

Optimization of roll calibration for flange shape rolling. Groove space

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Abstract. The most important component of any rolling mill is the calibration of the rolls. The ability to obtain a finished product of high quality at minimal cost depends on the right calibration. According to the previous experience and practice a large number of different calibrations for the flange profiles production are known. The universal ‘concept of two-stage optimization’, consisting of two successively carried out optimization stages developed in the Department of Metal Forming of the Ural Federal University in relation to optimization of the roll calibration for flange shape rolling is considered in this article. Common features of these shapes classification and their variation levels are identified and justified. This developed classification structure is the basis for the formation of spaces of groove schemes, due to which the groove space is formed. In the software implementation the groove space is represented as a ‘groove database’. In the future this database will be used to form the space of calibration schemes that are fundamentally suitable for these shapes rolling.

1. Introduction

As is known the mill rolls calibration is the central element of any section rolling production, because many characteristics of the technological process and the properties of finished rolled products depend on it. However, at present there are no specific scientifically based methods for design and further optimization of complex shape calibrations. The known methods are either limited in range or not brought to the state of practical applicability [1].

The most suitable basis for the methodology design creation of the optimal calibration is the system approach formulated in ‘Theory of Systems’ and ‘Theory of Optimal Control’ [2–8].

2. Main principles

Considering the calibration of section rolling rolls as a ‘variable groove system’, it can be concluded that, like any other functioning system, it has two components available for change and optimization. The first component is the structure of the system: a certain sequence of grooves of a certain shape, i. e. the so-called ‘calibration scheme’. The second component is the set of quantitative characteristics of the links between the elements of the system: distribution of reductions along rolling passes, i. e. ‘reduction mode’. In order to obtain an optimal roll calibration, it is necessary to achieve optimality of these two components: identify the optimal calibration scheme and select the optimal reduction mode for this calibration scheme.

Taking into account this idea of optimality the Department of Metal Forming of the Ural Federal University developed the universal ‘Concept of optimal calibration’, consisting of two successively



carried out optimization stages (figure 1). At the first stage, the choice of the optimal calibration scheme is made, and at the second stage – the choice of the optimal reduction mode [9–13].

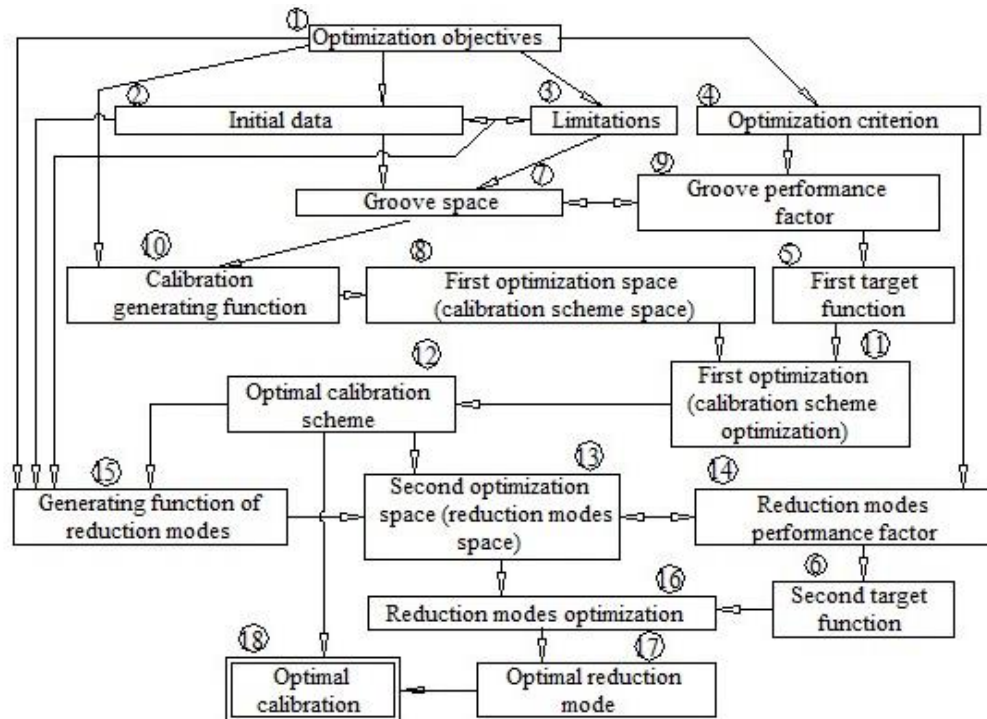


Figure 1. Structural flowchart of two-stage calibration optimization.

Considering the huge amount of information necessary for carrying out the optimization process, the use of a specialized optimization software package that is currently being created is required.

One of the main information blocks used in the first stage of optimization is the block reflecting the so-called ‘groove space’ [12]. This space includes all fundamentally possible grooves applicable to the rolling of a specific section at a specific rolling mill. At the first stage of optimization the term ‘groove’ will be understood as the groove scheme, which primarily determines the groove shape – the element shape, their relative position, the position of the groove connector, etc.

The groove space in the software implementation is a ‘groove database’, which includes all the fundamentally possible flange grooves used for rolling channels, rails and I-beams. For groove ordering in this space a classification method has been chosen. Identification of classification characteristics and their variation levels was carried out on the basis of the analysis of flange grooves known from the literature and practice [13]. Each combination of variation levels will correspond, in aggregate, to a specific point in the groove space, i.e. individual, unique groove.

3. General characteristics of the flange shapes classification

The analysis showed that the most common basic characteristics of rail, beam and channel grooves are the following:

- III – type of the neck (wall);
 - O – open flanges type;
 - 3 – closed flanges type;
 - C – groove symmetry;
 - T – groove type;
 - P – type of groove closure and the number of rolls that form the groove.
- The name of the elements is presented in figure 2.

Analysis of known grooves showed that the above characteristics have the following levels of variation.

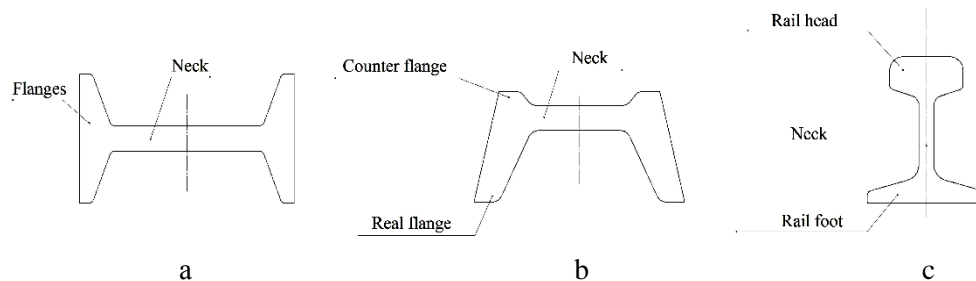


Figure 2. The division of flange shapes into elements: a – beams, b – channels, c – rails.

3.1. Groove characteristic ‘III – neck type’

Here we recognize the structure-forming feature that reflects the shape of the neck shape. Most real industrial calibrations used for the section rolling utilize four forms of the neck: straight, cut, curved and wavy. The straight neck has a rectilinear form and is used mainly in pre-finishing and finishing grooves. The curved neck is a U-shaped and is as a rule formed by segments of intersecting straight lines conjugated by a large radius. Cut neck shape is used to form a rough shape from a rectangular workpiece and is formed using split wedges. The wavy neck (having several bends) is mainly used to reduce the width of the groove cut into the mill rolls, thereby allowing an increase of the number of grooves located on the rolls and using a workpiece of a smaller width.

3.2. Groove characteristic ‘O – open flanges type’

5 types of open flanges are used: with a small incline, with an increased incline, curved outward, curved inward, without an incline. Direct open flanges with a small incline of groove have a small taper of 4 to 8% for beams and from 3 to 12% for channels. Straight open flanges with an increased incline have a taper of 10 to 40% for channels, up to 12% for beams, and the angle between the middle line of the wall and the outer face of the flange is 90. Outward curved open flanges are used for rolling in expanded grooves. Inward curved open flanges are used to reduce the width of the groove cut into the rolls and control the length of the flange.

3.3. Groove characteristic ‘3 – closed flanges type’

The analysis of the literature revealed 2 types of closed flanges: triangular and trapezoidal. However, during channels rolling in pre-finishing and finishing grooves there are no closed flanges, therefore, another level of variation is added – without closed flanges.

3.4. Groove characteristic ‘C – groove symmetry’

The groove symmetry can be characterized by the presence or absence of symmetry axes of the groove: horizontal and (or) vertical. For unambiguous interpretations the vertical axis of symmetry is taken as the axis perpendicular to the axis of the rolls.

3.5. Groove characteristic ‘T – groove type’

The term ‘Groove type’ refers to a structure-forming feature that reflects the groove purpose for the change of the cross-section shape. To indicate (name) the variation levels of this characteristic the external similarity of the groove corresponding to this groove level with one of the geometric objects, as well as the direction of the main axis of the groove is used.































3.6. Groove characteristic ‘P – groove closure type and the number of rolls forming the groove’

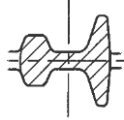
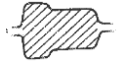





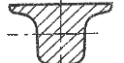

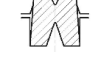









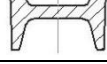


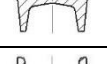
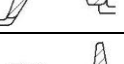



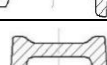
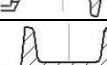
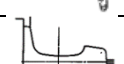

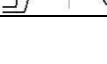

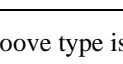
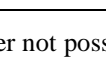
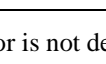
The term ‘closure type’ refers to the method of the groove placement relative to the position of the roll cross section. The method of groove closure affects primarily to the coverage level of the rolled metal in the groove, the control level of the metal by rolls. With the increase of the number of rolls the

control level of the metal by rolls increases. That is why the externally different, but functionally similar characteristics of 'groove closure type' and 'number of rolls forming the groove' are combined into a single characteristic of the groove 'P'.

Classification characteristics and all possible levels of their variation, as well as a schematically depicted groove shape and an example of groove use in real calibrations, are given in table 1.

Table 1. General characteristics of the flange shapes classification.

Classification characteristic	Name	Characteristic variation level	Rails	Channels	Beams	Source
Neck (III)	III1	Straight				11, figure I.23
	III2	Cut				11, figure I.22
	III3	Curved				11, figure I.24
	III4	Wavy	–			12, figure I.148
Open flange (O)	O1	Straight with a small incline				11, figure I.24
	O2	Straight with a increased incline				13, figure 18
	O3	Outward curved	–		–	11, figure I.80
	O4	Inward curved	–		–	13, figure 19
	O5	No incline	–		–	11, figure I.76
Closed flange(3)	31	Triangular	–		–	13, figure 17
	32	Trapezoidal				13, figure 16
	33	No flanged	–		–	14., figure 4.23 e
Symmetry (C)	C1	Assymetrical		–	–	12, figure II.2
	C2	Two axes of symmetry		–		12, figure I.147
	C3	Vertical axis of symmetry			–	12, figure II.17

	C4	Horizontal axis of symmetry		-	-	12, figure II.21
Groove type (T)	T1	Trapezoidal axial			-	14, figure 5.6
	T2	Trapezoid rib			-	14, figure 5.6
	T3	Cutting			-	14, figure 5.7
	T4	Tavrovy		-	-	12, figure II.64
	T5	Split				11, figure I.125
	T6	Flanged				13, figure 10
Groove closure type and the number of rolls forming the groove (P)	P1	Open				12, figure II.31
	P2	Half closed				14, figure 4.23
	P3	Closed top				12, figure II.27
	P4	Closed bottom				12, figure II.27
	P5	Diagonal				12, figure I.218
	P6	One side closed				12, figure II.2
	P7	Three-roll		-	-	14, figure 5.13
	P8	Four-rolls				12, figure I.295

Note: A space in the table cells indicates that this groove type is either not possible or is not detected in known industrial calibrations.

4. Conclusion

The identified common features of the groove classification intended for flange shapes rolling (channels, beams and rails) allow us to develop a general approach to the groove classification. The developed classification structure is the basis for the formation of spaces of groove schemes. In the software implementation the groove space is represented as a 'groove database'. In the future this database will be used to form the space of calibration schemes that are fundamentally suitable for these shapes rolling. The space of the calibration schemes will be the optimization space.

5. Acknowledgments

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References

- [1] Skorokhodov A N, Polukhin P I and Ilyukovich B M 1983 *Optimization of rolling production Metallurgy* (Moscow) p 432
- [2] Sadovsky V N 1980 *The System Approach and the General Theory of Systems: Status, Main Problems and Development Prospects* Science (Moscow)
- [3] Mesarovich M and Takahara 1978 *The General Theory of Systems: Mathematical Foundations* (Moscow)
- [4] Akof R L and Sasieni M 1971 *Fundamentals of Operations Research* (Moscow) p 536
- [5] Li H, Zhao Z, Zhang J et al 2019 Analysis of flatness control capability based on the effect function and roll contour optimization for 6-h CVC cold rolling mill. *International Journal of Advanced Manufacturing Technology* **100** (9-12) pp 2387–99
- [6] Wu L, Liu J, Dhanasekar M, Wang H and Wen Z 2019 Optimisation of railhead profiles for curved tracks using improved non-uniform rational B-splines and measured profiles *Wear* **418-419** pp 123–132
- [7] Wolf C, Stadler A T and Baumgartner W 2016 Cross-section optimisation for cold-rolled steel beams using a genetic algorithm. *METAL 2016 - 25th Anniversary International Conference on Metallurgy and Materials, Conference Proceedings* pp 507–12
- [8] Prinz K, Steinboeck A and Kugi A 2018 Optimization-based feedforward control of the strip thickness profile in hot strip rolling. *Journal of Process Control* **64** pp 100–11
- [9] Mikhaylenko A M and Schwartz D L 2018 The concept of optimal roll calibration. Report 1. The main principles *News of higher educational institutions. Ferrous metallurgy* vol **61** no **1** pp 21–27
- [10] Mikhaylenko A M and Schwartz D L 2016 The system approach to optimization the calibration of section rolling rolls *Production of rolled products* vol **17** pp 29–32
- [11] Ustinova E I, Mikhaylenko A M and Schwartz D L 2018 Selection of the optimal roll calibration scheme for channel rolling as the first stage of optimization *Mechanical equipment of metallurgical plants* vol **1** (10) pp 72–82
- [12] Schwartz D L, Mikhaylenko A M and Ustinova E I 2019 Optimization of roll calibrations for beam channel rolling part 1 General regulations *Chernye Metally* vol **9** pp 4–8
- [13] Schwartz D L, Mikhaylenko A M and Ustinova E I 2020 Method of optimization of roll calibration for channels. Groove space *Journal of Chemical Technology and Metallurgy* vol **3** (55) pp 657–65