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COMPUTER MODELING OF RODS AND WIRES PRESSING ON THE RADIAL SHIFT MILL OF THE NEW DESIGN

Abstract. In this article the Radial-shift mill (RSM) of a new design is proposed, which allows by combining of rolling and pressing to obtain high-quality rods and wires. The analysis of the stress-strain state (SSS) computer modeling results and heavily loaded elements vibration of the new mill stand using the finite element method and deformational model of the metal strength is presented. The influence of changes in the construction of frame parts on the elastic deformation of heavily loaded elements of the RSM stand is determined. It is shown that the new mill has a sufficiently high rigidity of the stand structure and satisfies the strength condition. It is noted that the pressing of small rods or wires on the proposed mill will lead to the obtaining of finished rolling with precise geometric dimensions. As a result of modeling the heavily loaded elements of the new mill stands elastic deformation, measures for their modernization were developed. The SSS of billets during pressing rods and wires on the RSM was also investigated in this work. By the method of finite elements and MSC. SuperForge program, quantitative data were obtained and the basic patterns of the distribution of SSS, temperature during the pressing of rods and wires on RSM with various single compressions were established. It is shown that pressing on a new designed RSM allows getting the optimal distribution of SSS, which leads to formation of a fine-grained structure in rods and wires.
Key words: radial-shift mill, frame, rolls, stands, matrix, bearings, elastic deformation, rod, wire.

Introduction. Mills of cross-helical and radial-shift rolling (RSR) [1,2,3], and also of radial-shift broaching [4,5,6] became the main equipment for the production of rods and wires. When using mills data, the rolling of the billets is carried out in the deformation zone formed by three working rolls unfolded to the feed and rolling angles and located after 120° around the deformed billet [3,7,8]. In this case, the longitudinal and rotational deformation of the metal is realized, which ensure a "helical" metal flow, which leads to the formation in the metal of the "spiral" microstructure. In this case, shift deformation degree increases significantly due to the development of macro-shift deformation along the section of deformed billet [9-12]. All this increases the quality of manufactured rods and wires [13-17].

According to the author of the work [18], designing of above-mentioned mills is carried out without taking into account the distribution of stresses on the volume of construction elements of the working stand, which leads to high metal consumption and unreasonable high manufacturing costs.

In our opinion, the use of computer technology and numerical methods, especially the finite element method (FEM), makes it possible accurately determine the SSS of heavily loaded elements of the mill stands and reduce metal consumption and manufacturing costs. For this reason, we believe that the calculation of the SSS of mills of complex construction is an actual task.

Rolling equipment designing method development via simulating modeling of complex construction of the mill and calculation the SSS arising when making heavy loads allows to reasonably choose the equipment characteristics taking into account technological, constructional and operational factors.

The target of the work is to develop the constructing algorithm of computer model of the designed mill and then by using a computer model to design and adjust the mill construction.

Materials and research methods. A radial-shift mill (RSM) of a new design is proposed at the present work [19]. By the combination of hot screw rolling and pressing the metallic rods of small diameters or wires with a fine-grained structure are producing at this mill.

The RSM for pressing rods and wires contains the main drive, working stand, roll knot and the press matrix. The three-roll RSM working stand consists of a frame, in the borings of which, after 120°, the knots of the working rolls are mounted. Working rolls are mounted on the pillows. Torque to the rolls is transmitted via spindles from electric motors. The rolls of this mill have wavy-cone-shaped capture and compression sections and a calibrating section. Note that the ledges and hollows of wavy-cone-shaped sections are made along the helical line. Wherein, the geometric dimensions of the ledges and hollows gradually decrease at the direction of rolling.

The working stand of the RSM consists of two continuous square frames. There are the mechanisms for installing the pillows of the upper and lower working rolls in the through holes of the frames. The approach and breeding of the upper and lower rolls are carried out using wedge- type pressing mechanism. Wedge- type pressing mechanism has rotating screws. To rotate the screws, a gear motor mounted on the frame is used.

Devices which allow adjusting the feed angle and the angle to the rolling axis are provided in construction of the RSM stand. The maximum feed angles values are 18 mm, and the angle to the rolling axis can be constructively adjusted based on the possibility of the rolling technology expansion on a new mill.

To eliminate all possible gaps between the rollers and pillows, wedge mechanisms and the frame, each pillow mounting mechanism was equipped with spring-loaded rods or hydraulic cylinders.

The design of the RSM was carried out by using the accumulated experience in the design of such equipment [20]. At the same time, we developed the frame design, constructed the drive and calculated the strength and rigidity of the heavily loaded elements and the drive power of the new mill, selected electric motors and developed working drawings of this mill.

It should be noted that existing methods for calculating the elastic deformations and vibrations of heavily loaded elements of the mill frames do not allow to take into account all the constructive and technological features of rods and wires hot pressing process. In this regard, the strength and vibration of the heavily loaded elements of the new mill were investigated by computer modeling. The original data for the calculation is the solid-state geometric shape of the RSM, the forces applied to them and the fixing conditions.

For calculating SSS, we applied the Patran Nastran [21] finite element analysis program and developed a computer model of RSM. The computer modeling system Patran Nastran allows to research the kinematics, the dynamics of the mechanisms with the ability to calculate the flexure, vibration, SSS and thermal state of both individual sections and the mill as whole.

When constructing a new mill in the MSC Nastran environment, the above indicators were calculated according to the following algorithm. In the KOMPAS program according to the working drawings, we created a three-dimensional geometric model of each detail and assembled the sections of the working stand. Further we imported the model into the Nastran Patran preprocessor with accepted kinematic connections. We chose the materials of the details, their mechanical and physical properties. Formed kinematic and static boundary conditions, simulated an estimated mechanical scheme, including the load distribution on the surface of the rolled billet. We brought the torque to the rolls (the torque was modeled by using RBE2 type MPC elements). Using the Mesh Seed options, we applied 6 and 8-node volumetric finite element mesh and determined the vibration and SSS.

When developing the calculation scheme, thickened finite element meshes were used in places of the expected stress concentration. Elastic bonds between the stand nodes were modeled by the spring - damper element CBUSH.

For automatic correction of the mill model geometry, the method of geometric sizes construction parameterization was used. This method allows making the corresponding changes in the construction of the new RSM frames, according to the results of heavily loaded parts of the RSM estimated strength, their movement and vibration.

As the material of the rolls and matrix was adopted Steel 9X1, for the frame stands - steel grade 40XC. And the material of other parts of the mill was adopted steel 45.

The software complex MSC.SuperForge was used for calculating the effort and SSS of the pressed rods [22]. A three-dimensional geometric model of the billet, rolls and matrix was built in the CAD Inventor program and imported into the CAE the MSC.SuperForge program. When creating the finite element model of the billet, rolls and matrix the three-dimensional volumetric element CTETRA (four-node tetrahedron), which is applying for modeling three-dimensional bodies was used.

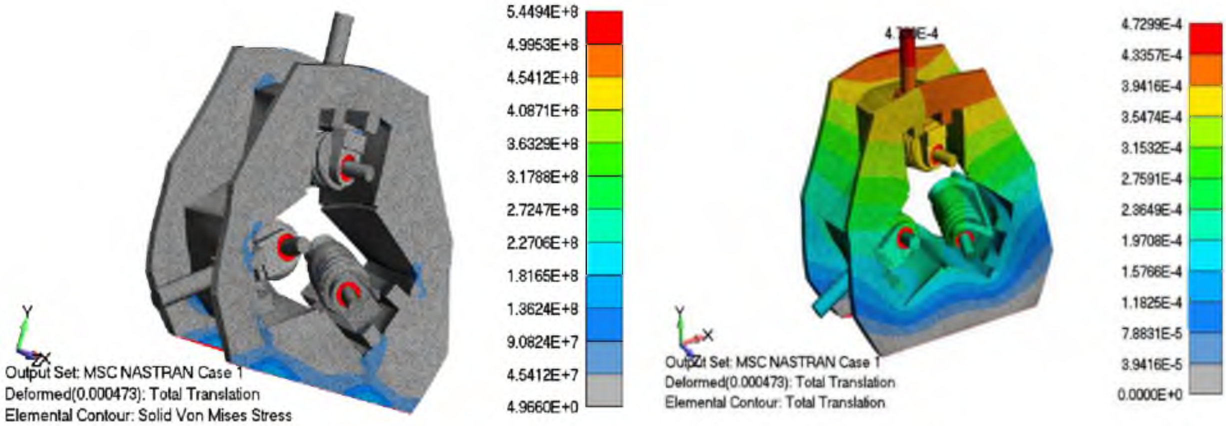
To search the pressing process in continuous RSM, a round billet of M1 copper alloy with a size of Ø40 × 150 mm was used. The billets pressing have been at a temperature of 300 °C up to Ø9 mm. For modeling the plasticity of the billet material, the Johnson-Cook elastoplastic model was chosen. From the database of the software complex "MSC.SuperForge" we set the rheological properties.

To calculate the SSS and normal pressure forces, the technical characteristics of the proposed RSM were used. The electric motor power is 15 kW, and the rotation frequency of the rolls is 70 rpm. Rolling was performed with a feed angle equal to $\beta = 15°$ and a rolling angle of $\alpha = 8°$. The contact between the tool and the rod was modeled by the Coulomb friction law; the coefficient of friction was adopted as 0.3.

We launched the MSC.SuperForge program, and by the step-by-step method calculated the contact pressure, contact area, SSS, and temperature distribution over the volume of the pressed billet.

To calculate the SSS of RSM heavily loaded parts by simulation modeling, we carried out a series of experiments on the pressing of the M1 copper alloy with different geometric sizes of the matrix. Based on the calculation results, the force acting in the contact zone was taken equal to 320 kN per roll and 280 kN to the matrix.

Obtained results and their discussion. As a result of a computer modeling of the M1 copper alloy pressing process at the RSM, were obtained the data that can be used to correct the construction of the mill at the designing stage. From figure *a*, it can be seen that the maximum equivalent stresses occur on the necks of the roll and amount 499.5 MPa. The calculated maximum values of equivalent stresses in heavily loaded roll and matrix do not exceed the maximum allowable value of the tensile strength of steel 9X1 (880 MPa). Stresses in the stand frame amounted 45.412 MPa, which is also significantly less than the tensile strength of steel St40XC (981 MPa).



a) *b*)

The distribution of equivalent stresses (a) and displacement fields (b) on a new design RSM

The greatest displacement under the load is 0.000434 mm and occurs in the necks of the rolls (figure, *b*). This value is within the tolerance limit on the diametrical sizes of the rods, with a diameter up to 20 mm. For the frame, the greatest displacement under a load is 0.000315 mm and occurs in its upper part, and for the RSM matrix this displacement is 0.000093 mm.

The calculation of the components of the stress tensor showed that during the rolling on a new mill the tensile principal stresses arise mainly in the necks of the rolls. The value of the main maximum, average and minimum stresses arising in the necks of the working rolls does not exceed 631.9, 263.8 and 69.95 MPa, respectively. The main maximum stresses arising in the frame stand are tensile and do not exceed 26.84 MPa. It should be noted that the main average and minimum stresses occurring in the frame stand are, in most cases, compressive and do not exceed 7.12 and - 43.97 MPa, respectively.

The results of computer modeling indicate that the RSM stand has a sufficient margin of safety. The estimated rigidity of the mill construction provides the production of rods with high accuracy diametric sizes.

The obtained data showed that the roll units of the designed mill have low rigidity in the horizontal plane. This is connected with the lack of supports in the mill stands, excluding the movement of the working rolls in the horizontal plane, and also the non-horizontal arrangement of the spindles of the mill drive. As a result, even small gaps between bearings, pillows and frame windows caused by fit tolerances and wear lead to horizontal dislocation of the vertical axial plane of the working rolls, i.e. working rolls are in an unstable position, and their axes can warp. This leads to negative consequences: High axial forces occur in the roll unit, and the size of the inter-roll gap is subject to unpredictable oscillations, which reduces the accuracy of rolling.

The calculation found that the pillows are elastically deforming in the vertical and horizontal plane and rotate for a small angle relative to the rolling axis. The elastic displacement in the direction of the load effect for pillows located on the roll' drive side is 1.41 times greater than for pillows located on the opposite side of the roll.

It should be noted that the use of spring-loaded traction to reduce gaps has insignificant effect on the elastic deformation of the bearings. Elastic deformation of bearings varies from 0.0028 to 0.0032 mm. However, the use of hydraulic cylinders to reduce the gaps leads to a significant reduction in value and square of elastic deformation of the bearings. In this case, the elastic deformation of the bearings varies from 0.0008 to 0.0009 mm. The external rings of the bearing have maximum deformation, while with a decrease of the rolls diameter, the area of highest elastic deformation of the bearing is shifted to the internal sides of roll neck. This is connected with a change in the load application scheme in the RSM roll unit.

In accordance with the conducted research, the RSM stand modernization activities were developed in the work. The research showed that it is necessary to install a hydraulic hold-down device in the stand in order to regulate the inter-roll gap of the working rolls. To ensure uniform load distribution and increase service life, it was proposed to replace the bearings. It was offered to use an angular- contact conic double-row roller bearing with a higher load capacity instead of a double row spherical roller bearing in the pillows of stand. To increase the rigidity of the RSM frame, stiffening ribs were attached to its plates. That is, inside the through apertures and around the perimeter of the plates, solid plates with thickness 30 mm were attached. These plates will be used as guides for the installation mechanism of the rolls pillows and wedges of the hold-down mechanism. The proposed design solutions will allow reducing the level of deformation of the mill main elements and getting 5-10 times the safety factor of heavily loaded parts of the mill stand.

It is known that during RSM operation, resonance oscillations that occur when matching the frequency of the construction and the frequency of external forces are especially dangerous. Therefore, it is important to determine the frequency of external forces. One of the main exciters of resonant frequencies in the design of rolling mills is the working rotation frequency of the working rolls drive, which spread the vibration to the mill.

During the amplitude estimating, the oscillations of the mill frame complete with a roll unit and a matrix, the following results were obtained:

- the highest oscillation amplitude gains the RSM matrix;
- at a natural oscillation frequency of the mill equal to 96.6 Hz, 121.08 Hz, 170.63 Hz, 173.01 Hz, 268.47 Hz and 277.73 Hz, the maximum amplitude value of the matrix oscillation is 0.26 mm, 0.199 mm, 0.00695 mm, 0.0168 mm, 0.0203 mm, 0.0763 mm, accordingly.

It should be noted that the RSM frame stand acquires average oscillation amplitude. Their value, at the natural frequency of the mill oscillation, is 96.6 Hz, 121.08 Hz, 170.63 Hz, 173.01 Hz, 268.47 Hz and 277.73 Hz equal to 0.0233 mm, 0.0166 mm, 0, 0556 mm, 0.00586 mm, 0.0218 mm, 0.12 mm, respectively. The least oscillation amplitudes the roll units of the designed RSM had.

The reason for the appearance of a relatively small resonant vibration in the matrix, frame and roll units of the proposed mill is the location of the RSM drive spindles at an angle to the axis of rolling, as well as the lack of a sufficiently high matrix and roll units rigidity in the vertical and horizontal plane.

It should be noted that hydraulic dampers were introduced into the design of the new mill to clamp the matrix and the roll assembly. The hydraulic damper consists of an elastic element, i.e. frame, and hydraulic cylinder. These elements are connected in parallel. In this case, under the action of rolling forces to the stand frame and its elastic deformation, exceeding the permissible value, a compression pressure is created in the damping hydraulic cylinder, which allows fully or partially damping the vibration.

In our opinion, the use of hydraulic dampers for clamping the matrix and the roll unit will eliminate horizontal and vertical displacement of the matrix and working rolls. In this case, the RSM drive will allow to transmit torques to the working rolls of the mill stands with a large reserve up to resonant vibration. It is expected that all this will contribute to the production of rods and wires with precise geometric dimensions and without surface defects.

Based on the MSC.SuperForge program, from the obtained results of numerical modeling of the M1 copper alloy pressing process the following conclusions can be made. On the surface of the billet, small tensile principal stresses σ_{11} arise, while in the outer layer, compressive principal stresses σ_{22} and σ_{33}effect on each element. During the deformation in helical rolls and matrix of the proposed design, in the deformation zone, the metal flows along a helical path with different speeds of external and internal layers. The movement of metal flows at different speeds causes intense shear displacements in the volume of the billet, which leads to a significant increase of the deformation intensity, and this contributes to a significant grinding of grains and obtaining an ultrafine-grained structure.

Large shear deformations are accompanied by heating of the metal. The temperature effect of heating is up to 100-150 °C. This heating allows reducing the heating temperature before pressing, and significantly optimizes the temperature interval of the processing.

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Conclusions. 1. By the dynamic modeling were obtained quantitative data and established the basic regularities of the SSS distribution and strength characteristics of heavily loaded elements when pressing rods and wires on the RSM.

2. Through the application of information technology, the rational design of the RSM was determined and methodology for selection the technological modes of deformation when pressing rods and wires on this mill was developed.

3. It is proved that when pressing rods and wires on the RSM, dangerous vibrations do not fall into the working range of acting external loads.

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ЖАҢА ҚҰРЫЛЫМДЫ РАДИАЛДЫ ЫҒЫСТЫРУ ОРНАҒЫНДА ШЫБЫҚТАР МЕН СЫМДАРДЫ СЫҒЫМДАУДЫ КОМПЬЮТЕРЛІК МОДЕЛЬДЕУ

Аннотация. Мақалада біріктірілген илемдеу және баспақтау арқылы жоғары сапалы шыбықтар мен сымдар алуға мүмкіндік беретін жаңа құрылымның радиалды-ығыстыру орнағы ұсынылған. Металл беріктігінің деформациялы моделін және шеткі элементтер әдісін қолдана отырып, жаңа орнақ қапастарының ауыр жүктелген элементтерінің дірілін және кернеу-деформациялы күйін компьютерлік модельдеу нәтижелеріне талдаулар берілген. Ралиалды-ығыстыру орнағындағы қапастардың ауыр жүктелген элементтерінің серпімді деформациясына, орнақтың құрылымдық бөлшектері өзгерісінің әсері анықталды. Жаңа орнақтың, қапастар құрылымының айтарлықтай қатты және беріктік жағдайын қанағаттандырарлық екендігі көрсетілген. Ұсынылып отырған орнақта кіші өлшемді шыбықтар мен сымдарды баспақтау накты ғеометриялық өлшемі бар дайын жаймалауға әкелетіні көрсетілген. Жаңа орнақ қапастарының ауыр жүктелген элементтерінің серпімді деформациялануын модельдеу нәтижесінде оларды модернизациялау шаралары жасалып шығарылды. Жұмыста, сонымен қатар, радиалды-ығыстыру орнағында шыбықтар мен сымдарды баспақтау кезінде дайындамалардың кернеу-деформациялы күйі зерттелді. Шеткі элементтер әдісі және MSC.SuperForge бағдарламасы арқылы сандық мәліметтер алынды және әртүрлі бірлік жаншумен радиалды-сығымдау орнағында шыбықтар мен сымдарды баспақтау кезіндегі температураның, кернеу-деформациялы күйдің негізгі таралу заңдылықтары белгілі болды. Жаймалаудың тиімді технологиясы жасалды. Бұрыннан белгілі және алынған мәліметтер негізінде баспақтау режимінің болаттар мен қорытпалар құрылымының қалыптасу әсеріне талдау жасалды. Жаңа конструкциялы радиалды-ығыстыру орнағында баспақтау үдерісі құрылымы ұсақтүйіршікті шыбықтар мен сымдар алуға мүмкіндік беретіні көрсетілген. Динамикалық модельдеу арқылы сандық мәліметтер алынды және радиалды-ығыстыру орнағында шыбықтар мен сымдарды баспақтауда ауыр жүктелген элементтердің беріктік сипаттамаларының және кернеу-деформациялы күйінің негізгі таралу заңдылықтары белгілі болды. Ақпараттық технологияларды қолдана отырып, радиал-ығыстыру орнағының тиімді құрылымы анықталды және аталған орнақта шыбықтар мен сымдарды баспақтау кезінде деформациялаудың технологиялық режимін таңдау әдісі жасалып шығарылды. Радиалды-ығыстыру орнағында шыбықтар мен сымдарды баспақтау кезінде пайда болатын қауіпті діріл, сыртқы жұмысшы жүктеменің жұмыс диапазонына түспейтіндігі дәлелденді.

Түйін сөздер: радиал-ығыстыру орнағы, тұғыр, біліктер, қапастар, матрица, мойынтірек, серпімді деформация, шыбық, сым.

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КОМПЬЮТЕРНОЕ МОДЕЛИРОВАНИЕ ПРЕССОВАНИЯ ПРУТКОВ И ПРОВОЛОКИ НА РАДИАЛЬНО-СДВИГОВОМ СТАНЕ НОВОЙ КОНСТРУКЦИИ

Аннотация. В статье предложен радиально-сдвиговый стан новой конструкции, позволяющий совмещением прокатки и прессования получать прутки и проволоку высокого качества. Представлен анализ результатов компьютерного моделирования напряженно-деформированного состояния и вибрации тяжелонагруженных элементов клети нового стана с использованием метода конечных элементов и деформационной модели прочности металла. Определено влияние изменений конструкции деталей станины на упругую деформацию тяжелонагруженных элементов клети радиально-сдвигового стана. Показано, что новый стан имеет достаточно высокую жесткость конструкции клети и удовлетворяет условию прочности. Отмечено, что прессование прутков малого размера или проволоки на предлагаемом стане приведет к получению готового проката с точными геометрическими размерами. В результате моделирования упругой деформации тяжелонагруженных элементов клетей нового стана разработаны мероприятия по их модернизации. В работе также исследовано напряженно-деформируемое состояние заготовок при прессовании прутков и проволоки на радиально-сдвиговом стане. Методом конечных элементов и программой MSC.SuperForge получены количественные данные и установлены основные закономерности распределения напряженно-деформируемого состояния, температуры при прессовании прутков и проволоки на радиально-сдвиговом стане с различными единичными обжатиями. Разработана рациональная технология прокатки. На основе известных и полученных данных сделан анализ влияния режимов прессования на формирование структур сталей и сплавов. Показано, что прессование на радиально-сдвиговом стане новой конструкции позволяет получить прутки и проволоку с мелкозернистой структурой. Динамическим моделированием получены количественные данные и установлены основные закономерности распределения напряженно-деформируемого состояния и прочностных характеристик тяжелонагруженных элементов при прессовании прутков и проволоки на радиально-сдвиговом стане. Путем применения информационной технологии определена рациональная конструкция радиально-сдвигового стана и разработана методика выбора технологических режимов деформирования при прессовании прутков и проволоки на данном стане. Доказано, что при прессовании прутков и проволоки на радиально-сдвиговом стане опасные вибрации не попадают в рабочий диапазон действующих внешних нагрузок.

Ключевые слова: радиально-сдвиговый стан, станина, валки, клети, матрица, подшипники, упругая деформация, пруток, проволока.

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REFERENCES

[1] Teterin P.K. Theory of helical rolling. M.: Metallurgy, 2001. 368 p. (in Russ.).

[2] Potapov I.N., Polukhin P.I., Kharitonov E.A., Zimin V.Ya. et al. Radial shift rolling – new possibilities of processing by pressure // Nonferrous metals. 1995. N 5. P. 63-65 (in Russ.).

[3] Galkin S.P., Kharitonov E.A., Mikhailov V.K. Reversible radial shift rolling. Essence, opportunities, advantages // Research Methods. Titanium. 2003. N 1. P. 39-43 (in Russ.).

[4] Raab A.G. Development of wire manufacturing process from low-carbon steel of increased strength and wear resistance by the combined method of drawing with shear: autoabstract. dis. ... Ph.D. Magnitogorsk, 2018. 16 p. (in Russ.).

[5] Bitkov V.V. Technology and machines for wire production. Yekaterinburg: UrB RAS, 2004. 343 p. (in Russ.).

[6] Kharitonov V.A., Manyakin A.Yu., Chukin M.V. et al. The improvement of the conditions of deformation and tool for drawing round wire // Magnitogorsk: G.I. Nossov Magnitogorsk STU, 2011. 174 p. (in Russ.).

[7] Kharitonov V.A., Usanov M.Yu. A model of nanostructure formation in a high-carbon wire during radial-shift broach // Physicochemical aspects of clusters, nanostructures and nanomaterials study. Interuniversity collection of scientific papers. Issue 4, 2012. P. 309-313 (in Russ.).

[8] Ussanov M.Yu. Improvement of carbon wire manufacturing technology based on increasing the efficiency of drawing deformation modes: Diss. candidate of tech. sci. Magnitogorsk, 2018. 178 p. (in Russ.).

[9] Chukin M.V., Korchunov A.G., Polyakova M.A., Yemaleyeva D.G. Continuous deformation method for forming an ultra-fine-grained structure of steel wire // Steel. 2010. N 6. P. 96-98 (in Russ.).

[10] Korchunov A.G., Chukin M.V., Polyakova M.A., Yemaleyeva D.G. Design principles of a continuous method for producing steel wire with an ultra-fine structure // G.I. Nossov MSTU's Herald. 2011. N 1. P. 43-46 (in Russ.).

[11] Ko Y.G., Namgung S., Son I.H., Rhee K.H., Shin D.H., Lee D.L. Spheroidization of medium carbon steel fabricated by continuous shear drawing // Journal of Materials Science. September 2010. Vol. 45, N 17. P. 4866-4870.

[12] Muszka K., Wielgus M., Majta J., Doniec K., Stefanska-Kaclziela M. Influence of strain path changes on microstructure inhomogeneity and mechanical behavior of wire drawing products // Mater. Sci. Forum. 2010. P. 314-317.

[13] Nekrassova Ye.O., Kharitonov V.A. Using computer modeling to analyze the process of screw broaching of high-carbon steel billet // Procurement in mechanical engineering. 2013. N 10. P. 44-47. (in Russ.).

[14] Mashekov S.A., Nugman E.Z., Mashekova A.S., Bekbosynova B.A., Tussupkaliyeva E.A., Absadykov B.N. Investigation of power and force parameters of pressing of precisions at the continuous pressing mill of new construction // News of the National Academy of Sciences of Kazakhstan. Series of geology and technical sciences. 2020. Vol. 1. N 439. P. 73-80. https://doi.org/10.32014/2020.2518-170X.9

[15] Pashinskaya E., Zavdoveev A., Varyukhin V. and others. Drawing with shear as an effective method of the control of the structure and the properties for low-carbon steel // High pressure physics and engineering. 2015. Vol. 25, N 3-4. P. 47-59.

[16] Maksakova A.A., Olshanetskiy V.Ye., Pashinskaya Ye.G. et al. Features of the structure and properties of the wire depending on the degree of deformation when drawing with a shift // New materials and technologies in metallurgy and mechanical engineering. 2014. N 2. P. 26-29 (in Russ.).

[17] Galkin S.P., Romantsev B.A., Kharitonov E.A. Realization of the innovative potential of a universal method of radial-shear rolling // Ferrous metals, 2015. N 1. P. 31-38 (in Russ.).

[18] Daeva E.V. Development and study of stands design and technology of helical rolling of high accuracy billets: autoabstract. dis. ... Ph.D. M., 2003. 19 p. (in Russ.).

[19] Patent of the Republic of Kazakhstan No. 27722. Mashekov S.A., Nugman E.Z., Alshynova A.M. and etc. Device for continuous pressing of the press product. Publ. 18.12.2013. N 12. 3 p. I ll. (in Russ.).

[20] Anuryev V.I. Designer machinist guide. In 3 volumes. 8th ed., Rev. and add. under the editorship of I.N. Zhestkova. M.: Mechanical Engineering, 2001. 912 p. (in Russ.).

[21] Kopanev D. Solution of dynamics tasks by means of MSC. Patran-Nastran. User Guide M.: MSC.Software Corporation, 2010. 169 p. (in Russ.).

[22] Soldatkin A., Golenkov Yu. and etc. MSC.SuperForge program as one of the elements of the virtual manufacturing and product quality management system // CAD and Graphics, 2000. N 7. P. 11-13 (in Russ.).