



UDC 601.77

DOI 10.17073/0368-0797-2024-1-106-111



Original article

Оригинальная статья

INVESTIGATING EFFECTIVENESS OF CHANGING CALIBRATION OF INPUT CONE OF ROLLS AND LINES OF A PIERCING MILL WITH TAPERED ROLLS USING COMPUTER MODELING

O. A. Panasenko¹, A. O. Khalezov², D. Sh. Nukhov² ¹ JSC “Severskii Tube Steelworks” (7 Vershinina Str., Polevskoi, Sverdlovsk Region 623388, Russian Federation)² Ural Federal University named after the first President of Russia B.N. Yeltsin (19 Mira Str., Yekaterinburg 620002, Russian Federation)

dnukhov@mail.ru

Abstract. Screw piercing of a workpiece is a process with complex cyclical nature of metal flow in deformation center. Setting up the deformation tool and its calibration, as well as the accuracy of the workpiece feed and release of the hollow billet from deformation zone, have a significant impact on the quality of the hollow billet: dimensional accuracy and presence of defects on its inner and outer surface. In the paper, a technical solution was proposed to increase the stability of piercing a continuously cast workpiece on screw rolling mills. Implementation of the idea involves the use of an improved calibration of the piercing mill tool. For both in order to achieve the workpiece alignment and its stable feeding along rolling axis of the piercing mill, it was proposed to add a special thickening (hump) on the roll input cone and to change calibration of its input section on the ruler in order to meet the workpiece with the rolls earlier: before the initial capture of the workpiece by the rolls, that is, before deformation of metal of the continuously cast workpiece by the rolls. To check and correct the proposed solution, the tasks of FEM-modeling of screw piercing process with a modified design of the tapered roll and ruler were set and solved using the QForm 3D software package. Results of the finite element modeling (FEM) showed that the use of improved tool calibration makes it possible to improve the alignment of the workpiece and ensure its stable position along the rolling axis of the piercing mill, thereby reducing the runout of the workpiece in the deformation center and thereby reducing the force on the rolls from 8 to 5 MN. The results of measurements of the hollow billets' geometric parameters obtained by FEM showed insignificant relative deviations that fit within the regulatory limits.

Keywords: screw piercing, size accuracy of hollow billet, process power parameters, computer modeling, solid-state model, piercing stability, FEM

For citation: Panasenko O.A., Khalezov A.O., Nukhov D.Sh. Investigating the effectiveness of changing calibration of input cone of rolls and lines of a piercing mill with tapered rolls using computer modeling. *Izvestiya. Ferrous Metallurgy*. 2024;67(1):106–111.

<https://doi.org/10.17073/0368-0797-2024-1-106-111>

ИССЛЕДОВАНИЕ ЭФФЕКТИВНОСТИ ИЗМЕНЕНИЯ КАЛИБРОВКИ ВХОДНОГО КОНУСА ВАЛКОВ И ЛИНЕЕК ПРОШИВНОГО СТАНА С ГРИБОВИДНЫМИ ВАЛКАМИ С ПОМОЩЬЮ КОМПЬЮТЕРНОГО МОДЕЛИРОВАНИЯ

О. А. Панасенко¹, А. О. Халезов², Д. Ш. Нухов² ¹ АО «Северский трубный завод» (Россия, 623388, Свердловская обл., Полевской, ул. Вершинина, 7)² Уральский федеральный университет имени первого Президента России Б.Н. Ельцина (Россия, 620002, Екатеринбург, ул. Мира, 19)

dnukhov@mail.ru

Аннотация. Процесс винтовой прошивки заготовки – это процесс со сложным циклическим характером течения металла в очаге деформации. Настройка инструмента деформации и его калибровка, а также точность подачи заготовки и выдачи гильзы из очага деформации оказывают существенное влияние на качество гильзы: точность размеров и наличие дефектов на внутренней и наружной поверхности гильзы. В работе предложено техническое решение повышения стабильности ведения процесса прошивки непрерывнолитой заготовки на станах винтовой прокатки. Реализация идеи предполагает применение усовершенствованной калибровки инструмента прошивного

стана. Для обеспечения центровки заготовки и стабильной ее подачи по оси прокатки прошивного стана предложено добавить на входном конусе вала специальное его утолщение (гребень), а на линейке изменить калибровку входного ее участка с целью более ранней встречи заготовки с валками – до первичного захвата валками заготовки, т. е. до начала деформации валками металла непрерывнолитой заготовки. Для проверки и корректировки предлагаемого решения были поставлены и решены задачи конечно-элементного моделирования процесса винтовой прошивки с измененной конструкцией грибовидного вала и линейки. Решение задач осуществлялось в программном комплексе QForm 3D. Результаты конечно-элементного моделирования показали, что применение усовершенствованной калибровки инструмента позволяет улучшить центровку заготовки и обеспечить стабильную ее подачу по оси прокатки прошивного стана. За счет этого удастся снизить биение заготовки в очаге деформации и тем самым снизить усилие на валках с 8 до 5 МН. Результаты замеров геометрических параметров гильз, полученные при помощи конечно-элементного моделирования, показали незначительные относительные отклонения, которые укладываются в нормативные пределы.

Ключевые слова: винтовая прошивка, точность размеров гильз, энергосиловые параметры процесса, компьютерное моделирование, твердотельная модель, стабильность процесса прошивки, МКЭ-моделирование

Для цитирования: Панасенко О.А., Халезов А.О., Нухов Д.Ш. Исследование эффективности изменения калибровки входного конуса валков и линейки прошивного стана с грибовидными валками с помощью компьютерного моделирования. *Известия вузов. Черная металлургия*. 2024;67(1):106–111. <https://doi.org/10.17073/0368-0797-2024-1-106-111>

INTRODUCTION

The critical step in producing hot-worked seamless pipes involves transforming a solid workpiece into a hollow billet [1 – 3]. The most effective method for this, both in terms of productivity and the accuracy of the hollow billet's geometry, is screw piercing of continuous cast workpieces (CCW) using rotary piercers [4 – 6]. The screw rolling process is modern and holds great promise; however, it is also exceptionally complex [7; 8]. This complexity arises from the unique way metal flows in the deformation zone, which makes the process particularly challenging [9; 10]. During screw rolling, the workpiece undergoes simultaneous rotation, axial movement, and radial compression by the rolls [2]. As a result, screw rolling is seen as a process with uncertain boundary conditions and a cyclic nature of deformation [5]. The setup and calibration of the deformation tool, along with the precision of the workpiece feed and the release of the hollow billet from the deformation zone, significantly affect its quality. This includes the dimensional accuracy and the presence of defects on its inner and outer surfaces [11 – 14].

PECULIARITY OF THE WORKPIECE FEEDING INTO THE PIERCING MILL AND ITS IMPACT ON THE HOLLOW BILLET QUALITY

It is widely recognized that for a stable piercing process at the rotary piercers, it is crucial to meet the conditions for initial and secondary capture, as well as to ensure the reliable completion of the piercing process when the hollow billet is released from the mill rolls [1 – 3]. In practice, however, achieving capture can be challenging. The study mentioned in [3] highlights that to guarantee the forward and rotational movement of the workpiece during its initial capture by the rolls, an external axial force must be applied to the workpiece's rear end. In this scenario, the pushing force should be applied to the workpiece until its circumferential velo-

city hits a critical point. At this juncture, the metal is axially fed into the rolls, and both the speed and force of the device pushing the workpiece into the rolls should be kept to a minimum [3].

Moreover, during its initial capture by the rolls of the piercing mill, the workpiece exhibits a considerable degree of movement freedom. This is partly because the entry guide is manufactured to a set tolerance for the inner diameter, and the working surface that supports the workpiece is subject to wear (Fig. 1). These factors lead to an increase in wall thickness variation and the out-of-roundness of the hollow billet's front end [14 – 16]. The deviation of the workpiece from the rolling axis, as shown in Fig. 1, can be exacerbated by the curvature of the continuous cast workpieces (CCW) themselves, as well as by lapping or burrs on their front face.

Therefore, the stability of the piercing process in its early stages is compromised by two main issues: the failure to adhere to the required workpiece feeding mode and the inadequacies of the existing feeding devices.

To improve the alignment of the workpiece and ensure its stable feeding along the rolling axis of the EZTM piercing mill at Tube Rolling Shop-1 of JSC Seversty Pipe Plant, a novel approach was suggested. This method

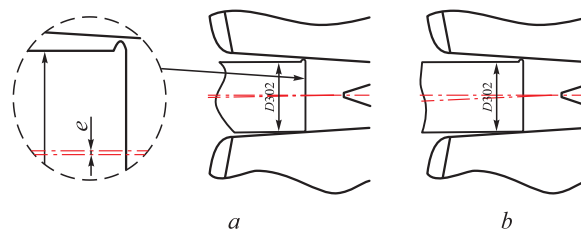


Fig. 1. Misalignment of the workpiece from rolling axis during the primary capture: eccentricity of axes of the workpiece and rolling (a); angle of the workpiece inclination (b)

Рис. 1. Отклонение заготовки от оси прокатки при первичном захвате: эксцентриситет осей заготовки и прокатки (a); угол наклона заготовки (b)

involves adding a special thickening, or hump, on the roll input cone, along with adjusting the calibration of its input section on the guide shoe. The aim is for the workpiece to engage with the rolls sooner – before the initial capture of the workpiece by the rolls, and thus before the deformation of the CCW metal by the rolls.

To achieve this, an additional tapered section is introduced on the roll input cone. This section extends from the roll end to the point where the workpiece is first captured by the mill rolls and is aligned parallel to the rolling axis (assuming the rolls are rotated to the necessary angle for rolling and feeding). This design is intended to keep the workpiece centered within the deformation zone of the EZTM piercing mill, thereby enhancing the stability of the workpiece's initial capture by the rolls (Fig. 2).

VERIFICATION OF THE TECHNICAL SOLUTION TO ENHANCE THE STABILITY OF THE SCREW PIERCING PROCESS IN THE MILL WITH TAPERED ROLLS

To validate and refine the proposed solution, tasks involving the FEM modeling of the screw piercing process at the rotary piercer with a modified design of the tapered roll and guide shoe were set up and conducted using the QForm 3D software package. This approach enabled the identification of workpiece shape change patterns within the deformation zone and facilitated the assessment of the hollow billet's dimensional accuracy [17].

To facilitate these tasks, a solid model of the piercing mill was developed using CAD modeling software, specifically KOMPAS-3D. The solid models of the rolls,

guide shoes, and the piercing head for the EZTM mill were prepared, aligning with the technological guidelines provided by JSC Seversky Pipe Plant. For the modeling process, a workpiece with a diameter of 290 mm was used. The positioning of the tools was determined based on the technological parameters of the piercing mill's configuration, as practiced at the production facility (refer to the Table).

As the modeling tasks were established, the following assumptions were made.

- The workpiece is 1000 mm long.
- The material of the workpiece is solid, isotropic, and incompressible AISI 1045 steel (equivalent to steel 45), for which the necessary parameters are available in the QForm 3D software database.
- In line with the specifications, the workpiece's temperature is set at 1200 °C, and the temperature of the working tools at 50 °C.
- The friction between the workpiece and the tool surfaces is described by the Siebel friction law: $\tau = \psi \tau_s$, where τ is the friction stress, MPa, ψ is the friction index, and τ_s is the shear deformation resistance of the material. For the surfaces in contact with the rolls, the friction index is presumed to be 0.8, while for those in contact with the piercing head and guide shoe, it's assumed to be 0.4 [5].

These assumptions were chosen to expedite the calculation process and are considered not to significantly affect the study's objectives. The solid model showcasing the workpiece piercing process and the process's initial stage, as visualized in the QForm 3D software, is illustrated in Fig. 3.

The results from the tasks solved using the QForm 3D software revealed several positive outcomes from applying the improved tool calibration:

- the stable initial capture of the workpiece by the mill rolls is achieved;
- significant compression of the workpiece in the deformation zone does not result in the premature opening of the CCW internal cavity;
- a consistent secondary capture without any workpiece runout in the deformation zone is assured.

As the calibration was refined, the optimal parameters for the input cone of rolls and guide shoes were determined (Fig. 4).

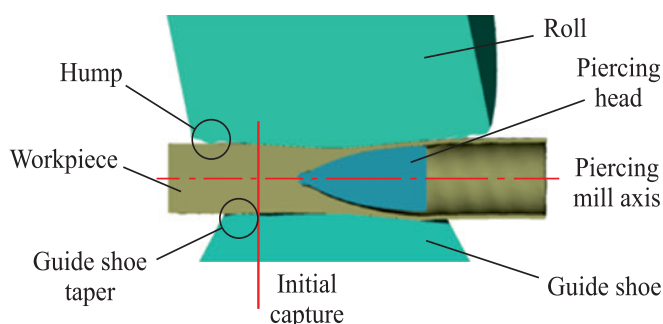


Fig. 2. Center of deformation during piercing of the workpiece in rolls with a hump on the input section

Рис. 2. Очаг деформации при прошивке заготовки в валках с гребнем на входном участке

Settings of the piercing mill

Параметры настройки прошивного стана

Distance between		The piercing head extending beyond the rolls overclamping, mm	Angle of, deg		Rolls speed, rpm
the rolls, mm	the guide shoes, mm		feeding	rolling	
253	286	100	9.5	12	30

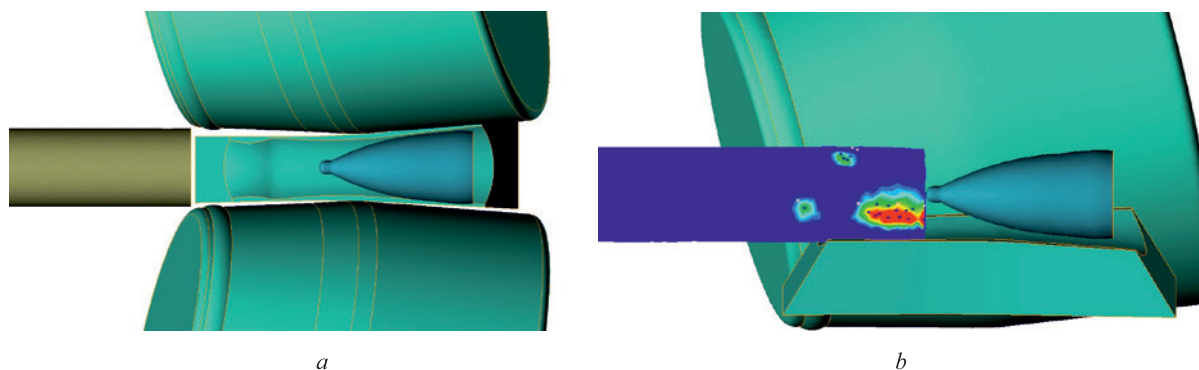


Fig. 3. Solid-state model of the workpiece piercing (a) and the initial stage of piercing process in rolls with a hump (b) in QForm 3D program

Рис. 3. Твёрдотельная модель процесса прошивки заготовки (a) и демонстрация стабильности первичного захвата и накопления деформации при прошивке в валках с гребнем (b) в программе QForm 3D

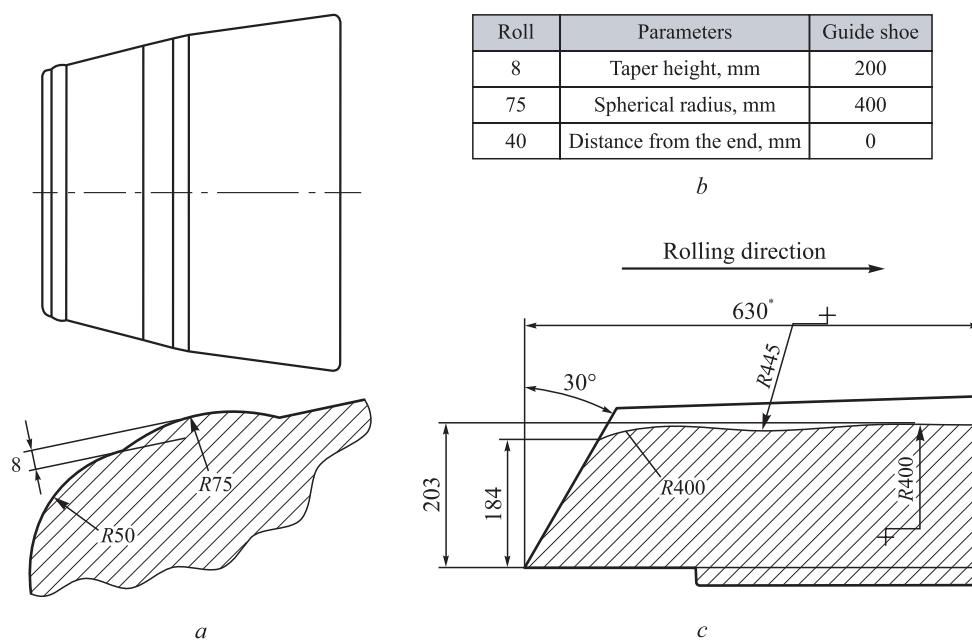


Fig. 4. Parameters of the hump on the roll and ruler: drawing of the roll with a hump (a); main parameters (b); drawing of the ruler with a taper (c)

Рис. 4. Параметры гребня на валке и линейки: чертеж валка с гребнем (a); основные параметры (b); чертеж линейки с конусностью (c)

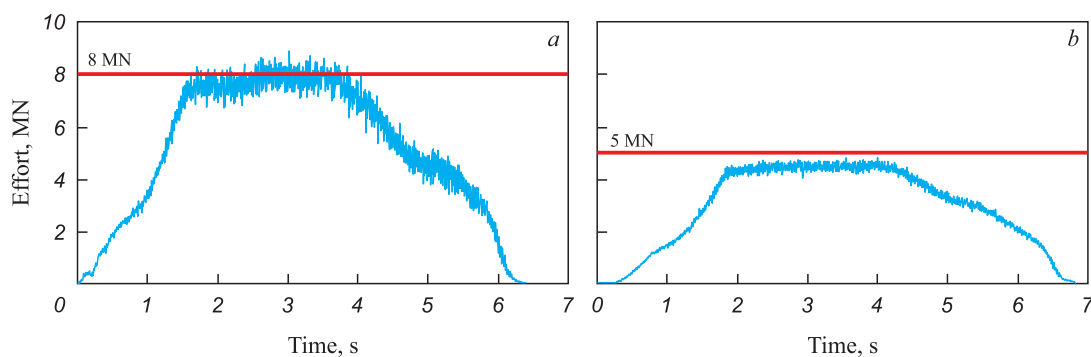


Fig. 5. Graphs of force on the piercing mill rolls during computer modeling: basic model (a); model with modified calibration (b)

Рис. 5. Графики усилия на валки прошивного стана при компьютерном моделировании: базовая модель (a); модель с измененной калибровкой (b)

The force graph on the rolls of the piercing mill validates that the calibration was accurately performed (Fig. 5).

This enhanced tool calibration effectively minimizes workpiece runout along the piercing axis, as evidenced by a considerable reduction in the piercing force (Fig. 5). The graphs demonstrate that piercing the workpiece with improved tool calibration can reduce the force exerted on the rolls from 8 to 5 MN.

The results of the FEM measurements for the hollow billets' geometric parameters revealed minor relative deviations:

- the average outside diameter did not surpass 0.8 % (within the standard tolerance of ± 1 %);
- the wall thickness deviations did not exceed 1.4 % (with a standard tolerance of ± 5 %).

Blanks refined with improved roll and guide shoe calibration have been successfully tested at the EZTM piercing mill and are now being utilized to manufacture hollow billets in Shop No. 1 of JSC Seversky Pipe Plant.

CONCLUSIONS

The paper proposes a technical solution to enhance the stability of piercing CCW on screw rolling mills. It suggested adding a special thickening (hump) on the roll input cone and altering the calibration of its input section on the guide shoe, enabling the workpiece to engage with the rolls sooner – before the initial capture and prior to the deformation of CCW metal by the rolls.

To evaluate and refine this solution, tasks for FEM modeling of the screw piercing process with a redesigned tapered roll and guide shoe were established and completed.

The FEM modeling results confirmed that utilizing improved tool calibration could significantly reduce workpiece runout in the deformation zone and lower the force on the rolls from 8 to 5 MN. The FEM-derived measurements of the hollow billets' geometric parameters showed negligible relative deviations, all within acceptable regulatory standards.

REFERENCES / СПИСОК ЛИТЕРАТУРЫ

1. Potapov I.N. Theory of Pipe Production. Moscow: Metallurgiya; 1991:424. (In Russ.).
Потапов И.Н. Теория трубного производства. Москва: Металлургия; 1991:424.
2. Danilov F.A. Hot Rolling and Pressing of Pipes. Moscow: Metallurgiya; 1972:591. (In Russ.).
Данилов Ф.А. Горячая прокатка и прессование труб. Москва: Металлургия; 1972:591.
3. Teterin P.K. Theory of Transverse and Screw Rolling. Moscow: Metallurgiya; 1972:270. (In Russ.).

- Тетерин П.К. Теория поперечной и винтовой прокатки. Москва: Металлургия; 1983:270.
4. Osadchii V.Ya. Production and Quality of Steel Pipes: A Textbook for Universities. Moscow: MSUPI; 2012:370. (In Russ.).
Осадчий В.Я. Производство и качество стальных труб: Учебное пособие для вузов. Москва: Издательство МГУПИ; 2012:370.
5. Bogatov A.A. Screw Rolling of Continuously Cast Billets from Structural Steel Grades: A Textbook. Yekaterinburg: UrFU; 2017:164. (In Russ.).
Богатов А.А. Винтовая прокатка непрерывно-литых заготовок из конструкционных марок стали: Учебное пособие. Екатеринбург: Издательство УрФУ; 2017:164.
6. Wei Z., Wu C. A new analytical model to predict the profile and stress distribution of tube in three-roll continuous retained mandrel rolling. *Journal of Materials Processing Technology*. 2022;302:117491.
<https://doi.org/10.1016/j.jmatprotec.2022.117491>
7. Gamin Yu.V., Galkin S.P., Romantsev B.A., Koshmin A.N., Goncharuk A.V., Kadach M.V. Influence of radial-shear rolling conditions on the metal consumption rate and properties of D16 aluminum alloy rods. *Metallurgist*. 2021; 65(5-6):650–659.
<https://doi.org/10.1007/s11015-021-01202-0>
8. Topa A., Kim D.K., Kim Y. 3D numerical simulation of seamless pipe piercing process by fluid-structure interaction method. *MATEC Web of Conferences*. 2018;203:06016.
<https://doi.org/10.1051/mateconf/201820306016>
9. Romantsev B.A., Skripalenko M.M., Ba Huy Tran, Skripalenko M.N., Gladkov Yu.A., Gartvig A.A. Computer simulation of piercing in a four-high screw rolling mill. *Metallurgist*. 2018;61(9–10):729–735.
<http://doi.org/10.1007/s11015-018-0556-7>
Романцев Б.А., Скрипаленко М.М., Чан Ба Хюи, Скрипаленко М.Н., Гладков Ю.А., Гартвиг А.А. Компьютерное моделирование прошивки заготовок в четырехвалковом стане винтовой прокатки. *Металлург*. 2017;(9):19–24.
10. Skripalenko M.M., Rogachov S.O., Romantsev B.A., Bazhenov V.E., Skripalenko M.N., Danilin A.V. Microstructure and hardness of hollow tube shells at piercing in two-high screw rolling mill with different plugs. *Materials*. 2022;15(6):2093.
<https://doi.org/10.3390/ma15062093>
11. Nguyen Q., Aleshchenko A.S. Research on the mandrel wear of a screw rolling piercing mill by the finite element method. *Key Engineering Materials*. 2022;910:381–387.
<https://doi.org/10.4028/p-4m4o75>
12. Goncharuk A.V., Fadeev V.A., Kadach M.V. Seamless pipes manufacturing process improvement using mandreling. *Solid State Phenomena*. 2021;316:402–407.
<https://doi.org/10.4028/www.scientific.net/SSP.316.402>
13. Rotenberg Zh.Ya., Budnikov A.S. Modernization of screw rolling technology in a multi-roll mill. *Izvestiya. Ferrous Metallurgy*. 2022;65(1):28–34. (In Russ.).
<https://doi.org/10.17073/0368-0797-2022-1-28-34>
Ротенберг Ж.Я., Будников А.С. Модернизация технологии винтовой прокатки в многовалковом стане. *Известия вузов. Черная металлургия*. 2022;65(1):28–34.
<https://doi.org/10.17073/0368-0797-2022-1-28-34>
14. Pavlova M.A., Zvonarev D.Yu., Akhmerov D.A. QFORM-based research how the accuracy settings of piercing mill

centering units axis influences hollow shell thickness. *Bulletin of the South Ural State University. Series: Metallurgy*. 2021;(4):56–62. (In Russ.).

Павлова М.А., Звонарев Д.Ю., Ахмеров Д.А. Исследование влияния точности настройки осей центрователей прошивного стана на разнотолщинность гильз с использованием QFORM. *Вестник Южно-Уральского государственного университета. Серия: Metallurgy*. 2021;(4):56–62.

15. Galkin S.P., Aleshchenko A.S., Romantsev B.A., Gamin Yu.V., Iskhakov R.V. Effect of preliminary deformation of continuously cast billets by radial-shear rolling on the structure and properties of hot-rolled chromium-containing steel pipes. *Metallurgist*. 2021;65(1–2):9–12. <https://doi.org/10.1007/s11015-021-01147-4>

Галкин С.П., Алешенко А.С., Романцев Б.А., Гамин Ю.В., Исхаков Р.В. Влияние предварительной деформации непрерывнолитых заготовок радиально-сдвиговой про-

каткой на структуру и свойства горячекатаных труб из хромсодержащих сталей. *Металлург*. 2021;65(2):54–61.

16. Toporov V.A., Tolmachev V.S., P'yankov B.G., Bushin R.O., Panasenko O.A., Ibragimov P.A. *Method of obtaining hollow sleeves on a sewing mill*. Patent RF no. 2578887. МРК В21В19/04. *Bulleten' izobretenii*. 2016;(33). (In Russ.).

Пат. 2578887 RU. *Способ получения полых гильз на прошивном стане* / Топоров В.А., Толмачев В.С., Пьянков Б.Г., Бушин Р.О., Панасенко О.А., Ибрагимов П.А.; заявл. 30.09.2014; опубл. 27.03.2016.

17. Toporov V.A., Stepanov A.I., Panasenko O.A., Ibragimov P.A. Use of finite-element modeling to improve the piercing operation on a piercing mill. *Metallurgist*. 2014; 58(7–8):563–567. <http://doi.org/10.1007/s11015-014-9954-7>

Топоров В.А., Степанов А.И., Панасенко О.А., Ибрагимов П.А. Применение конечно-элементного моделирования для совершенствования процесса прошивки на прошивном стане. *Металлург*. 2014;58(7):28–31.

Information about the Authors

Oleg A. Panasenko, Head of the Pipe Rolling Laboratory of the Research Center, JSC "Severskii Tube Steelworks"

E-mail: PanasenkoOA@stw.ru

Aleksandr O. Khalezov, Postgraduate of the Chair "Metal Forming", Ural Federal University named after the first President of Russia B.N. Yeltsin

E-mail: alekssanja633@mail.ru

Danis Sh. Nukhov, Cand. Sci. (Eng.), Assist. Prof. of the Chair "Metal Forming", Ural Federal University named after the first President of Russia B.N. Yeltsin

E-mail: d.s.nukhov@urfu.ru

Сведения об авторах

Олег Александрович Панасенко, начальник трубопрокатной лаборатории научно-исследовательского центра, АО «Северский трубный завод»

E-mail: PanasenkoOA@stw.ru

Александр Олегович Халезов, аспирант кафедры «Обработка металлов давлением», Уральский федеральный университет имени первого Президента России Б.Н. Ельцина

E-mail: alekssanja633@mail.ru

Данис Шамильевич Нухов, к.т.н., доцент кафедры «Обработка металлов давлением», Уральский федеральный университет имени первого Президента России Б.Н. Ельцина

E-mail: d.s.nukhov@urfu.ru

Contribution of the Authors

O. A. Panasenko – formulation of the research task, developing a technical solution for changing calibration of input cone of rolls and lines of a piercing mill, planning of a computational experiment.

A. O. Khalezov – development of calibration of piercing mill tools, formulation and solution of the problem of FEM of the screw piercing process with a modified design of tapered roll and ruler; measuring the geometric parameters of hollow billets.

D. Sh. Nukhov – processing the experimental results, design of the article, literary review, formulation of conclusions.

Вклад авторов

О. А. Панасенко – формулировка задачи для проведения исследований, разработка технического решения по изменению калибровки входного конуса валков и линеек прошивного стана, планирование вычислительного эксперимента.

А. О. Халезов – разработка калибровки инструментов прошивного стана, постановка и решение задачи конечно-элементного моделирования процесса винтовой прошивки с измененной конструкцией грибовидного валка и линейки, проведение замеров геометрических параметров гильз.

Д. Ш. Нухов – обработка результатов экспериментов, оформление материалов статьи, анализ литературы по тематике статьи, формулировка выводов.

Received 06.04.2023

Revised 15.01.2024

Accepted 22.01.2024

Поступила в редакцию 06.04.2023

После доработки 15.01.2024

Принята к публикации 22.01.2024