Abstract. Requirements for the quality of finished products is continuously increasing. It adds to improve existing and develop new schemes roll design. This paper contains the analysis of technological schemes for rolling channels, which are used in the CIS countries. Were described different ways of rolling channels and design features roughing and finishing passes. The authors were compared schemes of UPN-shaped profiles’ rolling on different Iron and Steel Works. The article describes methods for improving the roll design, proposed and implemented by domestic developers. These methods are based on the gained experiences of flange profiles’ rolling and developments of the modern world. It makes possible to reduce manufacturing costs and improve product quality of the channels.

Introduction

Flanged profiles are known as profiles where the axes of some separated elements are located angularly to their joining part. Such profiles include beams, channel sections, rails, T-sections, columned beams. Their rolling peculiarity doesn’t allow receiving these profiles from a rectangular metal billet or an ingot using uniform reduction on the width of profile in contrast to rolling of stripes, squares and others simple profiles, i.e. manufacturing technologies of flanged profiles are characterized with irregularity of deformations [1].

A channel section is a trough-shaped profile, which consists of a web and two flanges (fig. 1). The main characteristic of a channel section profile is the size defining height \( h \) (in centimeters) [2].

Profiles with DIN 1026-1 (DINEN 10279) certification and State Standards of Ukraine 3436 (all-Union State Standard 8240) are mostly produced. Standard channel sections with slopping inner edges (up to 10 %) and parallel edges are manufactured in compliance with all-Union State Standard 8240 [3]. Thin-web channel sections with narrow parallel flanges are rolled under 14-2-204-76 Engineering Specifications. They can be produced using section rolling mills or structural mills subject to size, profile design features and required power. For small and medium channel sections manufacturing (from №5 to №30) can be used linear, successive, semi continuous and continuous section rolling mills with roll diameter from 300 to 650 mm. Channel sections № 20–40 are part of rail and structural steel mills range set [4].

A lot of scientists such as D. I. Starchenko, I. Ya. Tarnovskiy, A. N. Skorokhodov, B. M. Ilyukovich, G. V. Bergeman, M. B. Luckij, A. A. Chichkan [5 – 9] and others went into questions of designing and updating roll pass design for rolling channel sections. Roll pass design of channel sections is developed with taking in account of rolling mill configuration and high-level standards are demanded. It is known that rolling mill efficiency, durability of equipment, quality and production price depend on roll pass design perfection.
Problem formulation

Improving roll design, as before, requires the forming of metal research. Today, many of the questions the behavior of metal at rolling in calibers remain insufficiently studied. This is due to multifactor complex processes that occur in the deformation, as well as the continuous development of production technology and rolling theory [10]. At present, experimental studies in production conditions difficult due to a high material costs. In connection with the above mentioned all computer technologies increasingly being used, allowing to investigate complex cases rolling.

There is a need to analyze the existing technological schemes of channel steel production on the basis of the current level of development of the theory and practice of rolling mills. It is necessary to find out the main directions of improvement of roll design and identify the most effective ways of rolling channel profiles.

The results of work

Two main ways are exploited for manufacturing of rolled channel sections: rolling with straight and unfolded flanges. Different methods of roll pass design exist (fig. 2) and can be used for rolling channel sections with straight flanges, for example: beam-type method, trough-shaped method (a), method when used scaled-up slop of a flange and method when used a web bending (b). Roll pass design with unfolded flanges is made with method when a web and flanges are bended (d) and with method of flanges bending (e). Besides, there are various methods when used an universal pass design (c).

These rolling ways were developed as a result of growing output using passes. That enables to foresee increased flanged reduction and to enlarge rollers lifetime. If flanges slope is grown, power consumption is reduced and rolls durability is risen because of smaller depth of roll groove [11].

The beam-type rolling method is the oldest type. Roughing forming passes are similar for rolling beams and channel sections of equal profile sizes [12]. That causes lots of reduction in counter flanges and because of this metal overflows from counter flanges into a web and flanges. Thus, error limit of finished sections is followed. The economy of rolls at the expense by use of general passes proved to be wrong because power consumption is raised. Nowadays this method is scarcely used. Such beam-type method with designing scheme and rolling channel sections remains when there are equipment peculiarities and mills assortment.
Trough-shaped technique of channel sections manufacturing is the advanced beam-type method. Such method presupposes the usage of a trough-shaped pass with reduced counter flanges in roughing passes (fig. 2, a). Main rolling defects of this type are connected with difficulties during entrance of profile in a finishing pass, because profile width along bent flanges is bigger than relevant width of a finishing pass. To remove these problems, angle of groove’s wall is sometimes decreased till 5 – 8 % in a pre-finishing pass and a finishing pass. Another way is to foresee widening of a finishing pass. The other defect of trough-shaped method of rolling channel sections is decreasing of finishing rolls lifetime because of small angle of groove’s wall of a finishing pass (1,5 – 2%). That makes rolling of channel sections with parallel edge flanges almost impossible.

Disadvantages of trough-shaped method are eliminated when a pass with straight flanges and a curved web is used (fig. 2, b). Angle of groove’s wall is raised till 20 – 40 % in such passes. The angle between a center side line and an edge of each flange is kept equal 90° [7]. Such reduction scheme allows deforming metal more intensely, cuts down numbers of passes and reduces rolls wearing [4]. The described technique is widely used in section mills with two-roll stand.

More developed rolling method of scaled-up slope of a flange and a curved web is when an universal stand is used in finishing stage (fig. 2, c). That offers some advantages towards scheme when a standard stand acts in a bending role, because it causes load reduction during rolling in a finishing stand.

Unfolded roll pass design is believed to be the most perfect (fig. 2, d). It showed good practice results when rolling small and medium channel sections [13 – 15]. At the very beginning of rolling channel sections, unfolded passes were used only as first passes [7]. This rolling way consists of gradual transition from a horizontal unfolded pass to a straight flanged pass when use a range of transitional curved flanged passes. That provides smooth profile forming. Bending of a unfolded profile into a channel section becomes easier, surface damages and folding in the base of flanges are prevented [4]. The main shortcoming is considerable increasing of the pass width, which makes difficulties for disposition of required number of passes on the body of roll.

Rolls pass design when used bending method (fig. 2, e) is advanced design with increased angle of groove’s wall. It combines rolling in strip passes with further rolling in forming passes and gradual flanges bending. Among advantages there is uniform reduction of all profile elements and small depth of roll groove. Disadvantages can be some problems with strip bending which causes
damages on the surface of flanges and wrong profile sizes [4]. It is also a serious shortcoming when a control pass with a prior bend pass are missed. Control of the flange width becomes hard [1]. Previously mentioned rolling method wasn’t widely adopted in domestic rolling mills, but it is sometimes used to receive small and medium size channel sections in medium- and small-section mills.

Nowadays in the CSI countries the main roll pass design method is considered to be the method with application of a big amount flanges angle in relation to horizontal [7]. Flanges angle is taken in the range of 15 – 20%. It is provided obtuse angle between a flange and a web (more 90°), and such a web bending that right angle must always be kept between a flange and a web in the position of their joint. Flanges slope can be reached using two methods simultaneously. The authors [12] of this research recommend to accept angle of groove (for channel-shaped passes) in the range from 12 to 8% during rolling process in roughing and middle passes, 4% in prefinishing passes, 1÷1,5% during construction of a finishing pass with a counter flange.

Alternation of disposition of pass split (during designing of channel sections) is absent as in rolling of I-beams. Passes are constructed using permanent splits in real flanges. In such a case there is no ability to control the height of profile flanges [16]. That’s why to regulate and to control the flange sizes scientists foresee control passes [7], which construction depends on designing method and rolling scheme.

Such passes can be closed and semi-closed type (fig. 3). Semi-closed control passes are more spread (fig. 3, a). They have the same slope direction of outside edges of grooves as prior passes in rolling of channel-shaped passes. They create favorable conditions for entrance in a control pass and give opportunity to enlarge the slope direction of outside edges of grooves in adjacent channel-shaped passes and to improve intensity of flange edge reduction. Closed control passes (fig. 3, b) are rarely used.

Bell-shaped passes (fig. 3, c) were applied as control passes during unfolded designing in the rolling mill 350 PJSC “Dneprovsky Integrated Iron and Steel Works named after Dzerzhinsky”. They were disposed in stands with vertical rolls arrangements [17]. The control of flanges height and flanges bending is performed in such passes. Net effect of these passes ensures the receiving of the profile with necessary size and symmetrical high flanges. Application of a control bell-shaped pass in a roughing stand allows using a shaped blank for two different channel sections

![Construction of control passes during rolling channel sections](image)

**Figure 3** – Construction of control passes during rolling channel sections [1]

During unfolded designing the number of control passes (especially closed-typed) is advised to limit because their usage is connected with decreasing of deformation coefficient (that raises the passway amount) and can increase the primary billet height [7]. In different schemes one or two test passes are usually applied. Moreover, one of them is a roughing pass; the other is a prefinishing pass. The second is sometimes called a control finishing pass [16]. There are some designing schemes which don’t require the usage of closed or semi-closed control passes.

A lot of attention is devoted how to update and develop modern methods of roll pass design for rolling channel sections by metallurgical enterprises in Ukraine and the CIS countries. Thus, a new method for channel sections rolling was worked out. It was designed to expand rated channel sections range to enlarge overall sizes but without reconstructing of the main lines of work stands. Passes with a variable curved web were offered to perform a task on OJSC «Alchevsk Iron and
Steel Works». The described technique [18] of rolling channel sections lies in combination of high-rated deformation and intense extension of a web in shaped passways. Meanwhile some roughing and preforming passways are made in passes with a variable curved web. The following web rebend is done in a prefinishing pass. Cross-section of a channel profile (during rolling in a profile bending pass) is shown in the figure 4.

Application of this designing process enabled to expand range of channel sections without reconstruction and to enlarge overall sizes from №20 to №36. Besides, it was proved that such design technique of rolling [7] made it possible to get a web spreading in shaped passways that exceeded a web spreading when used beam-type or trough-shaped method in 5-8 times. That happens because of intense web extension. Application of this method in roughing and former steps helped to decrease by 25-30% the area of cross-section of the billet, to reduce size of horizontal projection of profile, to increase profile temperature at the expense of better heat exchange between a web and flanges, to decrease loading, to low power inputs and rolls consumption.

A new unfolded designing of channel section № 24 UPN [19] was updated and applied instead of beam-type designing in the medium section mill 550 “EVRAZ”. It was done to reduce rolls wearing, to provide stability in passes and to control stable height of flanges. In this rolling scheme a prefinishing straight flanged pass was made open with angle \( \beta = 17^\circ \) between straight surface of profile flanges and a vertical line (fig. 5). New design allowed getting a steady profile without excess of load on driving mechanisms of stands. The usage of this unfolded designing makes it possible to roll large-scale channel-shaped profiles, which belong to the range of structural mill, in middle rolling mills with rolls size 300 – 500 mm.

Later, this designing technique was changed a little [20]. Now, rolling channel sections is made when used two straight flanged passes: a leader pass and a finishing pass, due to improved method. The slope of flanges ranges from 25% to 40% in this pair of adjoining passes. Other passes have curved shape of the outer parts of flanges. The technique of project designing of channel sections was also worked out. It helped to define the main elements of forming passes and modes of deformation.

Designing scheme of rolling channel sections in the medium-section mill 350 PJSC “Dneprovsky Integrated Iron and Steel Works named after Dzershinsky” is shown in the figure 6. It is possible to control of the flanges height with special passes in stands with vertical rolls. Two such passes are used for designing: an edging pass is applied in a 7-th stand and a bell-type pass is used in an 11-th stand [1]. Thus, control of the flanges height is done as well as their bending in these passes. Summary effect of mentioned passes lets obtain the necessary size profile with the symmetrical height of flanges.
A big problem existed in the mill 450 Novokuznetsk Iron and Steel Plant where are rolled UPN-shaped profiles for retractable metal posts. There was a large amount of shaped passways that decline general mill efficiency and temperature of profile. In turn, it also caused after growth such as deterioration of stability of rolling and extension of rolls wearing. Therewith, a big amount of closed forming passes and special mill construction led to impossibility to combine the neutral pass line with the centerline of rolls.

The new designing of UPN-shaped profiles was developed and implemented for better rolling process technique [21]. Using of this rolling way is shown in the figure 7. At first, gradual rolling of a billet in breakdown and forming passes is made. Symmetrical hexahedral and vertical rhomboid passes are used in roughing passes. Before the entrance, in the first forming pass billet is canted and rolled in the asymmetrical pass (relative to the horizontal axis) with one rhomboid-shaped groove and another square-shaped groove with breakdown bias. After next canting profile is set in the diagonal trapezium-shape pass with convex base. After that, profile is transferred in the prefinishing pass and the finishing pass with closed-type flanges and side protrusions. The application of offered designing method for UPN-shaped profiles gives a lot of advantages during the profile rolling for retractable metal columns C-24. For example, the number of required forming passes (for the particular profile rolling) was declined, efficiency and temperature in the end of rolling process was increased, rolling stability and rolls durability was grown, electrical power consumption was lowered and hand work inputs for the profile adjustment were scaled down.
This technique can be used for I-beams and rolling channel sections. Particularly, it was applied during rolling process of slitting passes of channel sections №10 in the mill 450 on Novokuznetsk Iron and Steel Plant [22]. In this method there are no axial forces in sloping beam passes, because passes divisions are done from the right and left sides at the closed horizontal levels. Thus, it is possible to place large quantity of beam passes along of body of a roll. The technique also improves conditions of gripping by rolls. Originality of this technique is that after rolling of rectangular billet in the roughing pass, it is rolled in two sloping beam passes with a canting between them on 90° and with orientation of curved wide edges of profile to the groove swell. After that, profile is subjected to 45° canting and further rolling in closed passes is performed.

![Figure 7 – Developed scheme of UPN-shaped profile designing](image)

Figure 7 – Developed scheme of UPN-shaped profile designing
(1 – 6 – the pass number; arrows show the canting directions) [21]

The special technique of channels rolling was applied at the metallurgical works PJSC «Severstal» in Cherepovets. There, rolling process in the last passway was performed with angle formation between a web and a flange. This angle ranges from 88,4 to 89,5°, and during cold straightening the flanges are bended under angle $\phi = 5,5 – 12°$ (fig. 8).

It was prove by experiment [23] that the angle between a flange and a web $\alpha = 88,4 – 89,5°$ compensate the thermal warpage when channel section is cooled from the end temperature of rolling process 950 – 1050°C. The exact performance of a profile provides better quality of a channel section and enlarges the outcome of standard output. When angels of sides $\phi$ is increased to 12° roll wearing is lowed.

The technique of rolling channel sections is written in [24]. It assumes that the deformation in the first one or two passways is done in a flat rolls, but in the others passways, except a prefinishing pass, it is performed in opened passes with elongation ratio less than 1,56 (fig. 9).
1 – cross section of a channel (after roll outputs) of the last stand; 2 – after air cooling; 3 – after cold straightening

Figure 8 – Realization of a new way of channel section rolling [23]

Figure 9 – New technique of rolling channel sections in the section mill [24]
After deformation in a flat rolls, the strip is deformed in vertical rolls with reduction 1,01-1,26. After deformation in vertical rolls, the strip is processed twice in rolls with slitting passes. Next the strip is rolled twice in slitting passes with elongation ratio 1,20-1,46 for each other. The deformation process finishes when the strip is rolled in straight flanged passes with such slope angle of flanges is increased uniformly from 30-45° to 90°.

The deformation in horizontal and vertical rolls with formation of the unfolded profile and further flanges bending eliminates demanded canting of the profile, lows the groove height and increases the allowed number of rolls remachining. Rolling process in first passway of flat rolls makes the strip elongation efficiently and raises the deformation uniformity across cross section of profile.

It was proved experimentally [24] that deformation in opened passes with elongation ratio less than 1,56 made the elongation of separated strip parts uniform, reduced probability of higher local wear of grooves, raised the roll durability and the strip quality. Implementation of this technique enables to improve channel quality and decreases rolls wearing.

In the CIS channels are mainly rolled in two-roll passes. But this rolling method has some disadvantages: relatively low durability of the finishing pass, which worsens the quality and geometry of the profile; high expenses on electricity because of uneven deformation in profile elements; the impossibility of rolling in negative tolerance range. To remove these problems, the roughing or finishing passes made with universal passes are used abroad for channels manufacturing [25].

The complex technique of flanged profiles rolling is believed to be effective [26]. It combines the main deformation of the billet in closed passes and the finishing deformation in universal stands. However, installation of universal stands in operating mills required capital investments. That’s why the most effective way for four-roll universal passes formation in duo or trio stands is to install vertical nondriven rolls by means of special equipment cassettes. In Ukraine they have already shown their industrial qualification usage in channel sections rolling process after application in some operating mills [25] (medium section mill 550 Yenakiyevo Iron and Steel Works, combination heavy section mill 600 Alchevsk Iron and Steel Works, rail and structural steel mill 800 Azovstal Iron and Steel Works). Results of channel sections studies [26] showed that usage of the finishing four-roll pass improves the metal structure. Mechanical properties of metal is raised up to 5 – 7%, the amount of longitudinal residual stress is lowed, the profile geometry and surface quality becomes better, dimensional accuracy is increased in comparison with rolling process in the finishing two-roll pass.

The engineering solution [22] how to get a stable and quality profile in the finishing universal pass was worked out on Novokuznetsk Iron and Steel Plant (fig. 10). It is stipulated that deformation of profile in the universal pass is in the thickness direction of the whole web, but flanges thickness is deformed only over 0,7-0,8 of their length from the free end with gradual growth of reduction to the flange end with minimum overall elongation of the profile. Thus, the deformation process is performed where it is needed and when there are possibilities of spreading. The flanges tips are deformed to get rid of overfilling of the strip in the control pass and to stable the profile position in the pass without shifting it off on the one side when flanges are deformed a little. Spreading in deformed elements minimizes elongation in the pass and makes steady exit of the profile without distortion of required profile parts. The prefinished unfolded profile with a curved web is used during rolling process. It has semi enclosed flanges which height is controlled. Application of this technique of rolling channel section has some advantages compared with existed technique, for example: the stable channel section profile during rolling process in the four-roll finishing pass, the high quality profile, growth of rolling efficiency, reduction of roll wearing.
Modern technologies are also applied in the CIS countries. One of them is rolling of flanged profiles in the structural mills with three-stand reversing group of continuous rolling with two universal stands – tandem mill. The possible rolling scheme of channel sections is shown on the figure 11. Tandem mills are differed with compact disposition of the equipment, which reduces transportation of metal and lows down thermal loss of billet during rolling process [27]. The stand duo is installed in reverse group between universal mill stands. Such mills are set in operation at Consolidated West Siberian Metallurgical Plant and Chelyabinsk Metallurgical Plant (Mechel) in Russia. A rolling mill at EVRAZ Consolidated West Siberian Metallurgical Plant consists of reduction and roughing stands-duo, a tandem mill and the finishing designing stand. Equipment is produced by company «SMS Meer» [28]. Manufacturing of sectional profiles on Chelyabinsk Metallurgical Plant foresees rolling process in a new reduction stand using closed passes or in a continuous three-stand rolling mill tandem and in a separate finishing stand [29]. This rolling mill was designed and produced by a company «Danieli». General production capacities of a rolling mill exceed 1 m. t. a year [30].

**Conclusion**

Analysis of examined literature shows that different designing methods and deformation schemes are used to manufacture channel sections. Beam-type designing is rarely used these days. The most common on metallurgical plants is unfolded roll pass design. Designing methods are continually updated to make the product better and to reduce roll wearing. Two-roll passes are mainly applied to get flanged profiles in the CIS. Advanced manufacturing science is implemented at Consolidated West Siberian Metallurgical Plant and Chelyabinsk Metallurgical Plant (Mechel) where tandem mills are used. It is also important to investigate how to improve roll pass design in the future. Further research of stress-deformed metal condition is required because of the development of rolling theory, a big amount of factors which influence the accuracy of rolling process and application of new equipment in rolling mill-plants.
Figure 11 – Scheme of rolling channel section in a tandem mill [31]

References


