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USE OF FINITE-ELEMENT MODELING TO IMPROVE THE PIERCING OPERATION ON A PIERCING MILL

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The authors evaluate the degree of agreement between results obtained from piercing continuous-cast semifinished products on a cross-rolling piercing mill and the indices of this process determined by finite-element modeling. New piercing-mill equipment has been developed to make thin-walled hollows. Computer software is used to evaluate the optimality of the mill's settings.
Keywords: *continuous-cast semifinished product, cross-rolling piercing mill, thin-walled hollow, finite-element method.*

One of the main priorities of the Severskii Pipe Plant at present is to reduce the cost of producing the pipes that it makes. The company's success in achieving this goal will depend largely on the efficiency of the manufacturing technology used at the plant and the amount of time needed to successfully introduce new products.

In order to make new products, the plant is rebuilding the cross-rolling piercing mill (made by the Elektrostal Heavy Engineering Works, EZTM) it uses to obtain hollows and is also installing an FQM mill in pipe-rolling shop No. 1. However, it is difficult to conduct experiments on the piercing mill because it is currently being run at its maximum allowable load. Thus, as is done at most companies in Russia and abroad, we decided to use recently developed computer programs that make it possible to accurately model the deformation of metal and the stress and strain distributions in semifinished products undergoing deformation and production equipment (rolls, mandrel, and guides) that is subjected to substantial loads.

The use of such systems is especially important for the Severskii Pipe Plant because of the ongoing reconstruction of its pipe-rolling complex.

One of the main objectives in the reconstruction project is to modify the piecing mill so that the hollows can be rolled on a continuous mill.

The following had to be done in order to be able to combine these pieces of equipment:

1) design the pass system of the new mill;

2) select the values of the parameters for making adjustments to the piercing mill; and

3) identify the bottlenecks in the rolling of hollows on the piercing mill in order to ensure that the continuous mill reaches its contractual level of productivity.

To model operations performed in pipe production, the factory acquired a license for the use of the software package QForm 7. This software has proven to be a valuable tool for industry both in Russia and abroad. The following models were constructed in order to evaluate the extent to which the results obtained by using QForm 7 to model the rolling of continuous-cast semifinished products on the piercing mill agree with the actual parameters of this process in the hot-rolled pipe section of pipe-rolling shop No. 1 at the Severskii plant:

1) a model to predict nonstandard situations in the piercing of continuous-cast semifinished products;

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Fig. 1. Band of metal extricated from the drum of the piercing-mill roll.

Fig. 2. Lap formation on the back end of the hollow.

TABLE 1. Geometric Parameters of the Hollow

Method of determination	Distance from the front end of the hollow, mm	Outside diameter, mm (average)	Wall-thickness (mm) at the measurement points (see Fig. 5)											
			0°	45°	90°	135°	180°	225°	270°	315°	min.	max.	av.	difference in wall-thickness
1	500	371.05	61.1	61.2	62.1	63.0	63.5	62.8	63.2	62.4	61.1	63.5	62.4	2.4
2		372.84	61.5	61.1	61.3	62.6	61.7	61.3	61.7	61.7	61.1	62.6	61.6	1.5
1	1100	370.86	62.5	61.5	62.3	62.3	63.3	63.0	63.5	63.9	61.5	63.9	62.8	2.4
2		370.21	61.8	61.4	61.0	61.1	61.6	61.9	63.1	62.6	61.0	63.1	61.8	2.1
1	1700	370.24	63.1	64.0	63.6	63.0	63.1	62.5	62.8	63.1	62.5	64.0	63.1	1.5
2		370.1	62.6	64.0	63.5	62.4	62.8	61.9	62.4	62.5	61.9	64.0	62.8	2.0
1	2300	370.45	62.8	62.7	63.1	63.0	63.4	63.1	62.8	62.2	62.2	63.4	62.9	1.3
2		370.18	62.4	62.4	63.0	62.5	62.9	62.7	62.6	61.7	61.7	63.0	62.5	1.3
1	2900	370.94	62.2	62.0	62.9	63.1	63.0	63.2	62.7	62.6	62.0	63.2	62.7	1.3
2		370.3	61.7	61.5	62.7	62.8	62.6	63.0	62.6	62.2	61.5	63.0	62.4	1.5

2) a model to evaluate the degree of agreement between the geometric parameters of the hollows obtained by modeling in QForm 7 and the hollows obtained on the piercing mill.

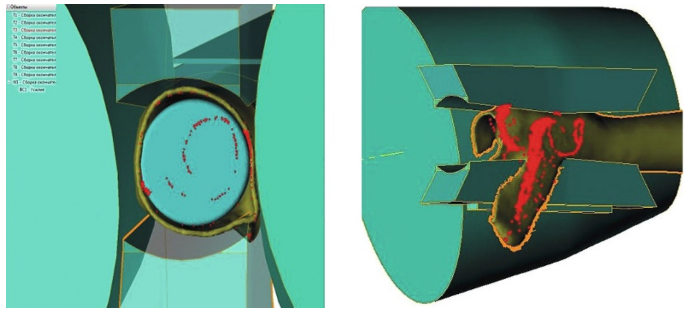


Fig. 3. Destabilization of the profile of the hollow (on the left); formation of the band (on the right).

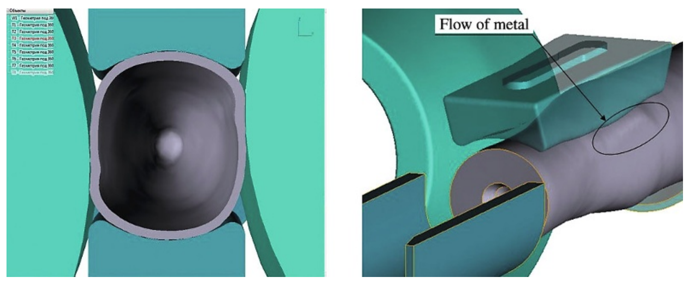


Fig. 4. Buckling of the hollow in the deformation zone (on the left); flow of metal into the gap between the guide and the roll of the piercing mill (on the right).

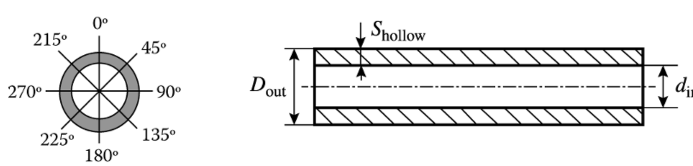
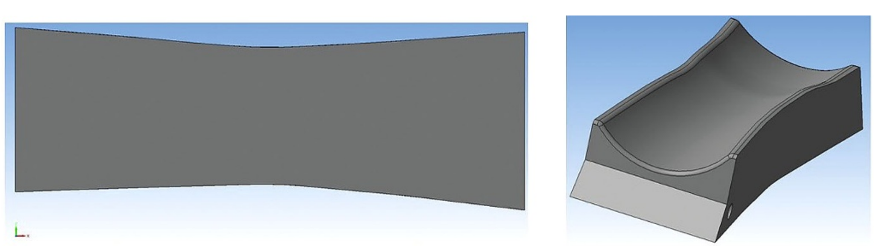


Fig. 5. Scheme used to measure the geometric parameters of the hollows.

a



b

Fig. 6. Newly designed guide for the piercing mill: view from below (*a*); general view (*b*).

It was decided to perform modeling by the finite-element method (FEM) in order to predict nonstandard situations during the piercing of continuous-cast semifinished products and check the level of agreement between the results obtained with QForm 7 and experimental results. Two nonstandard situations were examined in the experiment that was conducted:

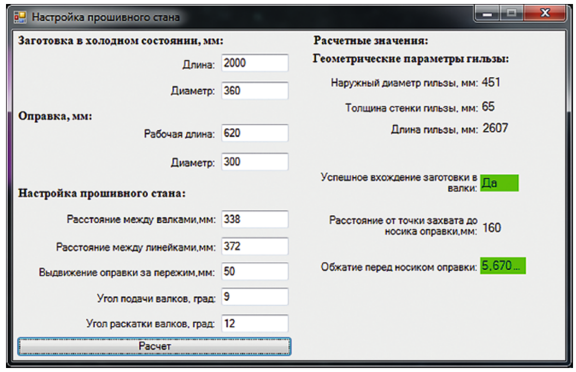


Fig. 7. Adjustment of the piercing mill.

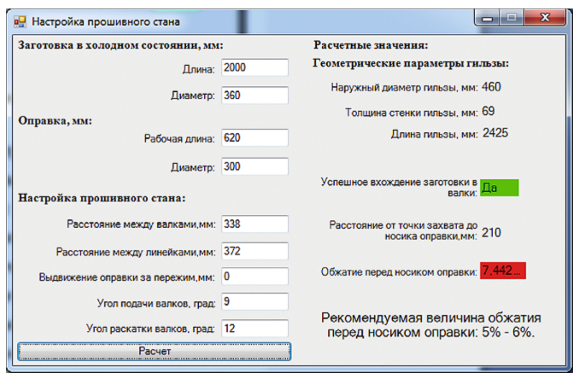


Fig. 8. Piercing-Mill Adjustment window with a suboptimal adjustment of the mill.

1) the formation of a band of metal in the deformation zone of the piercing mill (Fig. 1), which was due to an incorrect choice having been made for the working profile of the mill's mandrel: there was a large gap between the rolls and the guides, in addition to the guides' having had sharp edges.

2) lap formation on the hollow at the end of the piercing cycle (Fig. 2) due to its buckling at the mill's outlet and the flow of metal into the gap between the guides and the rolls; metal flows into the gap in this case because of the excessively large distance between the guides and the rolls.

The three-dimensional modeling system KOMPAS-3D was used to construct a three-dimensional model of piercing-mill equipment whose geometric parameters correspond to the geometric parameters of the equipment installed on the actual piercing mill that was used in the experiment. The completed model was loaded into QForm 7, which oriented the equipment in three dimensions in accordance with the parameter settings of the mill during the experiment and then modeled the rolling operation. The results obtained from the modeling are shown in Figs. 3 and 4.

The modeling showed identical emergency situations, which confirms the reliability of the results that were obtained in predicting nonstandard situations which are encountered when using QForm 7 to master the manufacture of a new type of product.

The next stage of the investigation was to check the degree of agreement between the geometric parameters of the hollows obtained by modeling in QForm 7 and the geometric parameters of the hollows obtained on the piercing mill built by EZTM. To perform this check, we modeled factory tests in which 360-mm-diameter semifinished products were used to obtain hollows with an outside diameter of 370 mm and an inside diameter of at least 245 mm. These dimensions made it possible to use a 239-mm-diam. mandrel to roll pipes 245 mm in diameter.

We constructed a model of the continuous-cast semifinished product and piercing mill equipment whose geometric parameters corresponded to the parameters of the piercing mill used in the experiment. The equipment was oriented in three dimensions in accordance with the parameter setting of the mill during the tests.

The geometric parameters of the hollows were measured by means of the scheme depicted in Fig. 5. The results are shown in Table 1 (method of determination 1 was the method used in the factory tests and method of determination 2 was the method used for FEM modeling of the rolling operation on the piercing mill).

It is apparent from the table that the results obtained by means of the FEM in QForm 7 are nearly identical to the results obtained in the factory tests:

• the difference in mean outside diameter is no greater than 0.5%;

• the difference in wall-thickness is 2.0%.

Thus, it has been determined that there is a high degree of agreement between the experimental results and the finite-element model constructed in Qform 7. The next step in making use of FEM modeling system that was acquired was to design and make the piercing-mill equipment needed for the continuous FQM mill which is currently being built: the rolls, guides, and mandrels. We developed equipment that makes it possible to obtain thin-walled hollows with the ratio $D/S = 16$ on the piercing mill designed by EZTM. The equipment was not part of the mill's original design. Figure 6 shows one of the guides of the mill, which have an asymmetric profile. The mill is designed to pierce 360-mm-diam. hollows with the use of this type of guide.

During the design of the mill equipment, the dependence of the deformation of the metal in the deformation zone on the mill's settings was determined by varying the following parameters within their working ranges:

• the distance between the rolls inside the gap in the deformation zone;

• the distance between the guides in that gap;

• the feed angle;

• the reeling angle;

• the diameter and working length of the mandrel; and

• the amount by which the mandrel projects past the gap.

These data were used to obtain regression equations for the outside diameter and wall-thickness of the hollows as a function of the mill's parameter settings. The equations were then used to construct a mathematical model with the aid of the program Piercing-Mill Adjustment, which was written in the language C++ (Fig. 7). In addition to determining the geometric parameters of the hollows, the Piercing-Mill Adjustment program makes it possible to also determine other parameters that are important to the production process: successful entry of the semifinished product into the rolls of the piercing mill; the distance from the point where the semifinished product is gripped by the rolls to the nose of the mandrel; the reduction made ahead of the mandrel nose.

In addition to numerical indicators, the program uses color to indicate status – the user will see the program's window when the parameter values exceed the recommended ranges (Fig. 8).

Installation of the program on the piercing mill for use by mill operators has significantly alleviated the formation of internal scabs during the rolling operation.

Conclusion. All the plans that are part of the piercing mill's reconstruction are now first being checked in QForm 7 and are recommended for implantation only after positive results have been obtained from the software's use. Approaching the design of the piercing operation in this manner makes it possible to avoid financial losses during the development of the new mill equipment and approve new operating regimes for the mill before they are permanently introduced.