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Influence of Thermal Condition Prorollers to Formation of Cross-Section Profile of Hot-Rolled Strips, Rolled on the Longitudinal -Wedge Mill

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Abstract This paper proposes a new design of mill. Using the software of finite element (FE) analysis, specialized for the calculation of metal forming processes MSC. SuperForge и MSC, visual Nastran 4D, calculated the stress-strain state (SSS) rolled billet and heavy-duty elements of the proposed mill. It is proved that when a new rolling mill thin strips deforming force reduced, the amount of elastic deformation and displacement rolls are small elements. The investigation has also shown that sufficiently high rigidity roller assembly work stand and resulting in heavy-duty elements of the equivalent voltage does not exceed the maximum allowable values, for the material strength.

Keywords Stress-Strain State, Roll Flattering, Thermal Profile of Rollers, Continuous Rolling, Computer Rolling Simulation, Working Felling

1. Introduction

In the last decades in world production of hot-rolled strips admissions decreased by characteristics of a cross profile that is caused by the general tendency of increase of requirements to quality of sheet hire [1]. It is relevant both for the most thin hot-rolled strips with thickness of 0,8 - 1,5 mm, directly used in engineering and construction, and for strips with thickness 1,8 - 3,0 mm sent as rolled steel for cold rolling mills for production of automotive sheets or other product mix with stringent requirements to the flatness and surface condition. In order to reduce the deviations standardized characteristics of the profile of hot-rolled strips (with transverse thickness, clinoid shape, local thickness deviation, the displacement of the peak) to the values defined by the tighter tolerances, we must influence the factors influencing on the accuracy of formation of the transverse profile [1-11].

The most significant of these factors - thermal profile of the work rolls (uneven distribution of thermal deformations along the drum), the elastic rolls and flattening their original shape (semolina) profiling [1, 5, 6, 7, 10, 11]. These factors, coupled with the uneven wear on the barrel length, distort the shape of the active form of the work rolls, which determines the distribution of the thickness of the width of the hot strip. The thermal profile of the rolls depends on the degree of uniformity of heat entering the bandwidth and the efficiency of cooling, controlled by the length of the barrel, and the elastic flattening rolls depends on the magnitude of the rolling force. If the hot-rolled strip intended for subsequent cold rolling distortion of their cross-section caused by the instability of the thermal regime of the rolls, the rolling force, are the main cause of deterioration of the flatness of hot rolled strips - one of the main indicators of quality. Thus, the improvement of energy-power parameters of rolling and thermal regime of bands and cooling rolls hot rolling mills - an urgent task not only for the hot rolling mill plants, but also for the whole plate rolling. Effective solution to this problem can be solved by improving the rolling equipment and roller systems, the development of automatic control systems in thickness, profile and flatness of the rolled strips, creating new ways of rolling and roller systems for their implementation. Some aspects of the modeling of elastic and thermal regime collapsing strips and hot rolling mill rolls were published in the last 15-20 years [1-11], but a comprehensive study of law that defines the geometric parameters of the output of rolled sheets, depending on the technological parameters of the rolling process and control actions to is still lacking. This is due to the complexity of the problem and the need to carry out industrial research on a large, high-performance steel equipment where extremely limited opportunities for scientific experiments. Thus, ensuring the competitiveness of plate rolling in the global steel market largely depends on the improvement of the thermal regime of rolling and hot rolling mill rolls, elastic profile and profiling sanding rolls, ie from the regulation of the transverse and longitudinal variation in thickness and flatness of the rolled strip.

In our opinion, the best method of controlling the transverse variation in thickness and flatness is the optimization of breakdowns and the efforts of hot rolling. To this end, we have developed a design of rolling mill [12], which allows to assign rational technological parameters of rolling.

The aim of this study is to investigate the influence of thermal conditions on the formation of rolling cross-section of hot rolled strips, rolled on longitudinal wedge camp.

2 Equipment, materials and methods of theoretical and experimental studies

Used to study a continuous strip rolling mill for steel and alloy contains a working mill, electric motor, clutch, bearing non-driven rollers, working the drive rollers, base frame, a support plate (Figure 1). The cages having the drive from the engine of alternating current, contain working and basic rolls of constant diameter, and in consistently located cages diameter of working rolls decreases, and diameter of basic rolls increases in the direction of rolling. In this case, the rotation of the rolls is carried out through individual clutch gearbox, pinion stand and spindles, and the diameters of the work and backup rolls are determined by the formula, accordingly:

$$D_{i+1} = \frac{h_i \cdot D_i \cdot n_i}{h_{i+1} \cdot n_{i+1}} \frac{(1+s_i)}{1+s_{i+1}}; \quad D_{j-1} = \frac{h_j \cdot D_j \cdot n_j}{h_{j-1} \cdot n_{j-1}} \frac{(1+s_j)}{(1+s_{j-1})};$$

$(i = 1, 2, \ldots, N; j = N, \ldots 2, 1)$,

where h_i and h_j - rolled strip thickness in the i or j cage;

n_i n_j - frequency of rotation of roll i or j cage;

N is the number of the cage;

s_i and s_j - ahead at the exit from the rolls i or j cage;

D_i and D_j are the diameters of working i and supporting j rolls previous stand.

In an offered mill horizontal axes of the top and bottom rolls of the first three cages without the press mechanism are displaced from a rolling axis in the vertical direction at a size $\Delta x_i = 0,2 \cdot k_n \cdot D_{pi} \cdot \alpha_i^2$, where by D_{pi} − diameter of new working rolls of i-that cage, mm; k_n − repoint coefficient; α_i− an allowed corner of capture for rolls of i-that cage.

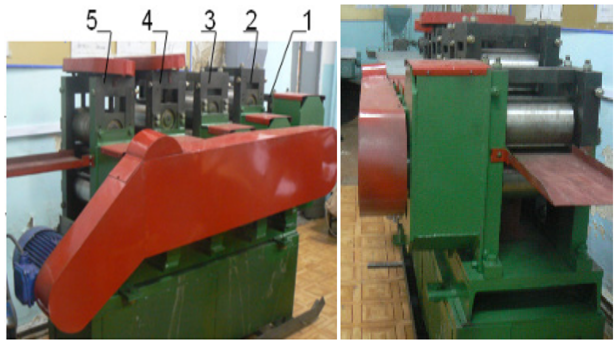


Figure 1. Five cages longitudinally-wedge rolling mill, 1 - Two-roll cage, without the pressure device, 2, 3 - four-high cage, without the pressure device, 4, 5 - four-high cage with a pressure device

It should be noted that the set distance between working rolls from one cage to another increases by advancing size. For the purpose of carrying out complex researches we carried out computer modeling of rolling on an industrial mill of an offered design. Computer simulation of the rolling process, i.e. the study of stress-strain state (SSS) of plates and some heavy-duty elements of the mill stands, is a complex process due to the very large number of governing parameters and the ambiguous nature of their influence [13]. The correct formulation of the problem, even for simple rolling leads to a system of integral-differential equations, to solve which analytically isn't possible. Currently, however, for such tasks is widely used finite element method, implemented in the software products of finite element analysis as MSC.SuperForge and MSC.visual Nastran 4D [13]. The objective of the study surround VAT plate rolling process is the point of contact, elastoplastic, nonlinear, taking into account the temperature mode of deformation, as well as large displacements and deformations. For these purposes use a software product FE analysis of nonlinear, nonstationary processes in metal forming. Calculation of conduct in the volume setting in consideration of the temperature field. Three-dimensional geometric model of relatively thick leaf was built in the CAD program Inventor and imported into the CAE program MSC.SuperForge. When creating the finite element model of a thin slab (table 1) and the roll was used three-dimensional volumetric element CTETRA (industry standard four-node tetrahedron), used for simulation of three-dimensional phone To calculate the VAT used technical description of the proposed work stands enlarged laboratory mill shown in Table 2. In hot strip rolling 1,0 × 200 mm in the continuous 5-cage mill used tackle thickness h0 = 5 mm.

Table 1. The geometric dimensions, the dimension of the finite element mesh and CAM rolled strips

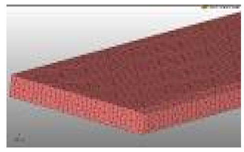
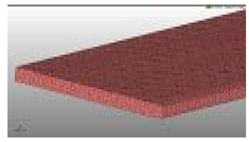
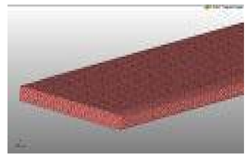
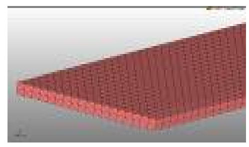
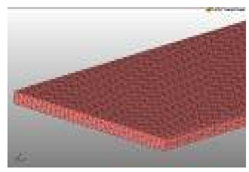
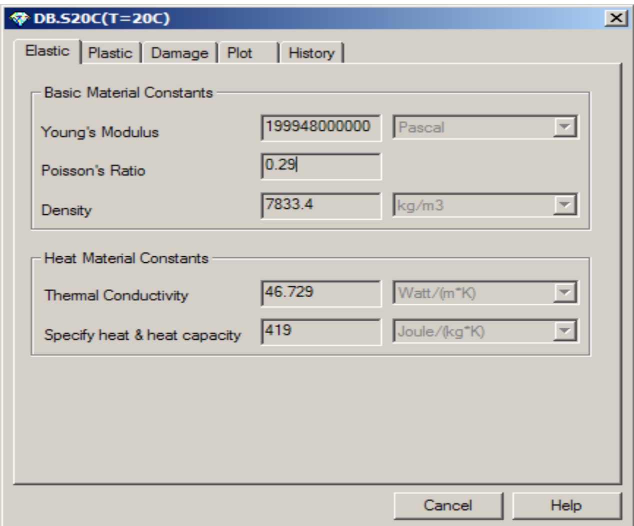
Cage number	geometric dimensions, *a**b mm	Dimension CAM		FE mesh
		quantity of nodes	quantity of elements	
I	5*200	11500	22996	
II	3,5*200	26603	53022	
III	2,485*200	27316	54586	
IV	1,789*200	10474	20944	
V	1,228*200	23824	47550	

Table 2. Technical characteristics of the working stands

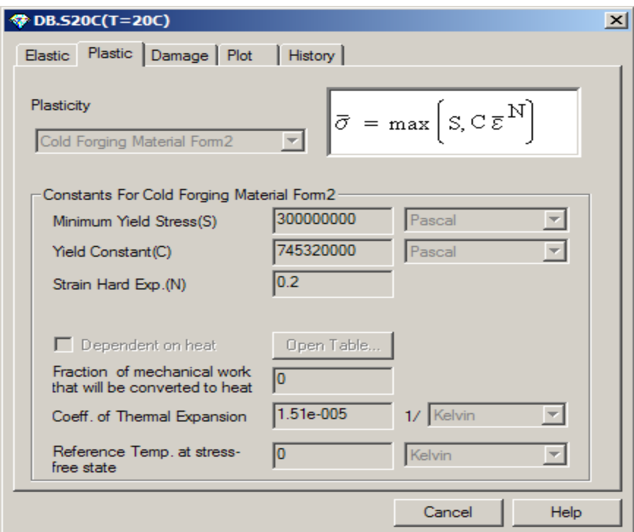
Parameters		Cage number				
		I	II	III	IV	V
Distance between cages, м		0,3	0,3	0,3	0,3	0,3
Diameter of rolls	D_r, mm	150	125	100	75	50
	D_{leg}, mm		75	100	125	150
Rolling speed, υ_r, m/s		0,5	0,67	0,92	1,45	2,03
Frequency of turns of working rolls, t/m		63,6	102,4	175,8	369,4	775,8
Thickness before rolling, h_0, mm		5,0	3,5	2,5	1,8	1,3
Thickness after rolling, h_1, mm		3,5	2,5	1,8	1,3	1,0
Absolute compression, Δh, mm		1,5	1,0	0,7	0,5	0,3
Relative compression: $\varepsilon=\Delta h / h_0$		0,3	0,29	0,28	0,28	0,23

To reduce computational costs and reduce dimensionality of the finite element model, it is necessary to reduce the length of rolled strip on the value of approximately (0,3 - 0,5)x b mm, where b is the width of rolled strip. This simplification allows to simulate the rolling process on a steady level without very expensive. Calculation time of the rolling process in each cage was 30 minutes on the computer Pentium Duo c speed 3.4 GHz 2 Gb. In the MSC.SuperForge tools are absolutely rigid and provide only the properties of thermal conductivity and heat transfer, thermal conductivity, specific heat and density are taken into account, and mechanical properties are ignored. Material from the database assign tool material Steel. For this material density and thermal properties of the program appointed by default.

Interaction between deformable material and workpiece set is modeled using the contact surfaces, which describe the contact conditions between the surfaces of the rolls and the surface of the plate. In the modeling process, contact conditions are continuously updated to reflect roll and deformation of the material, which allows to simulate slip between the roller and the workpiece material. Contact between the roller and thick plate is modeled friction on the Pendant, the coefficient of friction was adopted to 0.3. From the database of the rolled strip appointed material S20C (steel 08KP standard CIS), which has the following characteristics:



Elastic characteristics:



Plastic characteristics

Temperature during rolling consists of the exchange of heat between the roller is developed, a thin slab and the environment, as well as from heat effect due to deformation. The rolling process takes place at room temperature, so the initial temperature roller took equal 200 c. The working cage proposed a rolling mill is a multiple-machine that includes a rotating mill rolls, bearings, bed rolls, mechanisms, adjusting device and other components and parts. Constructing such a machine is a very difficult and time-consuming process that requires a large amount of calculation and graphic works.

In view of the above, the methodology for calculating implemented using finite element analysis program MSC. visualNastran4D. Computer simulation system of the visualNastran4D allows the MSC. study kinematics, dynamics of mechanisms with the ability to calculate the stress-strain and heat conditions, as separate links, and machinery in General.

In the design of the work stands among MSC.visualNastran4D, we performed the following operations:

- The creation of a geometric model of each part and assembly components work stand;
- Choice of materials and parts, mechanical and physical properties (modulus of elasticity, mass density, poisson's ratio, tensile strength etc);
- Generation of kinematic and static boundary conditions;
- The creation of a finite element grid details;
- Determination of the stress-strain state;
- Evaluation of the elastic deformations and stresses of every detail on the required stiffness and strength criteria and the introduction of corresponding changes to the design of the mill (the solid model of the machine).

The source data for the calculation of the solid geometry of the structure are the mill docking and power conditions attached to it, as well as the conditions of the pairing of kinematic pairs design stands.

Three-dimensional geometric model of the assembly of the mill was built in the CAD program Inventor, and by means of built-in translator imported into the environment MSC.visualNastran 4D with accepted kinematic constraints. This approach allows to improve the communication stage of the automatic design of complex mechanisms. To enable automatic adjustment of the model geometry mill was used parameterization geometric dimensions the structure. This method allows for the calculation results on the strength, to make appropriate modifications to the instrument.

In a preliminary analysis of the mill, based on the condition of symmetry of the design elements, as well as to simplify the design scheme, were taken to the calculation of the most loaded Structures - rollers, chromed, crates and neck rolls.

Kinematic relations between elements were simulated kinematic pairs of rotating and sliding to the General pairing surfaces. Take account of the impact and friction in rolls, stands, etc.

In order to determine the effect of rolling temperature on the elastic deflection and a flattening of the work rolls in rolling in the new mill is necessary to determine the intensity of the stress and strain and temperature field, arising at rolling in deformable band. To do this, vary initial temperature of rolling. Therefore, the initial temperature of the workpiece is assumed to be: 1200, 1100, 1000°C.

The results obtained by calculation in hot rolling (temperature 1200°C) profile 1.0 ′ 200 mm steel 08kp, tested on the semi-industrial mill. For rolling billets used of 4.2 × 200 × 500 mm. For bands with specified thickness, profile and tablet form made the adjustment solution rolls on adjustable stands using pressure mechanism. To obtain thin strips with the minimum thickness variation produced a decrease of relative reductions in the penultimate and last stands of the new mill, rolling was produced according to the following regime: 1 crate: ε = 22%; 2 stand: ε = 20%; 3 stand: ε=20%; 4 crate: ε = 10%; 5 crate: ε = 5%. In the laboratory, the strip flatness defects and variation in thickness was measured at the location of the free list in the control table with an ultrasonic thickness gauge "VZLET UT."

3. Results and Discussion

The process of rolling in the proposed mill, can be divided into four stages. So, for clarity, display the results of calculation of the data was taken for the four stages of deformation, i.e. were selected the following stage of rolling: first t = 0.01, the second t = 0,02, the third t = 0.03 and fourth - t = 0,04 stage (t - rolling mill with).

On the basis of the results of numerical simulation found that by rolling all the stands of the new mill intensity of the stresses and deformations are concentrated in the contact zone of the rolls with a deformable strip. Thus in these areas the temperature rises up to 250 to 350°C.

Figures 2 - 4 shows the results of calculation of effort, equivalent stress, deformation and total displacements of the rolls in rolling in the new mill in various directions of axes of coordinates x, y, z (in the direction of x-axis coincides with the axis direction of rolling) if the initial temperature of processing 1200°C. Valid values of the equivalent stresses, deformation and total movements are in digital form on the corresponding color plots. From these figures it is clear that when the nonstationary stage in all directions deformable strip rolling force is increasing, and under steady-state stage band deformed with a constant force.

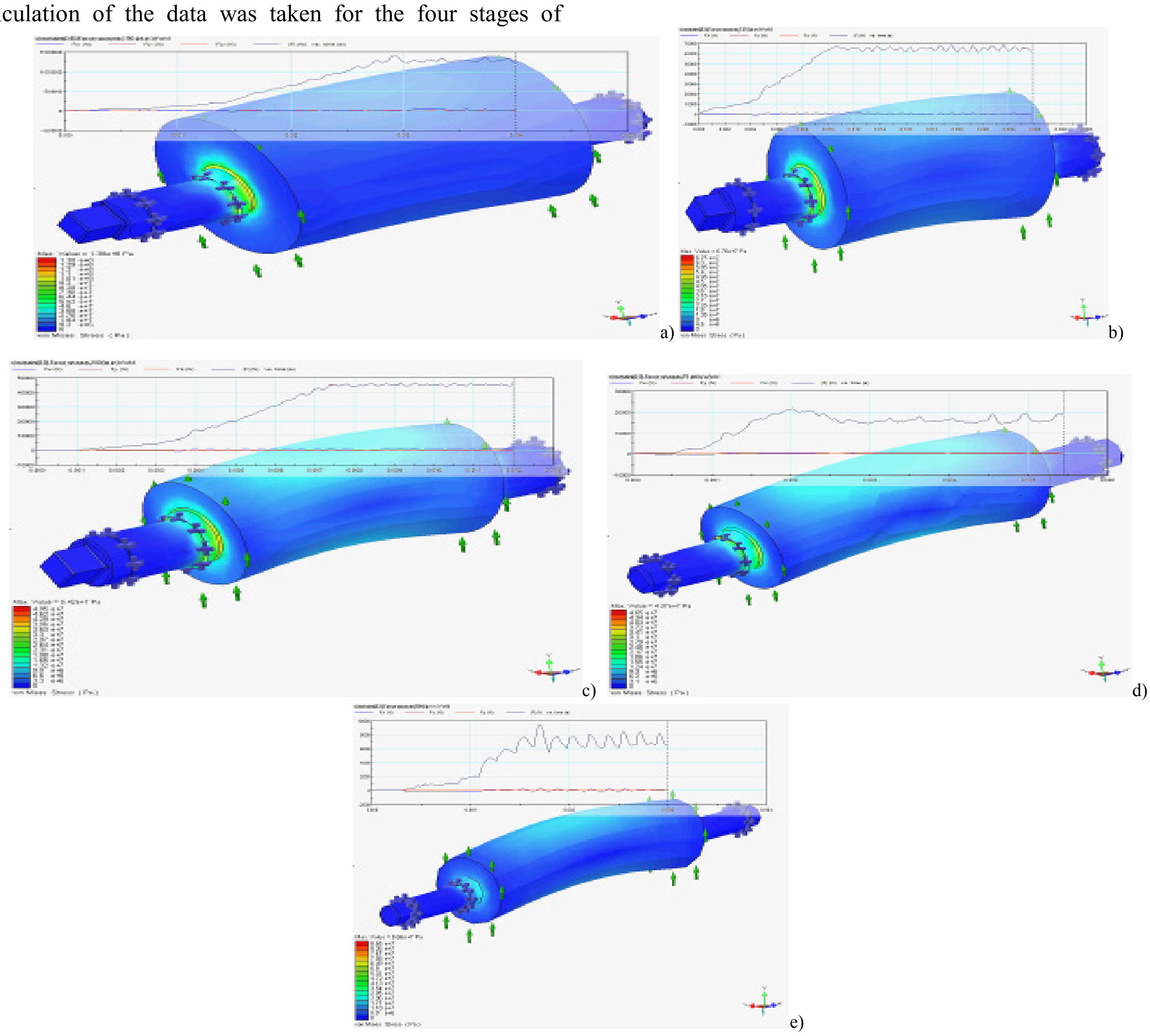


Figure 2. Distribution of equivalent stress rolls first (a), second (b) third (C), fourth (d) and the fifth (e) stands for a new mill (initial temperature rolling 1200°C)

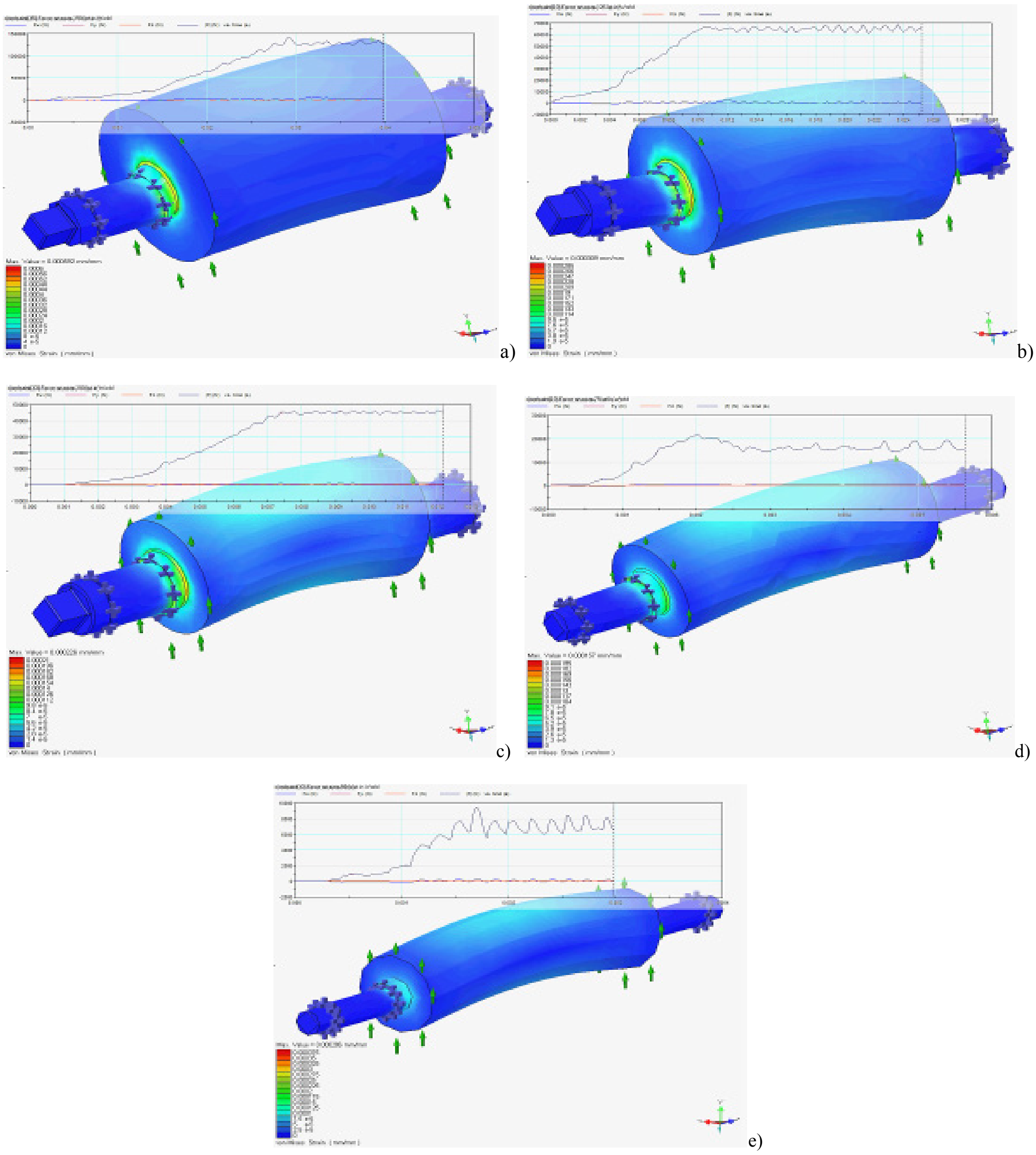


Figure 3. Distribution of the equivalent deformations rolls first (a), second (b) third (c), fourth (d) and the fifth (e) stands for a new mill (initial temperature rolling 1200°C)

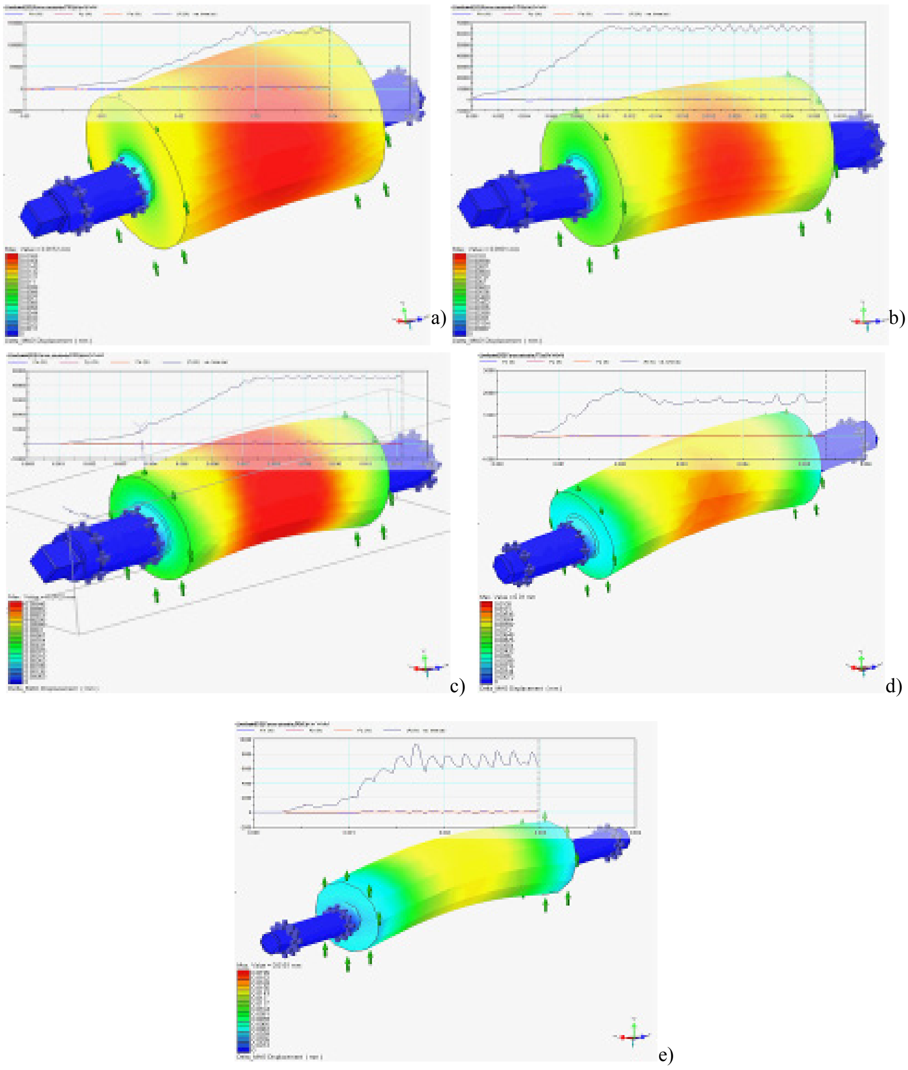


Figure 4. Distribution of the total displacements of the rolls first (a), second (b)third (c), fourth (d) and the fifth (e) stands for a new mill (initial temperature rolling 1200°C)

Calculations made on the finite-element models, have shown that:

- Irrespective of the rolling temperature maximum effort arising in the direction of the y-axis, i.e. In the vertical direction, leads to maximum elastic displacement (bending) in the same direction of rolling;
- When all the initial temperatures rolling greatest effort arising in the direction of the roll axis, i.e. The x-axis, leading to the emergence of symmetric largest elastic displacement of the material rolls in the edges of this instrument;
- Regardless of the initial temperature of the rolling concentration maximum efforts, emerging directions in the roll axis (i.e. Z-axis) on the edges of rolls in a checkerboard pattern lead to the appearance of maximum elastic displacement of the material rolls in these same places tool;
- If the initial temperature of rolling 1000°c roll force decreases from one stand to another and is: 250000 n; 160000 n; 94000 n; 57000 n; 36000 n respectively to the first, second, third, fourth and fifth stands;
- Processing at the temperature of rolling 1100°c also leads to reduction of rolling forces from one stand to another and is: 190000 n; 110000 n; 67000 n; 42000 n; 28000 n respectively to the first, second, third, fourth and fifth stands;
- The initial temperature of processing 1200°c also leads to reduction of rolling forces under the direction of rolling and is: 150000 n; 70000 n; 45000 n; 20000 n; 10000 n respectively to the first, second, third, fourth and fifth trains (figures 2 and 3);

At a temperature of rolling 1000°c maximum equivalent stresses in a barrel rolls are 8,56 e+7 pa, 4,185 e+7 pa, 4,092 e+7 pa, 4,96 e+7 pa and 7,552 e+7 pa for the roll necks - 3,232 e+8 pa, 15,84 e+7 pa, 11,616 e+7 pa, 10,912 e+7 pa and 9,735 e+7 pa respectively at rolling in the first, second, third, fourth and fifth stands of the proposed mill;

- Rolling at temperature 1100°c leads to the appearance of the maximum equivalent stress in the barrel rolls, equal 6,624 e+7 pa, 3,24 e+7 pa, 3,035 e+7 pa, 3,72 e+7 pa and 5,192 e+7 pa, and in the neck rolls - 2,424 e+8 pa, 11,385 e+7 pa, 7,986 e+7 pa, 8,184 e+7 pa and 6,785 e+7 pa respectively at rolling in the first, second, third, fourth and fifth stands of the proposed mill;

At a temperature of rolling 1200°C maximum equivalent stresses in a barrel rolls are 2,76 e+7 Pa (figure 2), 1,35 e+7 Pa, 1,32 e+7 Pa, 1,55 e+7 Pa and 2,36 e+7 Pa for the roll necks - 1,01 e+8 Pa (figure 1), 4,95 e+7 Pa, 3,63 e+7 Pa, 3,41 e+7 Pa and 2.95 e+7 Pa respectively at rolling in the first, second, third, fourth and fifth stands of the proposed mill;

- Received the maximum values of equivalent stress 15,84 e+7 Pa, 11,385 e+7 Pa, 4,95e+7 Pa (see above), do not exceed the maximum that the material values of tensile strength 1,380e+9 Pa;
- Rolls, under the action of applied forces, Flex in the direction of the force and neck rolls elastically deformed in the same direction, and at the temperature rolling 1000°C maximum value equivalent strain is for barrel rolls 0,0000272, 0,00001824, 0,0000231, 0,00001716, 0,00035, as for the roll necks- 0,001452, 0,0006688, 0,0005082, 0,000442, 0,000342 accordingly, the first, second, third, fourth and fifth stands the proposed mill;

At a temperature of rolling 1100°C maximum value equivalent strain is for barrel rolls 0,0000184, 0,00001311, 0,00001617, 0,0000117, 0,000232, as for the roll necks- 0,0009723, 0,000481, 0,000339, 0,000299, 0,00022 accordingly, the first, second, third, fourth and fifth stands the proposed mill;

- Rolling at temperature 1200°C leads to the appearance of a maximum largest equivalent strain (figure 3), which makes up for the roll barrel 0,000008, 0,0000057, 0,000007, 0,0000052, 0,0001, as for the roll necks- 0,00044, 0,000209, 0,000154, 0,00013, 0,0001 accordingly, the first, second, third, fourth and fifth stands the proposed mill;
- The distribution of the total elastic displacement in three directions consistent with a deformed form of rolls;
- At a temperature of rolling 1000°C maximum value of moving is for the middle part of the rolls 0,0528, 0,0291, 0,0293, 0,0294 and 0,0458 mm, and for the roll necks- 0,0212, 0,013, 0,00315, 0,0102, 0,00845 accordingly, the first, second, third, fourth and fifth stands the proposed mill;
- Rolling at temperature 1100°C leads to the appearance of maximal largest displacement of rolls, which for the middle part of the rolls are: 0,03828, 0,01998, 0,02183, 0,0225 and 0,03289 mm, and for the roll necks;
- 0,01518, 0,008442, 0,007245, 0,005014, 0,00572 respectively the first, second, third, fourth and fifth stands the proposed mill;
- The maximum value of the displacement at a temperature of rolling 1200°C is (figure 4) for the middle part of the rolls 0,0165, 0,00938, 0,00945, 0,00936 and 0,0143 mm, and for the roll necks- 0,0066, 0,00402, 0,00315, 0,00218, 0,0026 accordingly, the first, second, third, fourth and fifth stands the proposed mill;
- In the last rolling mill stands proposed, particularly for rolling phase transient increases resonant vibration is accompanied by variations in the rolled strip between the cage intervals. The growth time of the amplitude of vibration in the transient stage is 1 - 2. However, the steady stage, the rolling process is stabilized, which prevents breakage and increases the accuracy of the strip produced strip.

In general, the amount of elastic deformation, and moving elements of the rolls at an initial rolling temperature 1200°C low, which indicates a high rigidity roller assembly work stand. This guarantees a lateral variation in thickness and flatness of the rolled strips within the required tolerances. In our opinion, the initial rolling temperature of 1000 and 1100°C compensation move a roll the last stand of the new mill can be done by increasing the convexity of the work rolls at each new filling. Thus, with the filling of a new set of work rolls, they need to be prepared with profiling 0.03 - 0.05 mm.

Analysis of the transverse strip thickness variation, laminated on a semi-industrial camp, showed that the smallest possible value for the strips of thickness of 1,0 mm is in the range from 0,018 0,008 mm Average value of the transverse strip thickness variation is 0,012 mm.

Transverse thickness of the strips, rolled on the investigated the camp, meets the requirements of standards on 100% of the length of the band, except for the end-areas (98%).

Statistical study of the flatness of rolled strips for the proposed continuous mill showed that the average value of the amplitude flatness defects is 2.2 - 3.4 mm, and decreases as the thickness of the rolled strips.

4. Conclusions

1. To control the variation in thickness and flatness, as well as efforts to reduce rolling from one cage to another in the rolling direction of design of a new longitudinal wedge rolling mill;
2. To modeling VAT blank and bending rolls proved that when rolling thin strips on the new mill by reducing the pressure decreases rolling elastic deflection rollers and, consequently, reduced transverse unevenness and improved flatness of rolled strip;
3. Held rolling thin strips on a new semi-industrial camp and shown that the application of the new hot-rolling mill in the industry to reduce cross-gage strips;
4. It is proved that the amount of elastic deformation, and moving elements of the rolls at an initial rolling

temperature 1200°C low, which indicates a high rigidity roller assembly work stand.

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