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Development of profile pipes production technology, providing higher accuracy of geometric parameters compared to foreign manufactures

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Abstract. The method of profiling circular pipes is used in the lines of pipe-electric welding and profiling units in order to master the production of pipe products of non-circular cross-section from corrosion-resistant steel grades. Tubular products used in nuclear power generation facilities have higher requirements to mechanical properties and geometrical parameters. In particular, the most difficult aspect of manufacturing profile pipes-windings for turbo-generator stators with a rectangular cross-section is ensuring the flatness of flanges and achieving the radius of the outer corner rounding within a tolerance of ±0.10 mm relative to the nominal value. In order to successfully master the production of this type of product, a synthesis of the circular pipe profiling scheme was carried out. The authors developed the technology of profiling in drive rolls forming box gauges and in non-driven four-roll stands. Computer modeling of the profiling process was carried out in the Marc Mentat 2021 program. After experimental rolling, the profiles' geometric parameters were analyzed using an optical microscope and special software. Acceptance tests were performed in accordance with the requirements to profile pipes for windings of turbogenerator stators.

Keywords: shaping mill, pipe-electric welding unit (PEWU), profiling technology, outer contour corner radius, concavity of profile flanges, roll-pass design, computer modeling

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Разработка технологии производства профильных труб, обеспечивающей более высокую точность геометрических параметров по сравнению с зарубежными производителями

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Аннотация. Для освоения производства трубной продукции некруглого поперечного сечения из коррозионностойких марок сталей широко используется метод профилирования круглых труб в линиях трубоэлектросварочных и профилировочных агрегатов. К трубной продукции, применяемой в установках генерации атомной энергии, предъявляются повышенные требования к механическим свойствам и геометрическим параметрам. В частности, для профильных труб-обмоток статоров турбогенераторов прямоугольного поперечного сечения наиболее труднодостижимыми являются обеспечение плоскостности полок и получение радиусов наружного закругления углов в допуске ±0,10 мм по отношению к номиналу. Для успешного освоения производства данного вида продукции проведен синтез схемы профилирования круглой трубы. Разработана технология профилирования в приводных валках, образующих ящичные калибры, и неприводных четырехвалковых клетях. Компьютерное моделирование процесса профилирования было выполнено в программе Marc Mentat 2021. После проведения комплекса опытных прокаток авторы проанализировали геометрические параметры профилей с применением оптического микроскопа и специального программного обеспечения. Приемо-сдаточные испытания прошли в соответствии с требованиями к профильным трубам для обмоток статоров турбогенераторов.

Ключевые слова: профилировочный стан, трубоэлектросварочный агрегат (ТЭСА), технология профилирования, радиус угла наружного контура, вогнутость полок профиля, ящичный калибр, калибровка валкового инструмента, компьютерное моделирование

Для цитирования: Мозжегоров М.Н., Машенцева М.С. Разработка технологии производства профильных труб, обеспечивающей более высокую точность геометрических параметров по сравнению с зарубежными производителями. *Известия вузов. Черная металлургия*. 2025;68(1):8–13. *https://doi.org/10.17073/0368-0797-2025-1-8-13*

Research objective

The rapid development of industry is driving continuous increases in the requirements for the performance characteristics of products used in power generation facilities, including nuclear power plants [1]. Today, the uninterrupted operation of many enterprises in the nuclear industry depends on the availability of specific components – profile pipes with defined cross-sections for turbo-generator stators.

To meet the demand for profile pipes from power engineering companies in Russia, specialists at the Pipe Metallurgical Company (TMK) have explored the feasibility of manufacturing the required products.

During the preparatory phase for the production of profile pipes with dimensions of 10.0×3.8×0.9 mm, several challenges arose that prevented the consistent achievement of key quality characteristics [1] when using the drawing method, namely:

– concavity of the profile flanges exceeded the specified technical requirements (Fig. 1, *a*);

– surface defects formed during profiling (Fig. 1, *b*);

– effective radii of the outer corner rounding (measured in accordance with ASTM A554 [2]) exceeded the geometric tolerance requirements.

As part of the study, an analysis of the equipment available at the production site for manufacturing the required products was carried out, and the feasibility of producing welded profile pipes was assessed. Based on the analysis, a fundamental technological scheme for the production process of profile pipes on the PEWU T 30/35 line was developed, and a list of tools and equipment required for upgrading the PEWU was compiled to enable continuous production [3; 4]. The most technologically advanced solution for producing the required range of products is the continuous production of profile pipes from coil stock using the argon-arc welding method for circular pipe billets, followed by heat treatment and profiling to the specified dimensions on the PEWU T 30/35 line.

A preliminary analysis indicated that the successful implementation of continuous welded profile pipe production requires the following additional equipment and tools for the TESA T 30/35 line:

– a bright annealing furnace;

– two non-driven four-roll stands [5];

– roll forming, calibrating, and profiling tools.

Scientific research and technological solutions

To improve the technology under import substitution conditions, it was decided to organize pilot production of profile pipes with dimensions of 10.0×3.8×0.9×4000 mm from circular pipe billets using a semi-continuous process at the existing shaping mill.

To implement the proposed solution, a profiling scheme was designed, the roll-pass design was calculated [6; 7], and computer modeling of the circular pipe billet profiling process was performed [8 – 10]. To assess the performance of the new roll-pass design at the mode-

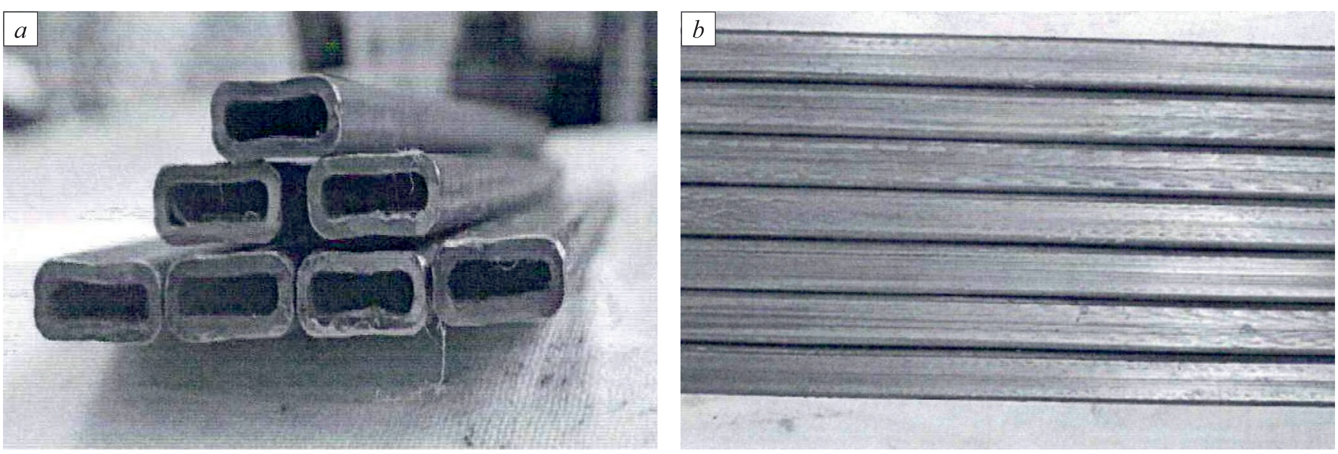
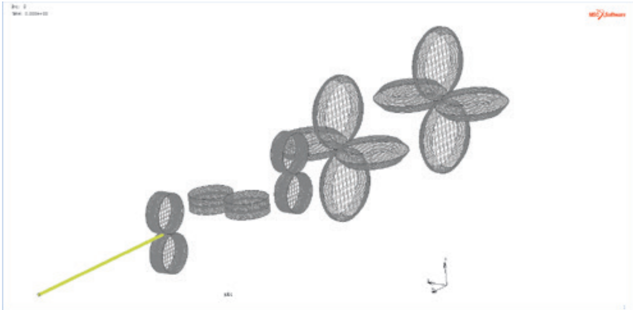
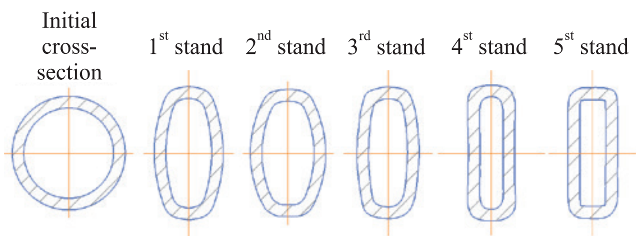


Fig. 1. Profile pipes made by drawing: cross-section (*a*); backfins on the outer surface (*b*)

Рис. 1. Профильные трубы, изготовленные методом волочения: поперечное сечение (*a*); задиры на наружной поверхности (*b*)



a



b

Fig. 2. Finite element modeling:
finite element model of rolling a pipe from a circle to a square (*a*);
cross-section of finite element model of a profile pipe (*b*)

Рис. 2. Конечно-элементное моделирование:
конечно-элементная модель прокатки трубы из круга в квадрат (*a*);
поперечное сечение конечно-элементной-модели
профильной трубы (*b*)

ling stage, a pipe billet with a diameter of 8.75 mm and a wall thickness of 0.9 mm was selected as the test object. The pipe model was divided into 3600 finite elements of the Shell 7[1] type [11]. Various bending simulation methods using the Marc (CAD/CAE) system were extensively studied by Zharkov A.V. The author [12 – 18] applied this type of element for thin-walled pipes where the wall thickness is significantly smaller than the diameter. To achieve high accuracy and reduce computational costs, mesh refinement was applied in areas of intense deformation [19]. The roll models were defined as perfectly rigid bodies [20], a common assumption in simulations of continuous pipe forming processes, which is considered acceptable given the small wall thickness. The finite element model of the profile rolling process is shown in Fig. 2, *a*.

The analysis of the simulation results assessed the stress-strain state of the pipe in the interstand space based on the distribution of plastic deformations, as well as the geometric parameters of the pipe. The cross-section after each stand is shown in Fig. 2, *b*.

The maximum plastic deformations occur in the regions where the future "corners" of the square profile are formed. These areas experience the highest tensile stresses on the outer diameter and compressive stresses on the inner diameter [21]. In the second and third stands, the primary deformation zone forms at the contact point between the roll tooling and the pipe. The pipe undergoes sequential deformation of its vertical and horizontal dimensions – height in the second stand and width in the third stand [22]. The final rolling stage is carried out in two identical stands: the fourth stand performs the final shape adjustments, while the fifth stand completes the profile calibration.

The geometric parameters of the finite element modeling are summarized in Table 1. To verify compliance with the specified requirements and evaluate the performance of the developed calibration, measurements were taken from the finite element model of the pipe profile, including height (*A*), width (*B*), and wall thickness at the front end (FE), center, and rear end (RE) of the pipe after each stand.

Based on the research findings, the following technological scheme for profile pipe production was approved:

– formation and welding of round-section tubes with dimensions 9.0×0.9 mm, lengths of 5 – 6 m, made of 08Kh18N10T stainless steel on the PEWU, using an argon-hydrogen gas mixture;

– heat treatment;

– straightening;

– profiling in a mill with two driven two-roll stands with box gauges and two non-driven four-roll stands to achieve the final dimensions of 10.0×3.8×0.9 mm, with pipe movement ensured by six driven two-roll stands equipped with rolls from the calibration set designed for 9 mm diameter pipes;

– secondary heat treatment;

– final acceptance tests.

Table 1. **Geometric parameters of pipe samples after modeling**

Таблица 1. **Геометрические параметры образцов труб после моделирования**

Stand number	Overall dimensions, mm					
	A			*B*		
	FE	center	RE	FE	center	RE
1	10.27	10.27	10.25	5.31	5.34	5.31
2	9.73	9.78	9.82	5.86	5.83	5.81
3	10.14	10.13	10.14	4.84	4.82	4.84
4	10.08	10.08	10.09	3.88	3.86	3.82
5	10.06	10.08	10.07	3.86	3.85	3.82
Quality requirements	10.00 ± 0.10			3.80 ± 0.10		

[1] Korneev A.B., Morgulets S.V., Klimov M.A., Devyatov S.V. Experience in Using the MSC Marc System to Solve Complex Problems. URL: https://www.cadmaster.ru/magazin/articles/cm_29_msc.html (accessed on December 12, 2024).

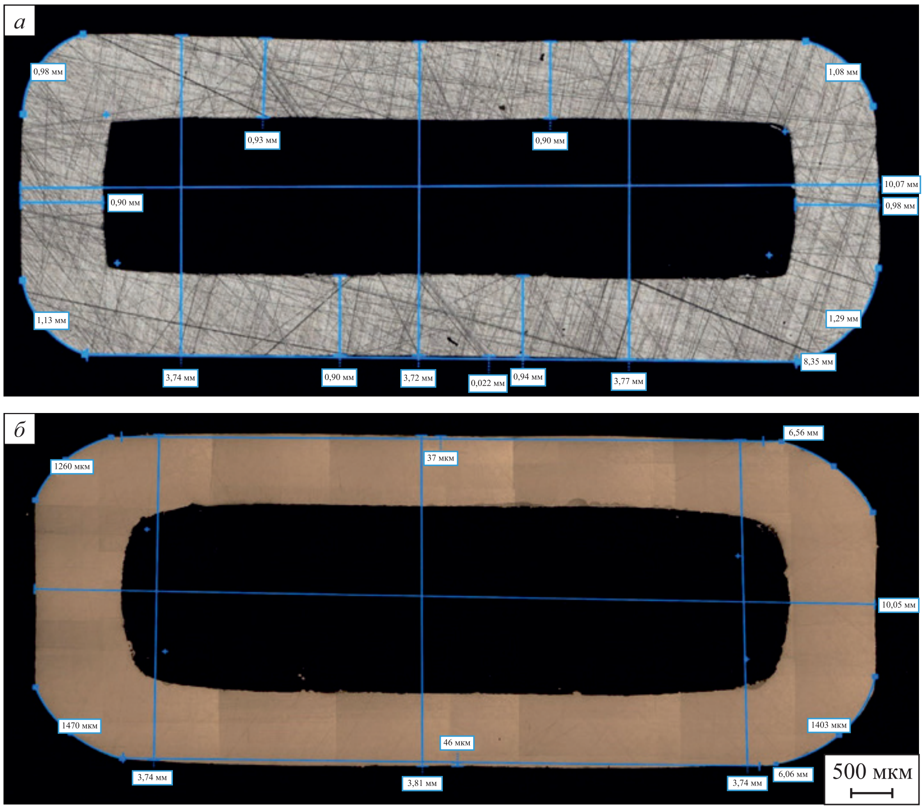


Fig. 3. Geometric parameters of pipes manufactured by: a Russian (*a*), and foreign enterprise (*b*)

Рис. 3. Геометрические параметры труб, произведенных на российском (*a*) и зарубежном (*b*) предприятиях

The shaping mill was upgraded and equipped with an additional motor to ensure the stable operation of the drive system and increased pulling capacity.

The next stage involved a series of pilot industrial rolling tests to refine the pipe profiling technology. Seamless pipes with diameters ranging from 8.40 to 8.75 mm and wall thicknesses from 0.88 to 1.05 mm were used as billets. Profiling modes were tested at speeds ranging from 0.5 to 1.5 m/min [23].

To ensure proper corner filling, sequential deformation of the billet in vertical and horizontal planes was applied, with minimal compression of the cross-sectional perimeter [24; 25].

As a result of the experimental rolling, a trial industrial batch of profile pipes with a total weight of 50 kg was produced. The geometric characteristics of the pipes were examined using an optical microscope and specialized software.

The measurement results are shown in Fig. 3, *a*.

For comparison of geometric parameters, similar studies were conducted on pipe samples supplied by a foreign manufacturer (Fig. 3, *b*).

Research results

Based on the results of the research and experiments, the developed profiling technology was approved as the standard for producing pipes with dimensions of 10.0×3.8×0.9 mm on the profiling mill.

The results of geometric parameter measurements for pipes produced at Russian and foreign facilities are summarized in Table 2.

Table 2. **Geometric parameters of pipe samples**

Таблица 2. **Геометрические параметры образцов труб**

Manufacturer	Overall dimensions, mm		Radius of corners' outer rounding, mm				Convexity/ concavity of flanges, mm
	A	*B*					
Russian enterprise	10.07	3.72 – 3.77	0.98	1.08	1.13	1.29	(–0.022) – (–0.030)
Foreign enterprise	10.05	3.74 – 3.81	1.26	1.56	1.40	1.47	(+0.037) – (+0.046)
Quality requirements	10.00 ± 0.10	3.80 ± 0.10	0.90 – 1.20				0.10

Conclusions

The developed profiling technology enables the production of profile pipes that outperform foreign counterparts in geometric characteristics, particularly in the radius of the corners' outer rounding.

The adoption of this technology has contributed to strengthening the technological sovereignty of the Russian Federation's economy, as outlined in Direction No. 13.1.3 of Government Decree No. 603, dated April 15, 2023.

Implementing the continuous profile production scheme, which includes heat treatment and profiling within the pipe-electric welding unit (PEWU) line, ensures full compliance with the requirements for profile pipes used in turbo-generator stator windings. This is achieved through significantly reduced variations in wall thickness in pipe billets produced by welding from coil stock.

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