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Comparative analysis of stress-strain state of rolls of rolling stand of cold reducing mill

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Abstract
The results of a complex analysis of the stressed-strain state of the rolls of the working stand of cold-pilger reducing mills (CRM) equipped with grooves in the form of half-discs and ring dies using information technologies and the finite element method are presented. A comparative analysis of the stressed-strain state of the working stand rolls of domestic CRMs is performed. It has been established that when rolling pipes of improved quality from hard-to-deformed steels and alloys, in view of the optimal stress-strain state and a significant increase in the rigidity of the roll-groove system, it is advisable to use rolls with ring dies in combination with a working stand of rational design on all types of CRMs of all sizes.
Keywords: PIPE, CRM, ROLLING FORCE, WORKING STAND, GROOVE, ROLL, BED, BEARING, STAND, STRESSES, ELASTIC DEFORMATION, RIGIDITY

Introduction

The competitiveness of domestic pipe-rolling enterprises under the conditions of modern production of cold-rolled pipes is mainly supported by high quality of the products. Pipes of high quality obtained by the method of cold-pilger rolling (CRM) are used in such branches as nuclear power engineering, aircraft building, chemical production, etc. At the same time, along with others, from an economic point of view, the important role is played by the cost of cold-rolled pipes, which directly depends on the costs of carrying out current and major repairs of CRM. Consequently, the parameters of the cold-rolled pipes production depend on the operating conditions and reliability of the individual base units of the CRM in general.

Due to the fact that in a number of domestic enterprises, there are technological lines producing cold-rolled pipes, where the work is carried out on obsolete equipment with CRM (the operational life of OAO "EZTM" design mills is more than 50 years), the issues of complex modernization of mills and technologies for cold-pilger rolling of pipes are relevant.

In turn, in view of both the moral and physical wear and tear of the basic technological equipment, the majority of CRM do not provide the expected quality indicators of finished pipes and do not open the world-known opportunities for producing high-accuracy cold-rolled pipes by implementing modern technical solutions and innovative technologies.

Problem statement

Proceeding from the foregoing, in the production part of the task the question on the improvement of the critical components of the main equipment and auxiliary components of the working stand of the CRM associated with the implementation of modern production technologies for high-quality thin-walled and extra-thin-walled cold-rolled pipes is raised.

It should be noted that during the implementation of CRM processes along with others, there appears an elastic deformation of the working stand elements, which have certain weights and rigidity. This system of interrelated deformations, generally called the "stand spring", in turn, is formed by imposing deformations of technological tools and other elements of the working stand, which is reflected in the geometric parameters of the wall of the pipe being manufactured. The overall picture of quality and geometry parameters (longitudinal and transverse wall thickness deviation) of finished products do not meet the requirements of existing standards and technical conditions [1 - 6].

It is known that the process of CRM is significantly affected by the elastic deformation of the rolls adjustment of the working stand. During the pipe rolling, the actual dimensions of the groove are composed of the total displacement of the base elements of the working stand such as the housing posts of the working stand, the rolls with grooves, beds with bearings, safeguarding mechanism, pressure mechanism, etc. The influence of the elastic deformation of the rolls adjustment and the elements of the working stand is appropriately taken into account when grooving the technological tool (groove and mandrel) [7].

The results of complex experimental studies and a description of the operational experience of working stands of CRM 32, CRM 55 and CRM 75/90 designs of OJSC "EZTM" are presented in [1, 2]. Studies have shown that the movement of the basic elements of the mill stands of CRM 32, CRM 55 and CRM 75/90, which form their total rigidity (spring), depends quasilinearly on the rolling force and only the movement of the safeguarding mechanism of working rolls varies nonlinearly.

The picture of the complete deformation of the working stand of the CRM varies depending on the arrangement of its elements. The presence of screw-down gear embedded in the wedge of the safeguarding mechanism of the working rolls significantly complicates this picture.

It should be noted that when using a safeguarding mechanism in the working stand, the deformation parameters of the system under consideration in general vary in a nonlinear way. Consequently, without the safeguarding mechanism, the rigidity parameters of the system are changed according to a quasilinear law. From experience of operation of installation of the rolls of the CRM 32, it can be seen that the share of strain indices in the overall picture of the spring of the working stand is approximately 17-18% [1, 4].

It is characteristic that the reliability of the functioning of the working stand of the CRM and the limited durability of the rolls mounting parts is largely determined by the strength indices of the rolls themselves. In most cases, the strength indicators of the roll adjusting elements are constraining factors when rolling thin-walled or extra-thin precision tubes from hard-to-deformed steels and special alloys with specified technological properties and the required geometric parameters.

The experience of operating domestic CRM shows that rolls are the critical element of the working stand. They have great compliance and low durability, due to this they are often subjected to destruction.

Figures 1 and 2 show the typical destruction of the rolls of CRM 32 and CRM 75, which are taken out of service due to the long-term work and imperfect of their design.

The *objective* of the work is development of rational technical solutions for the improvement of the rolls adjustment design of the CRM.

Method for solving the problem

Analytic methods and numerical methods for calculating working rolls of various models of domestic CRM for strength and rigidity are known [4, 5]. However, the results of these calculations are significantly different from actual operation indicators, in view of the impossibility of taking into account the influence of a number of external factors, the nature of the formation of the technological load and other process indicators on the features of the CRM operation.

In the study of basic technological equipment, both fundamental theoretical methods are used, which include mathematical modeling of the object under consideration, and physical modeling based on direct investigation of the object itself or a model similar to it [6].

Figure 1. The destroyed bottom roll of the rolls adjustment of CRM 32

It should be noted that with the development of modern information technologies in the study of complex machines and mechanisms that combine the advantages of fundamental methods in computer simulation (for example, the finite element method), it became possible to visualize the real state of the object under study in conditions as close as possible to the actual ones.

Figure 2. The destroyed bottom roll of the CRM 75 working stand

In [7], using computer simulations, the authors carried out a study of the roll of the CRM 32 for adjusting the groove in the form of a half-disk. The results of the stress-strain state of the roll in this paper are presented only in the deformation indices in one working position of the roll. Evaluation of the stress-strain state and strength characteristics of the roll, the rolls adjustment depending on the angle of its rotation is not carried out, which in many respects is the main factor in determining the indices of its strength and deformation.

For the expansion of the technological capabilities of the CRM of OOO "NPF Vostok Plus", the installation of rolls with annular grooves adapted for the existing design of the working stand frame for rolling thin-walled and extra-thin-walled pipes from highly plastic materials (for example, titanium and special alloys) has been developed and implemented.

Experiments with the operation of domestic CRM 32 mills show that when using a working stand of the rational design of OOO "NPF Vostok Plus" and a roll adjustment with ring dies, the rigidity of the entire mechanical system is repeatedly increased and the stresses in dangerous zones are stabilized. The high accuracy of the geometric dimensions of the finished pipes is achieved due to the use of the installation of rolls of constant rigidity with ring dies.

The use of a working stand rational in the arrangement of a roll installation with ring dies at the CRM 32 mill of "PO "OSKAR" resulted in a decrease in both the longitudinal and transverse wall thickness deviation in the pipes [4, 5].

Increasing the reliability of roll operation can be ensured by eliminating all zones of dangerous stresses concentrators on the working roll and optimizing the design of the rolls installation.

To carry out the complex of visualized computer studies, the software product Solid Works 2015 was used, which allowed simulating the working rolls spatially taking into account certain limitations and in the real field of force effects of the workpiece being treated [8].

At the same time, it is possible to load the working rolls that are as close as possible to the real processes of cold-pilger rolling of pipes and according to the characteristic physical conditions corresponding to the mechanical properties of the material of the rolled pipes.

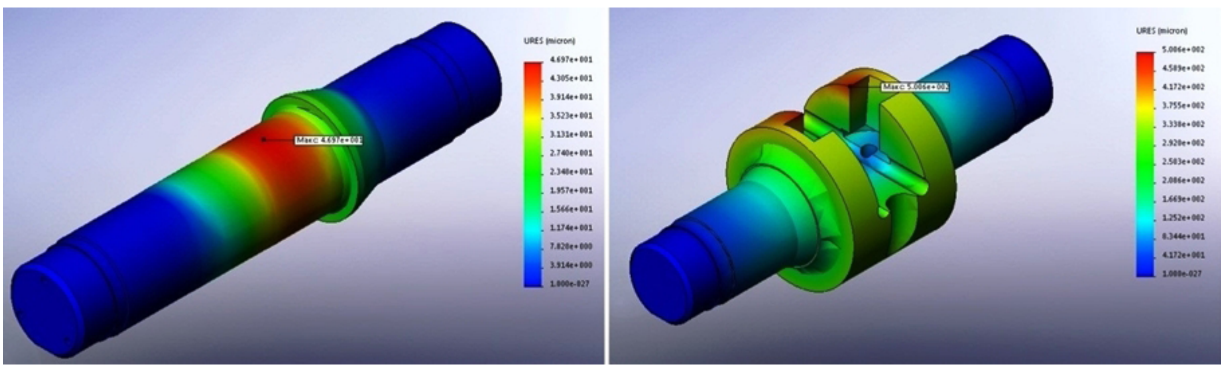
Figure 3 shows the basic components such as of the stresses, deformations and safety margins of working rolls with ring dies (new design) and rolls with grooves in the form of half-discs (old design) for the CRM 32.

These figures show the stress-strain state of working rolls at the positions of maximum stresses. Angle of rotation for rolls with grooves in the form of half-discs in this case corresponds to 12 degrees.

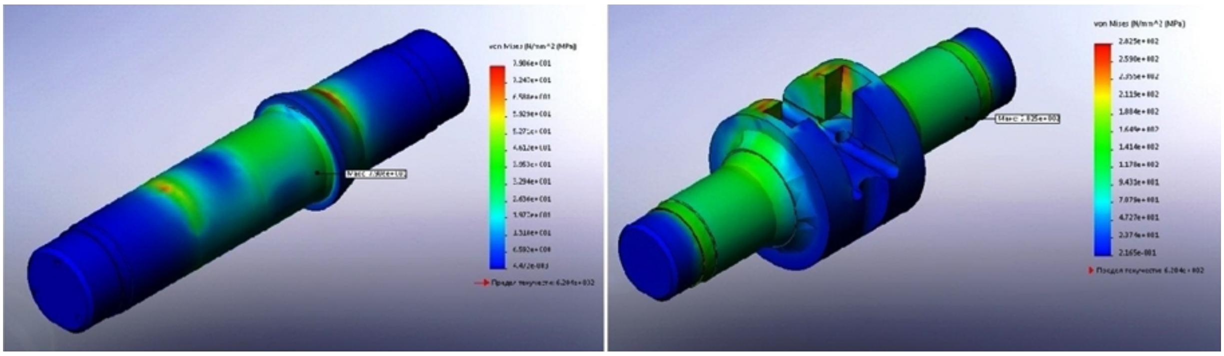
Numerical results of studies for rolls installation of the following mills CRM 32, CRM 55 and CRM 75/90 are given in Tables 1, 2, 3 and 4.

Table 1. The results of the study of the CRM 32 roll with grooves in the form of a half-disk (old design) when loaded with a pipe rolling force of 0.5 MN

Plane of force application	Rotation angle, degree															
	12	24	36	48	60	72	84	90	102	108	120	132	144	156	168	
Lower, micron	348	331	300	255	200	134	64	33	64	134	200	255	300	331	348	min
	175	164	146	122	93	61	32	30	32	61	93	122	146	164	175	av
	81	75	67	55	41	24	7	27	7	24	41	55	67	75	81	max
Side, micron	500	468	416	345	260	163	60	14	60	163	260	345	416	468	500	min
	333	297	278	220	166	105	42	14	42	105	166	220	278	297	333	av
	170	160	143	120	91	59	26	13	26	59	91	120	143	160	170	max
Stresses, MPa	283	264	233	193	144	105	72	63	72	105	144	193	233	264	283	



a)



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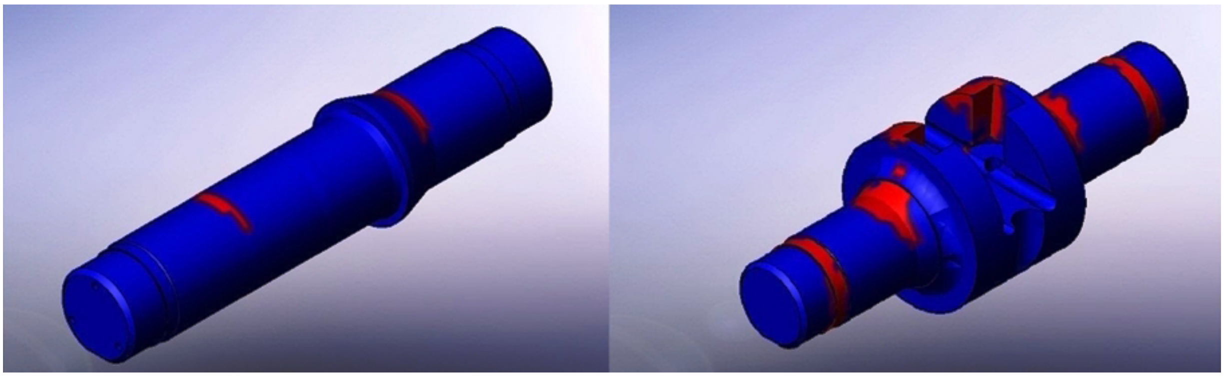


c)

I II

Figure 3. The stressed-strain state of the rolls of CRM 32: I - in the rolls of rolls installation with ring dies (new design); II - in rolls with groves in the form of half-discs (old design):
a - displacement, b - stresses, c - safety margin

Table 2. The results of studies of the CRM 55 rolls with grooves in the form of half-discs (old design), when loaded with the pipe rolling force of 1MN

Plane of force application	Rotation angle, degree															
	12	24	36	48	60	72	84	90	102	108	120	132	144	156	168	
Lower, micron	481	461	420	361	286	200	103	61	103	200	286	361	420	461	481	min
	248	192	172	144	113	78	51	50	51	78	113	144	172	192	248	av
	43	40	35	28	21	11	3	43	3	11	21	28	35	40	43	max
Side, micron	500	468	416	345	260	163	60	14	60	163	260	345	416	468	500	min
	333	297	278	220	166	105	42	14	42	105	166	220	278	297	333	av
	170	160	143	120	91	59	26	13	26	59	91	120	143	160	170	max
Stresses, MPa	863	810	722	602	456	290	150	144	150	290	456	602	722	810	863	max

Table 3. The results of the studies of the CRM -90 rolls with grooves in the form of half-discs (old design) when loaded with the pipe rolling force of 2MN

Plane of force application	Rotation angle, degree															
	12	24	36	48	60	72	84	90	102	108	120	132	144	156	168	

Lower, micron	603	580	530	458	365	257	137	90	137	257	365	458	530	580	603	min
	306	287	257	181	142	101	74	73	74	101	142	181	257	287	306	av
	51	48	42	35	26	11	6,6	60	6,6	11	26	35	42	48	51	max
Side, micron	931	870	772	640	480	300	107	26,7	107	300	480	640	772	870	931	min
	532	500	476	370	279	176	69	25	69	176	279	370	476	500	532	av
	221	210	188	160	123	83	42	23,6	42	83	123	160	188	210	221	max
Stresses, MPa	1197	1119	990	820	613	380	138	120	138	380	613	820	990	1119	1197	max

From the calculation, it follows that for rolls with ring dies, the stresses do not depend on the roll rotation angle.

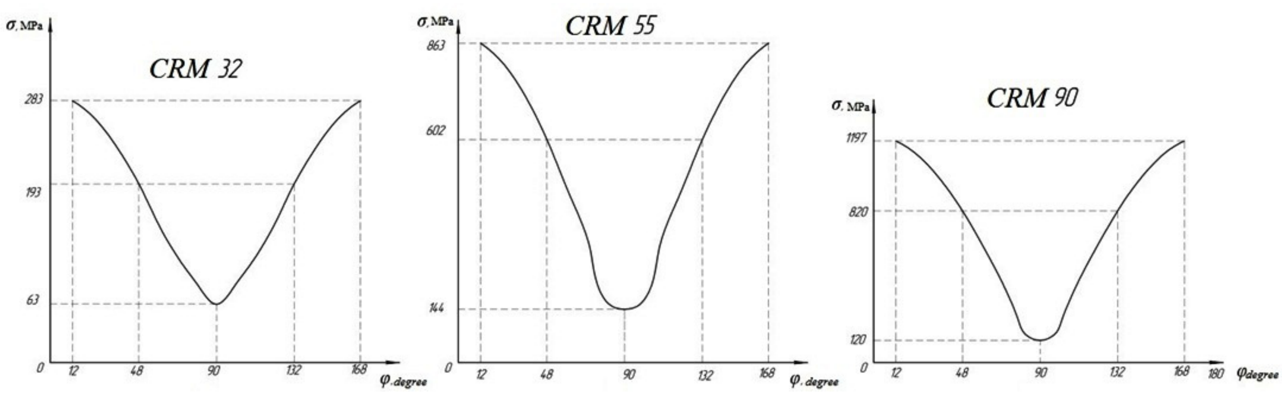
From the patterns of the stressed-deformed state of the rolls, it can be seen that the rolls of the old design have a lower safety margin in comparison with the rational design roll. In addition, the characteristic zones of stress concentration coincide with the places where further destruction of rolls with half-disk grooves occurs similarly to Fig. 1, 2

Table 4. Maximum values of stresses and displacements in working rolls of CRM with ring dies

	CRM 32 (0.5 MN)	CRM 55 (1 MN)	CRM 90 (2 MN)
Stresses, MPa	79	162	184
Displacements, micron	47	72.5	90

Considering the fact that the rolling force on rolls of the old design was applied along mutually perpendicular planes, the graphs of the resulting displacements (deflections) of the rolls were obtained depending on the angle of their rotation (Fig. 4).

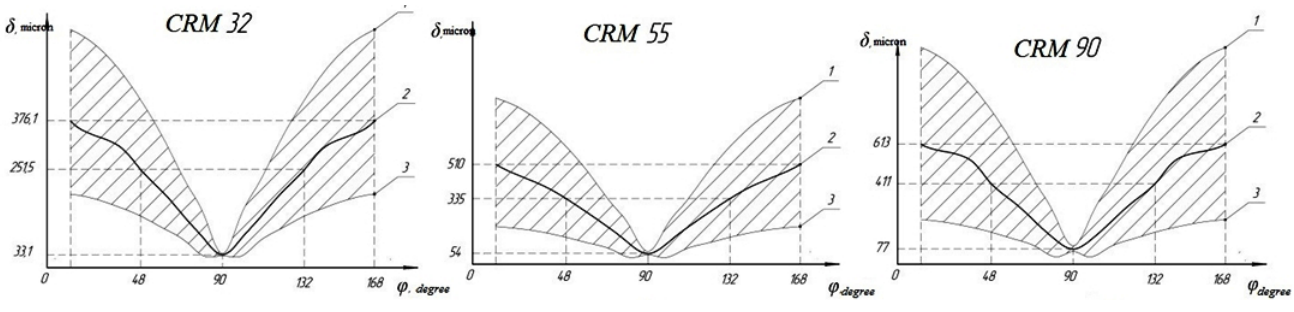
Analyzing the results of Tables 1, 2 and 3, the graphs of dependence of the stresses in the rolls on the roll rotation angle were plotted (Fig. 5).



a) b) c)

Figure 4. Graphs of maximum stresses in working rolls of CRM with half-disk grooves depending on the angle of rotation of the roll: a – CRM 32, the rolling force applied to the roll was 0.5 MN; b – CRM 55, rolling force applied to the roll was 1 MH; c – CRM 90, force applied to the roll was 2 MN

In Fig. 5 zones of possible deformation of the rolls are highlighted by hatching. It can be seen from the figure that in the course of the roll operation, the rolls with grooves in the form of half-disks with a conditionally constant force action from the treated pipe and the basic indices of its deformation are changed due to a change in its rigidity. It is minimal in the extreme positions of the roll. It is established that the stresses arising during the mill operation are also variable, and in the extreme positions of the working stand they are maximum, in the middle position they are minimal. When rolls are rolled along the pipe rolling course and back of the rolling course, the stresses in the rolls are changed alternating, which in time causes fatigue failure in the dangerous sections of the rolls and the elements of the CRM working stand, which are interconnected with the rolls.



a) b) c)

Figure 5. Graphs of maximum displacements in working rolls of CRM with half-disk grooves depending on the roll rotation angle: a – CRM 32, force applied to the roll was 0.5 MN; b – CRM 55, force applied to the roll was 1 MN; c – CRM 90, force applied to the roll was 2 MH: 1 - curve of the maximum roll displacement; 2 - curve of roll average displacement; 3 - curve of minimum roll displacement

Conclusions

As a result of simulating the rolls of the CRM working stand using information technology and performing finite element calculations, the following results were obtained, which showed the advantages of installing rolls with ring dies over rolls with grooves in the form of half-discs:

1. Stresses in the rolls of the rolls installation of CRM with ring dies (new design) are not changed depending on the roll rotation angle and are constant in their numerical value.

2. Stresses in the rolls of the rolls installation of CRM with ring dies (new design) are much lower than the stresses in rolls with grooves in the form of half-discs (old design) due to the simplicity of construction and the absence of stress concentrators.

3. The rigidity of the roll of the rolls installation of CRM with ring dies (new design) is constant and does not depend on the angle of rotation.

4. Rigidity of rolls with grooves in the form of half-discs is variable and varies depending on their angle of rotation, which in turn (the inconsistency of the roll stiffness) affects the stand spring and, as a consequence, the quality of the pipes produced.

5. Investigations of the stress-strain state and analysis of the strength indices showed that the rolls of the rolls installation of CRM with ring dies have a higher safety margin in the dangerous sections and stress concentration points with respect to the rolls of the old design.

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