180° and continuously measures its cross section behind the finishing block.

“Defektomat“, which measures and records surface parameters of the rolled stock in front of the finishing block by means of electromagnetic radiation. This method makes it possible to find out defects (their depth and number) on the rolled stock surface and carry out relevant classification of the final production, or quickly determine products with defects and thus prevent useless complaints about faulty products.

Transport and handling the coils, shipping

The supplier of transport equipment and coil handling devices is Swedish company Sund Birsta. The task of the hook conveyor equipment complex is to take the coils out of the collecting chambers places and transport them by means of the transfer cart to the following equipment (see Fig. 7.40). Every hook is equipped by the identification plate, including information on the coil.

After cropping ends the coil is weighed together with the pertinent hook; this information is preserved in the coil monitoring system VAX. Subsequently, the coil is transported by the hook conveyor to the area of two baling presses, where it is baled and bound by binding wire with diameter 7 mm in four places (see Fig. 7.41). In this station the information on the given coil is printed on the plate, which is then fastened by hand to the coil. After binding, the coil is transported by the hook conveyor to the unloading cart, which takes the coil off the hook and stores to the interim storage area. Then the empty hook returns and receives new information from the data bank. From the interim storage area the coils are taken out either directly for shipping or to the storage yard.



Fig. 7.40 Hook conveyor



Fig. 7.41 Baling press for coils SUND BIRSTA



Summary of terms of this chapter

Beams I, H – sections U – rails – sheet piles – angles – sections – steel bars – wire rod



Questions to discussed curriculum

- 7.1. What products are ranked to the assortment of heavy shaped rolled products?
- 7.2. What is maximum thickness of hot rolled wire rod?



Used references that may be used for further study

LEE, Y., Rod and Bar Rolling: Theory and Applications. New York : Marcel Dekker, 2004.

8. Groove – its kinds, parts, geometry and dimensional characteristics, neutral axis



Time for study: 1.5 hour



Target After studying this chapter you will be able to

- define basic terms concerning the grooving of rolls
- know the tasks laid on grooving of rolls
- resolve the position of the groove neutral axis



Presentation

8.1. Significance of grooving of rolls and basic terms

Rolling is used for the production of sheets/plates and sections of any dimensions. It is usually carried out in several passes. A number of passes is determined in dependence on the initial and final cross section dimensions. In the course of every pass (draft) the cross section area is diminishing, the shape and dimensions are gradually approaching the required profile.

In rolling the following basic groups of final products may be distinguished as per finish rolled products:

- **Flat products (flats)** – in rolling of flat products the plain rolls are used and thickness change is realized by changing the distance between rolls. The draft (thickness reduction, pass reduction) is uniform across the whole width of the rolled stock and rolling is accompanied by free spread.
- **Shaped steel (sections)** – rolling of sections is carried out in grooved rolls. It is characterized by a pronounced manifestation of the uneven pass reduction. The thickness reduction in cross sections across the groove width is considerably different. In lateral direction the deformation is manifested differently, i.e. restricted or forced spreading occurs.

From the above mentioned text results that grooving of rolls deals with questions of determination/ designing the correct pass schedules, shape and construction of grooves. That is the question of a summary of knowledge of metal forming theory, rolling process technology, as well as certain “rules”, acquired in practice, that have to be followed in designing the optimum mode of rolling for achievement of the required metal shape. The grooving of rolls is the most important part of the process technology of shaped steel rolling and it occupies an important place in questions of designing the rolling mills as well.

□ Basic tasks of grooving of rolls

The grooving of rolls must lead to fulfilment of following basic requirements:

- achievement of the exact cross section shape, together with correct dimensions
- rolled product surface has to be without defects, i.e. clean and smooth
- respecting minimum consumption of power, rolls and rolling time
- ensuring minimum internal stress in the final shaped product
- ensuring simple operation and minimum effort of roll stand operating personnel, with a chance of introducing mechanization and automation of the rolling process
- ensuring the required capacity of the rolling mill
- respecting rationalization in handling the rolls, i.e. assembly and replacement the rolls, roll turning, and so on

In searching the optimum rolling course from the viewpoint of grooving of rolls it has to be taken into account some technical and technological requirements of the formed metal and terms of rolling, which may be summarized in three characteristic groups:

Characteristics of final rolled product

- dimensions of final steel sections and permissible dimensional tolerances
- requirements for mechanical properties
- surface quality of steel after rolling

Characteristics of initial semi-product

- dimensions and weight of the semifinished product
- quality of rolled steel
- temperature of steel before rolling
- temperature of steel in rolling in particular passes

Characteristics of rolling mill

- number of roll stands, roll barrel
- roll diameter
- strength of rolls and components of the roll stand
- motor power
- rolling speed
- technological equipment of the rolling mill, and so on

□ Basic terms in grooving of rolls

Steel sections – can be rolled on plain rolls or rolls with slots/grooves. An example of rolling on plain rolls can be the flat bar. A typical shape for rolling in grooves represents the rail, see Fig. 8.1, in which contour of the crane rail is plotted.

Incision (slot) – area in the rolling plane restricted by cut in the roll body. You cannot roll out anything using only one roll, you always need two rolls (Fig. 8.2).

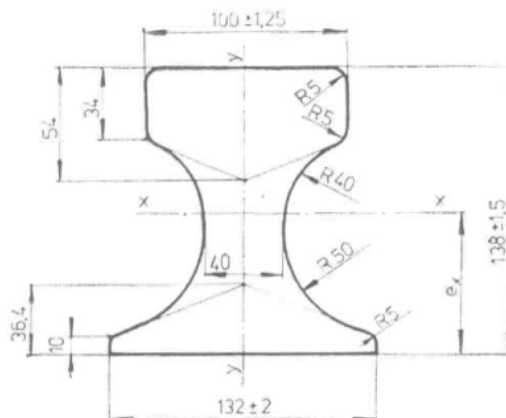


Fig. 8.1 Crane rail

Groove – two slots corresponding to a single pair of rolls with the defined roll gap

Roll gap – actual distance between the top and bottom roll, denoted s .

Flanges / Collars are parts of the work roll barrel that are not fully used, if their diameters are higher than diameters of rolls in the groove. Their number on the roll is always higher by 1 than the number of grooves. In case of usual construction of collars for steel rolls the flange width corresponds approximately to half of its height. In case of cast iron rolls the width equals the height. Width at edges is chosen differently.

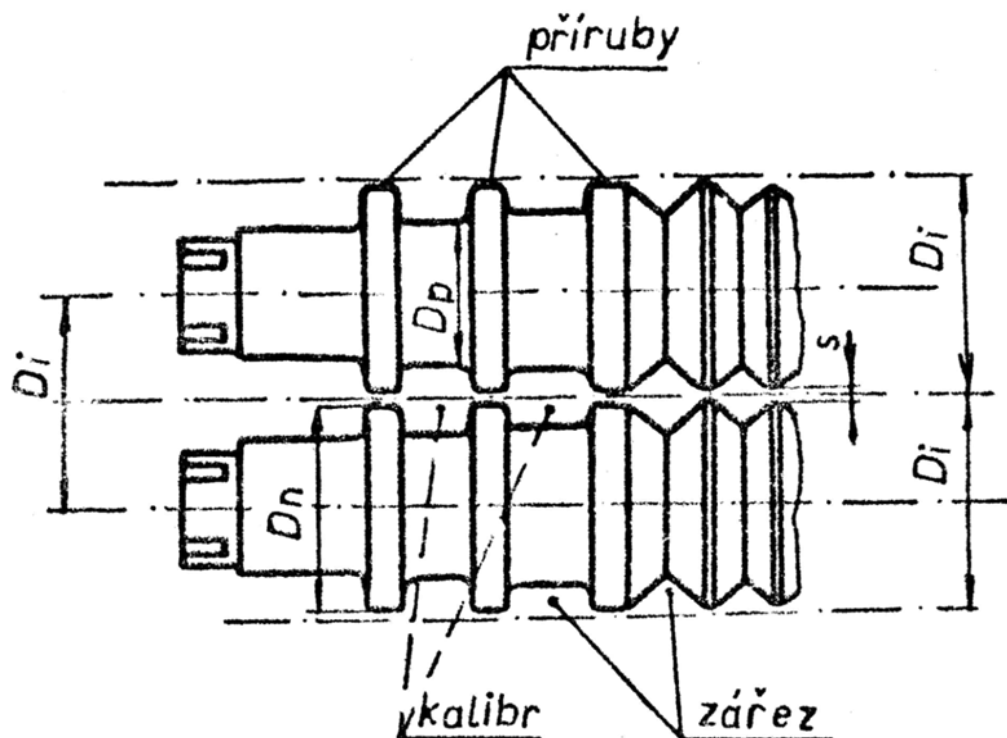


Fig. 8.2 Rolls used in billet rolling mill
(přiruby - flanges, kalibr - groove, zářez – slot)

Possible types of collars – see Fig. 8.3:

- a) edge positive
- b) edge negative
- c) double
- d) lock
- e) negative
- f) positive

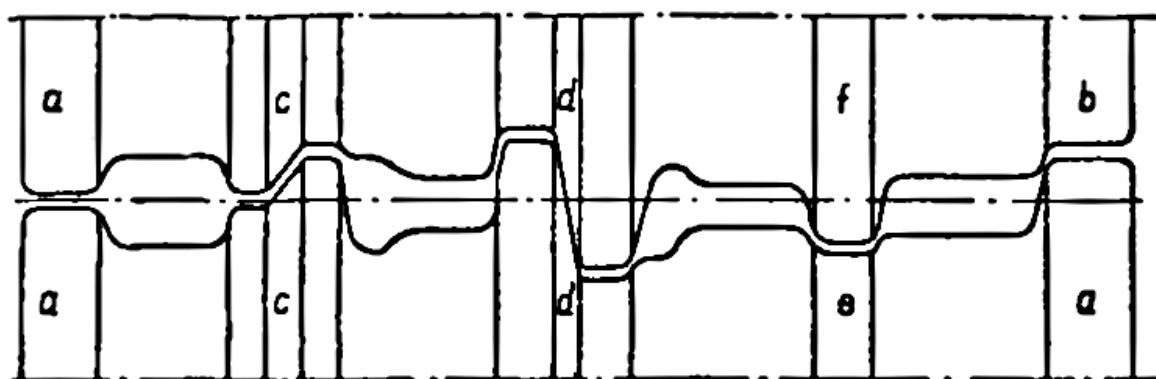


Fig. 8.3 Possible types of collars

□ Dividing of grooves/passes

As per a way of use the grooves are basically divided with respect to their function and location in the rolling mill into roughing, preparatory, leading and finishing. In Fig. 8.4 all basic types of grooves and their location in technological flow are shown.

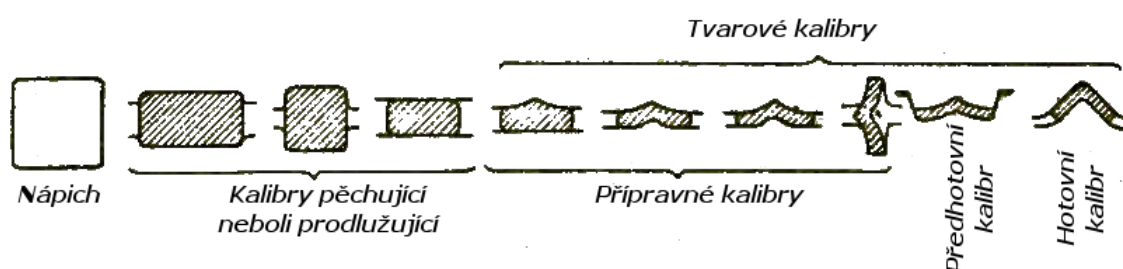


Fig. 8.4 Evolution and marking of grooves in pass sequence

(Nápich - initial pass, kalibry pěchující neboli prodlužující - upsetting (extension) passes, přípravné kalibry - preparatory passes, tvarové kalibry - shaping passes, předhotovni kalibr - leading pass, hotovní kalibr - finishing (final) pass)

Roughing grooves/passes (also named extension or elongation) are determined only for a progressive diminishing of the cross section area of the rolled metal. Box, diamond, square, oval and round passes belong to this group. Examples of particular types of passes are shown in Fig. 8.5. I suppose that you manage their correct assignment according to their names.

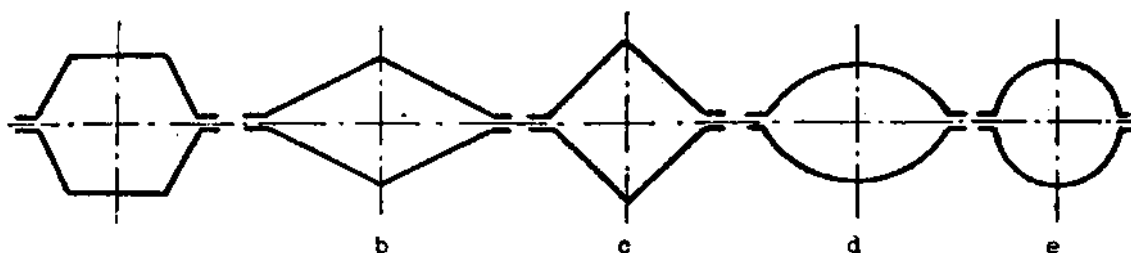


Fig. 8.5 Shapes of roughing passes

Roughing passes are determined for further diminishing of the cross section of the rolled material. At the same time a primary change in the sense of gradual achievement of the dimension and shape of the final profile occurs. A special case of the roughing pass can be incisive (pre-shaped) pass.

Leading passes serve for shaping the rolled stock in the last but one pass. By their shapes they are approaching the finish rolled product.

Finishing passes – in these grooves the final shape is acquired. The shape and dimensions correspond with shape and dimensions of the final rolled product. The finishing pass is designed with taking into account the thermal expansivity and permissible tolerances.

Further dividing is carried out as per a way of performance the slots on the roll body. We distinguish **open passes**, where in both cooperating rolls the slots are carried out and the pass opening forms an angle with the rolling axis $< 60^\circ$ (a, b in Fig. 8.6), and **closed passes** – in one roll there is a slot, in the other a shoulder, the pass opening is at an angle with the rolling axis $> 60^\circ$.

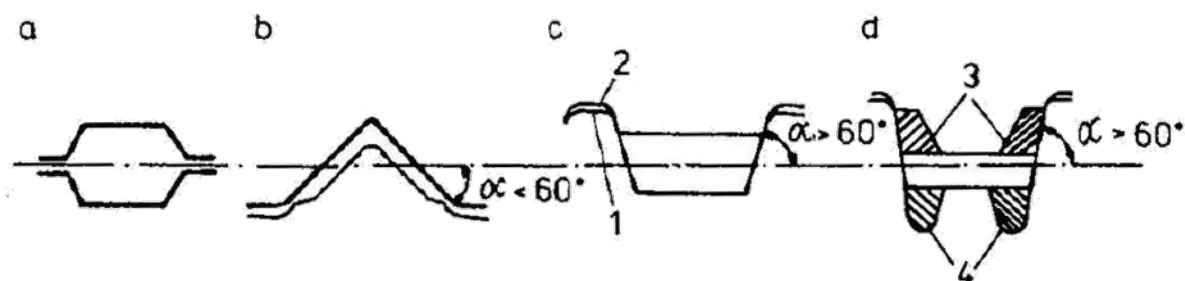


Fig. 8.6 Possible situations in carrying out the passes: 1 – positive collar, 2 – negative collar, 3 – open flange, 4 – closed flange

Further dividing the passes is according to their placing in the rolls. We distinguish the following passes:

- direct - passes, the vertical symmetrical axis of which is perpendicular to the rolling axis
- diagonal - the vertical symmetrical axis forms a certain angle with the rolling axis, e.g. intermediate passes for rolling of beams, rails, and so on

□ Influence of thermal expansivity

In designing the finishing pass it is necessary to take into account that lateral dimensions of the rolled material are larger at the finish rolling temperature than at the room temperature, at which measurement of important parameters of the rolled stock cross section is carried out. In general, the thermal length (linear) expansivity is a phenomenon, at which the length of the body heated to a specific temperature is extended in the given direction by a certain value. Isotropic bodies have the length expansivity in all directions the same, in case of anisotropic bodies, however, the length

expansivity can acquire various values in different directions (e.g. in crystals), therefore the given direction has to be specified.

An extent of thermal expansivity is determined by linear coefficient of thermal expansion α [K⁻¹], called also coefficient of proportionality. This physical quantity is exactly (i.e. without necessity of supposing the linear dependence of length on temperature) defined by the relation:

$$\alpha = \frac{1}{l_0} \frac{\partial l}{\partial t} \quad (8.1)$$

where l_0 is initial temperature at given temperature t .

For small temperature differences it is possible to use a simplification and to approximate the relation between the length change and temperature change to the linear dependence, it means to describe in the form:

$$\Delta l = \alpha l_0 \Delta t \quad (8.2)$$

For determination of length at chosen temperature this relation may be expressed as follows

$$l = l_0(1 + \alpha \Delta t) \quad (8.3)$$

In the roll grooving practice this relation is simplified to the maximum extent in such a way that l_0 is length at room temperature and for recalculation of length at a specific temperature the technical coefficient of thermal expansivity k_α , corresponding to extension of a specific material, is used. The relation is then changed to the form

$$l = l_0 k_\alpha \quad (8.4)$$

Values k_α , usual for structural steels, are given in Table 8.1

Table 8.1 Values k_α in relation to temperature

Temperature, °C	k_α	Temperature, °C	k_α
800	1.010	1100	1.013
900	1.011	1200	1.014
1000	1.012	1300	1.015

□ Neutral axis of groove

In solution of the appropriate distribution of grooves along the roll barrel the basic characteristics of the groove geometry have also to be taken into account. It was already mentioned that the groove of any shape is created by corresponding slots on the top and bottom roll body, together with the roll gap. For rolling of shaped sections various shaped grooves are used, which can be divided - with regard to their symmetry - into three groups:

- simple grooves, symmetrical according to axes x and y , among them grooves of simple geometric shape, e.g. oval, square, round, etc. and e.g. a series of finishing grooves, including some for shaped sections. These grooves have two axes of symmetry, their point of intersection passes through the centre of gravity. It means that the horizontal axis (x) is at the same time the neutral axis
- symmetrical grooves, but according to a single axis of symmetry (horizontal or vertical) only, among them a great part of preparatory grooves and further also a part of finishing grooves, e.g. grooves for I and/or U beams, angles, rails, etc.
- grooves that are not symmetrical according to any axis

The existence of at least one axis of symmetry of shaped grooves is helpful for determination of neutral axis. The neutral axis is the horizontal axis, to which the statical torques of forces related to the groove from the side of top and bottom roll are identical.

The neutral axis of the groove goes through the centre of gravity and is identical with its horizontal axis of symmetry. In case of complicated preparatory grooves with only the vertical axis of symmetry the neutral axis goes through the centre of gravity as well. In this case the task is simplified to defining the relevant height coordinate of the centre of gravity.

□ Modes of determination of groove neutral axis

Several modes may be used for determination of the position of the groove neutral axis. They are based on determination of the total groove cross section, its centre of gravity or the position of the centre of gravity of the groove contour. All used modes aim at determination of such position of the groove neutral axis that assures equivalent effect from the side of both top and bottom roll. It means equality of both rolls mean work diameters, speeds, etc.

Grooving designers in their practice tried to use various modes of finding the groove neutral axis – from the historical empirical rule method, characterized by balancing the groove picture, cut out of stiff cardboard, on the rule sharp edge, stretched wire or needle, to the planimetric method. This method was based on determination of surfaces by means of planimeter, most often in case of grooves with vertical symmetry, where the height position of the groove neutral axis was found and the groove shape was restricted across width according to the shape of the rolled section and through height arbitrarily. The resulting difference in surfaces was then divided by the chosen width B and the height h_1 was acquired. Subsequently the sum of heights was divided half, and thus the position of the neutral plane going through the centre of gravity was obtained.

The method using the effect of statical torques may be used as well. In this case tasks are solved in such a way that the groove cross section is divided into elementary parts in a geometric way and coordinates of their centre of gravity are determined separately. Hereinafter an example of the solution for the U cross section is given. The centre of gravity position is determined from the relation

$$y = \frac{M_1 + 2M_2}{S_1 + S_2} = \frac{S_1 y_1 + 2S_2 y_2}{S_1 + S_2} \quad (8.5)$$

where $S_1 = B_k d$ – is web surface of the channel (U section)

$S_2 = 0,5(a + b)h$ – is surface of one flange

a, b – sides of trapezoid,

M_1, M_2 – static moments of the areas,

$y_1 = \frac{d}{2}$ – is coordinate of web centre of gravity

$y_2 = \frac{h}{3} \left(\frac{2a+b}{a+b} \right)$ – is coordinate of flange centre of gravity

$z = d + y$ – is distance between groove outer edge and centre of gravity

This method brings satisfactory results in lots of solutions. However, from the theoretical point of view it has to be taken into account the magnitude of friction forces and mainly their change on roll flanges; therefore the optimum appears to be the method based on equality of the effect of mean work diameter of the top and bottom roll with taking into account friction forces, which solves consequences of the opening position in the upper and lower part of the groove.

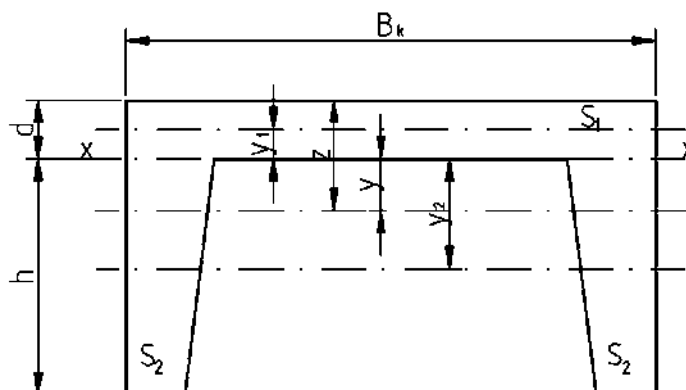


Fig. 8.7 Determination of centre of gravity



Summary of terms of this chapter (subchapters)

From this chapter you should know these terms:

shaped steel; slot; groove (pass); roll gap; collars; preparatory, roughing, leading, finishing grooves; grooves open and closed; neutral axis of groove



Questions to discussed curriculum

- 8.1. Explain the difference between shaped and flat steel.
- 8.2. What are tasks solved by grooving of rolls?
- 8.3. Which parts is the groove defined by?
- 8.4. How is defined the groove opening?
- 8.5. Enumerate and define groove types as per classification into particular sections of the rolling mill.
- 8.6. What used to be values of extension coefficient?
- 8.7. Define neutral axis of the groove.



Used references that is recommended for further study

GINZBURG, V. B.: Steel-Rolling Technology : Theory and Practice. New York : Marcel Dekker, 1989.

9. Basic grooves design, roll diameters characteristics and roll service life



Time for study: 2 hours



Target After studying this paragraph you will be able to

- define and construct basic shapes of extension passes
- define ideal mean roll diameter and work roll diameter
- describe relations between various roll diameter types



Presentation

9.1. Design of basic extension passes (grooves)

Before featuring particular roll diameters, which the groove designer can come across in practice, it is necessary to describe basic modes of designing the simplest extension passes. With regard to procedures used in the groove designing practice, the work starts with groove surface area S , based on which the groove height H and width B are determined.

□ Round groove

From the view point of designing the round groove it has to be distinguished whether we have in mind extension grooves or finishing grooves. For extension grooves the round groove design with one rounding-off radius is sufficient. This groove does not assure conditions for achievement of the quality and accurate round cross section, however, for using in the function of extension groove is suitable.

In case of designing the extension round groove the groove surface S , usually determined by previous calculations, is known. So, we start from the relation:

$$S = \frac{\pi}{4} d^2 \quad (9.1)$$

Groove diameter d and also its width B may be calculated as follows

$$d = B = \sqrt{\frac{4}{\pi} S} \quad (9.2)$$

The design of roll gap value s and rounding-off radius r may start from the groove diameter value d , usual values are $s \approx r \approx 0.1d$. In case of determination the roll gap value s from roll diameter we suppose that also the rounding-off value r is similar.

Designing the finishing round groove can be much more complicated, see examples in Fig. 9.1.

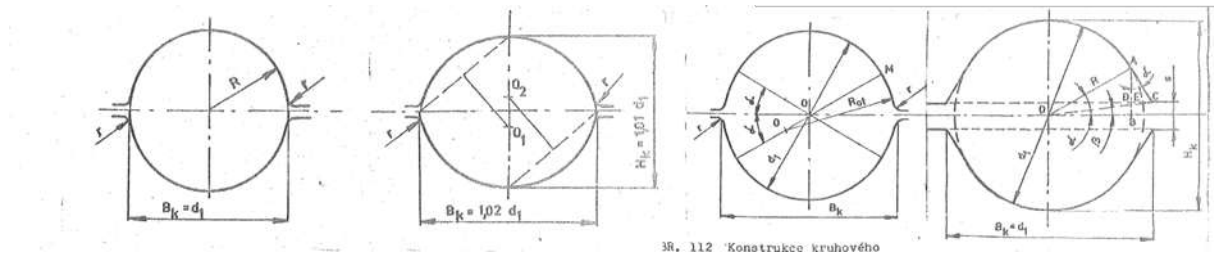


Fig. 9.1 Types of round grooves
(Konstrukce kruhového kalibru – construction of round groove)

□ Oval groove

The simplest design is in case of one-arc oval groove, which may be designed as so-called sharp with a large rounding-off or so-called blunt with a small rounding-off approaching the final round. In its designing we start from the groove surface S and the ratio of width B to height H , denoted α . For the groove construction the variable α is assumed: $\alpha = B/H = 1.5 \div 4.5$. For calculation of the oval groove surface S the following formula is used

$$S = \frac{2}{3}BH \quad (9.3)$$

Without knowledge of variable α calculation of groove width and height from the groove surface is not possible and the equation cannot be resolved. The example of surface calculation is given in solved examples. Arc radius R of the oval groove may be calculated from the formula

$$R = (B^2 + H^2)/4H \quad (9.4)$$

The roll gap value may be determined from the oval groove height according to the relation

$$s = (0.15 \div 0.2)H.$$

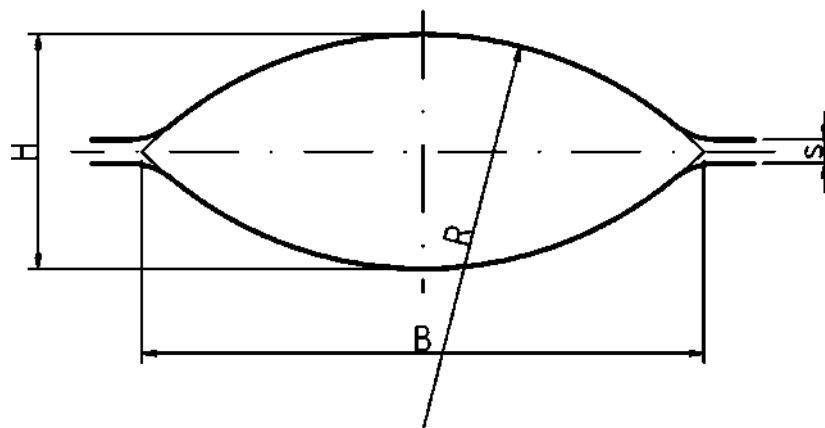


Fig. 9.2 Oval groove construction

□ Square groove

If we base our designing of the square groove on the known surface S , then we use the formula (9.5), where a is square side:

$$S = a^2 \quad (9.5)$$

Relation between square side a , groove height H and groove width B is as follows

$$B = H = \sqrt{2}a \quad (9.6)$$

This relation is valid when we are designing the final groove for rooling of square bars. In case of designing the extension groove, whether using the pass sequence oval – square or another one, a slight groove opening is used up to the vertex angle value ca 93° .

In Fig. 9.3 the groove construction with rounding-off can be seen. In case of finishing pass the construction without rounding-off is possible as well. The actual groove height h respecting rounding-off will be

$$h = \sqrt{2}a - 0,828r \quad (9.7)$$

The vertex rounding-off magnitude is usually chosen as

$$r \approx \langle 0.1 \div 0.2 \rangle a \quad (9.8)$$

The rounding-off value r_1 in transition from the slot to the collar used to be

$$r_1 \approx \langle 0.1 \div 0.15 \rangle H \quad (9.9)$$

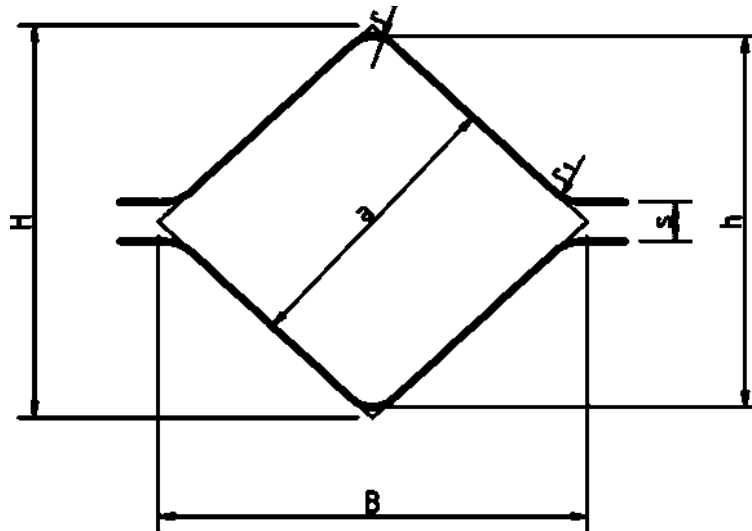


Fig. 9.3 Square groove construction

□ Diamond groove

In designing of diamond groove we start from the groove surface S (Fig. 9.4). The fundamental relation between variables S , the groove width without rounding-off B and the groove height without rounding-off H is as follows

$$S = 0.5 BH \quad (9.10)$$

The relation between diamond side a and groove dimensions is determined by the equation

$$a = \frac{H}{2 \sin \beta/2} \quad (9.11)$$

The proper shape of diamond may be expressed by means of angles α and β as well. The vertex angle β used to be around 110° in using the diamond groove in the pass sequence square – diamond. The dependence of the groove width without rounding-off on the groove height without rounding-off is determined by means of angle β as follows

$$B = H \tan \beta/2 \quad (9.12)$$

Recommended values for radius of rounding-off R at the groove flange are given by the relation

$$R = \langle 0.2 - 0.4 \rangle B \quad (9.13)$$

Radius of rounding-off at the groove vertex r acquires values

$$r = \langle 0.0 - 0.2 \rangle a \quad (9.14)$$

In case of choice the roll gap s the following dependence on roll diameter D may be used

$$s = \langle 0.01 - 0.02 \rangle D \quad (9.15)$$

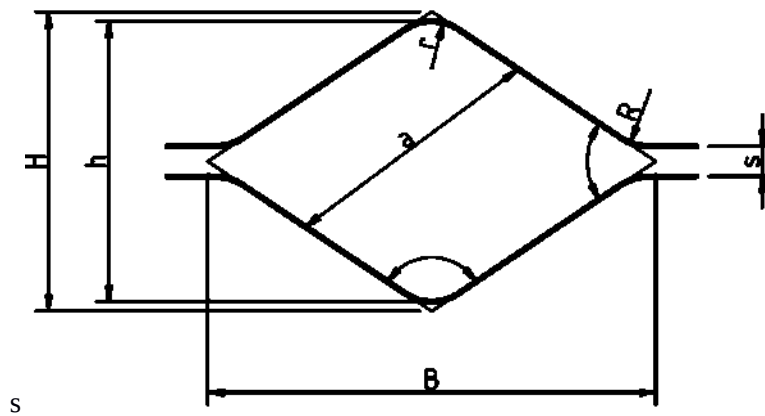


Fig. 9.4 Diamond groove construction

□ Box groove

Basic dimensions used in designing box grooves of the rectangular and square shape are shown in Fig. 9.5.

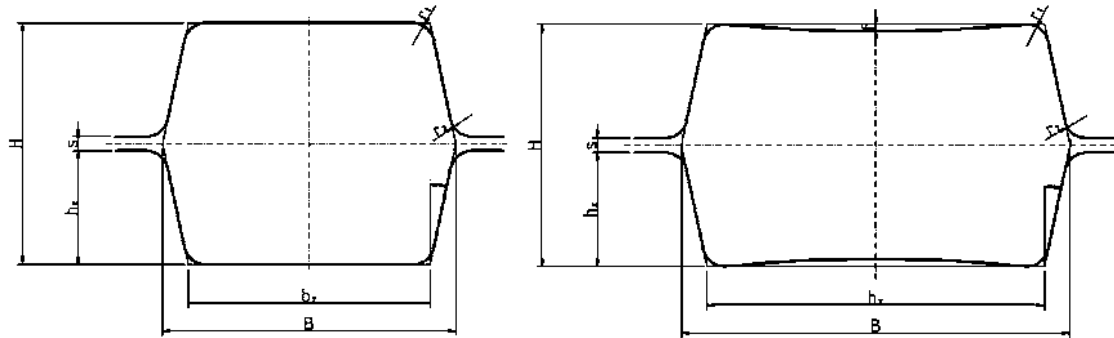


Fig. 9.5 Box groove construction

The slot depth h_z (groove height H) is designed in accordance with determination of the groove. It depends on the draft (height reduction), rounding-off the corners, ratio between the rolled stock sides, etc. The smaller is ratio between sides H/B at the rolled stock exit from the groove, the smaller slot depth is carried out. We can approximately choose the slot depth based on the following data:

Roller stocks with $H/B < 1.2 \rightarrow h_z = 0$

The same H/B with requirement for guidance of the rolled stock in the groove with rounding-off in corners $\rightarrow h_z = (0.2 - 0.3) H$.

Rolling of rolled stocks with ratio $H/B > 1.3$ and roll adjustment possibility $\rightarrow h_z = (0.35-0.45) H_{\min}$.

Roller stocks with ratio $H/B > 2$ without roll adjustment possibility $\rightarrow h_z = (H-s)/2$, where roll gap $s = (0.02-0.08) D$.

Groove widths b_z and B are determined in dependence on width of the rolled product at the pass entrance and its spread during rolling. For a good guidance of the rolled stock the width in the groove bottom b_z should be mildly smaller than width of the rolled stock entering the groove. If no rounding-off the corners in the box groove is considered, the groove has to be designed with respect to occurred spread $b_z = (1.00-1.05) b$. The groove width in place of its opening B is determined in dependence on the groove side walls incline and spread value Δb . The value of variable B has to be chosen in such a way so that no groove overfilling could take place. For blooming mills the following relation is recommended: $B = b + (1.25-1.75) \Delta b$. For box grooves in connection with plain part of rolls the relation $B = b_z + 2(0.1-0.2) h_z$ is recommended.

The side walls incline ranges in very wide limits, namely from 10 to 20%, for shallow slots and upsetting grooves can be even higher (40-50%). The choice respects the spread magnitude and deformation conditions.

Rounding-off radii r_1 and r_2 are chosen in relation to width of the rolled stock at the pass entrance. Based on real experience the following constructive relations are recommended

$$r_1 = \langle 0.15 - 0.25 \rangle h_z \quad (9.16)$$

$$r_2 = \langle 0.8 - 1.0 \rangle r_1 \quad (9.17)$$

In some cases the box grooves are designed with respect to prevention overfilling of grooves by the rolled metal, mainly at higher pass reductions. On these conditions the groove bottoms are designed with rounding-off. The rounding-off is carried out with as large as possible radius and with depth – considered from the groove bottom – halfway its width, ranged from 5 to 10 mm. In case of billet rolling mills the rounding-off (crown) of the box groove bottom is not carried out.

9.2. Roll diameters

One of the parameters featuring rolling mills is diameter of the used rolls. In the course of rolling, however, rolls diameters are constantly changing due to their wear and tear. Therefore the mills for rolling the shaped sections are characterized by rolls diameters of the pinion stand which remain constant. In case of roll stands with plain rolls they are their rolls diameters as well, unless we consider the roll gap. In case of grooved rolls, where we take into account the roll gap, such diameter the magnitude of which is determined by the distance between axes of top and bottom roll (see Fig. 9.6) is considered. This diameter is called mean ideal roll diameter $D_{i, str}$. It is a basic roll diameter, which is used not only for featuring the rolling mill but also in basic calculations of grooving of rolls (pass sequence).

In case when the roll gap is considered, then nominal roll diameter D_n is smaller than mean ideal roll diameter. Nominal roll diameters represent then the actual maximum diameters that the rolls have when they are placed in the roll stand. In case of grooved rolls these are diameters measured on flanges. The magnitude of nominal roll diameter is changing due to regrinding the rolls in the course of their service life from $D_{n, max}$ to $D_{n, min}$. For the top roll notation $D_{n, h}$, for the bottom roll $D_{n, sp}$ is used.

The relation between mean ideal diameter, nominal roll diameters and roll gap is as follows:

$$2D_{i, str} = D_{n, h} + D_{n, sp} + 2s \quad (9.18)$$

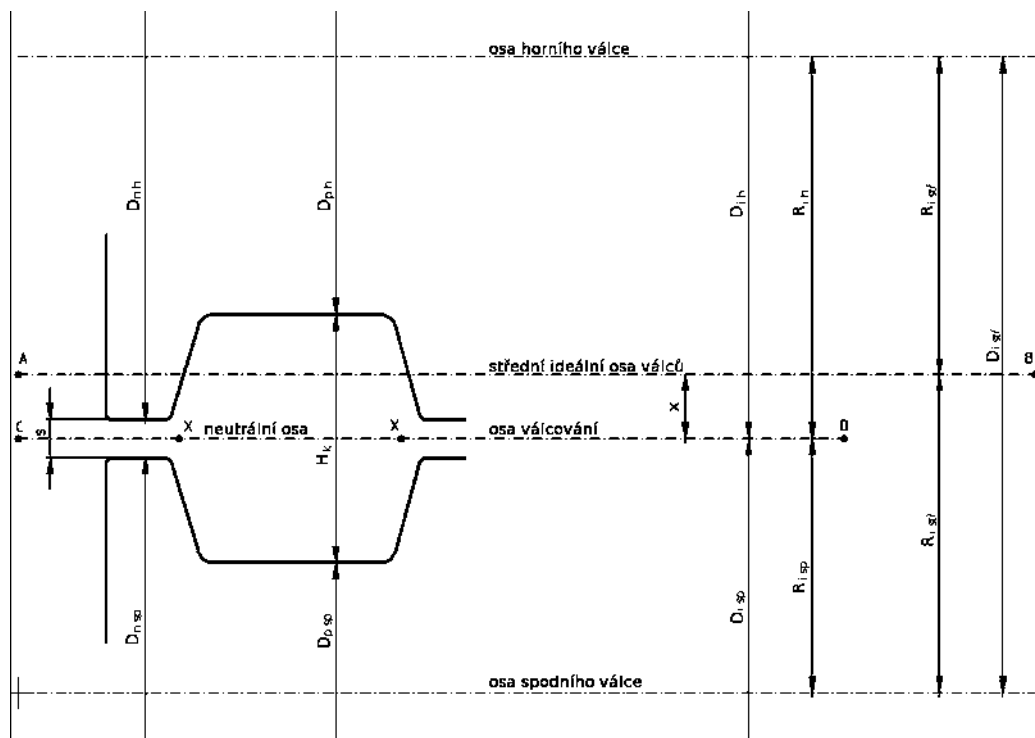


Fig. 9.6 Relation between particular roll diameters

(osa horního válce - top roll centre line, střední ideální osa válců - mean ideal roll centre line, neutrální osa - neutral axis, osa válcování - rolling axis, osa spodního válce – bottom roll centre line)

□ Work roll diameter

By work roll diameter D_p we understand the diameter that was measured in places where the formed metal contacts the roll surface (groove walls). From this results that we can define a whole series of work roll diameters. It depends only on the cross section shape of the rolled metal or on the roll shape.

In rolling on plain rolls we have only one work roll diameter – across the whole width of the rolled stock. The work roll diameter is in this case identical with the nominal diameter.

In case of grooved rolls very many work roll diameters exist. To each place across the groove width which has a contact with surface of the rolled metal belongs another work roll diameter. Differences in work roll diameters cause some difficulties in rolling of shaped sections, especially from viewpoint of kinematics of the rolling process. The speed of the grooved roll changes on the groove contour from $D_{p,max}$ to $D_{p,min}$.

With growing complexity of the groove shape also kinematic issues emerge. With the growing roll slot depth increases the speed difference in particular parts of the groove contour. A significant displacement of metallic particles across width occurs. In the formed metal stress is induced which can finally lead to waviness of the rolled metal. Further, during the rolling process underfilling of some groove parts, or vice versa their overfilling, can occur.

Therefore – another roll diameter, mean work diameter $D_{p,str}$ is introduced for alleviation unfavourable effects of all mentioned influences. It is defined as the roll diameter in a specific place on the roll contour at which the rolled product speed equals the rolls speed. Knowledge of mean work diameter of the roll is an important part of solution of a high number of pass design tasks.

$D_{p,str}$ may be generally expressed as follows

$$D_{p,str} = \frac{\sum_{i=1}^n D_{p,i}}{n} \quad (9.19)$$

In simpler cases, like rolling on plain rolls, mean work diameter is identical with work roll diameter across the entire width of the rolled metal. In case of box grooves the mean work diameter is determined in such a way that the diameter in the groove bottom is chosen.

For determination of mean work diameter the best solution is based on the balance of friction forces acting on slot surfaces in the top and bottom roll in the whole deformation zone. This solution is very difficult and therefore in practice some simplifications are applied.

Currently, basically three methods for determination $D_{p,str}$ are used; they are based on:

- utilization of contact areas between the metal and the groove
- appropriate mean height of the groove
- peripheral groove data

Using the first method, mean work diameter may be generally expressed by the relation

$$D_{p,str} = \frac{\sum_{k=1}^n D_{p,k} S}{l_k} \quad (9.20)$$

where $\sum_{k=1}^n D_{p,k} S$ is a sum of work diameters in every groove place on total contact surface between the metal and the roll in the deformation zone, l_k is total contact length. The value of $D_{p,str}$ depends also on a degree of filling the groove by the metal.

For a single-arc oval groove the mean work diameter is defined according to the following formula

$$D_{p,str} = D + 2r (1 - \cos \varphi_{str}) \quad (9.21)$$

where D – roll diameter in groove bottom

$$r - \text{rounding-off radius of oval groove} \quad R = \frac{B^2 + (H+s)^2}{4(H+s)} \quad (9.22)$$

φ_{str} – mean angle of a slot contour part between initial bite of the metal by rolls and final filling the oval

$$\varphi_{str} = 0.25 \left(\sin^{-1} \frac{b_0}{2r} + \sin^{-1} \frac{a}{2r} \right) \quad (9.23)$$

b_0 – width of the rolled stock at the rolls exit

B, H – width and height of the oval groove

s – roll gap

a – square side at entrance into the groove

For diamond groove at $B/K = 1.75$ and angle $b=120^\circ$

$$D_{p,str} = D - H + 0, B = D - H + 0.35H = D - 0.65H \quad (9.24)$$

For square groove

$$D_{p,str} = D - H + 0.35H = D - 0.65H \quad (9.25)$$

For round groove

$$D_{p,str} = D - d + 0.17d \quad (9.26)$$

A very simple method is the second one, which considers in its mathematical expression the appropriate (mean) groove height

$$D_{p,str} = D_{i,str} - h_{str} = D - \frac{S}{b} \quad (9.27)$$

where S – rolled stock cross section in the exit plane from the deformation zone

b – rolled stock width in the exit plane

However, using this method we do not acquire always correct results, especially in cases of rolling in complicated shaped grooves. The method does not take into account influence of side walls inclines in the groove. So, it is suitable for extension passes.

In references may be found other relations for determination of mean work roll diameter.

For a sinle-arc oval groove

$$D_{p,str} = D_{i,str} - \frac{2}{3}H \quad (9.28)$$

For diamond groove

$$D_{p,str} = D_{i,str} - \frac{0.5BH}{B} = D_{i,str} - 0.5H \quad (9.29)$$

For square groove (without rounding-off the corners)

$$D_{p,str} = D_{i,str} - 0.707a \quad (9.30)$$

With rounding-off the corners in vertices of grooves

$$D_{p,str} = D_{i,str} - \frac{a^2 - 0.86r^2}{1.41a - 0.83r} \quad (9.31)$$

With rounding-off the corners in vertices of grooves, but considering the roll gap

$$D_{p,str} = D_{i,str} - \frac{a^2 - 0.86r^2}{1.41a - s} \quad (9.32)$$

For round groove

$$D_{p,str} = D_{i,str} - 0.778d \quad (9.33)$$

In determination of mean work roll diameter for complicated shaped grooves (beams, rails, etc.) we start with using data on contact surfaces between the metal and rolls, provided that we accept some simplifications. Then for the beam groove is valid

$$D_{p,str} = \frac{\sum D_p l}{\sum l} = \frac{D_1 l_1 + D_2 l_2 + D_3 l_3 + \dots + D_n l_n}{l_1 + l_2 + l_3 + \dots + l_n} \quad (9.34)$$

where l_i is length on roll body with the corresponding diameter D_i .

□ Roll service life

In the course of rolling in grooves the permanent wear of the roll working surface occur. If the roll wear exceeds a certain limit, rolling has to be interrupted. Rolls have to be reground with the aim to reach the original groove dimensions again.

By every regrinding of roll surface the actual diameters D_n are becoming smaller. The roll nominal diameter value is gradually changing – from $D_{n,max}$ at the first built-in the new rolls to $D_{n,min}$ at their last putting in the roll stand. The initial value of nominal roll diameter $D_{n,max}$ has to be chosen with regard to depth of cut grooves at maximum reducing (weakening) the rolls.

It is recommended that maximum weakening the rolls $D_{n,min}$ should not exceed the value:

- for final grooves with simple and complicated geometric shape

$$D_{n,min} \geq (1/4 \div 1/6) D_{i,stř} \quad (9.35)$$

- for roughing rolling mills and rolling mills with preparatory trains for shaped sections

$$D_{n,min} \geq (1/3 \div 1/6) D_{i,stř} \quad (9.36)$$

Mean ideal roll diameter equals

$$D_{i,stř} = \frac{D_{n,max} + D_{n,min}}{2} \quad (9.37)$$

The allowed range of changes in roll diameter caused by regrinding can be expressed by means of coefficient k

$$k = \frac{D_{n,max} + D_{n,min}}{D_{i,stř}} \quad (9.38)$$

where k – relative decrease in roll diameter in the range of its applicability

From this results

$$D_{n,max} = (1 + k/2)D_{i,stř} \quad (9.39)$$

$$D_{n,min} = (1 - k/2)D_{i,stř} \quad (9.40)$$

If the roll gap s , which reaches even high values, is considered, then

$$D_{n,max} = (1 + k/2)D_{i,stř} - s \quad (9.41)$$

$$D_{n,min} = (1 - k/2)D_{i,stř} - s \quad (9.42)$$

The value of the regrinding coefficient k has to be chosen with regard to allowable diminishing of the roll diameter, biting capabilities of rolls, roll strength, etc. The following mean values of coefficient k are recommended:

- for roughing mills and mills for rolling shaped steel

$$k = 0.08 - 0.15 \quad (9.43)$$

- for wire rod rolling

$$k = 0.07 - 0.10 \quad (9.44)$$

- for hot rolling of sheet/plate and strips

$$k = 0.04 - 0.07 \quad (9.45)$$



Summary of terms of this chapter (subchapter)

After studying this chapter you should be able to explain the design of **round, oval, square, diamond, and box groove (pass)**.

Further to explain relations between **ideal mean roll diameter, work roll diameter, mean work roll diameter and nominal roll diameter**.



Questions to discussed curriculum

- 9.1. Explain the design of a simple round groove
- 9.2. Explain the design of a single-arc oval groove
- 9.3. How is designed the square groove?
- 9.4. Construct (plot) the diamond groove
- 9.5. Explain basis of designing the box groove
- 9.6. What is work diameter of the grooved roll?
- 9.7. What ways can be used for determination of mean work roll diameter?
- 9.8. What are usual values of maximum nominal roll diameter and minimum nominal roll diameter?



Tasks for solution

- 9.1. Plot the round groove for rolling of the round bar with diameter 40mm.
- 9.2. Plot a single-arc oval groove with surface area 160 mm².
- 9.3. Plot the square groove for rolling of the bar with side $a = 50$ mm.

- 9.4. Plot the diamond groove with surface area 225 mm^2 .
- 9.5. Design and plot the box groove for rolling of the stock with ratio $H/B=1.15$ and width 245 mm.

10. Contact surface of rolled stock with groove walls, spread in grooves of various types and roll service life under load



Time for study: 3 hours



Target After studying this paragraph you will be able to

- define the top and bottom pressure
- describe calculation of the contact surface between the metal and the groove
- resolve the slot depth in the roll



Presentation

10.1. Top and bottom pressure

From viewpoint of productivity and safety of the technological process it is necessary for the rolled metal to run out of the groove/rolls in straight direction. Therefore the top and bottom roll must have identical diameters. It is known from practice that situations occur or conditions originate when the rolled stock leaving the rolls is bent upwards or downwards. In these cases the runout fittings (guards) have to be built to both rolls. This random, but unfavourable influence must be excluded. A specific direction has to be forced to the metal, not later than it leaves the rolls. That is the reason for using the rolls with different diameters.

If there is in the roll stand the top roll of higher diameter, rolling with so-called top pressure is applied. If higher diameter has the bottom roll, rolling with bottom pressure is applied. Differences in rolls diameters cause that the roll with higher diameter has higher speed than the roll with lower diameter. Differences in exit speeds of rolled stock surface parts are determined according to the relation

$$v_1 - v_2 = \frac{\pi n}{60} (D_1 - D_2) \quad (10.1)$$

In case of identical revolutions of both rolls we get for rolling with top pressure

$$(D_1 - D_2) = m \quad (10.2)$$

and for rolling with bottom pressure

$$(D_2 - D_1) = m \quad (10.3)$$

So, the magnitude of the top and bottom pressure is determined by the difference between work roll diameters with consideration of sign + (plus) for top pressure and sign – (minus) for bottom pressure. In rolling with top pressure the runout guard is placed only to the bottom roll because the external speed from the top roll side creates conditions for bending the rolled stock downwards. The front end leaving the rolls slides on the guard and the rolled stock acquires the straightforward direction.

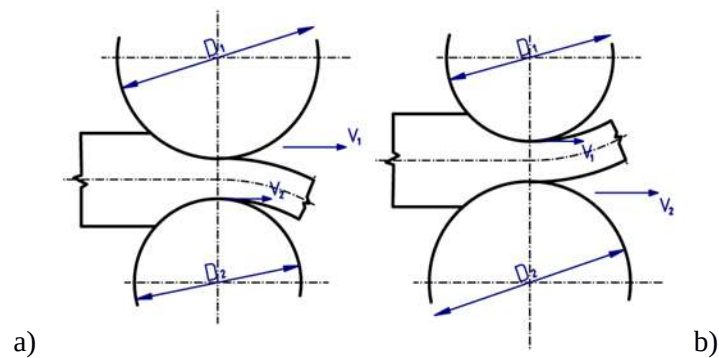


Fig. 10.1 Metal rolling with a) top pressure b) bottom pressure

In technological practice the rolling takes place mostly with top pressure. The rolling with bottom pressure is used in roughing mills. In rolling of ingots and slabs a probability of their bending or even reeling up the top roll is only little. The bottom pressure is here used mainly for the reason of reducing impacts from the bloom or slab leaving the rolls on the housing roller or initial rollers of the roller table. The bottom pressure magnitude in these rolling mills ranges around 10-20 mm.

On the other hand, different roll diameters show some shortcomings, from which the following may be mentioned:

- unequal draft (height reduction) – causes different wear of rolls
- different roll speeds – cause sliding between rolls and additional stresses in the formed metal
- impacts origin – the roll with larger diameter tries to increase speed of the roll with smaller diameter through mediation of the rolled metal

For the reasons mentioned above great differences in roll diameters are not recommended.

Based on knowledge gained in operation it is recommended:

- differences in rolls diameters in roughing mills and in rolling mills with box passes should not exceed 2-3%, in finishing pass 1% of ideal diameter
- differences in rolls diameters in other rolling mills with the extension grooves and open arrangement should not be higher than 1%
- in finishing rolling mills it is necessary, if possible, to eliminate differences between rolls diameters to zero

10.2. Groove placing in roll

The direction of running the metal out of the rolls depends on the position of neutral axis (as well as rolling axis) to the ideal centreline of rolls. If the neutral axis is placed in the ideal centreline of rolls, so-called ideal rolling conditions arise. It means identical speeds, straightforward exit the metal from the rolls, no stresses and/or impacts (shocks) in the roll stand, increase in roll service life and decrease in power consumption.

If the neutral axis of the groove is placed higher or lower, the rolled stock will be bent upwards or downwards. At the same time the rolled stock exiting the rolls will influence the rolling fittings. Some damage of the device can occur, or in case of rolled products with flanges their wedging (jamming) on the roll will originate. At the given value of pressure m it is possible to precisely determine the position of the rolling axis CD in relation to the ideal centreline of rolls AB (Fig. 9.6).

In general it is valid

$$(D_{i,h} - D_{i,sp}) = m \quad (10.4)$$

$$(R_{i,h} - R_{i,sp}) = \frac{m}{2} \quad (10.5)$$

It results from Fig. 9.6 that

$$R_{i,h} = R_{i,str} + x \quad (10.6)$$

$$R_{i,sp} = R_{i,str} - x \quad (10.7)$$

$$(R_{i,h} - R_{i,sp}) = 2x \quad (10.8)$$

Then it is also valid that $x = \frac{m}{4}$

Based on the above mentioned text the following procedure is chosen for correct placing of grooves in the rolls. At the given $D_{i,str}$, top or bottom pressure m and groove height h_k it has to be performed:

- plotting axes of bottom and top roll with pitch $D_{i,str}$
- splitting in half the distance between axes of bottom and top roll so that the ideal centreline of rolling AB could be obtained
- plotting the rolling axis CD in the distance $x = \frac{m}{4}$ from the ideal rolling axis; at top pressure it is plotted downwards, at bottom pressure upwards
- determination of work roll diameters D_p

$$D_{p,h} = D_{i,h} - \frac{2h_k}{2} \quad (10.9)$$

$$D_{p,sp} = D_{i,sp} - \frac{2h_k}{2} \quad (10.10)$$

- determination of roll gap s and value of nominal roll diameter on flanges D_n

$$D_{n,h} = D_{i,h} - \frac{2s}{2} \quad (10.11)$$

$$D_{n,sp} = D_{i,sp} - \frac{2s}{2} \quad (10.12)$$

- check of particular roll diameters

$$D_{p,h}/2 + D_{p,sp}/2 + h_k = D_{i,str} \quad (10.13)$$

The correct shape of grooves and their placing belong to main factors influencing the roll service life. In placing the grooves we must not forget the loads in particular grooves. The roll strength with respect to supposed loads in grooves has to be checked. The slot must not interfere with the theoretical shape of the roll. So, grooves with deeper slots are located nearer the bearing journals.

The theoretical roll shape is determined from the relation between the actual roll shape and its strain – see Fig. 10.2. It calculates with the shaft of length “A” and two supports located in halfway of the journal lengths. It is valid:

$$A = L + 2l \quad (10.14)$$

The bending moment acting in the given groove may be expressed by means of the force acting in a distance from the support, for the first groove will be valid

$$M_0 = F_1 a \quad (10.15)$$

The bending moment, expressed by means of permissible strain, is then

$$M_0 = 0,1y^3 k_0 \quad (10.16)$$

where y – represents radius of theoretical shape of the roll

k_0 – corresponds to material constant

From equality of both moments we can get after some modification the following form

$$y^3 = 10F_1 a / k_0, \quad (10.17)$$

and after simplification $y = \sqrt[3]{ca}$, which corresponds to equation of circular paraboloid, where c is defined by material properties of the roll.

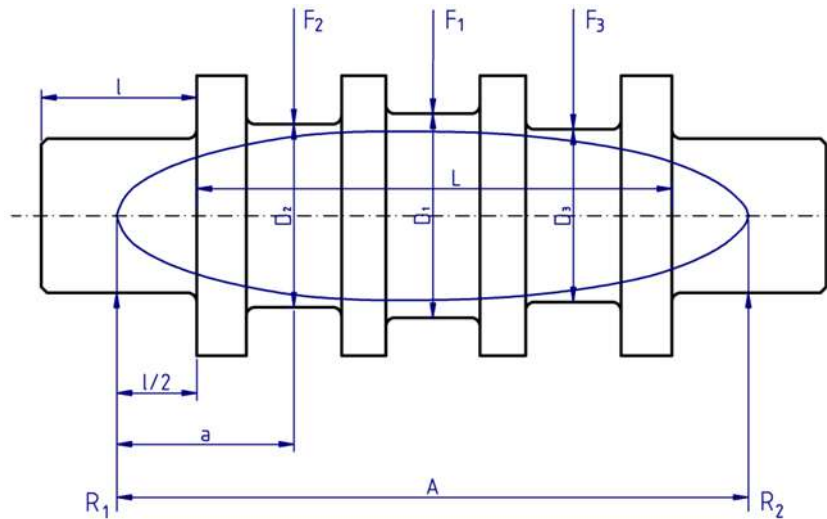


Fig. 10.2 Theoretical shape of roll

10.3. Metal deformation in grooves

In real conditions of the metal forming, as well as in rolling, we can always meet manifestation of non-uniform deformation. Particularly pronounced is manifestation of inhomogeneous deformation in rolling in grooved rolls. One of requirements of grooving of rolls is to make this deformation more uniform, mainly through height of the rolled metal.

Rolling in grooves, unlike rolling on plain rolls, is characterized by two important specialities. The first one consists in the following:

Rolling of metal with rectangular cross section on plain rolls is characterized by the fact that both absolute and relative thickness reduction across the whole width of the rolled stock is the same.

Otherwise it is in rolling in grooved rolls; here three different cases can occur:

- The cross section shape of the rolled metal before the pass is from geometric viewpoint similar to the groove shape and the absolute thickness reduction across the whole width of the rolled stock is the same, but the relative reduction is different.
- The absolute reduction across the rolled stock width is different, but relative reduction is the same, e.g. in rolling of the rhombic rolled stock after tilting in the diamond groove.

- In the most general case, both absolute and relative reduction across the whole rolled stock width have different values, e.g. in rolling of the rolled stock with square cross section in the oval groove, or in rolling of the rolled stock with oval cross section after tilting in the square groove placed diagonally.

From the viewpoint of general classification of the metal rolling and different ways of deformation manifestation across the groove width, four basic cases of rolling exist (Fig. 10.3). Typical rolling schemes are characterized by the change of basic parameters:

- initial height H_0
- groove height H_k
- work roll diameter D_p
- bite angle across width of the rolled metal α

These parameters can be constant or variable and by their combination 4 schemes of rolling originate. If all parameters are constant, that is the question of scheme I - see Fig. 10.3. In case of rolling in grooves the most often is scheme IV, where all mentioned parameters are variable.

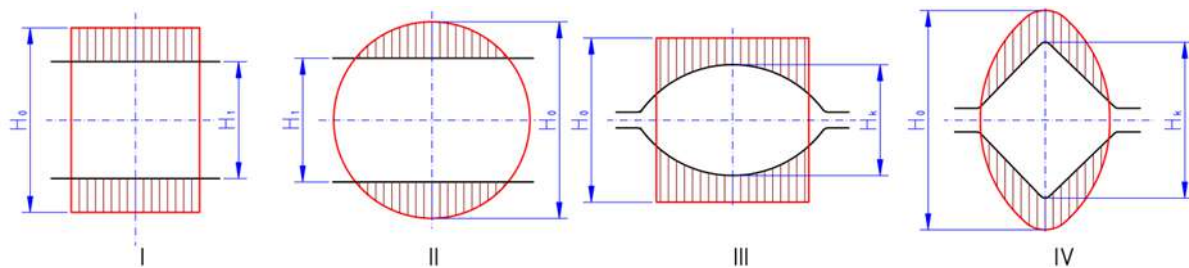


Fig. 10.3 Distribution of height deformation across rolled metal width

The second speciality consists in the fact that in rolling in grooves the deformation resistance differs in the lateral direction (spread) from the deformation resistance in rolling on plain rolls. In rolling on plain rolls the forces preventing the spread are expressed by means of friction forces acting in the lateral direction. In rolling in grooves except for friction forces also components of the horizontal projection of side roll forces act in the lateral direction. These forces either strengthen the deformation resistance in the spread direction or weaken it.

Reductions in particular parts of the groove should enable fulfilment of the mentioned conditions in every pass. Of course, due to grooves shapes with various extent of complexity, which we come across in normal practice, this cannot always be fulfilled. Therefore in grooving of rolls it is necessary to keep to the following:

The more complicated is the shaped steel cross section, the more important is in calculations of thickness reductions to shift their non-uniformities towards initial rolling passes.

In direction towards final passes we have to try making reductions more uniform across the whole width of the groove.

Such mode of rolling makes it possible to perfectly utilize formability of the rolled metal, especially in initial passes, where the steel metal has a sufficiently high forming temperature. In these rolling terms the future cross section shape may be very easily created, without danger of residual stresses origin.

In grooving of rolls it is desirable to assure that the distribution of both absolute and relative thickness reduction values across the rolled stock width was chosen in such a way so that the metal flow secured the creation of particular parts of the rolled metal required shape.

□ Linear coefficient of extension across groove width

That is the question of linear extension coefficient expressed by formula:

$$\lambda = \frac{L_1}{L_0} = \frac{H_0 + B_0}{H_1 + B_1} = \frac{S_0}{S_1} \quad (10.18)$$

where L_0 , B_0 , H_0 , S_0 are length, width, height and surface of the rolled stock before deformation in groove. With subscript 1 these values are after deformation in the groove.

From the formula it is clear that the linear extension coefficient features the reduction magnitude of the rolled metal cross section area. In rolling of complicated shaped sections also partial extension coefficients in particular parts of the rolled metal have to be considered.

Rolling of the rolled stock in complicated shaped grooves with a pronounced inhomogeneous distribution of the height deformation across the grooves width causes different values of extension coefficient in particular parts of the rolled metal. Due to different extension in particular parts of the rolled metal unfavourable phenomena occur. In places of small thickness reduction the metal loss, underfilling of flange parts of the groove, occurs. On the other hand, places with large reductions cause considerable forced spread.

In calculations of grooving of rolls the unified coefficient of extension, including the entire formed cross section, has to be considered, above all with regard to existence of rigid ends and mutual cohesiveness of the rolled metal.

Therefore in calculations so-called mean extension coefficient is introduced, related to the total cross section area of the rolled metal for a single pass. Knowledge of this coefficient makes the calculation and correct design of the required groove much easier. It enables to determine the extent of longitudinal shrinkage or forced spreading, namely with regard to correct filling of the groove by the rolled metal.

The simplest way of determination the value of coefficient of mean linear extension of the cross section surface area of the rolled metal assumes that the rolled stock length after exit the rolls is a mean arithmetical value of actual partial lengths. The coefficient of mean linear extension is then the mean arithmetical value of partial elongations:

$$\lambda_{str} = \frac{\sum_{i=1}^n \frac{H_{0,i}}{H_{1,i}}}{n} \quad (10.19)$$

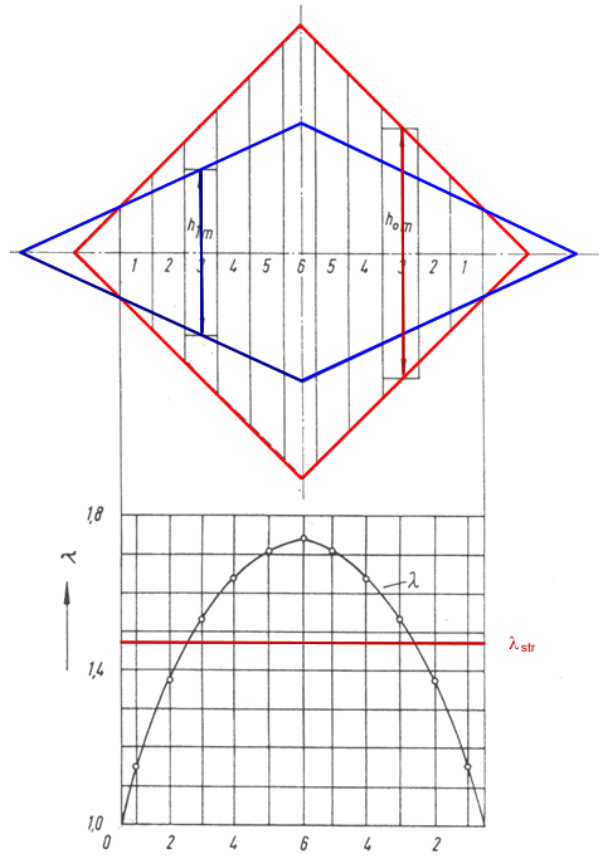


Fig. 10.4 Determination of mean coefficient of linearity

where n is a number of partial cuts across the groove width. A shortcoming of this relation is that it does not take into account the existence of spread, the law of constant volume and anyway deals with this question very simply. An example of solution is outlined in Fig. 10.4.

10.4. Utilization of thickness reduction for pass sequence calculation

Absolute thickness reduction (draft) of the rolled metal is distributed across the groove width very non-uniformly. Correctly determined reduction in the grooved rolling is a prerequisite for not only the correct calculation of the pass sequence, but also the calculation of spread, roll force and many other tasks. Approximate methods are used, the essence of which consists in conversion of complicated geometric shapes to simpler rectangular shapes at remaining identical cross section areas. The aim is to gain new equivalent dimensions that can be considered for solution of various cases of the grooved rolling.

□ Method of equivalent cross section and sides ratio

This method utilizes for conversion of an arbitrary cross section shape to a simpler rectangular shape of corresponding magnitude the following assumptions:

- Surface areas of both cross section shapes are of the same magnitude.
- Ratios of sides or their axes are identical.

From this results

$$S = \hat{S} \quad (10.20)$$

$$B/H = \hat{B}/\hat{H} \quad (10.21)$$

where S, B, H - are original cross section and its dimensions

$\hat{S}, \hat{B}, \hat{H}$ - are converted cross section and its equivalent dimensions

Determination of one of equivalent dimensions may be carried out as follows

$$S = BH = \hat{B}\hat{H} \quad (10.22)$$

$$B/H = \hat{B}/\hat{H} \quad (10.23)$$

$$\hat{H} = \hat{B} B/H \quad (10.24)$$

By substitution $\hat{H}$ into the relation for S we receive

$$S = \hat{B} \hat{B} B/H = \hat{B}^2 B/H \quad (10.25)$$

$$\hat{B} = \sqrt{S B/H} \quad (10.26)$$

$$\hat{H} = S/\hat{B} \quad (10.27)$$

The mentioned relations can be used for determination of equivalent dimensions of the rolled metal before and after deformation. In dependence on the rolled stock position at a specific moment of rolling, equivalent cross sections can have different ratios of sides or ratios of axes. E.g. the rolled stock with rhombic cross section can take up two positions. The first one corresponds to the case when

the rolled stock exits the diamond groove. The second one corresponds to the case when the rolled stock after tilting by 90° is located in front of entrance into the following diamond or square groove.

When this method was created, an assumption was applied that strain coefficients in rolling in extension passes are not much different compared to coefficients of equivalent cross sections. This assumption would be correct, if forces acting from the groove side walls against the rolled metal in the deformation zone did not exist. In reality this fact cannot be neglected and for a more accurate calculation the correction coefficients have to be taken into account.

□ Method of equivalent height

The method of equivalent height consists again in the change of the cross section of an arbitrary shape to the rectangular shape of equivalent cross section area. The new corresponding cross section has the same width like the original one. The height of the equivalent rectangular cross section, i.e. a mean height, is determined by ratio of the relevant shape cross section to its maximum actual width (Fig. 10.5). If we introduce the following notation, where

S_0, B_0, H_0 are original cross section and its dimensions before deformation

$\acute{S}_0, \acute{B}_0, \acute{H}_0$ are equivalent cross section and its dimensions before deformation,

then the following relations are valid

$$S_0 = \acute{S}_0, B_0 = \acute{B}_0, \acute{H}_0 = S_0 / B_0 \quad (10.28)$$

Similarly it is possible to proceed also in conversion of the cross section shape to the equivalent deformation. If we consider the above mentioned notation with subscript 1 (after deformation), then the following relations are valid

$$S_1 = \acute{S}_1, B_1 = \acute{B}_1, \acute{H}_1 = S_1 / B_1 \quad (10.29)$$

Examples of utilization in practice:

The absolute thickness reduction may be determined as

$$\Delta \acute{H} = \acute{H}_0 - \acute{H}_1 = S_0 / B_0 - S_1 / B_1 \quad (10.30)$$

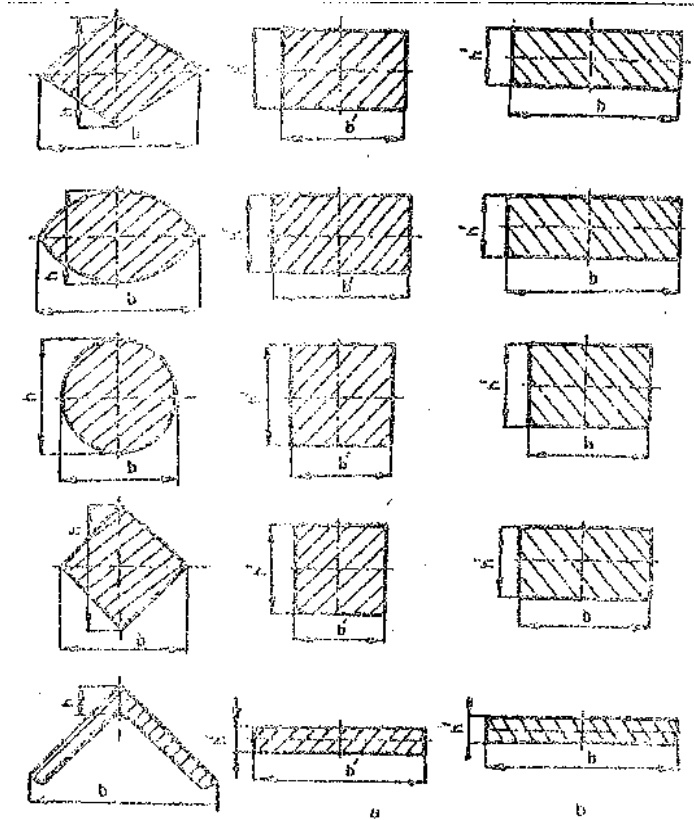


Fig. 10.5 Scheme of conversion of complicated geometric shapes to equivalent simpler rectangular shapes

10.5. Contact surface

The successful solution of grooving of rolls requires that attention should also be paid to the calculation of roll force during passage of the rolled stock through the groove. This task is strongly put in the foreground especially in association with optimization of forming processes from viewpoint of the uniform force acting or correct design of roll stands.

In a simple way roll force can be expressed in the form of the product

$$F = p_{str} S \quad (10.31)$$

where S – is projection of the contact surface to the plane perpendicular to the roll force direction

p_{str} – is mean average specific pressure in the total deformation zone

Thus, calculation of the roll force can be divided into solution of two tasks:

- **Quantification of contact surface between the metal and the roll**
- **Determination of mean value of total deformation resistance**

The quantification of the contact surface between the metal and the roll is relatively easier in comparison with the determination of mean value of total deformation resistance. So, we leave the solution of resistance characteristics in grooves to professional references and aim to the contact surface determination.

The task of the contact surface determination is mostly solved as its projection to the horizontal or vertical plane. In the most frequent cases the projection of the contact surface to the horizontal plane is considered. This solution brings under control a number of methods and mathematical relations. Many

of them are based on application of complex integrals. Some assumptions and simplifications are accepted in final forms of equations.

To current methods used for determination of the contact surface magnitude belong:

- Analytical mode
- Grapho-analytical mode
- Graphic mode

□ Analytical mode

Method of corresponding height

Based on this method the contact surface magnitude is determined from the projection of this surface to the horizontal plane. That is the question of a certain analogy of the contact surface determination on conditions of rolling on plain rolls. The difference is that we introduce into calculation the corresponding cross section dimensions of the shaped rolled stock, transferred to a simpler rectangular cross section.

In general form we can present the equation for calculation of the contact surface as follows

$$S = B_{str} \sqrt{\dot{R}_{p, str} \Delta \dot{H}} \quad (10.32)$$

Further the following relations have to be valid

$$\Delta \dot{H} = \dot{H}_0 - \dot{H}_1; \dot{H}_0 = \frac{S_0}{B_{0, max}}; \dot{H}_1 = \frac{S_1}{B_{1, max}} \quad (10.33)$$

$$2\dot{R}_{p, str} = D_n + s = D_i + \dot{H}_1 \quad (10.34)$$

where S_0, S_1 - are cross section areas of the rolled metal before entrance into and after leaving the rolls

D_i - is ideal roll diameter

s – is roll gap

After substitution into the relation we receive

$$S = \frac{B_0 + B_1}{2} \sqrt{\frac{1}{2} \left(D_n + s - \frac{S_1}{B_1} \right) \left(\frac{S_0}{B_0} - \frac{S_1}{B_1} \right)} \quad (10.35)$$

The relation in the given form can be used with some approximation for calculation of the contact surface in rolling in arbitrary shaped grooves.

Method of corresponding cross section and ratio of sides

This method is based on assumptions consisting in a simplification of cross section shapes of the metal before entrance into the rolls and after exiting the rolls, in accordance with the subchapter for calculation of the thickness reduction using the method of the corresponding cross section and ratio of sides. Using equations in this subchapter and by their substitution into the equation for calculation of the contact area on plain rolls we receive

$$S = \frac{1}{2} \left(\sqrt{S_0 \frac{B_0}{H_0}} + \sqrt{S_1 \frac{B_1}{H_1}} \right) \sqrt{\frac{1}{2} \left(D_n + s - \sqrt{S_1 \frac{B_1}{H_1}} \right) \left(\sqrt{S_0 \frac{B_0}{H_0}} + \sqrt{S_1 \frac{B_1}{H_1}} \right)} \quad (10.36)$$

The mentioned formulae represent a general solution, for combination of usual shapes of the rolled stock and extension passes it is possible to find the analytical solution by various authors in references.

□ Grapho-analytical mode

According to this method the pertinent groove shape and cross section of the rolled metal is plotted (Fig. 10.6).

The groove shape is divided by means of auxiliary straight lines into arbitrary partial surface elements $l_1, l_2 \dots l_n$. For each element the absolute thickness reduction ΔH and work roll radius R_p are determined. From the gained values the length of deformation zone is calculated for each partial surface element according to the known relation

$$l_d = \sqrt{R_p(H_0 - H_1)} \quad (10.37)$$

After quantification of individual lengths of the deformation zone across the groove width they are plotted into a graph. The ends points are connected and the gained curve determines the contact surface magnitude.

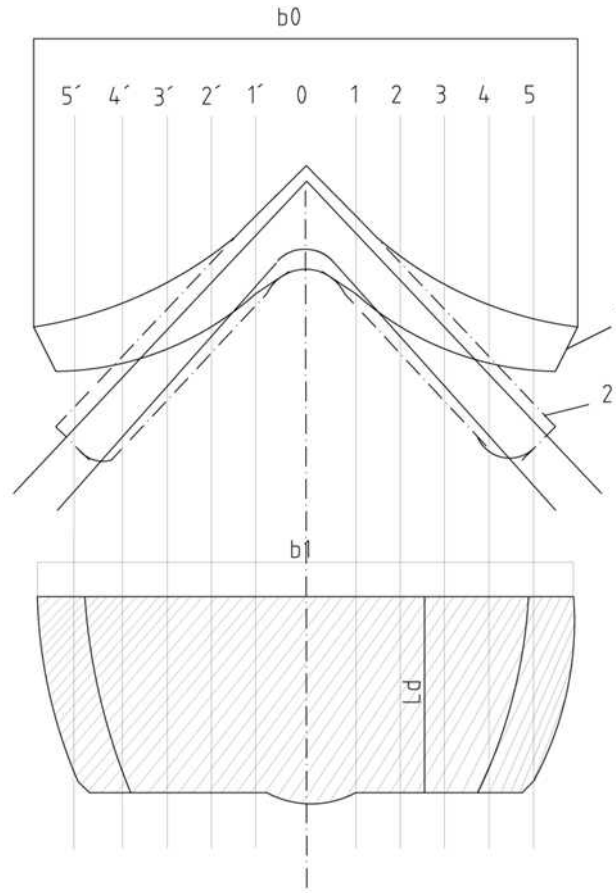


Fig. 10.6 Grapho-analytical mode of contact surface determination

The influence of the rolled stock spread in groove along the deformation zone is determined in such a way that a curve is led approximately from the vertex of the given rolled stock to the point on the groove contour which corresponds to maximum spread value in place where the rolled stock leaves the groove. For this part, ΔH , R_p , and l_d are determined in a similar way.

The total contact surface magnitude is determined by means of CAD system or – in an old way – by planimetry. This mode of determination the contact area is suitable not only in rolling in extension grooves, but it may also be used in rolling of more complicated shaped rolled stocks (Fig. 10.7)

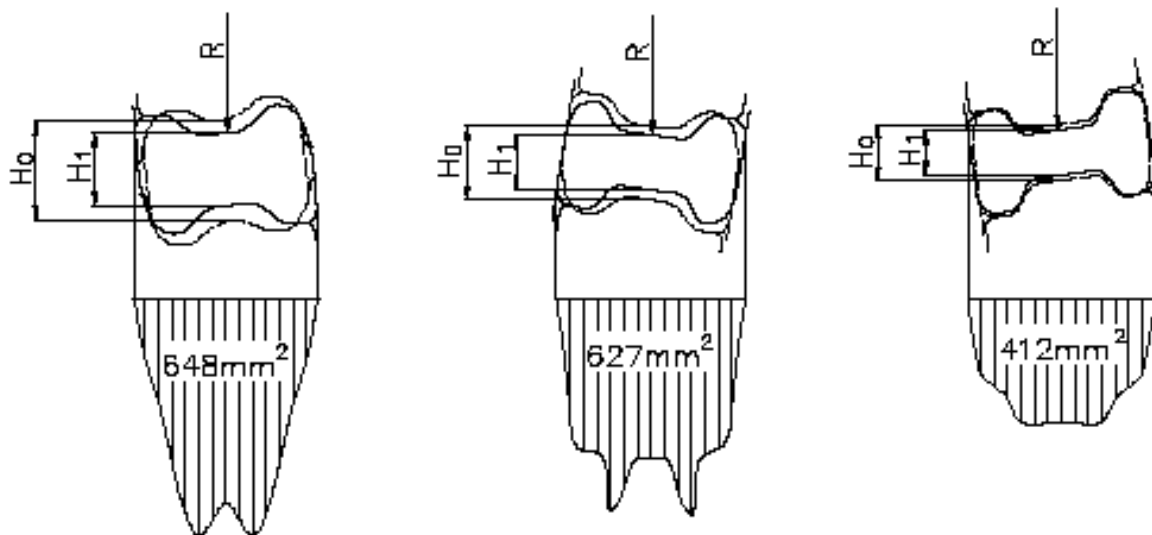


Fig. 10.7 Contact surface determination in rolling of special section

□ Graphic mode

The graphic mode of determination the contact surface is carried out in such a way that - based on the constructed groove contour and cross section of the rolled stock at its entrance into the rolls - the horizontal and vertical projection of the contact between the metal and rolls is plotted. Currently, this plotting may be carried out in CAD systems which enable the surface area calculation. In the past this task was solved by means of planimetry.

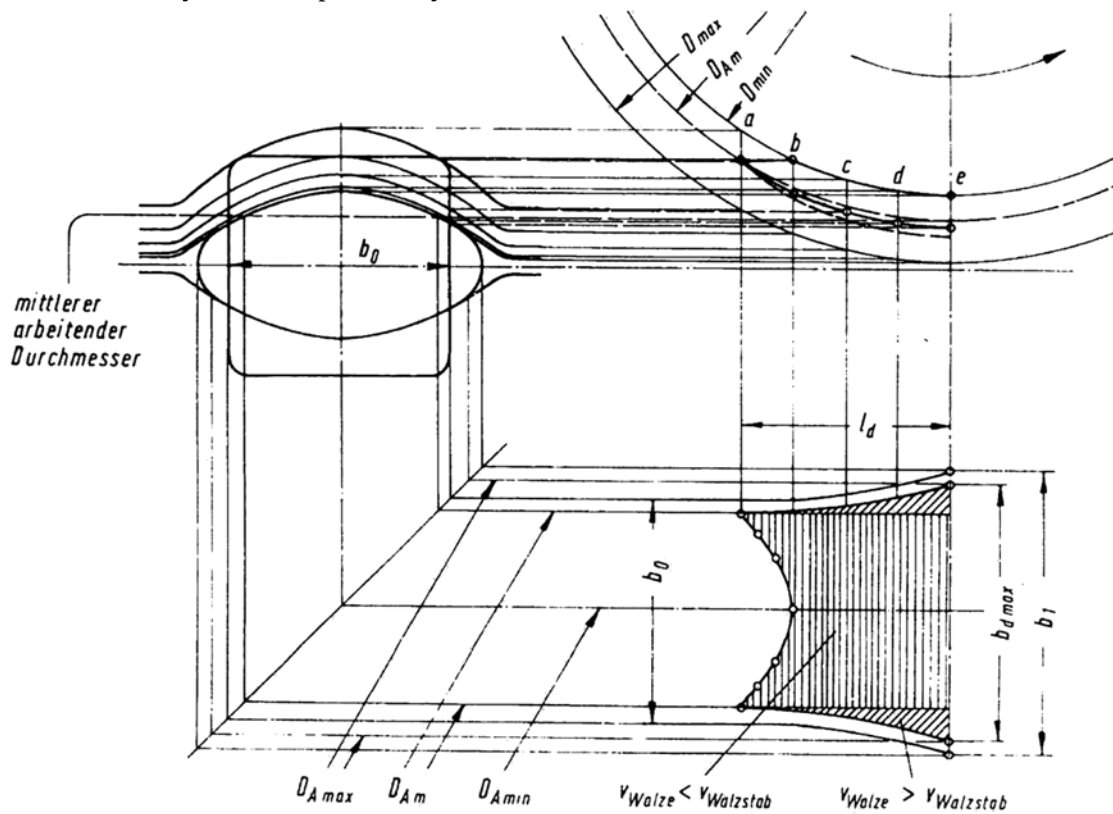


Fig. 10.8 Graphic mode of contact surface determination in oval groove rolling
(mittlerer arbeitender Durchmesser - střední pracovní průměr)



Summary of terms of this chapter (subchapter)

From this chapter you should obtain knowledge of terms: **top and bottom pressure, theoretical shape of roll, contact surface.**



Questions to discussed curriculum

- 10.1. What means top pressure and how is it reached?
- 10.2. How is defined coefficient of linear extension across groove width?
- 10.3. Define possible combinations of basic parameters influencing non-uniformity of deformation across groove width.
- 10.4. Describe theoretical shape of roll.

- 10.5. How is defined the method of corresponding height for determination of deformation in the groove?
- 10.6. Describe differences in determination of contact surface by means of analytical, grapho-analytical and graphic method.



Tasks for solution

Calculate and plot circular double-paraboloid in Excel. Start from the following specification of the equation $y_3 = ca$,

where: $c = 63250$, $A = 500$ mm, $l = 100$ mm.

11. General principles of pass sequences and grooving of rolls of steel bars with simple cross section shapes



Time for study: 3 hours



Target After studying this paragraph you will be able to

- define what the pass system is
- describe particular pass sequences
- know advantages and disadvantages of particular systems of pass sequences



Presentation

□ Grooving of rolls for rolling in extension passes

The extension grooves/passes are grooves/passes, in which diminishing of the rolled metal cross section during rolling takes place. Shapes of extension grooves/passes are different. In dependence on the rolled metal cross section, coefficient of extension and roll diameter, the extension passes are integrated in the rolling process in a certain sequence.

A series of gradually alternating specific shapes of grooves/passes is called system of grooves/passes of the given sequence (in short “pass sequence”).

From existing systems of the extension passes we can enumerate the following pass sequences:

- Box (rectangular) pass sequence
- Box pass - open box pass sequence (note: by open box pass we understand the plain part of the roll barrel)
- Square - oval pass sequence
- Square - square pass sequence
- Diamond - square pass sequence
- Diamond - diamond pass sequence
- Oval - upsetting oval pass sequence
- Oval - round pass sequence
- Universal pass sequence

In the following text selected pass sequences will be dealt with separately from viewpoint of their use in practice – in the area of pass designing in rolling of round and square bars.

□ Pass sequence oval – square – oval

This sequence belongs to the most used sequences of extension passes (Fig. 11.1). It is used for rolling of wire rod and round bars up to 20 mm in fine and up-to-date wire rod mills.

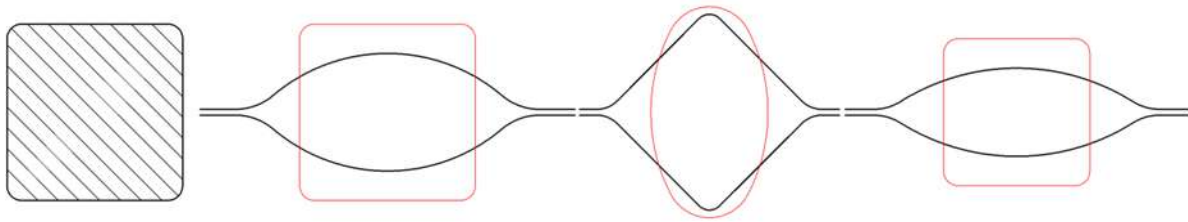


Fig. 11.1 Scheme of oval – square pass sequence

This pass sequence enables rolling of round bars with minimum number of passes. In combination with a suitable modification of leader oval it enables rolling of round bars even with higher diameters. It is also used in the function of preparatory passes for rolling of small shaped sections, up to square side 50 – 75 mm.

Among basic benefits of this pass sequence rank:

- Achievement of considerable extension. In oval passes coefficient of extension used to be in the range $\lambda = 1.3 - 1.8$, in particular cases even 2 and more. In square passes coefficient of extension acquires values $\lambda = 1.2 - 1.6$
- rapid diminishing of the rolled metal cross section causes
 - decrease in a number of passes
 - lower power consumption
 - decrease in a number of roll stands (passes) and a number of auxiliary equipment
- unlike box passes this sequence assures the permanent renewal of edges in places of original corners
- by tilting by 90° or 45° the rolled stock is formed from not only two sides, but four sides, which results in a favourable effect on the formed metal structure
- stability of the rolled stock with the square cross section in the oval pass is enormously high, entry and exit guides/guards are easily adjustable
- shallow slot in the oval groove in rolls

Among shortcomings are ranked:

- Considerable inhomogeneous deformation through height across the rolled stock width, in both the oval and the square pass. This deformation non-uniformity leads to
 - increase in stress in the formed metal
 - increase in wear and tear of the oval pass
 - increase in energy needed for displacement the metal in lateral direction
- With increasing of the cross section area of the rolled stock the non-uniformity across width increases.
- Deep slot in the square groove in rolling of large cross sections.
- Comparatively great differentiation of extension in oval and square passes, which leads to non-uniform wear and tear of rolls. Oval passes are worn more rapidly than square ones.
- Little stability of the oval rolled stock in square pass requires use of more demanding rolling fittings.
- For rolling of round bars with medium and large dimensions, as well as deteriorated formability, some modifications of the oval pass has to be used relatively frequently.

□ Pass sequence diamond - square

These pass systems (Fig. 11.2), where diamond and square passes are alternated, are used as roughing and preparatory passes for rolling of round bars and, above all, square bars.

This pass sequence finds use in the fine and medium section and billet rolling mills with the open, semi-continuous and continuous arrangement. It can also follow the box passes in the rolling process. This pass sequence is really used in all cases where are required smaller extensions than in the pass sequence oval – square. Coefficients of extension in both passes (diamond and square) are approximately the same and range from 1.15 to 1.40. The vertex angle of the diamond groove ranges usually from 110° to 115° .

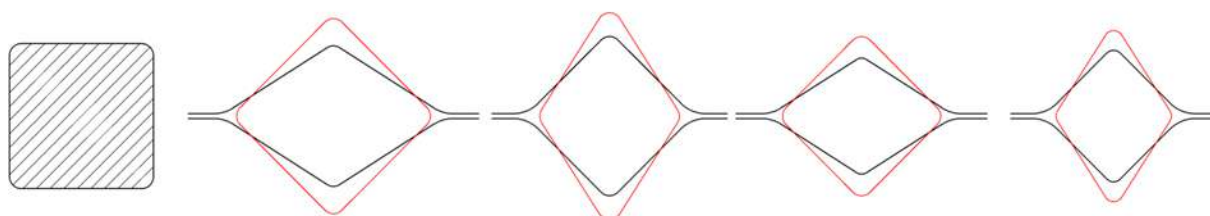


Fig. 11.2 Scheme of pass sequence diamond – square

Among basic benefits of this pass sequence rank:

- Possibility of gaining squares with accurate geometry and rounded-off corners
- Possibility of rolling square cross sections
 - from intermediate square passes with omitting a pair of passes
 - of near dimensions by changing the top roll adjustment
- High stability of the rolled stock for rolling in both diamond and square groove
- Rolling of the rolled stock with effect of pressure on the entire groove contour
- These passes enable to gain rolled stocks without cracks and wrinkles on the rolled metal edges.

Shortcomings typical for this pass sequence:

- As compared to box passes, passes of the sequence diamond – square have deeper slot in the roll, which leads to weakening the roll bodies and decrease in their strength
- In case of overfilling the grooves a danger of creating defects - fins (“rolling edges”) and laps - originates
- Considerable difference in work roll diameters across the groove width leads to different peripheral speeds.

□ Universal pass sequence

The universal pass sequence is characterized by the following system: plain part of the roll barrel or the rectangular open box pass – rounded-off plain part of the roll barrel or the upsetting square box pass – leading oval – finishing round. From the scheme in Fig. 11.3 is evident that the rolled stock of rectangular cross section, rolled on plain part of rolls or in the rectangular box pass, can enter into upsetting grooves with a mildly rounded-off part of rolls or with the square shape.

The upsetting grooves have a wide use in practice. They allow an appreciable control of cross section dimensions, compared to square grooves that are cut in the diagonal position.

Among significant advantages of the universal pass sequence rank:

- By a change of the roll adjustment, the rolling of round bars with several dimensions (4 to 5 near dimensions) in the same grooves is possible.
- Possibility of rolling the stocks with free spread, which excludes creation of wrinkles and laps.

- Easy falling-off the scale from side surfaces of the rolled stock during rolling.
- Possibility of rolling round bars with better quality surface (the rolled stock is rolled with convex side walls). In the course of rolling no wrinkles on the rolled stock surface originate.
- Considerable shortening of a number of roll changes. The rolls are not changed due to changing the cross section associated with a change of the product mix, but only due to the groove wear.
- Shortening of time needed for the pass preparation for rolling.
- Assurance of relatively uniform distribution of the height deformation across the groove width in late three passes.

This pass sequence is used for rolling of round bars with diameter 20 – 100 mm and higher, of both carbon and alloy steel. The universal pass system is put for rolling in the medium and heavy mills with the open and continuous arrangement.

The methodology of calculation of particular universal passes is not distinguished by any specialities. In grooving of rolls the modes of calculation are used which were mentioned for the box pass sequence or the pass sequence oval – round.

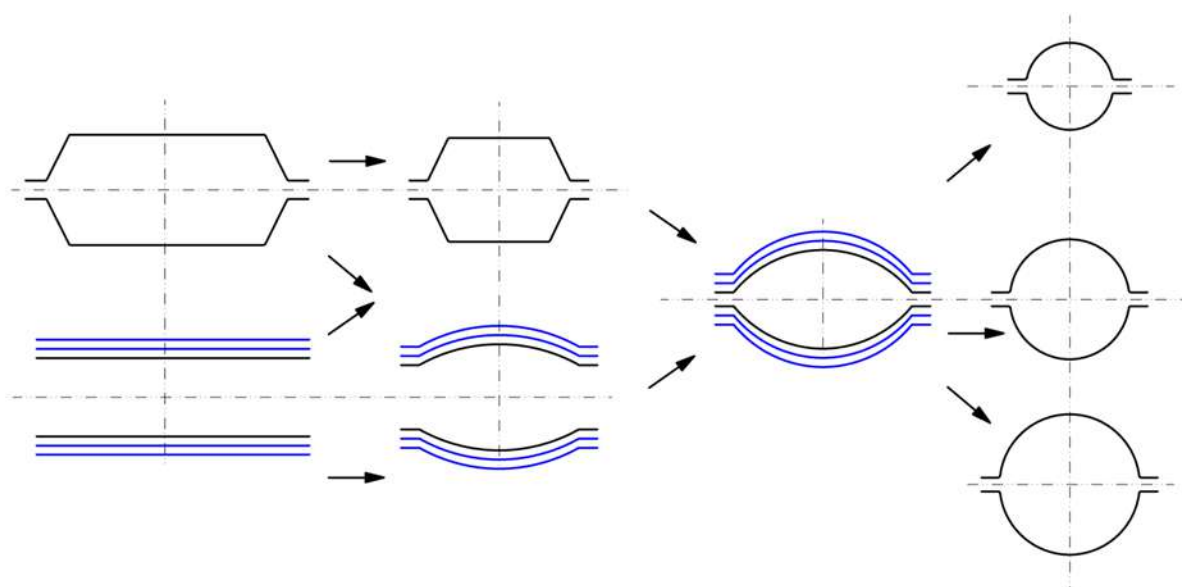


Fig. 11.3 Scheme of universal passes

□ Pass sequence oval – upsetting oval

This pass sequence, where normal oval is alternated with upsetting oval (Fig. 11.4), is used above all in fine continuous rolling mills. Normal oval grooves are cut into vertical rolls and upsetting (egg-shaped) oval grooves into horizontal rolls of the continuous rolling mill.

A basic advantage of this system is that the rolled stock need not be tilted.

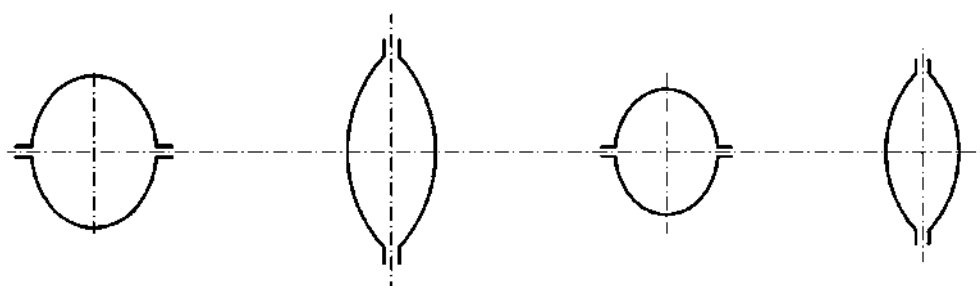


Fig. 11.4 Scheme of pass sequence oval – upsetting oval

□ Pass sequence oval - round

This pass sequence, where round and oval passes are alternated (Fig. 11.5), is mostly used in rolling mills with the open arrangement for rolling of round bars. It is used, above all, in cases where the product mix is characterized by round diameters very close to each other.

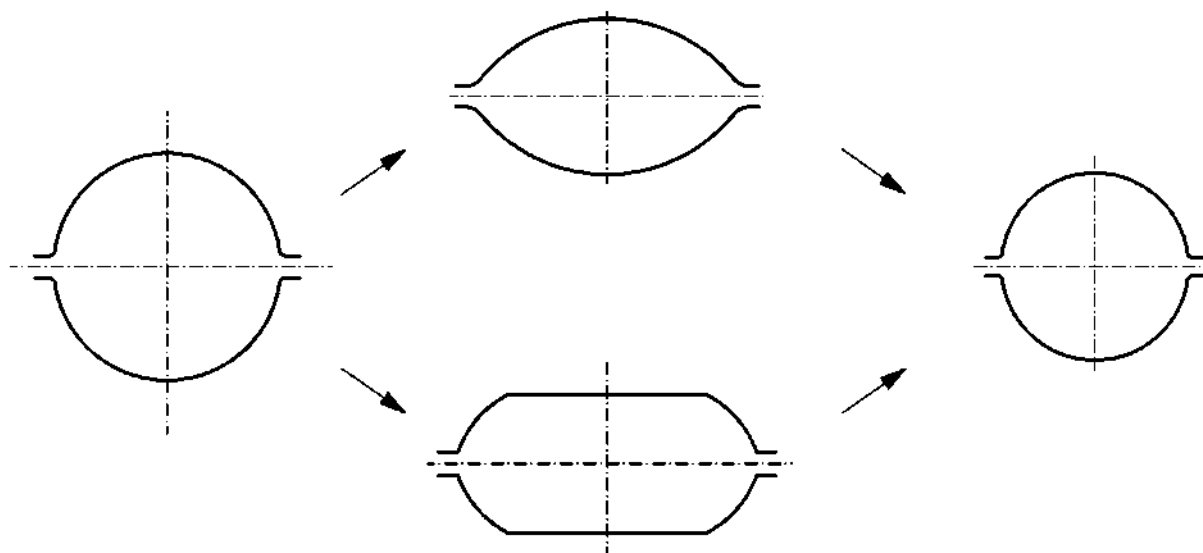


Fig. 11.5 Scheme of pass sequence oval - round

This system is also used in late roll stands of the finishing block in continuous rolling of wire rod. In this case the intermediate round pass is used as the finishing pass for rolling of wire rod with higher diameter.

In specific cases the use of the pass sequence oval – round is beneficial for rolling of high-alloy steels, where achievement of the quality surface of round bars is required. This mode of rolling excludes wrinkles on oval-shaped rolled stocks.

Among benefits of the pass sequence oval – round rank:

- Rolling of rolled stock in these grooves is carried out without sharp edges and sudden transitions, which secures more uniform distribution of the height deformation. The more uniform distribution of the height deformation prevents origin of internal stress in rolled stocks.
- The groove shapes and mode of rolling contribute to easier falling-off the scale.
- Minimum wear and tear of grooves.

Using this pass sequence we do not avoid some shortcomings, such as

- difficult feeding of the oval-shaped rolled stock in the round pass
- possibility of the rolled stock bevelling in the groove
- relatively low values of the extension coefficient $\lambda = 1.2 - 1.4$

□ Pass sequence oval – gothic square

Rolling of round bars using the pass sequence oval – gothic square is very similar to the pass sequence oval – square. It is used for rolling of round bars of all steel grades, approximately from diameters exceeding 30 - 80 mm.

For this pass sequence is typical the more uniform distribution of the height deformation across the rolled stock width in its rolling in the rhombic groove. Further, wear and tear of oval passes is smaller. The cross section of the gothic square is characterized by the fact that its sides are mildly convex. In calculation of the pass design the side A is determined from the empirical relation. It is always smaller than in case of the normal square because the rhombic groove area is larger than in case of the inscribed square

$$A = (0.9 \div 1.0)d \quad (11.1)$$

The camber convexity of the square is determined in a constructive way or in dependence on diameter of the finishing round steel

$$a = (0.05 \div 0.1)d \quad (11.2)$$

The rounding-off radius of side walls of the rhombic groove can be equal to the groove width $R = B = B_k$, or is determined in an analytical way from the segment of a circle

$$R = \frac{A^2 + 4a^2}{8a} \quad (11.3)$$

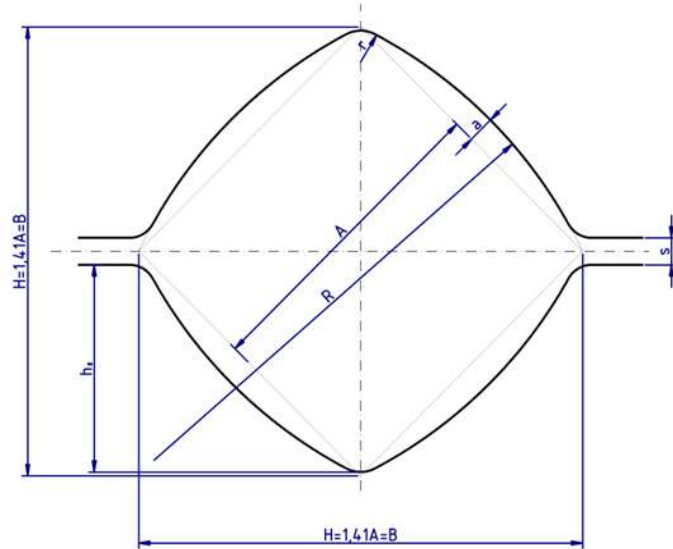


Fig. 11.6 Construction of gothic square

When rounding-off is chosen, only a continuous transition between R and r is taken into account.

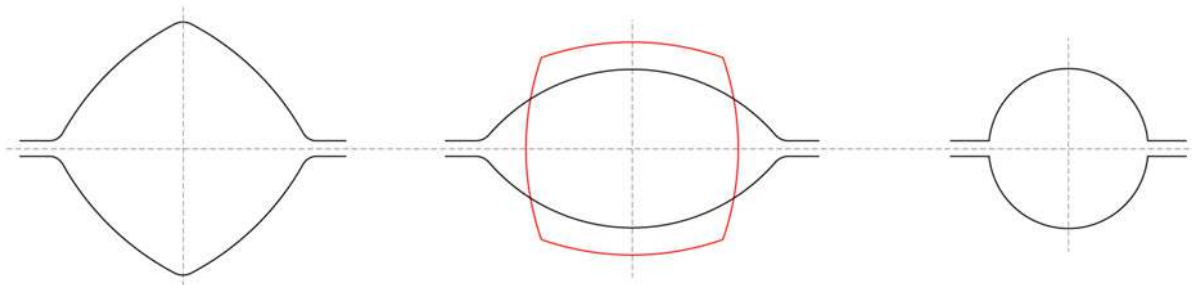


Fig. 11.7 Scheme of rolling in pass sequence oval – gothic square

□ Pass sequence diamond - diamond

This system of passes, where only diamond passes of various magnitudes alternate each other, is used in rolling of square steel with a lowered formability in medium and heavy mills.

Among benefits of this pass sequence the following may be mentioned:

- Possibilities of gaining the geometrically precise square cross section with sharp edges
- Small internal stress in the formed metal
- Relatively little spread manifestation in rolling of rhombic rolled stocks in diamond passes

Among disadvantages of this pass sequence may be ranked that rolling in diamond passes is limited by extension coefficient in the range 1.1 - 1.3. Further, in the rolling technology a danger of winding up the rolled stock on the roll is real, with possibility of lap creation.



Summary of terms of this chapter (subchapter)

Basic terms in this chapter are **pass sequence** in the following combinations: **square – oval, diamond – square, oval – upsetting oval, oval - round, universal pass sequence**



Questions to discussed curriculum

- 11.1. Enumerate advantages and disadvantages of the pass sequence oval – square.
- 11.2. Depict a way of renewal the edges in places of original corners in the pass sequence oval – square.
- 11.3. Depict a way of rolling a family of square dimensions by changing the top roll adjustment in case of square pass.
- 11.4. Depict basic scheme of rolling in the pass sequence diamond – square.
- 11.5. Present benefits of the pas sequence diamond – diamond.
- 11.6. Explain construction of the groove in the form of gothic square.
- 11.7. What are benefits and shortcomings of the pass sequence oval – upsetting oval?
- 11.8. What steel grades are usually used for rolling in the pass sequence oval – round?
- 11.9. What grooves/passes represent the universal pass sequence?



Tasks for solution

- 11.1. Plot the pass of gothic square of cross section area $S = 120 \text{ mm}^2$.
- 11.2. Construct the square pass, diamond pass and final square pass for rolling of square bars with side 20 mm. The thickness reduction in the last pass is defined by coefficient of extension $\lambda=1.15$. In the leading pass the coefficient of extension is $\lambda=1.27$.

12. Pass design foundations of selected types of shaped rolled products



Time for study: 3 hours



Target After studying this paragraph you will be able to

- distinguish between particular types of shaped products
- describe modes of pass design used in production of sections L, I, U and rails



Presentation

□ Pass design for rolling of angles

The cross section shape and dimensions of angles are given by the dimensional standard ČSN 42 5541 (equivalents DIN: 1028:1994, EN: 10056-1:1998 (N), 10056-2:1993) and ČSN 42 5545 (equivalents DIN: 1029:1994, EN: 10056-1:1998 (N), 10056-2:1993).

According to these standards we distinguish two kinds of angles:

- Equal angles (Fig. 12.1), the arm width ranges from 20 mm to 200 mm and the arm thickness from 3 to 20 mm, permissible deviations of the arm width are $\pm 1 \div \pm 3$ mm, for the arm thickness are different: plus from 0.50 to 1.50 mm, minus from -0.40 to -0.70 mm.
- Unequal angles (Fig. 12.2), the larger arm width ranges from 25 mm to 160 mm, the smaller arm width from 16 to 100 mm, the arm thickness ranges from 3 mm to 14 mm.

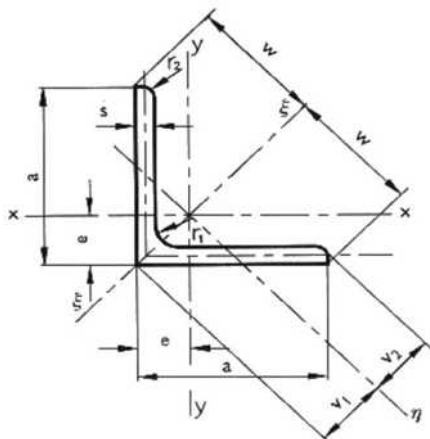


Fig. 12.1 Equal angle



Fig. 12.2 Unequal angle

The historical development of rolling of angles consisted in searching a more economical cross section shape, which led to rolling of angles with use of minus tolerances up to rolling of thin-walled angles.

Pass design modes of angles

Pass design with equal arms in closed grooves (Fig. 12.3a)

It is ranked to the oldest pass design of angles. This pass design is characterized by straightness of the angle mean fibre in all grooves. In the course of rolling the angle arms are created by breakdown of the rolled stock. Therefore this mode is also named “breakdown mode”.

The angle arms opening angle is gradually changing from the value $135^\circ \div 145^\circ$ in the preparatory pass to the value 90° in the final pass. The thickness reduction value gradually falls as well, from the first pass up to the final pass.

One of shortcomings of this pass design is a deep slot into the rolls, which causes considerable differences in speeds of rolls. A significant wear and tear of grooves occurs. Rolling is realized with higher power consumption. Deep slots decrease the roll strength and lead to diminishing of the height deformation and thus growing a number of passes.

Another disadvantage of this pass design is the fact that due to gradual breakdown of the rolled stock the segregations can have access to its surface, especially in places of the angle arms contact.

The only benefit of the pass design with equal arms in closed grooves consists in a simple construction of grooves and relatively little sensitivity to the roll adjustment. This angle pass design mode was maintained up to now in rolling of angles with small dimensions and in rolling mills of older design.

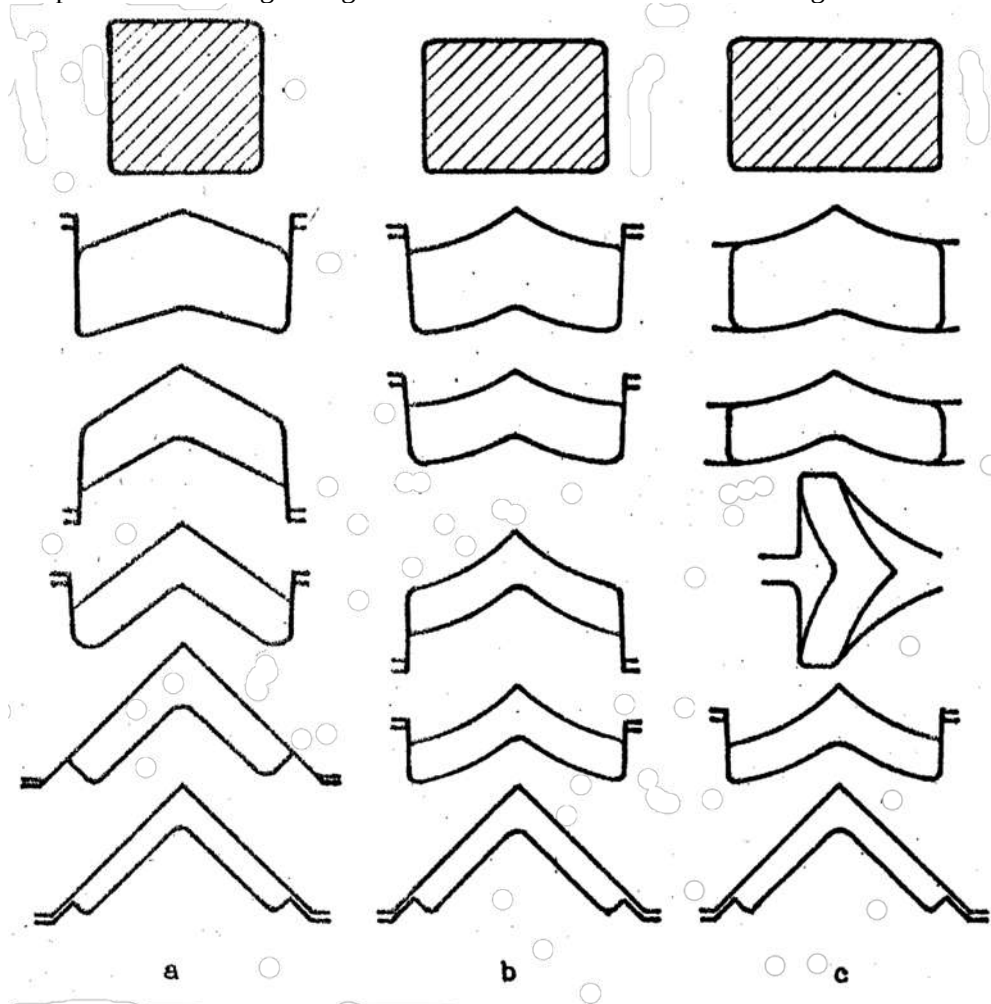


Fig. 12.3 Angles pass design modes

Pass design of angles with opened arms and restricted spread (Fig. 12.3b)

Currently this pass design belongs to widespread pass design modes. It removes disadvantages of the equal arms pass design. This mode features construction of the leader pass and further shaped passes.

The mean fibre of the angle arms is bent in the form of a curve – therefore designation “butterfly design”. Straightening of angle arms is realized just in the last pass.

The arm bending enables to enlarge the roll force vertical component. The opened arms of the groove create favourable conditions for construction of slight slots in rolls. The roll strength is not decreased. Rolling is realized with higher thickness reductions. The deformation process is more intensive, a number of passes is decreased and the rolling mill output increased. The mentioned pass design makes it possible the angle rolling without laps. If they come to existence, then only as a result of incorrect adjustment of the roll stand. The aforementioned mode assures the angle rolling with accurate width of arms. Actual groove shapes restrict spread. The grooves opening alternates regularly and enables a progressively increased reduction ratio of angle arm ends.

The butterfly design places higher demands on the actual performance and is relatively sensitive to the roll adjustment. It enables precise rolling with closer dimensional tolerances. The butterfly design of angles is currently utilized for pass designing and rolling of thin-walled angles as well.

Pass design of angles with opened arms and free spread (Fig. 12.3c)

This mode is the most progressive in the angle pass design. Compared with previous pass designing, grooves have the least slots in the roll body. The groove shapes are very simple. The roll stress is lesser. Higher deformations through-thickness may be used.

The great advantage of this pass design consists in a chance of rolling angles of different magnitudes in the same set of rolls. Grooves with the free spread do not require flanges on rolls. They enable to use rolls with smaller diameters. The danger of the lap origin is eliminated. Nevertheless, grooves with the free spread have also some disadvantages. The free spread in preparatory passes is difficult to control. For achievement of the required angle arms width the leading pass is designed as closed, with restricted spread, and in such a way so that width of the rolled stock leaving the rolls corresponded with the calculated width.

The more preparatory passes with free spread precede the leading pass, the worse is keeping the angle arm width in relevant limits, and the more carefull has to be adjusting of roll stands. To make adjustment of roll stands easier, the upsetting passes are used.

Their use makes it possible to obtain the required rolled stock dimension for its entrance into the leading closed pass. Introduction of the upsetting pass contributes to better universality of this pass design mode. The benefit of the upsetting pass is justifiable in case of angles rolling with larger arms thickness. Otherwise a danger occurs that instead of thickness reduction only arms bending (deflection) will be achieved. A wide use of the upsetting pass is applied mainly in the angle rolling in continuous mills.

□ Pass design for rolling of I-beams

The general performance and denotation of the I-beam cross section is given in Fig. 12.4. Beams, even though they are identical as far as their shape is concerned, differ by their dimensions. Their dimensional differences are stated in relevant standards. To important characteristics of the beam cross section shape belongs:

- Cross section area
- Beam weight per running meter
- Cross sectional moments of inertia W_x and W_y
- Radii of inertia, featuring resistivity value related to cross section area
- Specific web thickness d/h , featuring the beam stability (strength) and shape; it points in a most substantial way to rationality of the cross section strained to bending
- Specific flange thickness t/b , featuring the flange strength and shape

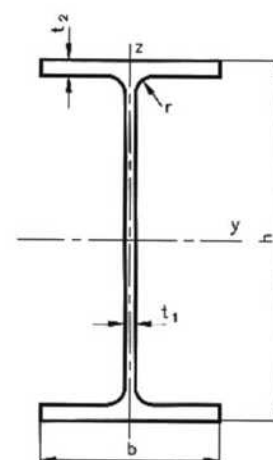


Fig. 12.4 IPE section

- Specific web area S_w/S , featuring the metal distribution between the web and flanges

Beam pass design modes

Pass design of I-beam using horizontal grooves

This mode finds its use in rolling mill of older design. The rolling mode is shown in Fig. 12.5a. It is applied for rolling of standard beams. The typical pass design mode that uses horizontal grooves is used for preparatory passes for rolling of channels (U-beams) as well.

In the course of the entire rolling process no tilting of the rolled stock occurs. Compared to inclined grooves the horizontal grooves occupy less place along the roll barrel. Rolling in horizontal grooves is beneficial for the beam production with a higher incline of internal flange walls with a small flange width. This pass design mode may not be used for rolling of wide flange beams. During the deformation process it is not possible to cause a more pronounced force effect on flanges in the vertical direction. The side draft (thickness reduction in lateral direction) is more applied.

By rolling in horizontal grooves the required flange width is difficult to reach. A small incline of the external flange edges in the beam pass (2-4%) causes difficulties at running the rolled metal out of the rolls. The occurred friction between the metal and the rolls makes filling the flange parts of the groove more difficult and increases the roll wear and tear. Rolls have to be much more (to a higher depth) turned in grooves renewal. The roll diameter diminishing occurs markedly more rapidly and so their utilization is lowered.

Currently, when economical structural beams are rolled, this typical pass design does not comply any more. Beams with a smaller incline and enlarged width on flanges are difficult to roll. Thickness reduction in closed flange parts of the groove is diminishing, in open parts does not grow markedly either. The roll wear and tear and power consumption are increasing.

Rolling of light-weight/economical beams requires higher deformation in grooves, i.e. more pass reduction. A limiting element for achievement of the required flange width is the flange open part where no direct draft (thickness reduction) can be realized. The lateral reduction may be applied at the expense of higher incline of flange external parts. Therefore higher incline was introduced, from original 2-4% up to 12%. The increased flange incline is often carried out with regard to the web deflection.

Currently, preparatory passes with the beam web deflection and with incline of the external flange parts in the range 5-10% are used in practice. Good results were reached also in use of grooves with the refracted web and refracted flanges. The inclines of external flange edges range between 2 and 3% in closed parts and up to 10% in open parts of flanges. The pass design with the straight web, but

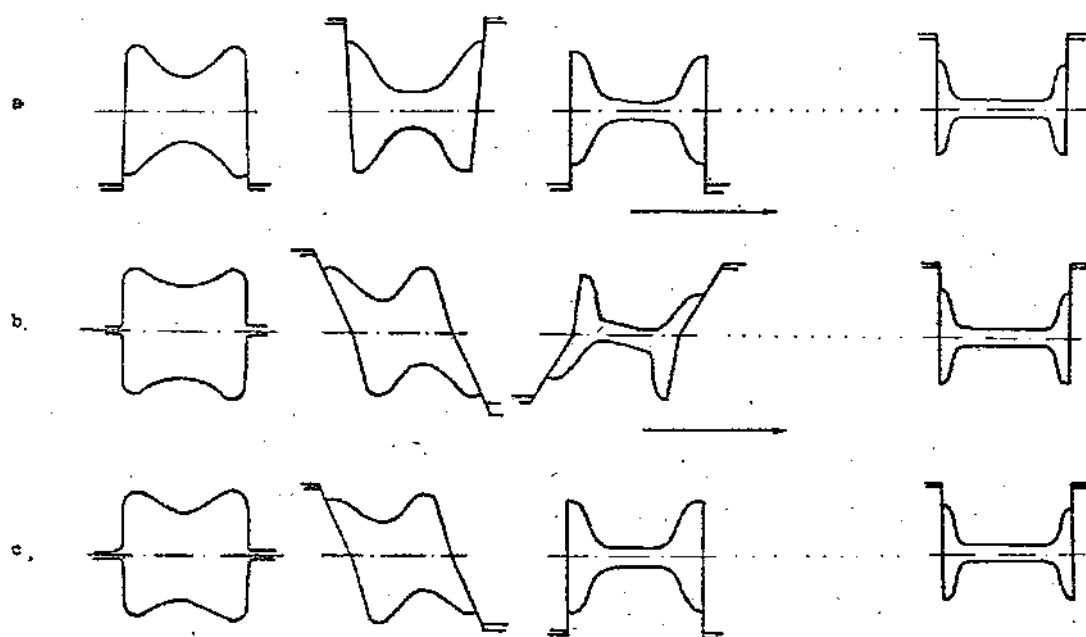


Fig. 12.5 Modes of beams rolling

refracted flanges is used as well. In closed external flange parts the bevelling is 2-3%, in open parts up to 12 %.

Pass design using oblique grooves (with incline)

This mode, which is plotted in Fig. 12.5b, enables rolling of beams with wider flanges and a smaller incline of the internal flange wall in the beam groove. The oblique (with incline) placing of grooves in the rolls allows a better (more intensive) work with the vertical component of the height deformation. This effect manifests itself favourably in the open flange part of the groove, where easier spread of the beam flange occurs. The pass design with oblique grooves enables to achieve the beam required dimensions more easily. This pass design enables rolling with a smaller number of passes. Wear and tear of rolls is lesser compared to the previous mode. The regular alternation of opened and closed groove parts in the the material flow is applied. On the other hand, distribution of grooves along the roll barrel requires more place. The oblique grooves in rolls cause axial forces, which have to be prevented by stepped bearings and/or locks creation. The closed flange parts of the groove using the oblique grooving of rolls are designed as straight. Wider flanges of grooves require performance of deeper slots in the rolls. It means that it is necessary to work with larger roll diameters.

Beam pass design using horizontal and oblique passes

That is the question of a combined pass design mode, which is shown in Fig. 12.5c. It uses both horizontal and oblique passes and serves for rolling of all beam kinds. The mentioned mode eliminates shortcomings of previous modes in an appropriate way and utilizes their advantages. It enables using rectangular initial semifinished products of smaller dimensions than it is possible in case of rolling with horizontal passes.

□ Pass design in rolling of wide flange beams

The cross section of wide flange beams is distinguished by wider flanges compared with standard beams and economical beams. The wide flange beams are produced in wider dimensional ranges. In countries where beams are produced they are standardized. Each standard indicates certain specialities – e.g. density (frequency) of beam series, or specifics - e.g. according to the dimensional DIN standard 3 series of wide flange beams with parallel flanges (normal, weakened and strengthened) and one series of wide flange beams with incline of internal flange edges 8% are standardized. In practice that is the question of beams with the web height from 100 mm to 1000 mm.

From viewpoint of static values the wide flange beams are characterized by high magnitudes of moments of resistance and moments of inertia, compared with normal beams.

Wide flange beams may be produced by three manners:

- welding
- rolling in normal beam mills; also using universal roll stands for medium and higher dimensions of beams
- rolling in special mills with the main universal and auxiliary two-high roll stands

By welding it is possible to produce beams of different shapes and dimensions. The disadvantage of this method is high labour-intensity and high production costs. Currently all kinds of wide flange beams are mostly produced in special rolling mills. Such rolling mill consists of two horizontal and two vertical rolls with axes placed in the same vertical plane. In immediate proximity of this main roll stand is located the reversing two-high roll stand, determined only for the web deformation.

Such arrangement enables rolling of beams with wide flanges and high quality. The reason is that in the rolling process the deformation is realized in all parts of the rolled stock simultaneously.

The pass design for rolling of wide flange beams is characterized by some specialities. As far as the pre-shaped semifinished products rolled in the roughing mill is concerned, they must have symmetrical top and bottom flanges or, in general, accurate dimensions (height and width) of the

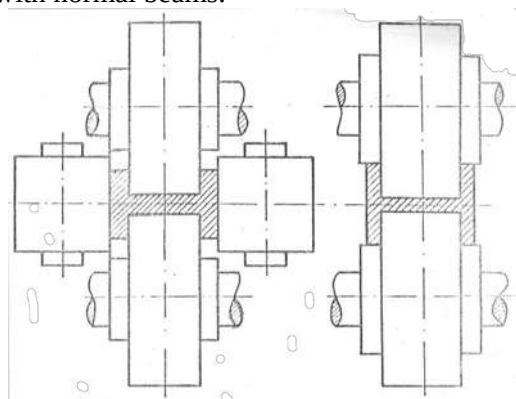


Fig. 12.6 Scheme of wide flange beams rolling in universal mill

rolled stock. The reason is that in deformation in the universal roll stand really the same strain coefficients are used for both the web and the flanges.

The current trend utilizes the semi-product prepared by continuous casting in the form of “dog bone”; this shape is already prepared for creation of flanges and a tall web. Rolling then proceeds exclusively in universal roll stands, completed by horizontal two-high roll stands, as the case may be, see scheme in Fig. 12.6.

□ Pass design for rolling of channel (U-profile, U-iron)

The general performance and denotation of the basic cross section of U-profile (channel) is given in Fig. 12.7.

To important characteristics of the cross section shape belongs:

- Cross section area
- Beam weight per running meter
- Cross sectional moments of inertia W_x and W_y
- Radii of inertia i_x and i_y
- Web specific thickness t_1/h
- Flange specific thickness t_2/b
- Web specific area S_{st}/S
- Web slenderness ratio h/t_1
- Flange slenderness ratio b/t_2
- Relative width of beam shape b/h
- Shape cross section economy W_x/C
- Specific moment of resistance against bending

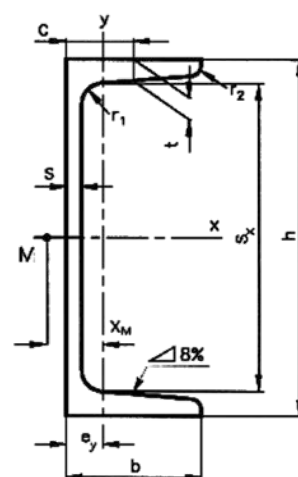


Fig. 12.7 U-profile

In the pass design for rolling of channels we distinguish essentially three basic modes:

“Straight” pass design. The scheme is given in Fig. 12.8a. The width of flanges (arms) of the channels is larger than in case of I-beams of the same No. It means that their required length is created with more difficulty. Therefore this pass design uses the opposite, i.e. false flanges. Existence of these flanges and the deformation within contribute to creation of the required length of channel arms.

“Beam” mode is a variant of the “straight” pass design (Fig. 12.8b). It is characterized by the fact that preparatory passes are common for rolling of both channels and I-beams of corresponding dimensions (numbers). This mode features opposite (false) flanges. The necessity of large thickness reductions in false flanges causes a considerable displacement of the metal to the web and true flanges (arms), which may cause difficulties with maintaining the dimensional accuracy of the cross section shape.

Advantageous is smaller number of required sets of rolls and hence smaller number of roll changes associated with changing the rolling schedule for rolling of I-beam. On the other hand, considerable thickness reductions in false flanges cause higher power consumption. From viewpoint of the production technology the requirements for quality parameters of the final rolled product are deteriorated. Deep slots in rolls decrease the roll strength. Small inclines of external flange walls cause higher wear and tear of the grooves; in turning the rolls it is necessary to remove larger thickness of the metal from the roll surface, which leads to faster fall in their service life. Rolling with small flanges inclines requires a higher number of passes.

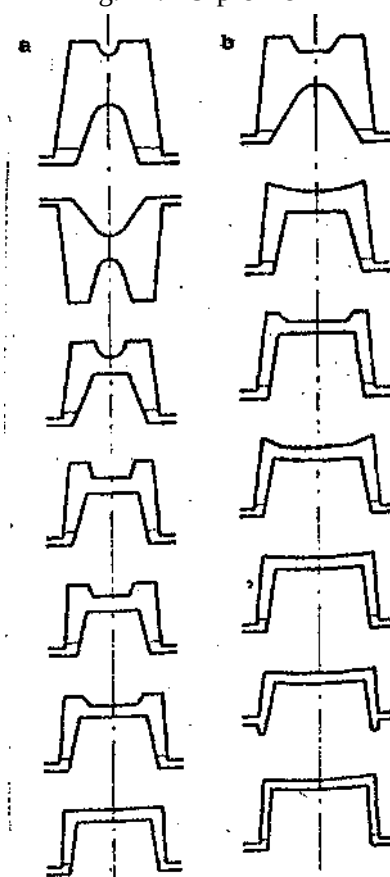


Fig. 12.8 “Straight mode” of pass design of the channel

The “beam mode” of the pass design currently remains in those rolling mills where there are conditions (their design, equipment, etc.) for its application. In new rolling mills this pass design mode is used only very rarely, or by no means.

Pass design with high incline of channel arms (Fig. 12.9). This variant of the “straight” pass design is used a little bit more frequently. It is distinguished by a high incline of external flanges walls of grooves, which ranges from 15 to 20 %.

The high incline of flanges creates favourable conditions for better implementation of the lateral deformation. The required length of the channel arms is achieved more easily in the course of introduction the rolled stock from the leading pass with the high incline of flanges into the finishing pass.

To basic benefits of this pass design belongs:

- Possibility of intensive deformation of the metal rolled in grooves
- Occurrence of the relatively uniform distribution of the height deformation in particular parts of the rolled metal
- Smaller number of passes
- Lower wear and tear of rolls due to decrease in differences of rolls speeds in particular parts of grooves
- Relatively shallow slots of grooves in rolls (higher strength and service life of rolls)
- Perfect grooves renewal in turning the rolls

Among shortcomings a relatively high width of grooves may be mentioned, and thus lesser utilization of the roll barrel. In many cases this may be compensated by lowering a number of shaped passes.

Pass design with progressive convergence of arms. It eliminates basic shortcomings of the “straight” pass design. The false arms of channels are very small. The groove shapes enable to realize shallow slots into the rolls and allow implementation of large thickness reductions.

Existence of opposite (false) flanges creates a strengthened part in places where the web and flanges are connected. This node with a higher material concentration has a tendency to resist bending the arms to square (right angle). Therefore a more robust construction of the entry guide for introduction the rolled stock into the rolls is required. Collars are subjected to more stress. Unfavourable conditions for the wrinkle formation on the collar external walls, as well as external walls of the rolled metal arms, are created.

“Butterfly mode” – this pass design came into being by elaboration of the basic idea of the pass design with opened arms. This mode is based on considerable reductions in initial passes - when the channel arms are created, in the following passes then smaller reductions are realized.

The butterfly pass design is characterized by deflection of the channel arms and web in all passes except for the final and leading pass. Construction of channel grooves is relatively simple. The pass design creates favourable conditions for designing the auxiliary rolling fittings and for their operating in the course of rolling.

The butterfly pass design is advantageous also for rolling of economical channels.

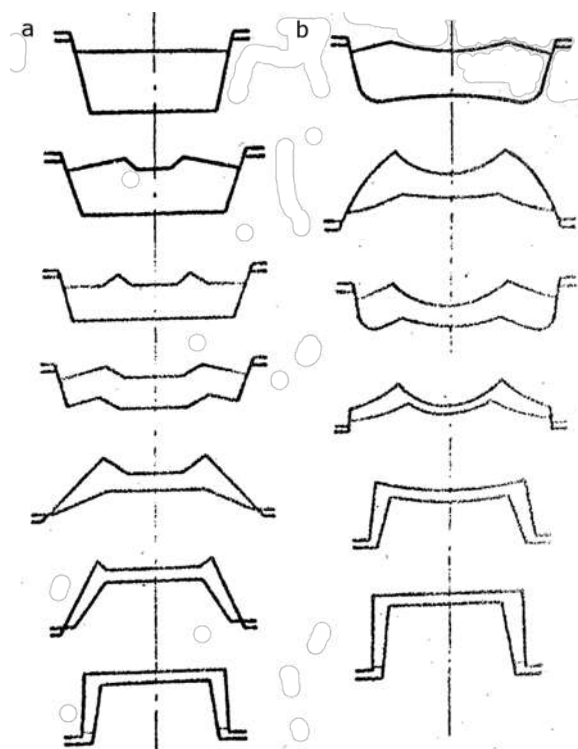


Fig. 12.9 Pass design mode of channels with opened arms

Specialities of groove designing and rolling of channels

The cross section shape of channels may be considered as the I-beam shape, of course with neglecting flanges on one side. Such view made it possible origin of the straight pass desing based on the beam mode.

Conditions of the rolled stock deformation in grooves for rolling channels have their specialities, from which some should be pointed out:

- With regard to the fact that length of the channel flanges is higher than in case of I-beams of the same No., the pass design respects the existence of false, or even so-called opposite flanges. False flanges serve for shaping the arms of required lengths and sharp corners in places of contact between the arm and the web of the channel.
- In the course of rolling the channel stock (in all passes) no alternation of opened and closed flanges occurs, unlike the pass design of I-beams.
- Groove opening is designed only with respect to true flanges (arms) of channels
- During rolling of channels the relatively considerable deformations in all parts of grooves occur.
- In rolling of channels the upsetting (checking/master) grooves are used. Their task is to control dimensions of arms, especially their length, in the course of rolling - whether the required value has been reached.

□ Pass design for rail rolling

In the rail transport different kinds of rails are used. They differ from each other by dimensions, cross section area and shape. Rails of all types belong to a family of flange shaped steels.

With regard to their use in practice the rails are divided into railway, mine and special. The railway rails are used for building the railway lines and sidings. The mine rails serve for building mine and field railways. By their shape they are similar to railway rails, but they have smaller dimensions and weight. Their weight reaches up to 25 kg per running meter of the rolled product. To a group of special rails belong grooved (tramway), crane, turnout (points, switch), tongue, and cross frog rails.

In our case that is the question of typical railway rails, normally used in the railway traffic. The general rail performance and designation of their parts is given in Fig. 12.10. From the viewpoint of the pass design the rail belongs to a group of asymmetrical shaped steels. The complexity of rails rolling consists in the fact that groove shapes are symmetrical only with respect to the horizontal axis. The asymmetry of the gross section shape and different conditions of deformation in the rail head and foot make the pass design (grooving of rolls) very complicated. Rolling is carried out using considerable lateral reductions. The flanges are formed by lateral thickness reductions, the web by the direct-acting thickness reduction, rail head by the direct-acting and lateral thickness reduction.

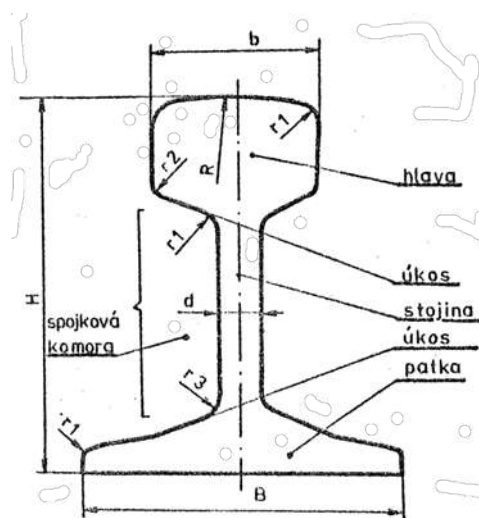


Fig. 12.10 General performance and designation of rail

(hlava - head, úkos - bevel, stojina - web, patka - foot, spojková komora - cross rail bond)



Summary of terms of this chapter

Basic terms you got to know are the following: **pass design of angles with opened arms and restricted spread, pass design of angles with opened arms and free spread, pass design of I-beams using horizontal grooves, pass design using oblique grooves, direct pass design of channels, pass design with large incline of channel arms**



Questions to discussed curriculum

- 12.1. Describe the difference between the unequal and equal angle.
- 12.2. Enumerate and plot basic differences between the pass design of angles with straight arms and opened arms.
- 12.3. Explain the difference between the pass design of I-beam in rolling mills with horizontal stands and universal rolling mills.
- 12.4. Describe the pass design of I-beam with using horizontal passes.
- 12.5. Evaluate advantages and disadvantages of straight pass design for rolling of channels.
- 12.6. Plot a scheme of the pass design with progressive convergence of arms for rolling of channels.

13. Bending in rolls and shaping of flat products in production of shaped sections and welded tubes



Time for study: 2.5 hour



Target After studying this paragraph you will be able to

- define types of thin-walled sections
- describe different production technologies of thin-walled sections
- resolve the neutral fibre length



Presentation

13.1. Thin-walled sections

Characteristic properties of thin-walled sections are:

- low weight per running meter
- shape variability of sections
- dimensional accuracy
- surface quality
- mechanical and technological properties

To benefits of thin-walled sections belong a low weight and favourable static cross section values (cross section characteristics). Thickness of hot rolled sections is often given by minimum dimensions that may actually be produced, not by strength requirements. Smaller thickness in case of cold formed sections is more suitable not only for manufacturing reasons, but also for the reason of possibility of the cross section optimum shape selection, which brings considerable savings. The building construction design performed of thin-walled sections enables to lower the weight of the construction by 15 to 30%.

Principle of producing thin-walled sections

- by longitudinal forming the required shape of the profile is gained
- mainly the shape is changed
- cross section (thickness) is changed only minimally
- shaping proceeds in cold state, the material in the deformation course is subjected to work-hardening

Use of thin-walled steel sections

- machinery
 - transportation - aircraft, land
- civil engineering
 - building constructions
 - roof design
 - demountable systems of storehouses, etc.

- sheet coverings

Basic division

- Open thin-walled sections (Fig. 13.1)
 - edges do not touch each other
 - edges are in contact, but they are not continuously connected mechanically or by the metal
- Closed thin-walled sections (Fig. 13.2)
 - made of thin-walled tubes
 - prepared usually by bending in rolls into shape of the tube with a gap, continually welded

Thin-walled sections are produced by cold forming of steel. They are formed by bending in rolls, cold rolling, stretching and pressing.

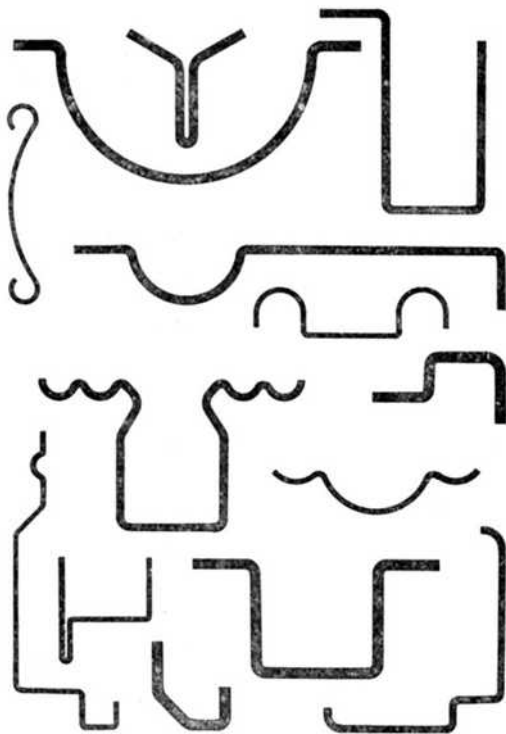


Fig. 13.1 Open thin-walled sections

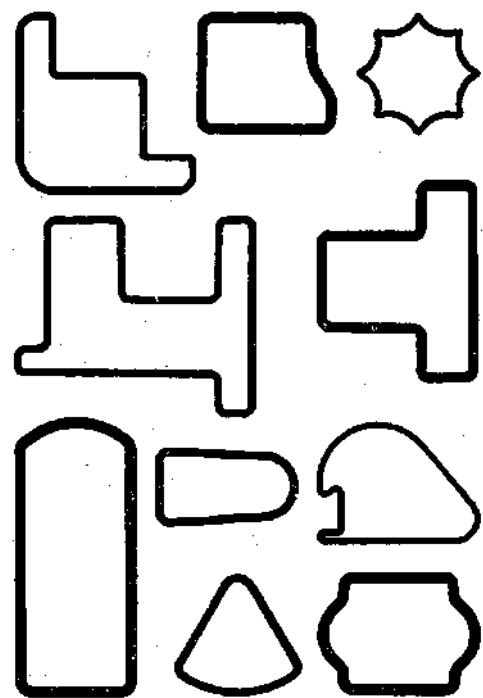


Fig. 13.2 Closed thin-walled sections

Types of input semi-products:

- hot rolled strip
- cold rolled strip
- thin-walled tubes

Material:

- steels
 - commercial grades
 - carbon, alloy
 - stainless austenitic
 - metal-clad, galvanized
- non-ferrous metals
 - copper, bronze, brass
 - aluminium, zinc, magnesium, and their alloys

Thin-walled sections can be produced almost of all types of steel, which is rolled to strips and sheets. Using carbon steels is normal, but also alloy steels, stainless steels, steels with higher corrosion-resistance or steels of type Atmosfix are used. By cold forming the sections of high-strength steels are also produced, however, sufficient elongation is required in this case, which is a prerequisite for creation the bends. For the production also very small thicknesses (even smaller than 1 mm) are used. Sections have relatively close tolerances and the mechanical properties improved by cold forming. Their surface corresponds to surface of the input steel strip and the production technology. Surface of sections is either dark or lustre. The dark surface with fine scale is typical for sections produced from hot rolled strips. The lustre (metallic gloss) surface is characteristic for sections produced from cold rolled strips and/or produced by drawing. The smooth lustre surface enables to ensure good corrosion prevention. Such surface is provided with paint or coat, in case of sections made of stainless steels the surface is polished. Wide bent sections are delivered with a zinc layer on both sides of the surface, aluminium coated or varnished.

The advantage of thin-walled sections is freedom in choice of shape. Shape is possible to be adapted to functional requirements at simultaneous beneficial static effects. An example of such advantageous connection may be ceiling and roof gable sheets, hollow sections of columns, C-shaped downstand beams, etc.

The initial material for the production of thin-walled sections is sheets and wide strips. Sheets are used for the production on press brakes, whereas strips serve for the production of sections on shaping (profiling) machines by cold forming. Strips are coiled in coils, strip thickness used to be up to 3 mm. The strip width is chosen according to the developed section width. In case of more complicated sections the strip width has to be exactly maintained in the entire strip length, otherwise difficulty in the production would appear and section edges would be wavy. Therefore in front of the profiling machine the circular shear is installed, which trims the strip edges to accurate width. Non-trimmed strips are used only for the production of simple opened sections. The loss by trimming the edges is diminished when wide strip is slit into several narrower strips with the required width. When hot rolled strips are used as the input material, the scale is removed from their surface, mostly by pickling in acids, so that they could not cause galling (abrasion) of profiling rolls. The production in profiling machines is a continuous production process. Before coiling is finished, the subsequent strip is welded to the previous one (in the meantime the strip from the looping pit is processed), so the forming process is fully continuous.

The basic production technology may be divided into three following modes:

- profiling/shaping (bending in rolls)
- drawing
- pressing in press brakes

13.2. Profiling/shaping technology

By cold bending in rolls the open and closed sections are produced in shaping (profiling) machines. In the course of this process the strip is subjected to successive lateral bending by pairs of rolls, thus gaining the required cross section shape (Fig. 13.3). There is a series of roll pairs, usually more than 6, their number depends on the cross section shape.

Preparatory procedures are:

- pickling
- blasting
- dividing (cutting)

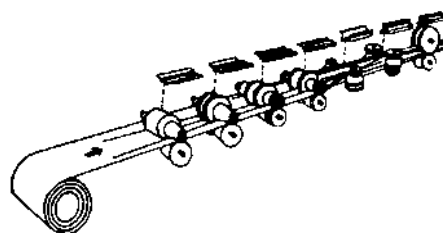


Fig. 13.3 Schematic illustration of profiling line

The section production by shaping (bending in rolls) proceeds in the profiling machine in successive steps:

- The steel strip is uncoiled from the storage feed drum, passing through the feeding jaws.
- After grasping by first pair of shaping rolls it is drawn-in by friction effect between the rolls and is bent in lateral direction.
- The whole profiling (shaping) process is carried out in several pairs of rolls. Profiling machines are designed and built with 10, 16, and even more shaping rolls.
- The pass number depends on the global shape of section, its dimensions, type of material and its mechanical properties.
- The basic principle is that the section is shaped in the bottom roll by bending the strip edges upwards.

The shaping machines are divided into two basic groups: machines with overhung spindles and machines with supported spindles. The machines with overhung spindles have the spindles mounted in bearings only on one - the driven - side. The overhung spindles are typical for small and light machines. Changing of roll sets is in their cases simpler, but for shaping only small pressures may be used, so they are suitable only for small thicknesses.

The machines with supported spindles have rolls mounted in bearings on both sides. Either only bottom or both spindles are driven. These machines occur much more often, they work with closer tolerances and are suitable also for sections of larger thicknesses and more complex shapes. Rolls service life is higher as well.

In each pair of rolls a partial bend of the cross section is realized. The shaping procedure for a simple open section is shown in Fig. 13.4. The main principle in cold forming is that the bottom roll forms the cross section by bending the strip edges towards the top roll. This principle is possible to maintain in case of simpler cross sections, for more complicated cross sections the bottom roll bends at least the cross section middle part. In bending in rolls of hollow sections also side pairs of rolls are used, so the cross section is shaped on its whole perimeter. Shaping of the section proceeds relatively fast. Speed depends on the strip material and the shape complexity. In case of large sections the speed amounts

10 to 30 m/min, in case of small dimensions 20 to 90 m/min. In forming the formed material is heated considerably, therefore it is cooled continuously by water emulsion. Non-uniform cooling can lead to marked internal stress in the product.

The correct shaping requires that the strip entering the machine has to be straight and introduced into the machine in the correct vertical and horizontal position. That is why the feed rollers are installed in front of the first pair of shaping rolls. The last pair of rolls is followed by the sizing and straightening equipment, which ensures accurate dimensions of the produced section, including straightening and levelling of various local defects of this type.

The worn shaping rolls are reground, which contributes markedly to their service life increase. When the production of normal sorts of sections with not very complicated cross sections is considered, it is

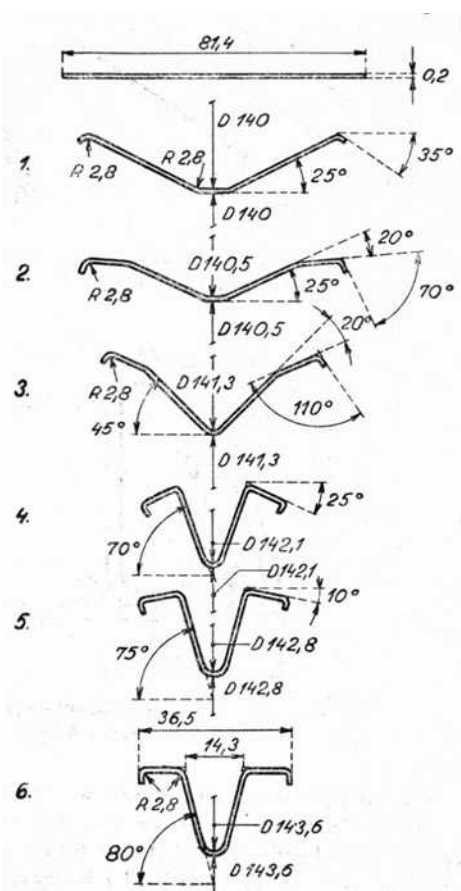


Fig. 13.4 Open section shaping procedure

possible to estimate that without regrinding ca 1.2 million meters of sections may be produced on a single set of shaping rolls.

Procedures after profiling

The shaping (profiling) machine is directly followed by the following procedures:

- straightening and levelling – elimination of curving defects and waviness originated in the course of bending in rolls
- straightening equipment
 - of table type, with replaceable jaws
 - with a pair of swivelling rolls, for decrease in friction the rolls are made of another material than is used for the produced section
- cutting to required lengths, it is carried out by
 - flying shear
 - circular or band saw
 - abrasive grinding carborundum disks
- surface treatment
- perforating of section walls for decreasing the weight or for assembly holes
- roll bending

The profiling machine creates a key element of the line for the production of thin-walled sections, see Fig. 13.5. In Fig. 13.6 the line for the production of hollow or open sections is schematically shown. The steel strip is uncoiled (1), levelled in rolls (2), goes through the welder (3) where the strip ends are welded together by a butt weld, coils on the drum (4) and is stored in the frame (5) which can be put out of the line; this device finishes the preparation phase of the strip for its actual shaping. The proper shaping line begins with drums (6) and then particular machines/equipment in succession follow: feeding rolls (7), flying shear (8), shaping machine (9) with eight stands, saw (10), welding machine for hollow sections (11), cooling section (12), drawing rolls (13), sizing equipment (14), flying saw (15), storage area (16). Instead of recoiling strips on drums the deep looping pit may be installed in front of the shaping machine, which supplies the shaping machine with strip in time of welding the subsequent strip and thus ensures the production continuity.



Fig. 13.5 Profiling line for shaping of longitudinally welded tube

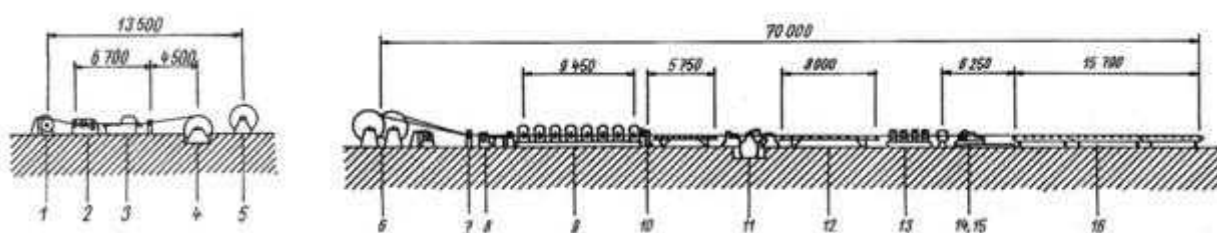


Fig. 13.6 Schematic layout of the whole technological process of profiling

□ Basic principles and procedures of pass design

- Choice the correct section placing in rolls – shaping of the whole cross section, or at least a substantial part of the basic form, has to be performed in the bottom roll by pressure of the top roll
 - If sections are produced from the strip, one side of which is polished, this surface has to be placed upstream so that it could be checked in the course of shaping, whether scratching occurs or not
- Design a number of passes – for the production of simple angles and channels with flat walls 3 to 4 pairs of rolls are sufficient
- Design a correct position of the section centreline in the shaping machine – i.e. the axis in the middle of rolls, which goes through the centre of the gap between both stands and should be identical with vertical axis of the section
- Design and calculation of shapes and cross section areas in particular passes
 - This step is based on the developed cross section width, determined in the neutral cross section fibre. Calculation of the developed width has to be carried out very precisely. The neutral fibre of the cross section is shifted in bends towards the curvature centroid. In general this phenomenon can be expressed by the relation:

$$R = r + k \cdot t \quad (13.1)$$

where: R - radius of curvature of neutral fibre,

r - internal bending radius,

t - strip thickness,

k - coefficient expressing magnitude of the neutral fibre shift ; $k \leq 0.5$

- For strip thickness up to 1.5 mm coefficient k can be chosen as per internal bending radius as follows
 - for $r > t$, $k = 0.50$
 - for $r < t$, $k = 0.33$
- For internal bending radius $r < 0.5$ mm the curvature radius of the neutral zone is determined from equation $R = (0.2 \div 0.3) \cdot t$, the lower value is valid for sections of higher thicknesses and smaller bending radii.
- For material thicknesses higher than 3 mm coefficient k is chosen as follows:
 - for $r < 1.5 \cdot t$, $k = 0.33$
 - for $r = (1.5 \div 5) \cdot t$, $k = 0.40$
 - for $r > 5 \cdot t$, $k = 0.55$
- The last step is carrying out working drawings of shaping rolls



Solved tasks

□ Example of section width calculation

Without considering the shift of neutral fibre you calculate the input strip width for curvature of the section as per Fig. 13.7.

□ Solution

$$l = a + b + \pi(r_1 + t/2)\alpha_1 + \pi(r_2 + t/2)\alpha_{21}$$

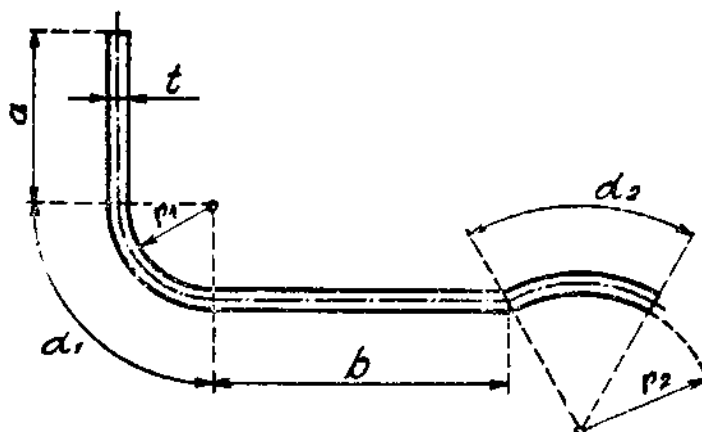


Fig. 13.7 Example of open section

13.3. Drawing of sections

By cold drawing mainly closed sections are produced. For drawing of hollow sections the drawing benches are used. They are usually designed for drawing of one section, but the design of some benches makes it possible to draw two sections simultaneously. Drawing force achieves up to 400 kN, the bench length ranges from 8 to 12 m, the drawing speed from 12 to 18 m/min.

Particular production phases for the closed sections:

- production of thin-walled welded tube by shaping (profiling)
- tube preparation for drawing
- continuous mandrel drawing in dies

Production of thin-walled welded tube by shaping (profiling):

- The steel strip is slit (trimmed) in the circular shear for gaining
 - the accurate strip dimension
 - metal-pure edges, making welding easier
- Individual coils are mutually connected by transverse welds
- The prepared strip passes the machine with bending rolls, in which acquires shape of the tube with a gap
- After bending in rolls further procedures performed in continual succession follow:
 - Electric or flame welding of the tube.
 - Requirement for as small as possible weld reinforcement - the external can be removed by planing, the internal is removable very difficult.
 - Cutting to required production lengths - carried out mechanically (circular or band saw, abrasive grinding disks, or breakage after local induction heating).

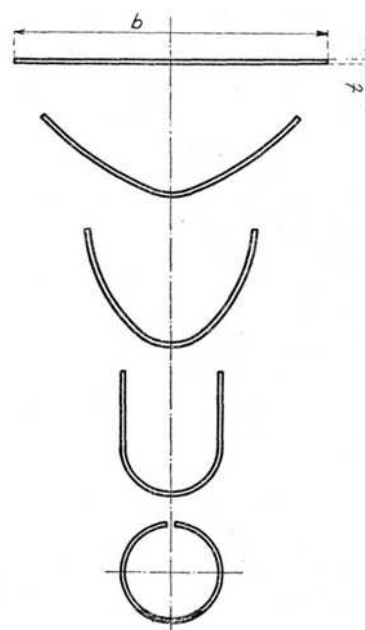


Fig. 13.8. Strip bending in rolls into tube

The production of hollow sections by drawing is distinguished by two independent (from viewpoint of technology) procedures. The first one is the production of the input semifinished product – thin-walled welded tube, the second one the actual production of the closed section by cold drawing. Welded tubes are produced from steel flats and strips supplied in coils. The strip first comes to the circular shear, which trims the strip to accurate width with pure edges, which makes the perfect weld performance easier. Then the strip passes the shaping machine for bending in rolls, where - after passage the set of rolls - acquires the shape of a slit tube (tube with a gap). Subsequently the tube is subjected to electric, resistance or high-frequency pressure welding. The external weld reinforcement is removed by planing, the internal reinforcement remains as its removal would be difficult. Welded tubes are cut to required lengths by the circular saw or abrasive grinding disks.

Procedures before actual drawing:

- Pointing – creation of a tip at the tube end, serving for pulling the tube through the drawing die and grasping in jaws of the drawing cart. Up to the tube diameter 40 mm it is carried out in the cold state, in case of higher diameters in the hot state. Mandrel length is ca 200-400 mm. A single pointing is sufficient.
- Heat treatment – normalizing - stress relief annealing and carrying out structural changes in the tube, in the vicinity of the weld and tip.
- Pickling – scale removal.
- Phosphatizing – friction decrease in the drawing die in the course of drawing, or lubrication by emulsification grease.

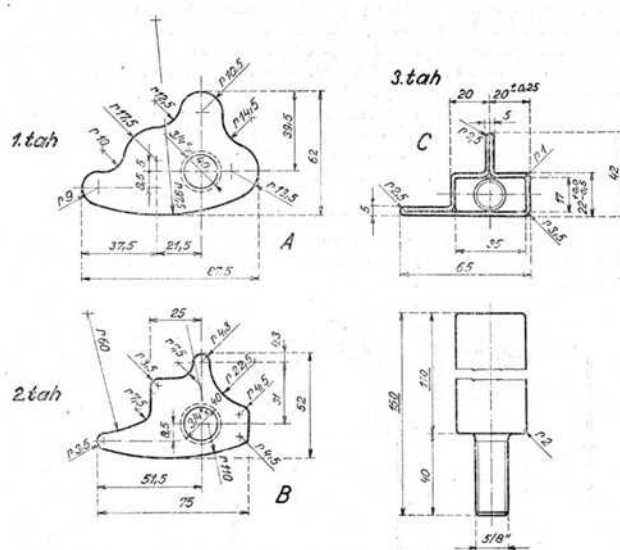


Fig. 13.9 Drawing of closed section in three step
(1.tah, 2.tah, 3.tah - 1st draw, 2nd draw, 3rd draw)

The drawing procedure of closed sections depends on the section complexity:

- simple, square or rectangular shapes are drawn by a single pass
- more complex shapes are drawn successively in several drawing dies, mostly four draws are used

Due to exhausting of plasticity the recrystallization annealing has to be integrated. By cold drawing the initial tube length is extended, which is caused mainly by the fact that the perimeter of the hollow cross section after drawing is smaller than the perimeter of the initial tube. In the course of drawing also the section thickness is a little bit changed. The internal cross section is defined in each draw by the drawing mandrel. Final sections are delivered to customers with metallic lustre, i.e. unannealed, or stress relief annealed or normalized. The final operation is cutting-off the tips and cutting to required lengths.

13.4. Pressing on press brakes

Press brakes are devices appropriate for the production of both simple and complicated section shapes, produced in small quantities. Conversion from one section to another is in case of the press brake markedly simpler than in case of the profiling machine. In case of the profiling machine all rolls have to be replaced, which is very time-consuming, and only such sections can be formed, for production of which the forming rolls were already made before. The design and production of new rolls are very costly. In case of the press brake only the squeezing stroke is adjusted or press tools (dies, rulers) are replaced when the section is changed, which is not time-consuming. The resulting section length is limited by the press width. Width of most of presses is 3 to 4.5 m, but in some plants we can find

presses of width even 6 to 9 m. Thickness of sheets/plates which can be processed in the press brake reaches up to 20 mm.

In presses the strips cut to the required length and with the required developed width of the section are bent. Sections after pressing are straight/flat and do not require additional straightening/levelling. The dimensional accuracy of sections is lesser than in case of cold formed sections produced in profiling machines.

The press tools are adapted to shape of the required section. They are made of two parts. The bottom half - lower die - is fixed and fastened in the press frame, the top half - punch - is movable and deduces the actual pressure. As far as shape is concerned, the tools are tailored to the produced section shape. By each stroke one bend of the section is carried out. The simple angle is bent by a single stroke (Fig. 13.10 left). The dies used to be also rotating around the horizontal axis and have various recesses (cavities) on all four sides, so they may be used for the production of a higher number of different sections. More complicated sections are bent consecutively, or they are transferred, swivelled and equipped with specific punches (Fig. 13.10 right). The press brake can ensure also bending of the section walls to the arc form. Circular parts of the section are pressed by rounded-off tools. Sections that are closed to a great extent cannot be pressed in one stroke. Bending is carried out by several strokes and the appropriate tool is used for each stroke.

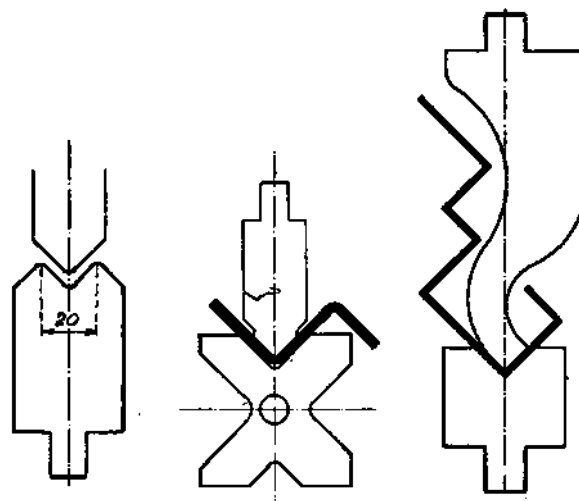


Fig. 13.10 Bending in press brake (left – bending of angle, right – bending of a complex section)

Pressure of the press depends on the sheet thickness, opening the die and the section length. Pressures range from 10 to 100 MPa per running meter of section, as per thickness. Press brakes are of hydraulic or mechanical design. Service life of hydraulic presses is high; however, more accurate are mechanical presses. Presses work with pressures up to 1000 MPa. A number of strokes of the press brake depends on its size. Some presses work with up to 50 strokes per minute, but big presses can work with only 2 strokes per minute.

13.5. Production of spiral-seam tubes

- Characteristics of the whole technology from the material preparation to the final tube is that is fully continuous
 - high output, high utilization of the charge material
- Typical feature is weld in the form of helix (spiral) on the tube perimeter
- Initial material is steel strip in coils
- In comparison with longitudinally welded tubes, the input material is - for the same tube diameter - ca 1.5 times smaller
- For the production of tubes up to diameter 150 mm the cold rolled steel strip is used, for larger diameters the hot rolled.
- The technological process of automatic submerged-arc welding may be used for tubes with diameter from 20 mm to 1500 mm.
- Normally strips with thickness 1.5 to 10 mm, or 15mm are welded.
- From the strip of the same width the tubes of different diameters can be welded.

□ Strip preparation for welding

- The initial steel strip is delivered in coils of big weight, so that its sufficient store for continuous welding process could be created
- Coils are uncoiled and levelled in 5 or 7-roller levellers
- Then uneven front and rear ends of coils are cropped (ends with camber, inconvenient width)
- Welding the coil ends, most often in the form of perpendicular weld
- In front of the equipment for bending in rolls the storage loop is created, making it possible the welding process proceeding independently on the strip preparation
- Trimming of strip edges to the accurate strip width and their finish for welding by means of circular shear or planer tools
- In case of strips with thickness above 8mm the weld bevel is necessary

□ Strip bending

- The strip is bent by winding to the tube shape
- The strip is strained by 3D-bending and torsion in the area of elastic-plastic deformations
- Two basic modes of bending are common
 - by winding on the cylindrical mandrel, corresponding to inner diameter of the tube
 - in twisting guide (roller gauge), corresponding to outer diameter of the tube
- The bending equipment is combined with welding heads, so the tube is welded at the same time with bending

□ Bending principle

Parameters describing the entire process are as follows:

- outer diameter of bent tube D
- strip width B
- helix angle α
- lead of helix $MN = \frac{B}{\sin \alpha}$
- tube diameter and initial strip width are bound by equation $\cos \alpha = \frac{B}{\pi D}$
- for maintaining the same helix angle it is necessary to use wider strips in case of the tube with higher diameter

For determination of strip width the following relation can be used

$$B = \pi(D - t) \cos \alpha + kt \quad (13.2)$$

where:

- k expresses influence of melted edges and ranges around 1.5
- t is strip thickness

□ Bending by winding on mandrel

The process proceeds as per Fig. 13.12.

- the strip is uncoiled from the coil (1) and passes the leveller (2)
- at feeding it is directed by the guiding rollers (7)
- it is wound on the rotating mandrel (4) at pertinent angle α
- by means of pressure rollers (5)
- in place (3) the welding head is located
- this mode enables welding only from external side

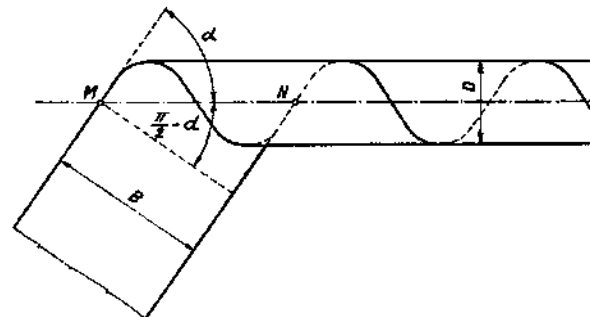


Fig. 13.11 Principle of production of wound tubes

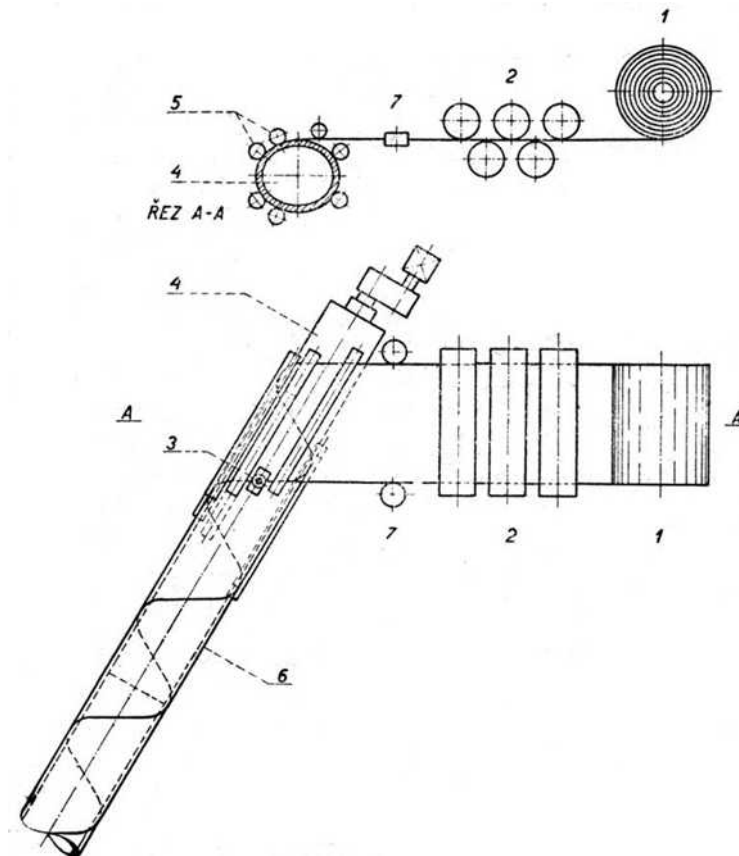


Fig. 13.12 Mode of tube production by winding on mandrel
(ŘEZ A - A – SECTION A – A)

□ Bending in roller gauge

The process is outlined in Fig. 13.13.

- the strip is uncoiled from the coil (1) and passes the leveller (2)
- the strip is fed in the roller gauge under pressure of pressure rollers (3)
- before entrance into the gauge the strip is guided by two pairs of vertical rolls (4)
- the actual bending proceeds between the pinch rolls (7)
- between the pinch rolls the external and internal welding heads (5) and (6) are placed
- this mode makes it possible welding only from external side

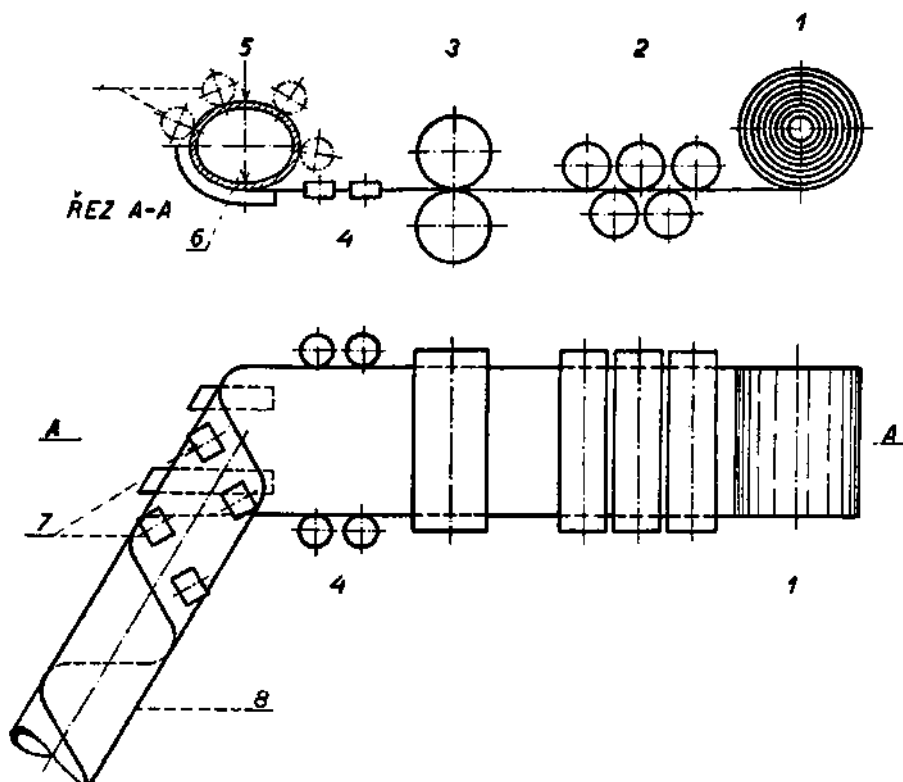


Fig. 13.13 Mode of tube production by bending in roller gauge
(ŘEZ A - A – SECTION A – A)



Summary of terms of this chapter (subchapter)

Important terms that you should be able to distinguish are: **open section, closed section, profiling (shaping) technology, drawing of section, pressing of section on press brakes, production of spiral-seam tube.**



Questions to discussed curriculum

- 13.1. What types of semifinished products for the production of thin-walled sections exist?
- 13.2. Enumerate materials for the production of thin-walled sections.
- 13.3. What are preparatory operations in the shaping (profiling) technology?
- 13.4. Describe particular technological steps during material passage through the profiling line.
- 13.5. Write a general formula for calculation of curvature of the neutral zone.
- 13.6. What are values of coefficient of neutral fibre shift in strip profiling up to thickness 1.5 mm?
- 13.7. Enumerate particular technological procedures in the production of sections by drawing.
- 13.8. What is dimensional accuracy of cross sections in pressing on press brakes?
- 13.9. Derive the relation defining the dependence between the spiral-seam tube diameter and the initial strip width.



Tasks for solution

Calculate the length of the neutral plane of the rafter cross section as per drawing in Fig. 13.14.

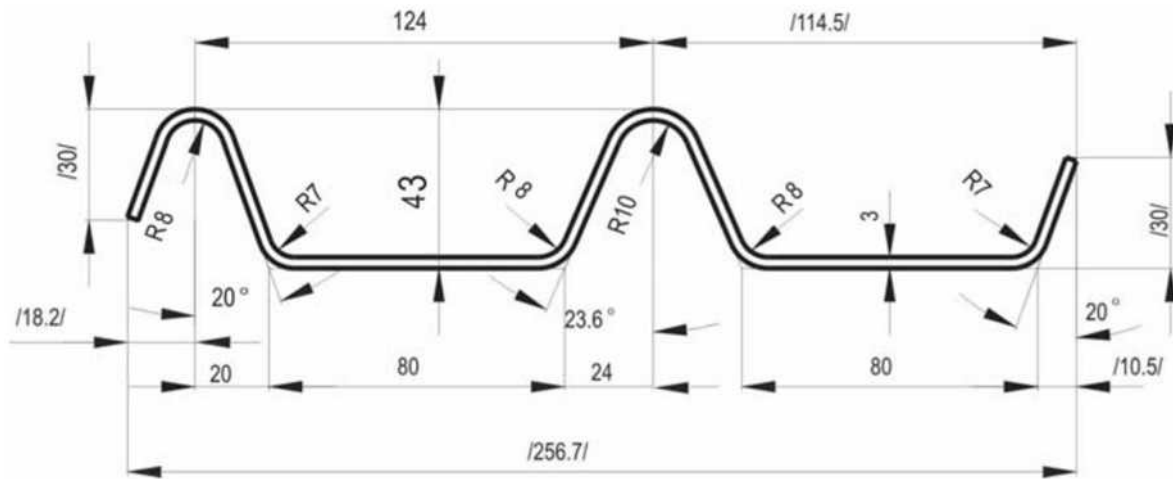


Fig. 13.14 Drawing of the rafter cross section

14. Methods of tubes production



Time for study: 5 hours



Target After studying this paragraph you will be able to

divide basic sorts of tubes, describe the production of seamless and welded tubes, specify basic technologies of piercing and elongation of seamless tubes and obtain a survey on the manufacturing plants in our region dealing with the production of seamless tubes.



Presentation

14.1. Sorts of tubes

As per the basic steel tubes production modes we distinguish:

- a) **Seamless tubes** (made of solid material and/or hollow semifinished products with compact walls). As per production technology they can be:
 - hot and cold rolled
 - extruded
 - expanded
 - reduced
 - drawn
- b) **Welded tubes** (made by winding the steel strip into the tube shape and its welding, or bending in rolls of the sheet table and welding. The weld proceeds along the tube parallel to its centreline, or in helix with a high lead – Fig. 14.1)

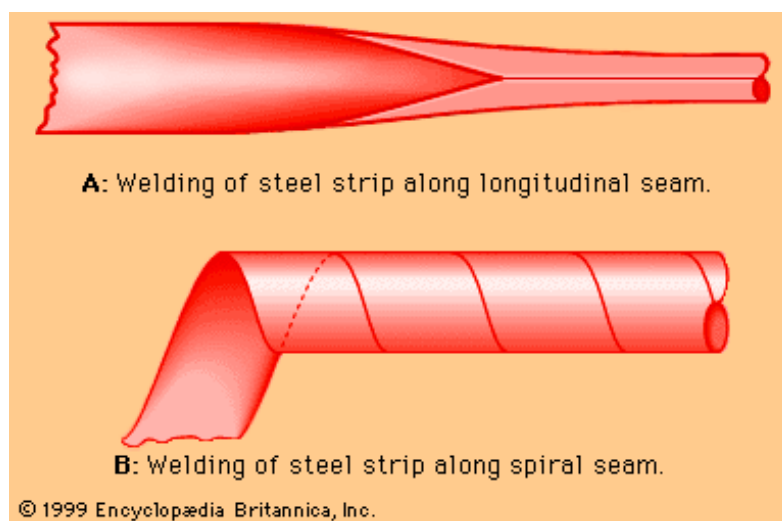


Fig. 14.1 Welded tubes – A weld parallel to centreline, B spiral seam

14.2. Production of seamless tubes

□ Initial material:

- round billets – CCS or rolled
- round ingots (also pre-drilled) – tubes of larger diameters,
- hollow semifinished products produced by centrifugal casting
- semifinished products produced by powder metallurgy

□ Reheating:

For the material reheating mainly rotary-hearth furnaces are used (Fig. 14.2). Reheating of the charge material requires uniform heating with soaking of the metal.

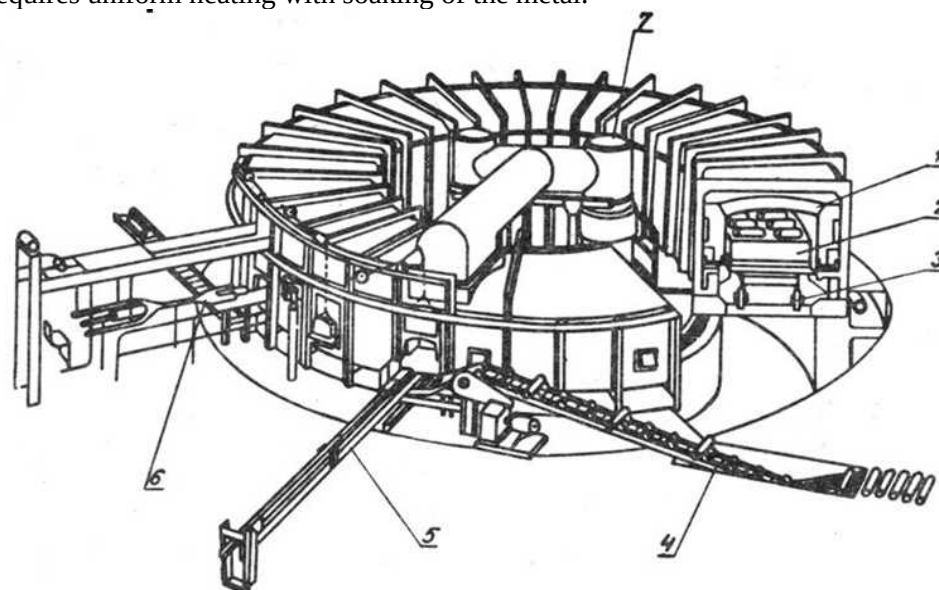


Schéma karuselové pece (pec s otočnou nístějí)
 (1) klenba pece, (2) nístěj pece, (3) pojízdná kola nístěje,
 (4) dopravník k sázecímu zařízení, (5) sázecí zařízení,
 (6) vytahovací kleště, (7) rekuperátor

Fig. 14.2 Scheme of rotary-hearth furnace

(Schéma pece s otočnou nístějí – scheme of rotary-hearth furnace, (1) furnace roof, (2) furnace hearth, (3) hearth travelling wheels, (4) roller table to charging device, (5) charging device, (6) pulling-out tongs, (7) recuperator)

□ Basic production process

For most of seamless tubes production modes the technological process consists of two separate, but consecutive main production phases:

a) Production of hollow thick-walled semifinished products

The hollow semifinished products are produced either by the cross-rolling process (diagonal rolling) in two-high or three-high roll stands, or by pressing, or by piercing in combination with thrust-pressure rolling.

b) Further processing of hollow semi-products into tubes

by longitudinal periodic rolling, or by longitudinal rolling (may be combined with pushing-through), or by cross-rolling, or by extrusion.

With respect to mechanical and plastic properties of steels all the production processes are realized in the hot state.

❑ Piercing

The conventional technological procedure, where the hollow semi-product is produced from the solid charge material and is further processed to the final tube, is the cross (diagonal) rolling. It creates the basis of the Mannesmann and Stiefel production process and is used as the first technological procedure also in case of other modes of seamless tubes production. The scheme of piercing by cross rolling is in Figs 14.3 – 14.6.

Among further piercing modes ranks e.g. piercing realized by pressing Fig. 14.7.

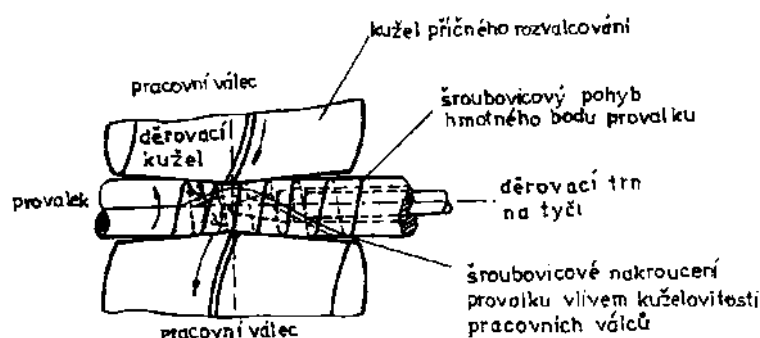


Fig. 14.3 Scheme of piercing by cross (diagonal) rolling

(pracovní válec - work roll, kužel příčného rozválcování - cross-rolling cone, děrovací kužel - piercing cone, provalok - rolled stock, děrovací trn na tyči - piercing plug bar, šroubovicový pohyb hmotného bodu provalku - rolled stock mass point spiral movement, šroubovicové nakroucení provalku vlivem kuželovitosti pracovních válců - rolled stock spiral twisting due to cone-shaped work rolls)

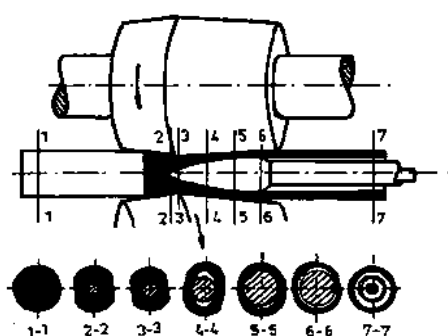


Fig. 14.4 Scheme of piercing by cross rolling

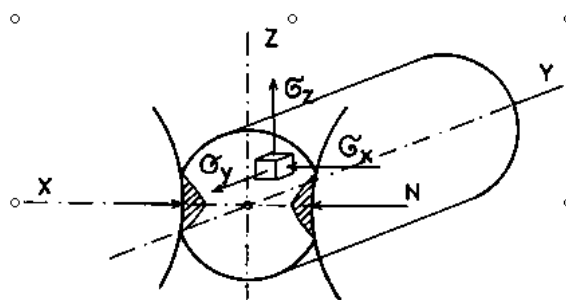
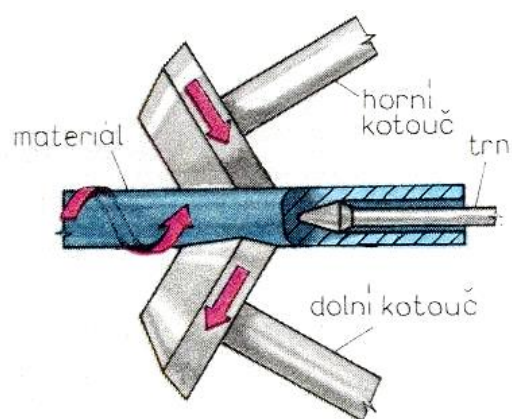
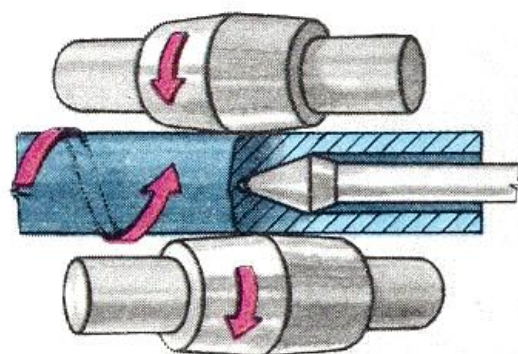


Fig. 14.5 Inhomogeneous penetration of deformation, origin of tensile stresses in centreline



Výroba trubek Stiefel



Výroba trubek Mannesman

Fig. 14.6 Various modes of piercing by cross / diagonal rolling
(**Výroba trubek Stiefel - Tube production by Stiefel mode, Výroba trubek Mannesmann - Tube production by Mannesmann mode, materiál - rolled material, horní kotouč - top roll (disk), trn - plug, dolní kotouč— bottom roll (disk)**)

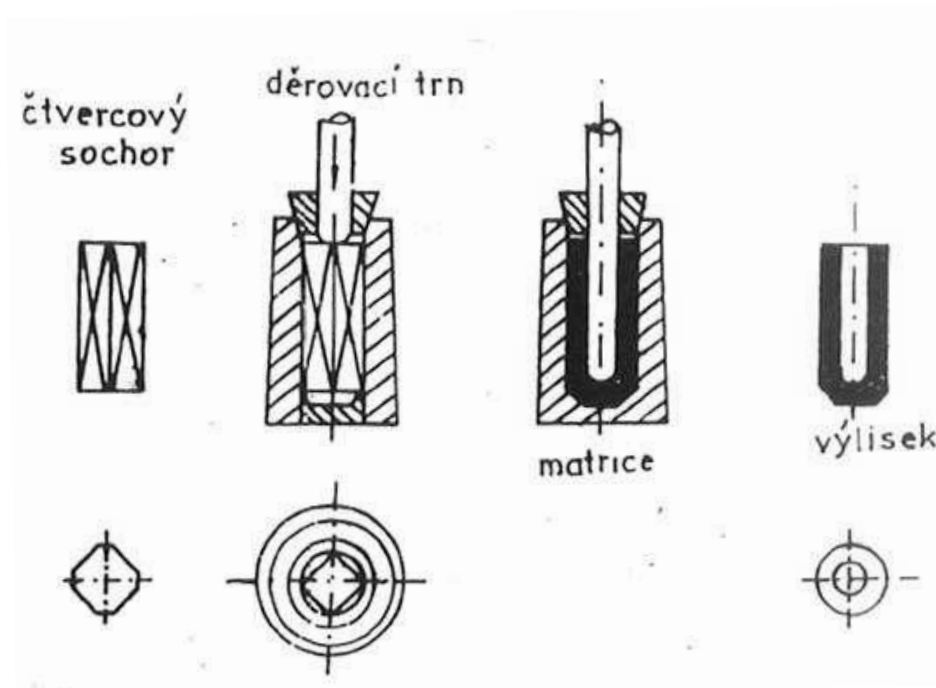


Fig. 14.7 Piercing with using press
(**čtvercový sochor - square billet, děrovací trn - piercing mandrel, matrice - die, výlisek – pressing**)

□ Elongation

The pierced thick-walled semi-product (Fig. 14.8) has to be subjected to elongation, this can be realized in:

- continuous rolling mills,
- pilger rolling mills – Mannesmann mode,
- automatic plug rolling mills – Stiefel mode,
- rolling mills with three-high expanding roll stands – Assel mode,
- rolling mills with expanding roll stands with skew rolls axes and longitudinal driven disks – Diescher mode



Fig. 14.8 Pierced thick-walled semi-product

Rolling in pilger roll stand

Pilger rolling is periodic longitudinal rolling on the cylindrical plug, diameter of which corresponds to inner diameter of the rolled tube (Figs 14.9 – 14.11).

The forming process is realized by rolling away the roll grooves on the hollow semi-product, slipped over the cylindrical plug and mounted in the feeding equipment of the pilger roll stand. This rolling away results from rotating motion of rolls and the backward longitudinal motion of the plug with the slipped over hollow semi-product. The pilger rolling features a high elongation of the rolled product. It is used for tubes with a large wall thickness and materials with worse formability. Disadvantages of pilger rolling are as follows:

- uncompleted rolling at ends, wavy surface
- slow rolling (cooling of the material threatens)
- higher share of tensile stresses
- imperfect surface

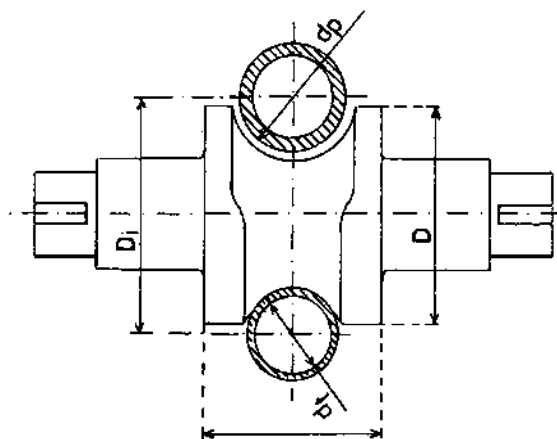


Fig. 14.9 Pilger roll shape

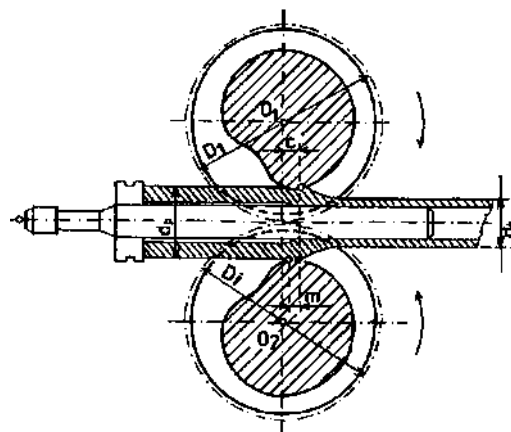


Fig. 14.10 Scheme of pilger rolling



Fig. 14.11 Pilger roll stand – rolls and elongation process

Rolling in automatic plug mill

That is the question of a widespread production mode of seamless tubes, known in technical practice as Stiefel mode. The rolling mill is equipped by the piercing roll stand for cross-rolling, the roll stand automatic for longitudinal rolling, the smoothing machine and the sizing machine. The whole production process proceeds continuously in all above mentioned machines. Rolling in the automatic plug mill is a type of longitudinal rolling in the round groove on the taper plug.

In this rolling the tube is rolled in a single groove using two, or sometimes three, passes. Before each pass the rolled stock is turned around its longitudinal axis through an angle of 90° and the new cool plug is put in with diameter by 1 to 2 mm higher than the diameter of the previous pass (Fig. 14.12). As the groove diameter remains the same, the required wall thickness of the tube is modified in such a way that the plug is utilized for increasing the inner diameter of the tube.

By longitudinal rolling in the automatic plug mill the tube is elongated, whereas the initial diameter and wall thickness of the hollow semi-product are decreasing. As the plug is mounted in the supporting bar, fastened in the roll stand frame, the length of the rolled tube is limited by admissible length of this bar. So, maximum length of the rolled tube is 15 m.

Another procedure is smoothing in the smoothing machine (Fig. 14.13), where – except for equalizing the wall thickness – scribing lines arising by longitudinal rolling on the plug and rests of spiral raised spots after piercing (not completely smoothed in the plug mill) are removed. The final operation is sizing of the tube.

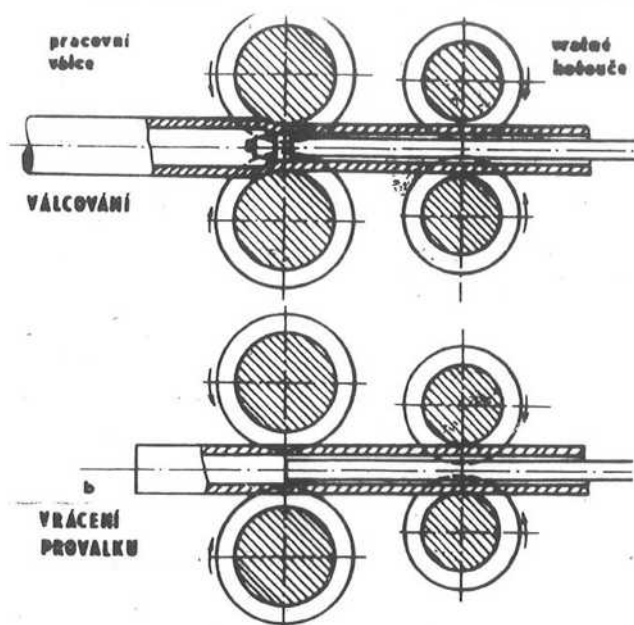


Fig. 14.12 Scheme of rolling in automatic plug rolling mill

(VÁLCOVÁNÍ - ROLLING, VRÁCENÍ PROVALKU - ROLLED STOCK RETURN, pracovní válce – work rolls, vratné kotouče – reversible rolls (disks))

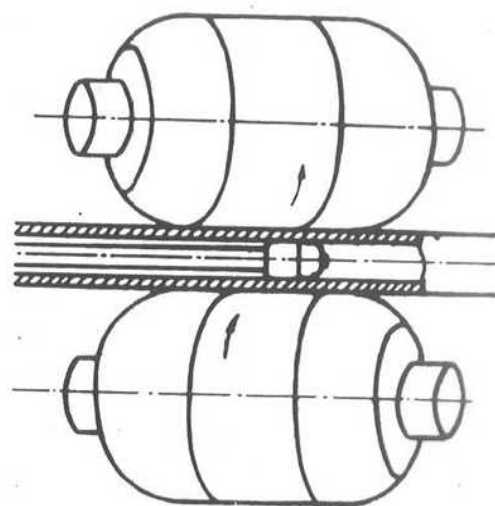


Fig. 14.13 Smoothing rolls in automatic plug rolling mills

Rolling of tubes in three-high roll stand

Thick-walled tubes with wall thickness higher than 5 mm are favourably produced in rolling mills with the piercing three-high roll stand and the finishing three-high roll stand, which serves for finish rolling of the tube. Rolling of seamless tubes in three-high roll stands is known in the technical practice as Assel mode. Tubes produced in this way are distinguished by significant dimensional precision and good excentricity.

That is the question of cross rolling of the hollow semi-product on the cylindrical plug between three rolls with skew axes (Fig. 14.14).

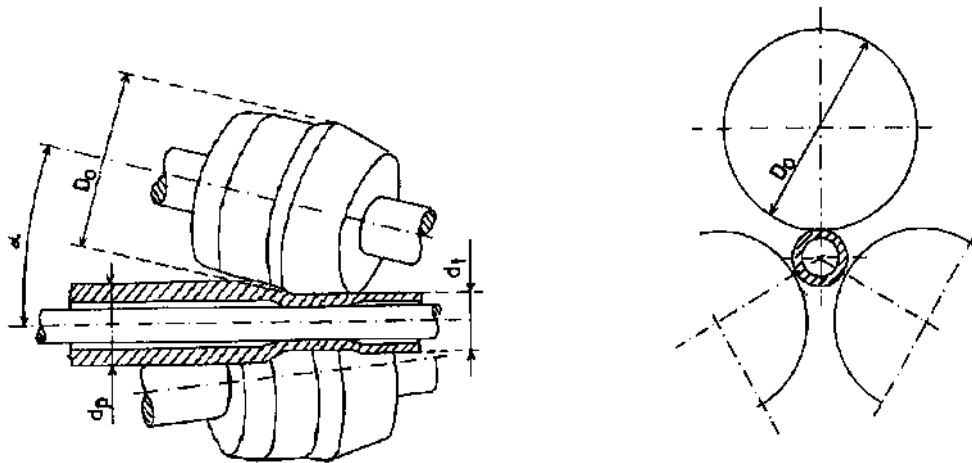


Fig. 14.14 Scheme of cross rolling in three-high roll stand

Continuous rolling of tubes

Main features and advantages of continuous rolling of seamless tubes are the following:

- high rolling speeds
- comparatively simple production technology
- continuous rolling mills with good technological equipment make it possible rolling of tubes with small wall thickness (to 2 mm)
- quality of produced tubes (surface and dimensional tolerances) is better than tubes produced in pilger or automatic plug rolling mills

The disadvantage is that a large inventory of relatively costly tools, plugs and rolls has to be maintained and only tubes with smaller diameters (up to 152 mm) can be rolled. Even though the plug length limits the possible length of the rolled tube, tubes up to length 30 m can be rolled. The scheme of continuous rolling is given in Fig. 14. 15.

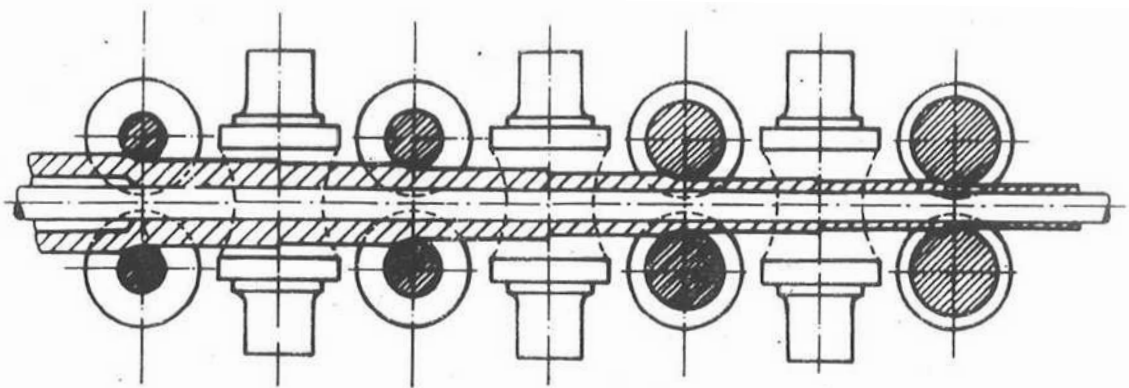


Fig. 14.15 Continuous rolling in round passes (H – V) on the plug bar

Rolling of tubes in roll stands with cross rotating disks

This mode of rolling of seamless tubes, so-called Discher mode, is based on principle of cross (skew) rolling. It is used above all for the production of tubes of small and medium diameters, from 50 to 150 mm, with minimum wall thickness 3 to 2.5 mm. Initial billets have the round cross section. In the finishing rolling mill with cross arranged rotating disks the tubes are rolled on the long cylindrical

plug, the length of which limits the length of rolled tubes to 10 to 15 m (Fig. 14.16). Tubes are characterized by uniform wall thickness across and along and by good surface quality.

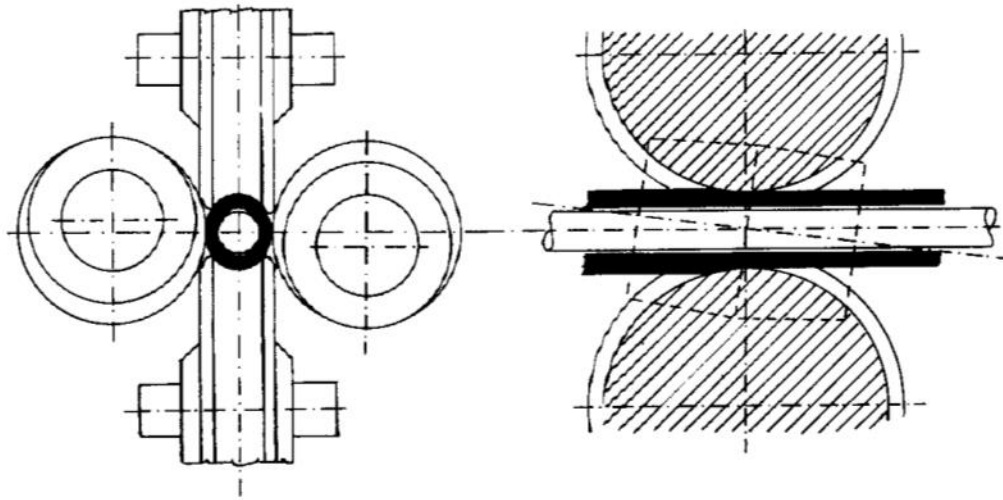


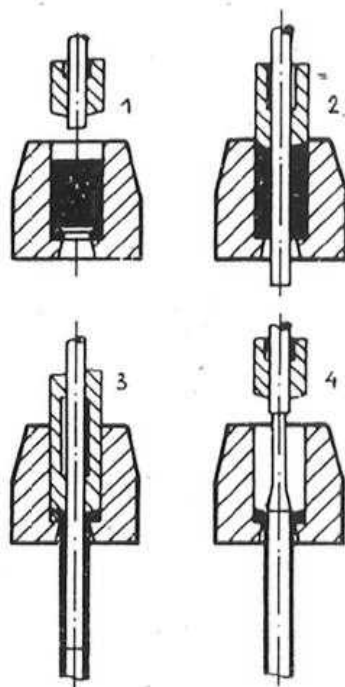
Fig. 14.16 Rolling in stands with cross arranged rotating disks

Rolling of tubes in mills with push bench

The production process is realized by pushing the initial hollow pressing with bottom, put on the long cylindrical mandrel, through a series of successively located round grooves.

Production of tubes by extrusion

By extrusion the seamless steel tubes of the required dimensions can be produced by a single technological operation (Fig. 14. 17). The production aggregate is mechanical vertical or hydraulic horizontal presses.



- 1 – start,
- 2 – piercing,
- 3 – extrusion,
- 4 – end

Fig. 14.17 Production of tubes by extrusion

Expansion of tubes by hot rolling

Using expansion of seamless tubes by the cross rolling shifts their dimensional range to diameters which cannot be produced by normally used rolling procedures, i.e. usually from 500 to 600, or even 700 mm. The principle of the tube expansion by cross rolling is shown in Fig. 14.18. Axes of conical overhung rolls are approximately at angle 60° with centreline of rolling in horizontal plane. Between the rolls the tapered mandrel is inserted, put on the supporting mandrel bar.

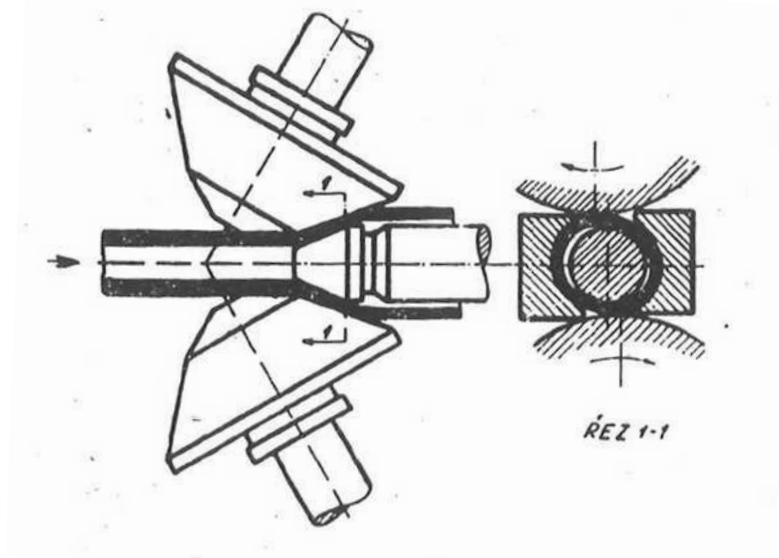


Fig. 14.18 Principle of expansion of tubes by cross rolling
(REZ 1-1 – SECTION 1-1)

Reducing of tubes by hot rolling

This is the process of longitudinal continuous rolling in round grooves, where the internal contour of the tube is not limited by any tool (Figs 14.19, 14.20). The outer diameter of the tube is diminishing, which affects its wall thickness change. The grooves are created by two or three, or even 4 rollers.

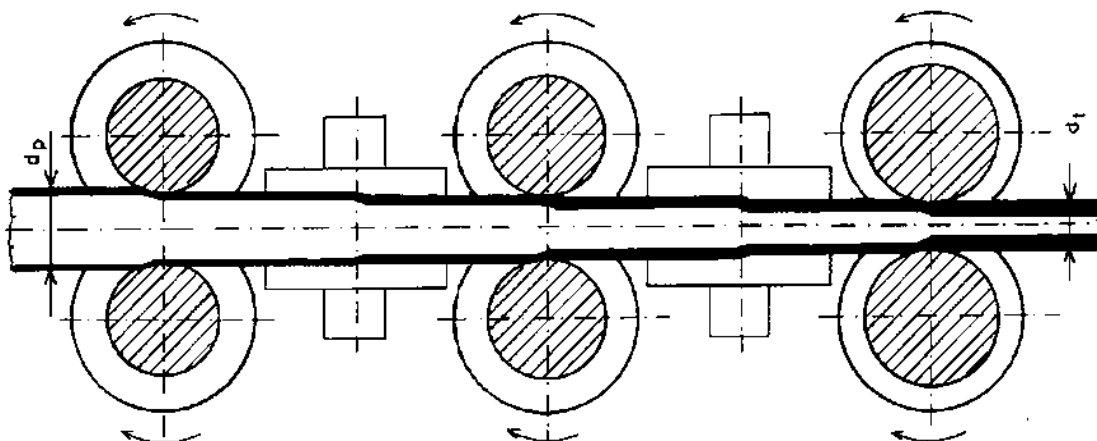


Fig. 14.19 Scheme of reducing of tubes by rolling



Fig. 14.20 Tube reducing mill

Production of tubes by cold drawing

Basic modes of cold drawing of tubes are die drawing on the fixed mandrel, die drawing on the free (floating) mandrel and drawing on the mandrel bar (Fig. 14.21).

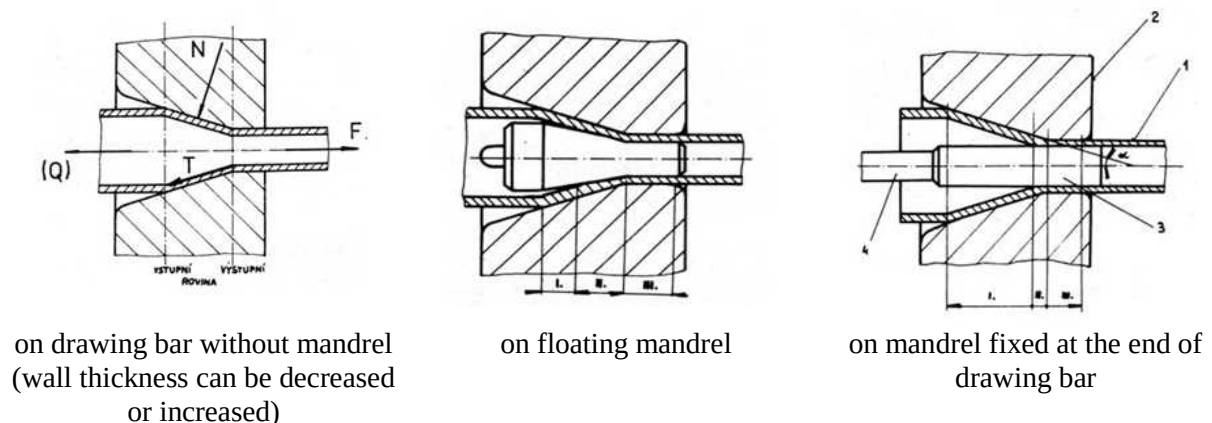


Fig. 14.21 Schemes of tube drawing

Cold rolling of tubes

Cold rolling is the technologically and economically advantageous mode of the production of accurate seamless tubes with small and large diameters, made of carbon and alloy steels. Minimum diameter of tubes produced in this way is 10 mm, maximum up to 400 mm. By surface quality these tubes rank to the precision tubes. The initial semifinished product is tubes produced by some of hot formed technologies. The cold rolling is often combined with cold drawing.

Cold rolling of tubes is the longitudinal periodic rolling, realized by the reciprocating rolling process ("rolling away"). It is the pilger rolling on the tapered mandrel by two rolls that have the round groove only on a part of perimeter (Fig. 14.22).

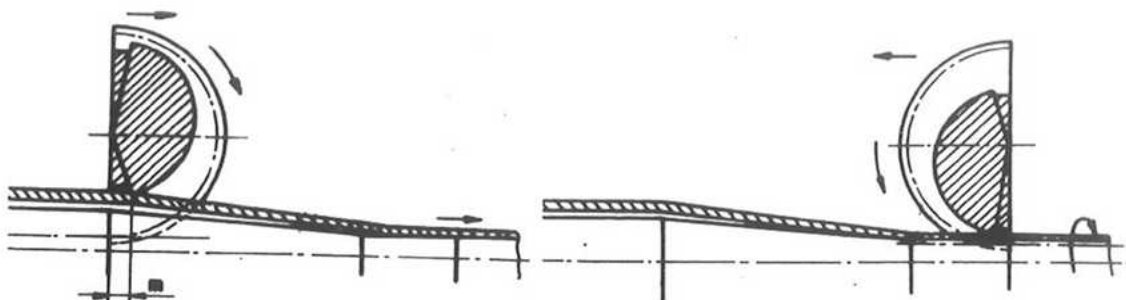


Fig. 14.22 Roll groove for cold rolling of tubes

□ **Třinecké železářny, a.s. – Tube rolling mill**

The original production plant came into being in the framework of the former Vítkovické železářny, where the first tube was produced in December 1883 as in the gas-fired furnace butt welded tube – the first tube produced at all in the former Austro-Hungarian Empire. Seamless tubes were produced by Erhardt's mode from year 1896, in year 1908 the Stiefel rolling mill was commissioned with participation of inventor of this production mode. In years 1918 to 1919 the rolling mill Velký Mannesmann was built, jointly with the finishing plant and thread-turning shop for oil tubes. This rolling mill was commissioned in September 4, 1919. In years 1926 to 1927 the rolling mill Malý Mannesmann was built and commissioned. Both these rolling mills produce tubes up to these days. In years 1947 – 1971 also Mannesmann rolling mill created a part of the tube drawing mill Svinov. In year 1962 non-destructive testing of tubes began operation. The operation of the tube cold drawing mill was finished, together with shutdown of one of the Stiefel rolling mills, in year 1997. Since year 1999 the company became a joint stock company, independent on the Vítkovice group. The only shareholder was up to September 2005 the company ASTONIA, a.s., belonging to the SHIRAN GROUP, currently the owner is the company TŘINECKÉ ŽELEZÁŘNY, a.s. from the group MORAVIA STEEL a.s.

The production symbolic diagram of the tube rolling mill is shown in Fig. 14.23. In Figs 14.24 to 14.29 particular key nodes of the rolling mill Velký Mannesmann are shown.

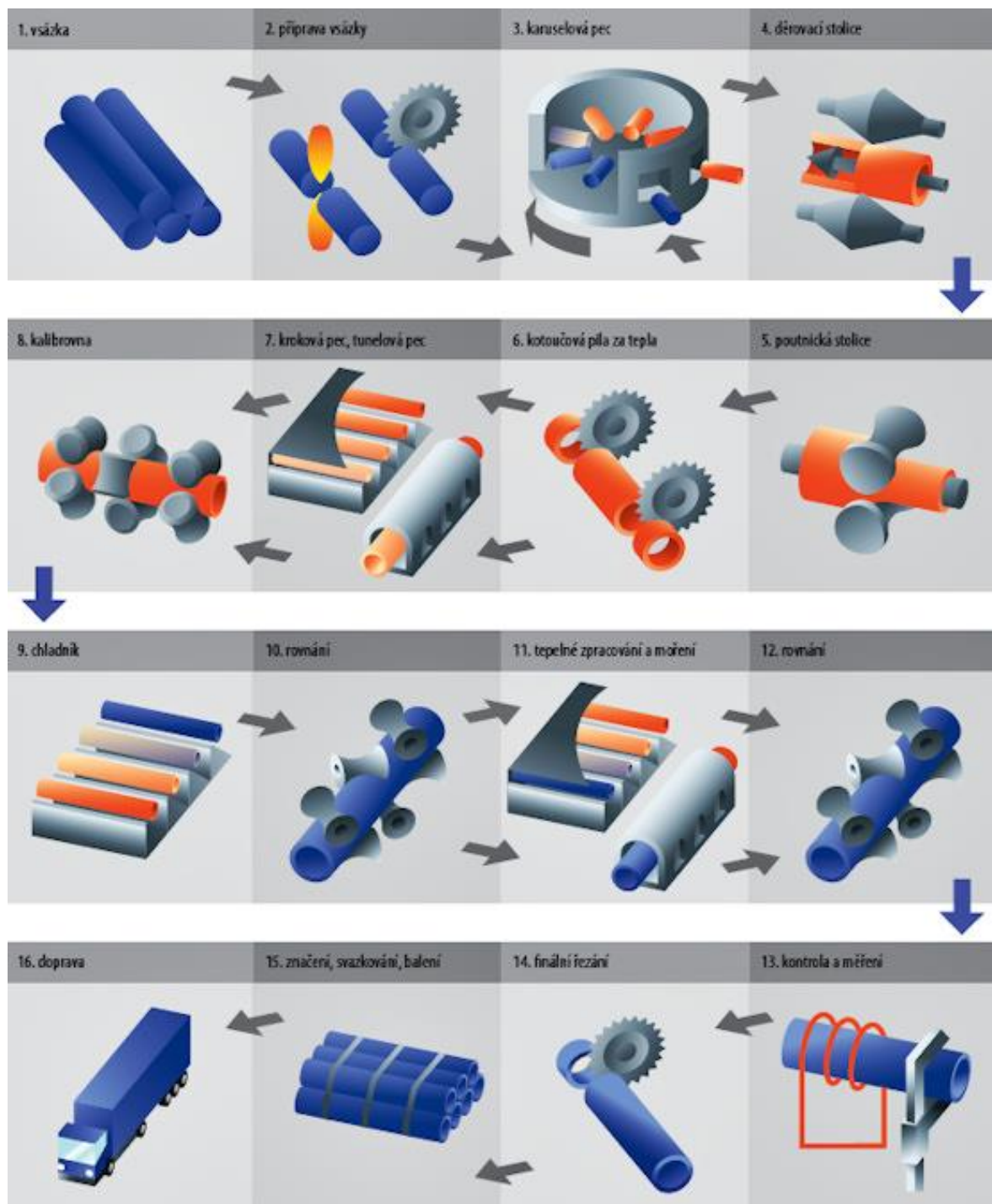


Fig. 14.23 Symbolic diagram of tube mill production

(1 - charge, 2 - charge preparation, 3 - rotary-hearth furnace, 4 - piercing mill, 5 - pilger mill, 6 - hot circular saw, 7 - walking beam furnace, tunnel furnace, 8 - sizing mill, 9 - cooling bed, 10 - straightening, 11- heat treatment and pickling, 12 - straightening, 13 - testing/inspection and measurements, 14 - final cutting, 15 - marking, binding, bundling, 16 – transport)



Fig. 14.24 Rotary-hearth furnace – charging of semifinished products in the furnace



Fig. 14.25 Transport of the semifinished product to the piercing mill



Fig. 14.26 Piercing mill – front view



Fig. 14.27 Piercing mill – rear view



Fig. 14.28 Transport of the thick-walled tube to the pilger mill



Fig. 14.29 Pilger mill

▣ ArcelorMittal Tubular Products Ostrava, a.s.

It is the largest producer of tubes in the Czech Republic. The crucial product mix of the works consists of seamless tubes rolled in two Stiefel mills St 4-10" and St 140 in performance of bare pipes, threaded pipes, flanged pipes and oil pipes. Tubes in both rolling mills are produced exclusively from continuously cast semifinished products. The most demanding product is oil pipes – casings, tubings, drill pipes and line pipes. Since 1957 the works is entitled to use the designation of oil pipes by monogram API (American Petroleum Institute). Except for normal API threads, the works supplies also casings and tubings with the gasproof threaded joint.

Production of seamless tubes in rolling mill Stiefel 4-10"

That is the question of the automatic plug rolling mill, the scheme of which is given in Fig. 14.30, where 1- charging beds, 2- rotary-hearth furnace, 3- piercing machine No.1, 4- piercing machine No.2, 5- automatic plug mill, 6, 7- smoothing machines No.1, No.2, 8- sizing machine, 9- cooling beds, 10- collecting pocket for defective billets, 11- collecting pocket for cooled billets

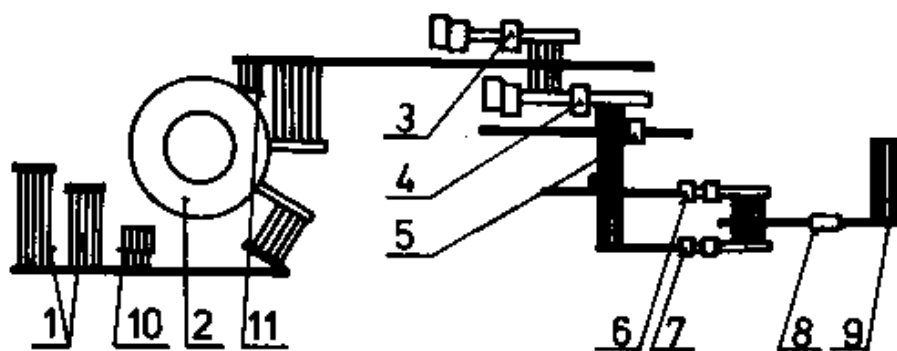


Fig. 14.30 Scheme of rolling mill

Reheating of the material for tubes production is carried out in the rotary-hearth furnace with the annular hearth, onto which the billets are put. Billets are of diameter 160 and 210 mm. The hearth is rotary, against fixed walls tightened by the flume. The hearth motion is realized on rollers, driven by electric motors, and can be either continuous or so-called walking, with particular steps by 1° to 3° . Moving the hearth is possible also in the opposite direction of rotation. The heating space of the furnace is divided into 4 zones (preheating, heating and soaking). Temperature in the preheating, non-fired zone amounts $1\ 050 - 1\ 100\ ^\circ\text{C}$.

Piercing machine No. 1

The piercing machine No. 1 is the first and basic forming aggregate of rolling mill St 4-10". It is the stand with the skew in the horizontal plane mounted rolls and fixed guides in the vertical plane. The piercing rolls have convex contour, their axes are skew due to oblique mounting in the roll stand. The used plugs are pointed, without cooling water spraying, or two-stepped. The scheme is shown in Fig. 14.31, where: 1 – feeding trough, 2 – feed device, 3 – feed pipe, 4 – proper piercer, 7 – trestle, 8 – piercing bar, 9 – cart, 10 – bed, 11 – gearbox, 12 – electric motor, 13 – bed, 14 – bed, 15 – centring units, 16 – extraction rollers, 17 – roller table.

The reheated billet is transported from the main roller table to the feeding trough of the piercing machine. It is fed by the pneumatic pusher between the rolls of the piercing roll stand; the rolls have the same direction of rotation. The billet is pierced by diagonal rolling to the thick-walled rolled stock. Then the cart with the plug bar goes out of the rolled stock and the stock is transported for the next operation. After going the cart with the plug bar back in between the rolls, the whole procedure is repeated.

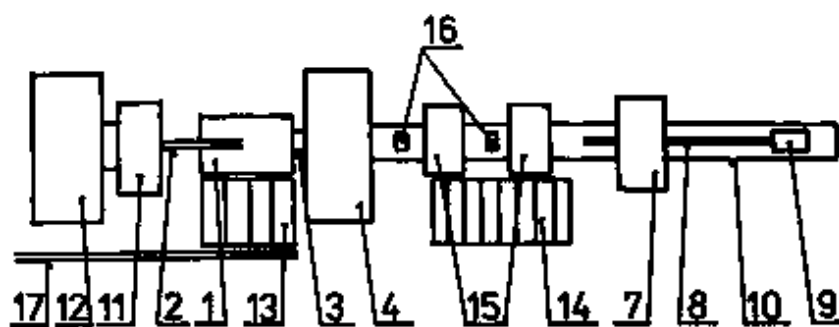


Fig. 14.31 Scheme of piercer No. 1

Piercing machine No. 2

It is of the same design like piercer No. 1. It processes the thick-walled semi-products from piercer No. 1 in such a way that they are rolled out to larger diameter and length and thinner wall. The semi-products must have such parameters so that they were suitable for further processing in the automatic plug mill. It means that they must have required dimensions and wall thickness, must be without defects on the external and internal surface, must be centric with gloss walls and uniform wall thickness in both longitudinal and cross section, and must be produced sufficiently fast so that they could not cool down. The semi-product from piercer No. 1 is transported to the feeding trough of the piercer No. 2 and by diagonal rolling on the dull plug is rolled (elongated) into the rolled stock of higher length, larger diameter and thinner wall. Then the cart with the plug bar goes out of the rolled stock and this is transported to the automatic plug mill. After going the cart with the plug bar back in between the rolls, the whole procedure is repeated.

Automatic plug rolling mill (automatic)

The automatic consists of two robust housings, connected in the upper part, in which two work rolls are mounted. Rolls rotate in opposite directions and are provided by 4 grooves. The bottom roll is mounted in a fixed position, the top roll is movable in the vertical direction and it is balanced. The work rolls are followed by a pair of adjustable reversible rolls, placed always after the groove. In front of the automatic is the feeding trough with driven rollers, movable along the automatic and hence adjustable against the groove just in operation. At the end of the feeding trough, turned away from the automatic, is the pneumatic pressure roll with the piston rod ended with the pusher (so-called ram), which pushes the rolled stock in the groove. In between the trough rollers is built the device that swivels the rolled stock by 90° around its axis in pauses between particular passes. Between the trough and the groove is built the device for changing the plugs. The plugs are self-adjustable and placed against the plug bar, built in the supporting frame on the other side of the automatic. The rolls are driven by DC motor, revolutions are controlled via the pinion stand. Between the motor and the pinion stand is the flywheel, which absorbs shocks at entrance the rolled stock into the rolls so that they could not be transmitted to the motor. The automatic scheme is shown in Fig. 14.32, where: 1 – pressure roll, 2 – ram, 3 – feeding trough, 4 – ejector, 5 – automatic, 6 – reversible rolls, 7 – plug bar, 8 – guide bush, 9 – runout trough, 10 – plug bar holder, 11 – bed with stop, 12 – bed to hot saw, 13 – device for automatic putting on the plugs, 14 – tube tilter.

The rolled stock is transported from piercer No. 2 to the trough of the automatic, put by the pusher into the clamped work rolls and rolled by 2 passes to the required length and wall thickness in the automatic plug mill. Returning the tube from the runout side to the feeding trough is carried out by the reversible rolls. Between passes, the tube swivelling by 90° and automatic changing the plug occur. Subsequently the whole process is repeated. The tube of the required length and wall thickness is transported by the rotating ejector to the saw, where cropping the tube ends (up to wall thickness 6.3 mm), its blowing-through (oil/grease from the automatic, chips) and cooling to the required temperature is carried out.

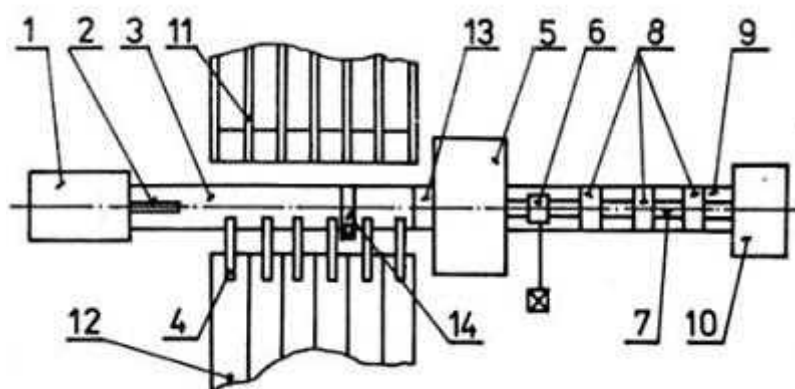


Fig. 14.32 Scheme of automatic plug mill

Smoothing machines No. 1, No. 2

The construction of smoothing machines is very similar to the construction of the piercing machine. They are stands with rolls mounted skew in the horizontal plane. The bottom guide is fixed; the top guide is replaced for the pressure roller. Shapes of rolls and plugs differ a little from the piercing machine because the deformation of the rolled stock in smoothing machines is smaller and a cavity is not created in the solid semi-product, only the diameter enlarges by 4 to 9 % at simultaneous reduction of the wall thickness by 5 to 4 %. The rolls are convex, plugs conical. The plug is supported free by the smoothing bar, shiftable in the cart. The scheme of the smoothing machine is shown in Fig. 14.33, where: 1 – entry pipe, 2 – proper machine, 3 – gearbox, 4 – electric motor, 5 – centring unit, 6 – trestle, 7 – runout bed, 8 – cart, 9 – smoothing bar, 10 – bed, 11 – extracting rollers.

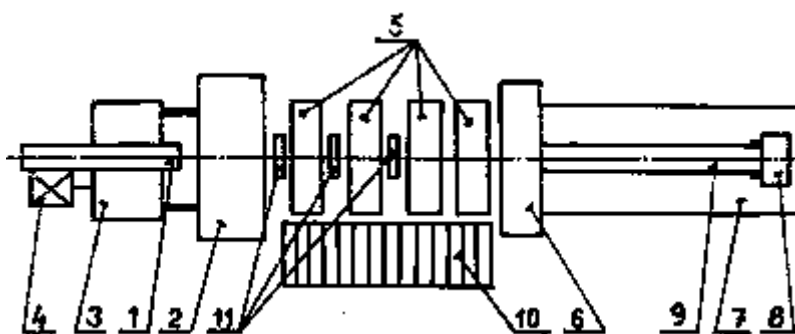


Fig. 14.33 Scheme of smoothing machines No.1, No. 2

Tubes are transported by roller tables to roll stands. By the skew mounted table rollers the tubes are swivelled in the direction of the stand rolls. The inner and outer surface of tubes is smoothed by cross-rolling, simultaneously the tube diameter is enlarged by 6-8 mm. Smoothing is controlled by rolling mill operators, who control adjustment of one of the work rolls, the second one is set up for the given dimension before. After the tube is smoothed, the cart with the bar is running out of the tube, the tube is transferred by the rotating ejector to the roller table leading to the sizing machine and the whole smoothing process is repeated.

Sizing machine

The sizing machine consists of 5 stands, alternately turned by 90° against each other. The grooves of the final pass and the leader pass, i.e. of fifth and fourth pair of rolls, are precisely circular. In the sizing machine the tube is hot sized in such a way that after cooling it acquires the outer diameter required by the relevant standard.

The hot tube leaves alternately the smoothing machine No. 1 and No. 2 and is led by the roller table to the sizing machine, where is hot sized to the precise diameter, and further transferred by the roller

table to cooling beds. From the cooling beds the tube is transported by the roller table to the straightening machine.

14.3. Welded tubes

The production of steel welded tubes is older than the production of seamless tubes. Due to improved electric welding the welded tubes currently find widespread use and appropriately complete, or even replace the seamless tubes. Up-to-date modes of welding enable the production of welded tubes of miscellaneous sorts of carbon and alloy steels, including high-alloy steels.

Properties of welded tubes are given above all by properties of the initial material and by welding mode. The advantage of welded tube consists in their smaller weight and simple production, the disadvantage is the welded seam. The initial material is steel strip, hot rolled or cold rolled, or also plate in tables in case of tubes with large diameters.

For the production the following welding modes are used:

- a) **pressure welding** – material heated to the welding temperature is connected by effect of steady pressure or impact
- b) **fusion welding** – the connection takes place by local melting of connected parts of the metal, or adding the filler metal of the same or similar chemical composition, but without mechanical pressure or impacts

Of various modes of electric welding the following are used in the production of steel:

- resistance welding by low-frequency current,
- resistance welding by high-frequency current,
- induction welding,
- resistance welding by direct current,
- flash welding (a sort of resistance welding),
- submerged-arc welding (a sort of fusion welding),
- shielded arc welding (a sort of fusion welding)

□ Technological process in production of welded tubes with longitudinal seam

The initial material is sheets cut-to-lengths as per lengths of produced tubes, usually up to 8 m. In case of higher lengths the considerable difficulties with forming the sheet into the shape of the tube with a gap exist. This forming is carried out in devices separated from the actual welding machine (line). It takes place by bending in rolls (rounding) in rounding machines with three or four rolls, or in presses (Figs 14.34 – 14.36), afterwards the rounded tube is transported to the welding machine.

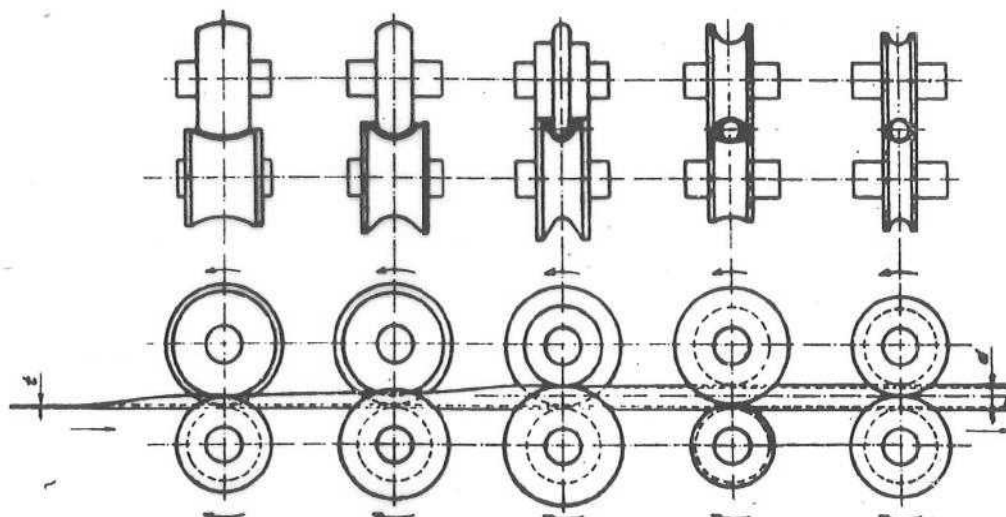


Fig. 14.34 Rounding the strip into shape of the tube with a gap (longitudinal seam)

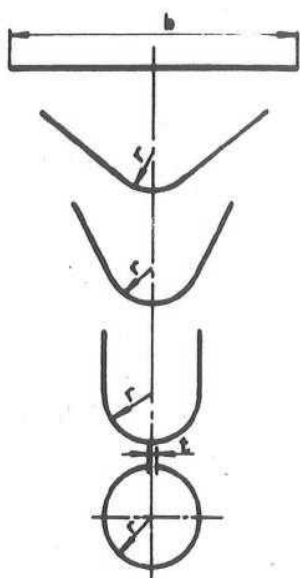
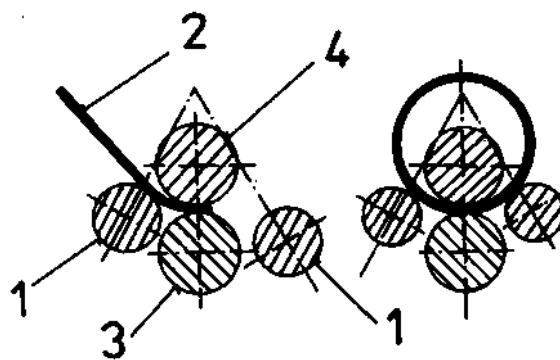


Fig. 14.35 Two types of grooving of rolls for rounding of strips in continuous line



(1) vnější boční přitlačné válece, (2) zakružovaný plech,
(3) vnější prostřední válec, (4) vnitřní prostřední válec

Fig. 14.36 Rounding of the plate in the machine with four rolls

((1) - external side pressure rolls, (2) - plate bent in rolls, (3) - external middle roll, (4) - internal middle roll)



Summary of terms of this chapter

Seamless tubes – welded tubes – hollow thick-walled semifinished product – piercing – elongation – pilger mill – automatic – three-high roll stand – continuous rolling of tubes – extrusion – expansion of tubes – reduction of tubes – cold drawing – cold rolling of tubes – pressure welding – fusion welding – tubes with longitudinal seam – tubes with spiral seam



Questions to discussed curriculum

- 14.1. What is basic division of tubes?
- 14.2. What are procedures of the production of seamless tubes?
- 14.3. What are specifics of rolling in the pilger mill and the automatic plug mill?
- 14.4. Describe some equipment for the production of seamless tubes.
- 14.5. Note welding modes of the production of welded tubes.



Used references recommended for further study

GINZBURG, V. B., Steel-Rolling Technology : Theory and Practice. New York : Marcel Dekker, 1989.