Development of radial-shear rolling mill special stands for continuous cast billets deformation

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Abstract. The article offers the structure of the three-roll stand for radial-shear rolling that is designed to deformation of continuous cast billets. The stand can be installed in the pipe rolling mill manufacturing line that shall ensure manufacturing flexibility. To achieve the objective set, elaboration of working rolls integration with the drive as well as verification against the allowable torque and strength calculations in SolidWorks Simulation were performed at the design stage. For the major part of the frame, stresses do not exceed 60 MPa and the design rigidity rate will be 2.86 MN/mm. The special stand has a specific frame structure to ensure its mounting on the existing equipment base. The configuration of rolls sets is selected considering the possibility of integration with the spindle assemblies of the group drive and maximum allowable cross angle (≤ 15°). The developed design proves to have sufficient strength margin with the relatively small weight. The special radial-shear rolling mill stand will allow increasing total strain degree and reducing the number of billets sizes.

1. Introduction

Rolling mills are generally considered to be unique and high-performance metallurgical units [1–4]. The design development is performed considering the developed process and size range of the manufactured products. The equipment should ensure long-term failure-free operation and proper quality products release [5–8] that is why development of units and mechanisms designs should be carried out along with engineering calculations of effective loads and strength analysis [9]. Moreover, when designing any equipment, safety and reliability of working tools [10–13], design specifics, efficient and sustainable distribution as well as weight and energy consumption reduction should be taken into consideration [14, 15].

At present, metallurgical companies involved in manufacture of steel seamless pipes use steel continuous cast billets (CCB) to manufacture initial billets [12, 16–19]. First of all, transfer to CCB application is attributed to the advantages and benefits of this method in terms of manufacturing costs reduction and through yield output increase. However, there is a number of restrictions imposed on the application of CCB. A wide range of seamless pipes manufactured using the same unit implies application of different diameters billets. At the same time, manufacture of a huge number of CCB of different diameters is quite cost-ineffective. Secondly, possible defects of CCB may result in rejection of non-repairable pipes due to internal and external slivers. Three-roll radial-shear rolling (RSR) mill can be used to decrease the size range of billets and pre-strain prior to piercing [20]. This method is used to manufacture round bars from different types of steel [21, 22], aluminum [23] and titanium [24, 25]. Results of numerous investigations prove that combination of large feed angles and special calibration of rolls will allow decreasing the centerline porosity and grain size variation along the bars cross-section [26, 27].

Pervouralsk New tube (Novotrubny) Works, JSC, plans to install a RSR stand to perform pipe billets pre-deforming that is used to manufacture pipes using Pipe Rolling Plant 160 (PRP-160) [28]. Since the existing equipment configuration in the shop makes it impossible to install an additional unit, the option of mounting a stand in the PRP-160 line by fast replacement of the three-roll reeling mill stand with the special stand intended to perform reduction of solid billets is considered. Therefore, the new equipment should integrate with the existing drive of the reeling mill stand and operate in conjunction with the equipment of the ingoing and outgoing side.

The objective of this study is to develop the design of a special RSR mill stand intended to perform deformation of CCB. This will allow increasing the total strain degree and reducing the number of initial billets sizes.

2. Development of the stand basic design

Since the developed stand should be integrated into the existing manufacturing line and installed instead of the reeling mill stand, a number of restrictions were considered during the design stage, namely: the stand group drive with the limit cross angle for spindle heads of 15°; maximum torque of the working roll of 40 kN·m, the main drive capacity of 1.6 MW; the possibility to integrate with the existing ingoing and outgoing side of the reeling mill. The specification summary is given in Table 1.

Table 1. The specification summary for RSR stand rolling mill.

Parameter name	Value
Billet diameter, mm	120–220
Roll diameter, mm	290
Roll body length, mm	350
Feed angle, degree	18
Toe angle, degree	5
Screw-down mechanism	Electromechanical (screw and nut)
Type of drive	Group (drive TRP-160)
Drive power, kW	1600

The developed cage of RSR rolling mill (Figure 1, a) had a massive welded box-type frame made from plates. Two cartridges with top working rolls and a cartridge with the bottom stationary working roll are placed in through openings. No change in the feed angle or toe angle is provided for the structure design; these values are set structurally based on the need to match the existing structure of the PRP-160 drive. The stand is mounted directly on the bottom of the existing roll housing (Figure 1, b). RSR mill stand is fastened to the base using wedges similarly to the way the top part of the reeling mill stand is fixed. The roll housing of RSR mill consists of two vertical plates with the thickness of 50 mm that are mounted on the base. Similar welded pedestal-shaped structures are mounted to the left and to the right of base plates to be installed on the base and fastened with wedges. To make the frame stiff, the base is reinforced with stiffeners that are 70 mm thick. Massive plates with the thickness of 50 mm are welded inside the plates slots and are used as guides for rolls cartridges installation. The bottom roll should be attached rigidly to the base plate. The rolling force should be transferred from the bottom roll to the frame plate.

The working roll cartridge consists of the cartridge with bore holes where the working roll and the chock are installed. Working rolls chocks should be fixed in cartridge bore holes through the projected parts. The roll mounted on slide bearings of chocks.

The screw-down mechanism of working rolls top cartridge is made in the form of screw-nut pair and is driven in rotation due to motor-gear mounted on the frame top. Every top cartridge fastened using the hydraulic counter weight to avoid any possible gaps between the cartridge, the crew-down mechanism and the frame.

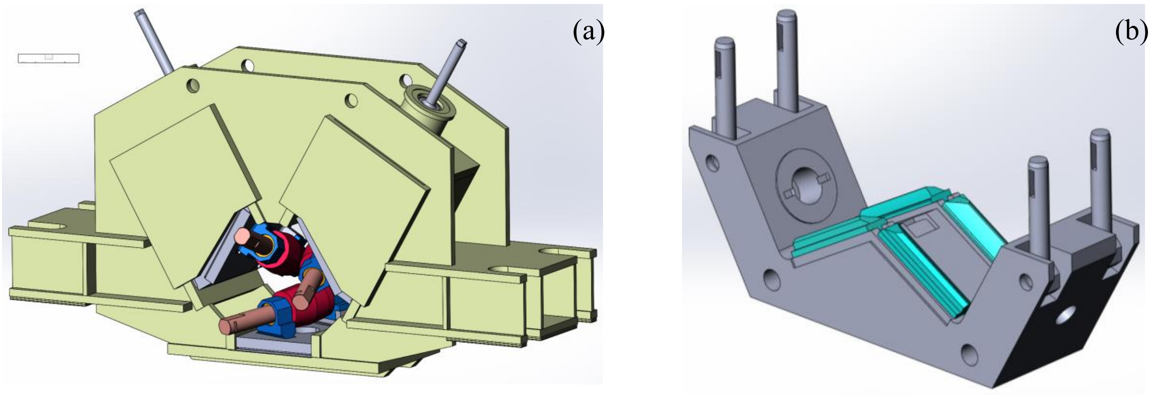

Figure 1. Three-roll stand of RSR mill (a) and the base of the reeling mill PRP-160 frame (b).

Since the bottom roll is stationary, the rolling axis position in case of change into a different billet diameter will be changed. This option should be considered during re-adjustment of the ingoing and outgoing side.

3. Elaboration of integration and checking calculations

3.1. Elaboration of the stand integration with the main drive

The major task of the stand design is to join and match the working rolls and the existing drive of the PRP-160 reeling mill stand. The main drive of the reeling mill stand is of group type and consists of electric motor, gearbox, several sections of the main shaft and multipurpose spindles. The decision to change the configuration of working rolls by rotating them relative to the rolling axis by 60° (Figure 2) was taken to reduce the cross angles for the spindle set when mounting RSR mill stand with increased feed angles (18–21°).

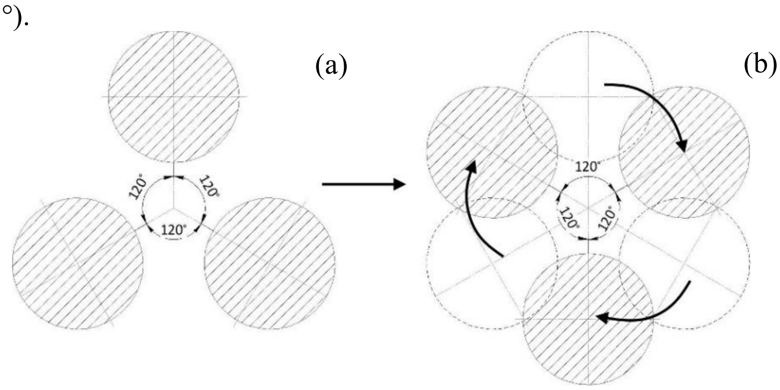

Figure 2. The original position of PRP-160 rolls (a) and the layout of rolls rotation (for the special stand) (b).

Then possible cross angles were assessed depending on the working rolls positioning in the stand (feed angle, toe angle, working rolls installation as per the roll pass) for the selected configuration of working rolls. The analysis was performed using the SolidWorks software by 3D modeling parts and assemblies of the stand. Therefore, a three-dimensional model of the multipurpose spindle was developed based on available drawings. The toe angle varied from 2° to 5°. The feed angle varied from 15° to 20°. The roll pass diameters (of bars manufactured) were selected within the range of 90…190 mm for the analysis. Results of measurements taken are specified in Table 2.

Table 2. The correlation between the maximum cross angle and the varying parameters.

Varying parameter		Maximum cross angle
Toe angle δ (°) (β = 18°, $D_к$ = 100 mm)	2	14.61
	3	14.68
	4	14.85
	5	15.12
Feed angle β (°) (δ = 5°, $D_к$ = 100 mm)	15	11.59
	18	15.12
	20	17.52
Distance between rolls $D_к$ (mm) (δ = 5°, β = 18°)	90	15.10
	100	15.12
	125	15.15
	150	15.19
	170	15.22
	190	15.25

If the toe angle increases by 1°, the cross angle of the spindle increases by 0.2° as an average, in case the feed angle increases by 1°, the cross angle of the spindle increases by more than 1°. Changing the distance between the rolls does not significantly affect the spatial cross angle of the spindle half coupling. In case of any change within the range from 90 to 190 mm, the angle changes by 0.15°.

Considering the obtained measuring data and the above conditions of roll sets configuration we decided to use working rolls with the diameter of 290 mm, feed angle β = 18° and toe angle δ = 3–4° in the structure design.

3.2. Elaboration of the stand integration against the allowable torque

Another important evaluation criterion for the equipment design is the level of power parameters – the force of metal applied on the roll, the rolling torque and the rolling power. Power parameters (force and torque) were calculated as part of the study for the rolling process of CCB with the diameter of 156 and 220 mm.

Calculations were made for billets reduction with the diameter of 156 mm to achieve bars with the diameter of 140–90 mm as well as the billets with the diameter of 220 mm to achieve the bars with the diameter of 210–170 mm. The rolls diameter is taken to be equal to 290 mm. The feed angle is equal to 18 degrees, the taper angle within the deformation zone of the reduced area is 10 degrees, the coefficient of tangential reeling within the reduced area is 0.3, and the number of cycles within the sizing area is 3. Calculations results are given in Figure 3.

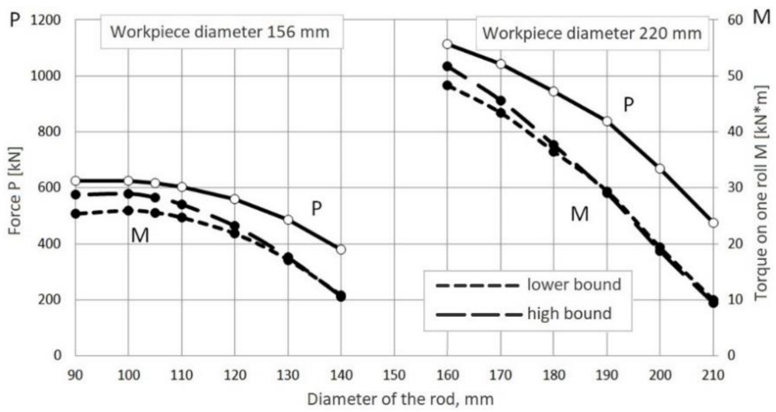

Figure 3. Effect of the rolled stock diameter on force P and torque M and M_c when reducing workpieces with the diameter of 156 and 220 mm.

For billets with the diameter of 156 mm, the maximum reduction force for the diameter of 90 mm is about 630 kN, while the maximum rolling torque is less than 30 kN·m. For billets with the diameter of 220 mm, the maximum reduction force for the diameter of 160 mm will be 1100 kN, while the rolling torque will be about 50 kN·m. Since the spindle units are designed for the maximum torque of 40 kN·m, one-pass reduction can result in the diameter of not less than 180 mm for the billets with the diameter of 220 mm. Based on this restriction, the maximum force when calculating strains and stresses of the design stand is selected to be equal to 1000 kN.

3.3. Checking calculation of the stand structure strength

The rigidity of the designed stand structure was preliminarily assessed using SolidWorks Simulation to perform verification of the design concept.

Top rolls and cartridges were excluded from the calculations to make the design model simpler. Steel grade A 516-55 (AISI) is taken for all the frame parts from the CAD system, the roll material is 55NiCrMoV 6 (L6 AISI), the bearings material is bronze (Cu-Al-Fe-Mn). The stand is installed on the base of the reeling mill PRP-160. Conditional rigid fastening of support surfaces in SolidWorks is shown in Figure 4 in green arrows. Load application areas are conditionally shown in purple arrows in Figure 4. The force is applied to bottom rolls for calculations. Since top rolls and cartridges are excluded from calculations to make the model simpler, the force of top rolls is applied to adjusting thrust screws, since they will take up the major load transmitted by rolls sets.

Stress diagrams (Figure 4, a) and cage frame absolute displacement (Figure 4, b) are found as a result of calculations. The obtained data show that maximum stresses occur in the rolls set and amount to 140 MPa. These values occur within the load application areas and acute angles of parts mating. However, the design model has a number of assumptions; in particular, rounding, bevels and welded joints are not taken into consideration, that is why it can be assumed that no peak stresses will occur within the areas of frame parts joining. For the major part of the frame, stresses do not exceed 60 MPa that is 3.7 times less than the yield strength for steel grade A 516-55 (221 MPa). Therefore, sufficient strength margin for the stand frame is ensured.

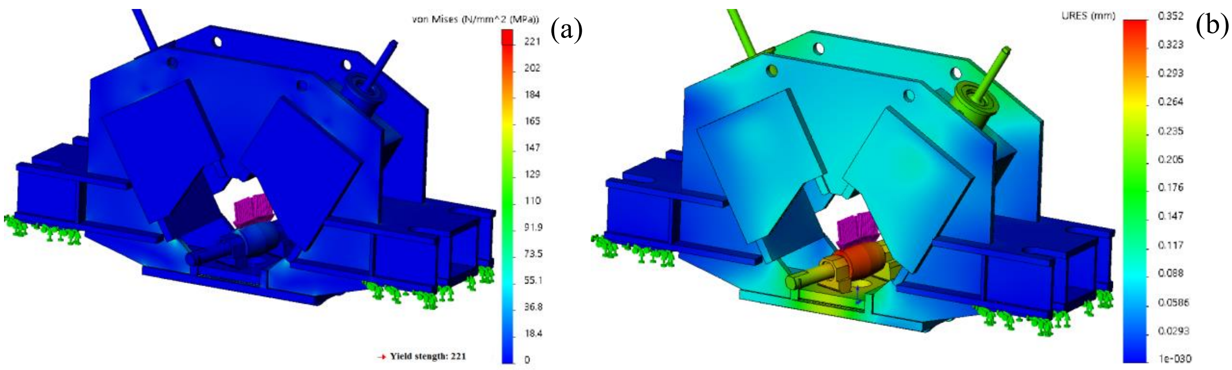

Figure 4. Stress diagram (a) and stand absolute displacement diagram (b).

The maximum displacement under load makes 0.35 mm and occurs on the bottom roll within the load application area. The frame base is additionally reinforced with stiffeners to reduce bottom rolls set strain. The design rigidity rate will be 2.86 MN/mm.

Results of virtual experiment show that the stand has sufficient strength and rigidity margin.

4. Conclusion

The article offers the design of the three-roll stand for RSR mill to manufacture CCB using PRP-160 manufacture line in Pervouralsk New Tube (Novotrubny) Works, JSC. The issues associated with the equipment installation, mating with the existing drive of the reeling mill, as well as checking calculations against the allowable force and rolling torque are taken into consideration during the design. The developed equipment design has sufficient strength margin and provides for the required manufacturing capacity.

References

[1] Romantsev B A, Gamin, Y V, Goncharuk A V and Aleshchenko A S 2017 *Metallurgist* **61** 217–22
[2] Galkin S P, Romantsev B A, Ta D X and Gamin Yu V 2018 *Chernye Metally* **4** 20-7
[3] Galkin S P, Goncharuk A V, Daeva E K, Mikhailov V K and Romantsev B A 2003 *Steel in Transl.* **33(9)** 45-7
[4] Romantsev B A, Aleshchenko A S, Goncharuk A V and Galkin S P 2012 *Metallurgist* **55** 918–24
[5] Romantsev B A, Goncharuk A V, Aleshchenko A S, Onuchin A S and Gamin Yu V 2015 *Metallurgist* **59** 386–9
[6] Romantsev B A, Goncharuk A V, Aleshchenko A S and Krasil'shchikov M V 2012 *Steel in Transl.* **42** 769–70
[7] Shatalov R L, Medvedev V A 2020 *Metallurgist* **63 (9-10)** 1071-6
[8] Shatalov R L, Medvedev V A 2019 *Metallurgist*, **63 (1-2)** 176-82
[9] Overhagen C, Braun R, and Deike R 2020 *tm - Technisches Messen* **87(5)** 343-8.
[10] Aleshchenko A S, Gamin Yu V, Chan B K and Tsyutsyura V Y 2018 *Chernye Metally* **8** 63-70.
[11] Romantsev B A, Matyko O K, Goncharuk A V, Aleshchenko A S and Ananyan V V 2008 *Steel in Transl.* **38** 897–9
[12] Romantsev B A, Aleshchenko A S, Tsyutsyura V Y, Tyshchuk I N and Lube I I 2017 *Metallurgist* **60** 1062–9
[13] Shatalov R L, Grigoryan G G, Sharov A A and Savin V A 1987 *Steel in the USSR* **17 (9)** 416-9
[14] Overhagen C and Mauk P J 2014 *Key Eng. Mater.* **622–623** 879–86
[15] Budnikov A S, Romantsev B A and Kharitonov E A 2018 *Izv. Ferrous Metall* **61 (9)** 683-8
[16] Romantsev B, Goncharuk A, Aleshchenko A, Gamin Y and Mintakhanov M 2018 *Int. J. Adv. Manuf. Technol.* **97** 3223–30
[17] Smirnov E N, Smirnov A N, Sklyar V A, Mikheev V V, Belevitin V A, Orlov G A and Verzilov A P 2019 *Steel in Transl.* **49** 631–7
[18] Marchenko K L, Fadeev M M, Romantsev B A, Goncharuk A V and Ananyan V V 2008 *Steel in Transl.* **38** 402–4
[19] Matyko O K, Fartushnyi R N, Mul'chin V V et al. 2009 *Steel in Transl.* **39** 161–3
[20] Galkin S P, Romantsev B A and Kharitonov E A 2014 *CIS Iron Steel Rev* **9** 35-9
[21] Galkin S P, Kharitonov E A and Romanenko V P 2009 *Steel in Transl.* **39** 700
[22] Malakhov A Yu, Saikov I V, Denisov I V, Cherezov N P, Gamin Yu V and Romantsev B A 2020 *IOP Conf. Series: J. of Phys.: Conf. Series* **1431** 012033
[23] Gamin Y, Akopyan T, Koshmin A, Dolbachev A, Aleshchenko A, Galkin S P and Romantsev B A *2020 Int. J. Adv. Manuf. Technol.* **108** 695–704
[24] Karpov B V, Patrin P V, Galkin S P, Skripalenko M N, Samusev S V, Huy T B and Pavlov S A 2018 *Metallurgist* **61** 884–90
[25] Romancev B A, Goncharuk A V, Aleshchenko A S and Gamin Yu V 2015 *Russ. J. Non-ferrous Metals* **56** 522–6
[26] Akopyan T K, Aleshchenko A S, Belov N A and Galkin S P 2018 *Phys. Metals Metallogr.* **119** 241–50
[27] Shurkin P K, Akopyan T K, Galkin S P and Aleshchenko A S 2019 *Met Sci Heat Treat* **60** 764–9
[28] Aleshchenko A S, Budnikov A S and Kharitonov E A 2019 *Izvestiya. Ferrous Metallurgy* **62 (10)** 756-62