Statistical roll pass design: Case study

Introduction

The initial (break-down passes) are frequently conducted in so-called box grooves. At this stage of the technological process, the steel temperature is at its highest level and consequently, the deformation resistance is low, thus allowing for high reduction and intensive changes in the cross-section geometry. In order to optimize the geometry of these passes, we can use the knowledge extracted from structured database describing the large number of similar passes used in a variety of rolling mills. The following study illustrates several analytical steps involved in statistical roll pass design (RPD).

Case study

Typical box-groove (Figure 1) consists of osculating curves defined by Equation (1).

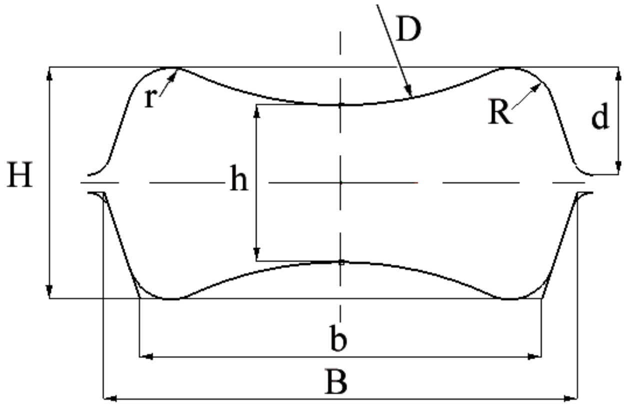


Figure 1: Typical box groove

Table 1 shows an excerpt from the series of passes, expressed in terms of the parameters of equation (1).

$$y(x) = \frac{-(\beta x+\phi)+\sqrt{(\beta x+\phi)^2-\gamma(\alpha x^2+2\delta x+\delta^2+\varepsilon)}}{\gamma} \tag{1}$$

Six parameters denoted by Greek letters α, β, γ, δ, ε, and ϕ, allow for defining an arbitrary osculating curve of the roll groove shown in Fig. 1 in analytical terms of Eq. 1. In the case of newly redressed grooves (before rolling has started), all osculating curves are arcs of circles. The excerpt shown in Table 1 includes exclusively such newly redressed grooves and this allows for some simplifications in explaining the procedure of statistical analysis.

It is important, however, to keep in mind that all six parameters are required once the roll groove contour has undergone changes in geometry (wear) due to continuous process of fine abrasion. Moreover, the generic form defined by Eq. (1) allows for introducing more complex curves when this results in optimisation of the groove function.

In the present simplified scenario |*δ*| and |*ϕ*| are *x* and *y* coordinates of the circle centre, respectively, and *R* is the radius of the arc of a circle.

$\varepsilon = \delta^2 + \phi^2 - R^2$; therefore, R can be calculated from the parameters ε, δ and ϕ.

The values of *δ*, *ϕ* and *R* allow for constructing the characteristic circles that define both the entering profile and the groove contour.

Table 1: Excerpt from the box groove passes database; in all rows $\beta = 0$ and $\alpha = \gamma = 1$

				EXIT PROFILE								ENTRY PROFILE	
	separation point S									centre			
	X coordinate							δ3 = 0		Y			
	TREND	real	δ1	ε1	ϕ1	δ2	ε2	ϕ2	ε3	ϕ3	ordinate	δ	ε	ϕ
|a-b|	a	b	c	d	e	f	g	h	i	j	k	l	m	n
0.08	40.39	40.32	-34.50	1752.34	-24.46	-26.74	1025.43	-22.50	-2790.06	63.20	28.50	-30.00	1700.00	-30.00
0.17	42.65	42.48	-37.02	1492.14	-12.56	-27.84	671.14	-11.00	-12562.57	268.63	24.50	-26.74	1025.43	-22.50
0.44	40.61	41.05	-35.10	1610.20	-20.35	-26.74	1025.43	-22.50	-2790.06	63.20	28.50	-30.00	1700.00	-30.00
0.05	43.27	43.32	-36.95	1422.25	-10.30	-27.84	671.14	-11.00	-12562.57	268.63	24.50	-26.74	1025.43	-22.50
0.22	28.42	28.20	-18.50	431.83	-13.77	-16.13	326.45	-14.50	729.00	-27.00	27.00	-11.00	671.14	-27.84
0.22	28.19	28.41	10.40	-1459.63	-5.68	-16.13	326.45	-14.50	729.00	-27.00	27.00	-11.00	671.14	-27.84
0.47	175.82	175.35	-155.00	34085.62	-104.69	-141.43	25602.74	-90.00	-1385708.97	5089.68	138.00	-130.00	31300.00	-130.00
0.78	182.14	181.36	-165.00	32427.79	-76.34	-155.18	26706.27	-65.00	-1242760.43	6084.32	103.00	-141.43	25602.74	-90.00
0.34	177.01	177.35	-155.80	34171.26	-103.91	-141.43	25602.74	-90.00	-1385708.97	5089.68	138.00	-120.00	25200.00	-120.00
0.91	182.85	183.76	-164.78	32540.85	-77.55	-155.18	26706.27	-65.00	-1242760.43	6084.32	103.00	-141.43	25602.74	-90.00
0.23	112.50	112.27	-100.50	23490.45	-116.34	-80.41	21191.11	-125.00	-24025.00	155.00	155.00	-65.00	26706.27	-155.18
0.55	120.14	120.69	-105.00	16532.19	-75.92	-87.91	14927.45	-90.00	-926705.71	3953.22	119.00	-80.41	21191.11	-125.00
0.29	112.44	112.73	-99.00	22571.19	-113.87	-80.41	21191.11	-125.00	-24025.00	155.00	155.00	-65.00	26706.27	-155.18
0.58	120.29	119.71	-105.00	17363.38	-81.01	-87.91	14927.45	-90.00	-926705.71	3953.22	119.00	-80.41	21191.11	-125.00
0.45	126.47	126.92	-97.50	10818.02	-47.03	-89.13	10350.23	-57.50	-789726.14	4608.14	86.50	-90.00	14927.44	-87.91

By extracting knowledge from database that includes the parameters observed in similar rolling series, it is possible to derive sophisticated modifications in the groove geometry, providing that:

- (i) That particular groove presents drawbacks such as high wear or frequent adjustments
- (ii) The parameters *α*, *β*, *γ*, *δ*, *ε*, *ϕ*, and S for this particular groove, deviate significantly from the statistical trend inferred from the database.

Point S shown in Figure 2 below demarks the location where the hot steel separates laterally from the groove contour. The significance of the point S is in that determines the minimum depth of the groove. The maximum contact width of the exiting bar with the groove surface will lie in the vicinity of the point S. If the point S is too close to the point M (maximum groove width) there will be tendency for overfilling the groove.

If the distance between the points S and M is too large or too small, this is usually a sign of the pass design insufficiency. Examples of the insufficiencies in the former case include too small draft (inefficient use of the groove which can lead to unnecessary large number of passes), poor control of the lateral draft and the bar symmetry, etc.

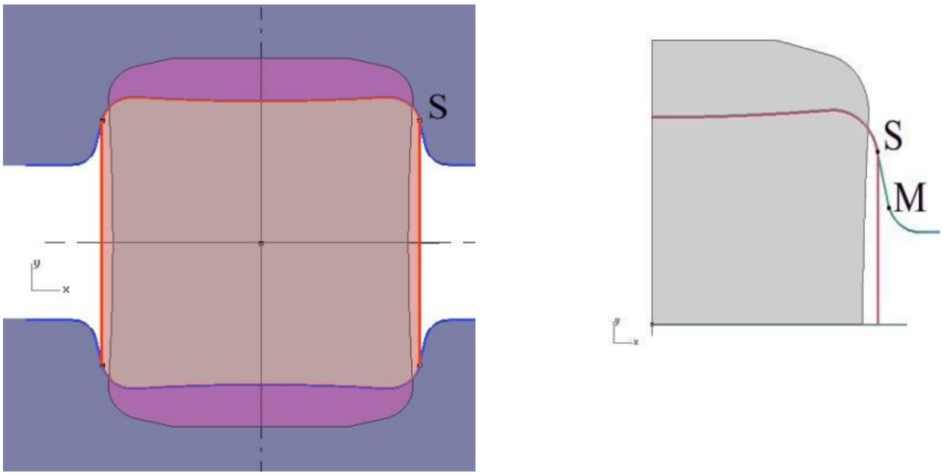


Figure 2: Typical pass in box grooves (a) Pink contour of the steel bar entering the groove changes into red contour illustrating the exiting profile; blue contour demarks the roll groove. (b) The symmetry allows for defining the whole pass by the geometry in the first quadrant of the Cartesian coordinate system

Ideal configuration of points S and M allows for optimizing the grove depth. Too deep grooves require unnecessary large amount of the cutting into the roll diameter during redressing, i.e. the roll life is shortened. On the other hand, too shallow grooves increase the risk of the occurrence of overfilling.

The knowledge about an ideal configuration can be gained by analysing the parameters α to ϕ from a sufficiently large database of similar passes.

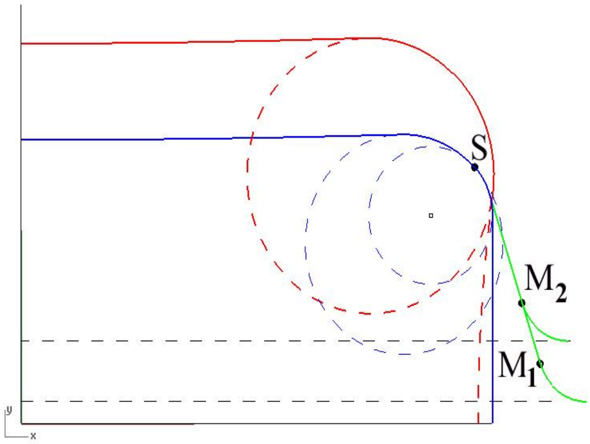
For example, the pass highlighted in yellow in Table 1 has a history of low wear (long life). More detailed scrutiny (Table 2 and Figure 3) revealed that there is too large distance between the points S and M_1. In Fig 3 the red coloured lines show the entry profile; blue coloured lines denote the exit profile; green colour indicates possible contour of the groove surface that is not in the contact with the rolled steel; dashed lines present the construction elements. In this case it is recommended to increase the draft in the analysed pass (the current height reduction of the entry profile is 70 mm at the groove centre).

This can be done by bringing the roll axes closer if the roll gap allows for this. Otherwise, the same groove geometry (shown by blue colour) can be cut to lower the collar height as indicated by point M_2. This later option would set the conditions for multiple benefits, such as allowing for multiple passes in the same groove, occurrence of the increased roll diameter at the groove bottom, etc.

Table 2: Details for entry and exit parameters, for the pass highlighted in yellow in Table 1 ($\beta = 0$, $\alpha = \gamma = 1$)

						EXIT PROFILE						
	separation point S										centre	abscisa
	X coordinate							δ3 = 0			Y	x
	TREND	real	δ1	ε1	ϕ1	δ2	ε2	ϕ2	ε3	ϕ3	ordinate	observed
|a-b|	a	b	c	d	e	f	g	h	i	j	k	l
0.91	182.85	183.76	-164.78	32540.85	-77.55	-155.18	26706.27	-65.00	-1242760.43	6084.32	103.00	190.90
						ENTRY PROFILE						
	separation point S									centre	abscisa	curve
	X coordinate		y							Y	x	R
	TREND	real	real	δ	ε	ϕ	δ4	ε4	ϕ4	ordinate	observed	at "t"
|a-b|	a	b	b1	m	n	o	p	r	s	t	u	v
0.91	182.85	183.76	92.98	-141.43	25602.74	-90.00	-141.43	25602.74	-90.00	138.00	185.80	-4951.68

Figure 3: Pass geometry defined in Table 2; the red coloured lines show the entry profile; blue coloured lines denote the exit profile; green colour indicates possible contour of the groove surface that is not in the contact with the rolled steel; dashed lines present the construction elements



The above discussion has addressed just a few limited issues as an example of what can be analysed using the statistical roll pass design. More details about background theory can be found in references listed below. Our experts have constructed a generic database that embraces the observations from a number of rolling mills. The organisation that merges their roll pass design data into the generic database developed by the *My Statistical Consultant Ltd Company* will gain the competitive advantage because the statistical scenario will be adjusted to the conditions specific for their rolling mill. Typically, the customer’s data will be translated into the parameters of the oscillating curves and then analysed within the whole database as it has been done in the case that is highlighted in yellow in Table 1.

Benefits

Statistical RPD method allows for improvements in rolling process efficiency, minimising downtime and resource consumption, as well as for enhancing the product quality and system sustainability. In particular, our method is suitable for introducing new roll pass design to widen the range of rolled products in section, universal, plate, bar, rod and wire mills.

Rolls can be designed in various manners at the same costs to produce grooves of differing geometries with significant economic consequences for both maintenance and operations.

Introducing our sophisticated roll pass design allows for:

- ✓ progressive optimization of rolling process by means of detecting the weak points, the elimination of which will improve the whole manufacturing system,
- ✓ modification of the breakdown passes to enhance roll bite by increasing drafts and rolling velocity, while decreasing the probability of interfacial damage,
- ✓ improving the key performance indicators and techniques used to evaluate and control the rolling process performance.

Contact information

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References

Spuzic S. and Abhary K. (2013) "A Contribution to Rolling Mill Technology - Roll Pass Design Strategy for Symmetrical Sections", Presented at the *83rd AIKW Conference (Association of International Roll Pass Designers and Rolling Mill Engineers*; http://www.aikw.org/) held in Ostrava EU on 9-11th October 2013, and to be published in journal Der Kalibreur Vol. 75 by mid 2014 (PowerPoint presentation is available at http://goo.gl/Bd2klX)

Abhary K., Spuzic S. and Ghomashchi R. (2013) "Some Aspects of Design Optimisation in Rolling Technology " Presented at the *International Conference Materials Innovation in Surface Engineering (MISE 2013)* held in Adelaide 19th – 21st November 2013; (also submitted for the peer reviewed publication of the papers through Materials Forum – Annual Review Journal of Materials Australia) www.materialsaustralia.com.au/MISE2013 (available on request)

Huang B., Xing K., Spuzic S. and Abhary K. (2010) "Development of Parameterized Roll Pass Design Based on a Hybrid Model", *ICMET 2010 Conference Proceedings*, IEEE Press, Singapore, pp. 91-93; International Conference on Mechanical and Electrical Technology (http://www.icmet.ac.cn/index.htm)

Huang, B, Xing, K, Abhary, K & Spuzic, S. (2011), "Investigation of Roll Pass Optimal Design Based on IGA", *Advanced Materials Research*, Vol. 211-212, pp. 195-199.

Abhary K., Garner K., Kovacic Z., Spuzic S., Uzunovic F. and Xing K. (2010) "A Knowledge Based Hybrid Model for Improving Manufacturing System in Rolling Mills" *Key Engineering Materials*, Vol. 443, pp. 3-8 (http://www.scientific.net/KEM.443.3)

Spuzic S., Izzo A. and Abhary K. (2006) "A New Method for Roll Pass Design Optimisation", Proceedings of the *5th Pan-European Conference on Planning For Minerals and Transport Infrastructure: PEMT'06* - Sarajevo 18-20 May.