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# STUDY OF THE DEFORMED STATE CONNECTION OF THE PISTON WITH THE ROD OF THE UNREGULATED PISTON PUMP

*The technological processes of cold rolling of precision workpieces and ring parts, rolling of pipes, rolling of piston-connecting rod axial-rotor piston pump, which are a kind of processing of metals by pressure and contain changes in the shape of workpieces according to performing relative to the axis of the workpiece radial rotational motion. The workpiece can remain stationary or rotate.*

*It is shown that by means of technological process of rolling of pipes, unrolling of preparations various hollow axisymmetric metal products receive, the specified processes are combined by the mechanism of deformation, namely: at them two deformations of compression and one - tension are realized. This mechanical deformation scheme creates favorable conditions for plastic deformation, because intercrystalline displacements are difficult, leading to the violation of mechanical bonds, and plastic deformation occurs mainly due to intracrystalline displacements.*

*It is shown that in the process of connecting the piston-connecting rod in compliance with the process parameters (output supply pressure, feed rate, leaving time) the value of the specified gap either exceeds the maximum value or decreases to the value at which the next operation of the piston-connecting rod spell.*

*The deformed state in the technological operation of rolling the piston-connecting rod pair at different stages of shape change is studied, the process control mechanism is revealed, which prevents the defect in the form of deviation from the regulated gap after rolling between the piston and the connecting rod.*

*The used resource of plasticity at different stages of rolling is calculated, the deformability of the piston workpiece in the rolling process is estimated.*

***Keywords:*** *.technological process, connecting rod, deformed state, used plasticity resource.*

**Problem statement.** In unregulated pumps and hydraulic motors 310.224, which are designed for hydraulic drive of construction, road and municipal vehicles, one of the most important structural elements is a piston-connecting rod pair.

When performing the technological operation of rolling the piston with the connecting rod, the main defective feature is the instability of the axial gap between the connecting rod and the piston (see Fig. 1). The maximum value of this gap should not exceed 0.12 mm.

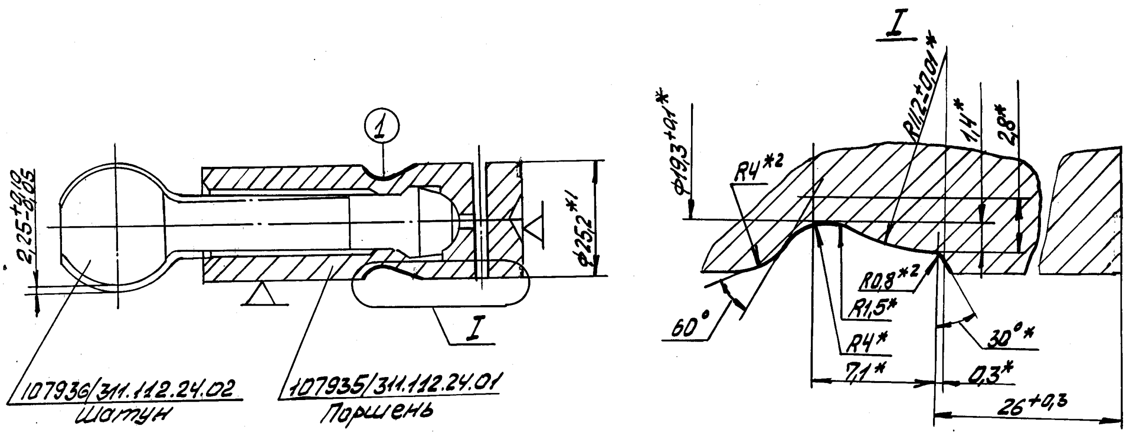


**Fig. 1. Drawings of the piston with a rod after rolling**

In the process of rolling in compliance with the process parameters (output feed pressure, feed rate, leaving time) the value of the specified gap either exceeds the maximum value or decreases to a value at which in the next operation of the piston-connecting rod jamming occurs.

Another problem that arises in the manufacture of piston-connecting rod pairs is breakage during their operation, in particular, there is a break in the connecting rod.

**Analysis of recent research and publications.** Technological processes of cold unrolling of precision workpieces and ring parts [1, 2], rolling of pipes [3, 4], rolling of piston-connecting rod axial-rotor piston pump are a kind of metal processing by pressure and contain changes in the shape of workpieces according to the required shape of the product by periodic compression of the working bodies, carrying out relative to the axis of the workpiece radial rotational motion. The workpiece can remain stationary or rotate.

By means of technological process of rolling of pipes, unrolling of preparations receive various hollow axisymmetric metal products, the specified processes are combined by the mechanism of deformation, namely: at them two deformations of compression and one - tension are realized. This mechanical deformation scheme creates favorable conditions for plastic deformation, because intercrystalline displacements are difficult, leading to the violation of mechanical bonds, and plastic deformation occurs mainly due to intracrystalline displacements.

Rolling is a high-speed high-precision method of manufacturing parts of constant and variable cross section from simple source blanks.

The rolling process is reduced to a plastic change of shape by moving metal particles. This reduces the cross section and the corresponding elongation of the workpiece by moving the metal along the axis in two opposite directions. The use of rolling as a method of processing is possible for materials that are not only subject to significant plastic deformation, but also have fragility. Cold drawn or calibrated steel is used as blanks. When rolling, the volume is preserved, the strength of the metal increases, at the same time, as when machining metals by cutting, there is a decrease in the initial volume, as well as deterioration of the original quality of the metal due to fiber cutting.

Cold deformation that occurs during rolling, significantly affects the change in physical and mechanical properties of the metal. All indicators of resistance to deformation increase. This is due to the strengthening, which increases the shear strength and, consequently, increases all the mechanical characteristics.

Of great practical importance is the nature of changes in mechanical characteristics depending on the degree of rolling:

$$q = \frac{A_0 - A}{A_0} = \frac{d^2 - d_1^2}{d^2} \qquad (1)$$

The limit of hardening for carbon steels subjected to rolling, as shown by experimental studies, occurs at degrees of deformation of 40-50%. The hardness increases unevenly throughout the cross section. A more uniform distribution of hardness is observed at the degree of deformation q = 45-50%, and less at q = 10-30% and q = 65-80%. At q = 45% the value of hardness in the center of the section is less than that of the surface layers. When q = 50% the value of hardness in the Central layers is close to the hardness of the surface layers. At this degree of rolling, the cross-sectional hardness of the sample is distributed most evenly, its values determine the average resistance of the metal to plastic deformation in small areas.

When rolling, it is necessary to strive for minimal inhomogeneity of deformations, because the deformation gradient increases the average specific force and reduces ductility, which can lead to premature failure and creates residual stresses in the deformed product.

We will note that the assessment of deformability of preparations at rolling was practically not carried out that causes need of research of this parameter of quality of preparations.

An effective way to obtain axisymmetric products from tubular workpieces is rolling with a friction tool, when from its deformation force is transmitted to the deformed metal in the process of sliding the metal relative to the tool [4]. Rolling with a friction tool differs from rolling with a roller in that the whole process of deformation up to the closing of the workpiece walls is carried out in one pass of the tool.

In fig. In Fig. 2 shows diagrams of rolling tubular workpieces with a friction tool. All these schemes are implemented in separate designs of rolling machines.

Rolling (Fig. 2, a) is used in the production of seamless gas cylinders: tubular workpiece 1 with heated to the forging temperature end is rotated around its axis 0 - 0; at the same time tool 2 - rotation of 900 around the axis perpendicular to the axis of the workpiece. The created local pressure of the tool on metal provides deformation of preparation to the profile set by the tool. Deformation occurs in the process of friction - sliding between the tool and the workpiece.

Rolling (Fig. 2, b) is easily carried out on lathes, which consists in the following: the tubular workpiece, the end of which is heated to the forging temperature, report the rotational motion around its axis. Simultaneously, the tool 3 is given a translational movement in the direction perpendicular to the axis of rotation of the workpiece, so that the workpiece is deformed to a given shape.

Rolling (Fig. 2, c) is carried out by turning the tool 4 by 3600 relative to the axis 0 - 0, the parallel axis of rotation of the workpiece.

Each of the given and possible kinematic schemes of process of rolling has the features considering at development of technological processes and designing of the equipment.

Currently developed and used in the rolling industry with different options for mutual movement of the tool and the workpiece, which greatly expands its technological capabilities (Fig. 3).

The tool in all cases is calibrated so that at the given movement concerning the rotating tubular preparation, its section at smooth transition corresponds to the set forms forming a rolling preparation.

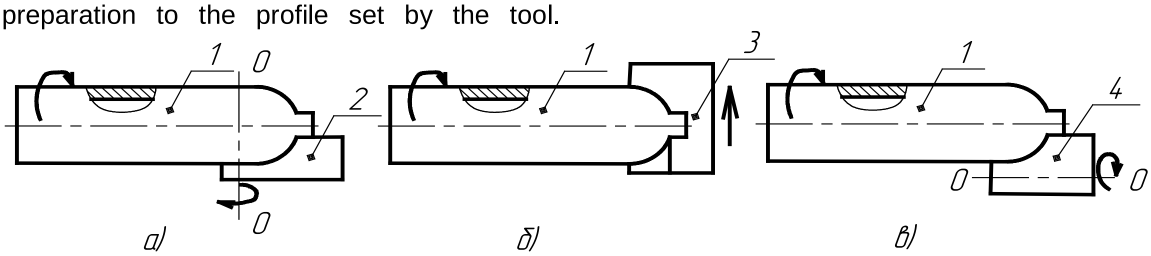


**Fig. 2. Scheme of rolling of tubular blanks:1 - blank; 2 - 4 - tools.**

**The purpose of the study.** The actual work is devoted to the study of the deformed state in the technological operation of rolling the piston-connecting rod pair at different stages of deformation, in order to identify the process control mechanism that prevents failure in the form of deviation from the regulated gap after rolling between piston and connecting rod.

It is also of practical interest to identify the used plasticity resource at different stages of rolling, in other words, the assessment of the deformability of the piston workpiece during rolling.

**Presentation of the main material.** To solve this goal, it is necessary to determine the stress-strain state of the piston-rod workpiece during their rolling at the stages of shape change until the final geometry (Fig. 1 (I)).

The study of the mechanics of deformation during rolling was performed experimentally. Seven piston-rod blanks were made, and a 1 mm dividing mesh base was applied to the inner surface of the piston before rolling with a specially sharpened sharp cutter. The grid was applied both in the longitudinal and in the circumferential directions. Then the workpiece was subjected to rolling, the parameter of which is taken:

$$m = \frac{D-d}{2t}, \quad (2)$$

where D- is the diameter of the piston before rolling, d- is the minimum diameter of the piston after rolling, t- is the wall thickness of the piston. The parameter m characterizes the degree of deformation of the piston workpiece as a whole.

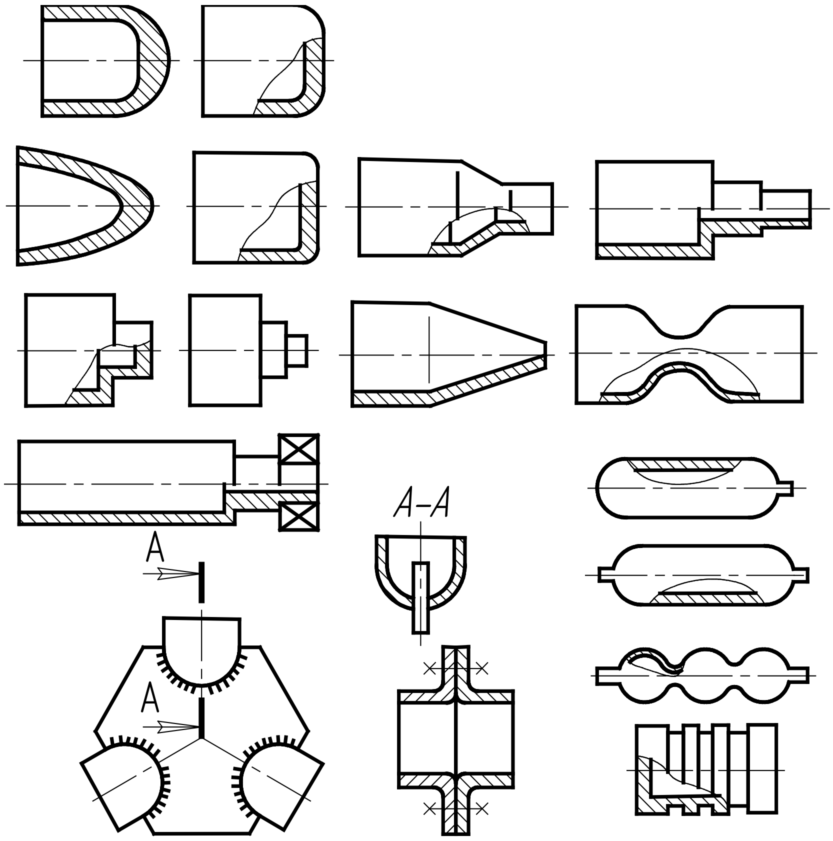


**Fig. 3. Axisymmetric parts and products obtained by rolling pipes**

Table 1 shows the modes of deformation of the seven workpieces, which studied the stress-strain state in the process of rolling the piston with a connecting rod.

Table 1

Modes of rolling of preparations of the piston with a connecting rod

| № sample | Rolling parameters | Note |
|---|---|---|
| **1** | 0,24 | Rolling with a connecting rod, without pauses |
| 2 | 0,51 | Rolling with a connecting rod, without pauses |
| 3 | 0,64 | Rolling with a connecting rod, pause 3 s |
| 4 | 0,65 | Rolling with a connecting rod, pause 3 s |
| 5 | 0,62 | Rolling with a connecting rod, pause 3 s |
| 6 | 0,63 | Rolling with a connecting rod, pause 3 s |
| 7 | 0,49 | Rolling without connecting rod |

After deformation according to these modes, the piston blanks were cut along the meridional section, the resulting surface was ground and polished.

Then in the meridional section of the piston blank was measured Vickers hardness at 30-40 points under a load of 50 Newtons. Previously built a calibration graph of steel 38H2MYUA after heat treatment, which is used to make piston blanks, in the coordinates: hardness HV, stress intensity - $\sigma_u$, strain intensity - $e_u$, according to the method described in роботі [5]. Isolines $\sigma_u$ = const, $e_u$ = const were constructed on all seven piston blanks using a calibration graph on the hardness isosclasses of the piston blank.

The components of the logarithmic strain tensor at different stages of rolling were calculated by the formulas:

$$e_m = \ln \frac{z_i}{z_0}, \quad (3)$$

$$e_\varphi = \ln \frac{d_0}{d_i}, \quad (4)$$

$$e_r = -e_\varphi - e_m, \qquad (5)$$

and the intensity of deformation

$$e_u = \frac{2}{\sqrt{3}}\sqrt{e_m^{\ 2} + e_m e_\varphi + e_\varphi^{\ 2}} . \qquad (6)$$

In the relations (3), (4), (5) - $e_m$, $e_\varphi$, $e_r$ - respectively, the meridional, circumferential and radial components of the tensor $Z_0$, $Z_i$ - the distance between the nodes of the dividing grid in the meridional direction of the piston workpiece before and after deformation; $d_0$, $d_i$ - diameters of the inner surface of the meridional section before and after deformation. These distances were measured on an instrument microscope with an accuracy of ±0.01 mm.

In fig. In Fig. 4 shows the distribution of logarithmic deformations at seven stages of deformation of the piston blanks after rolling, in its inner cavity.

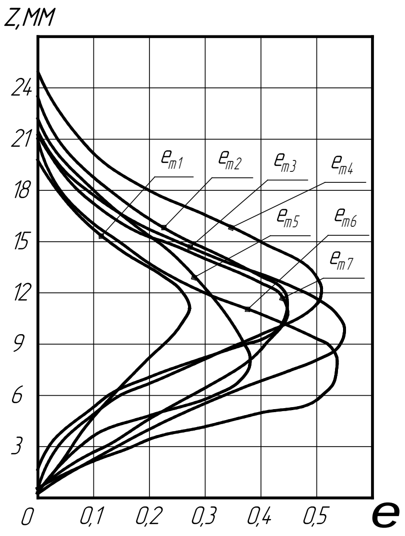


**Fig. 4. Distribution of the main logarithmic deformation in the longitudinal direction of the piston after rolling (internal cavity)**

As follows from the results, the maximum value $e_m$ varies from $e_m = 0.25$ to $e_m = 0.55$. Note that in 3 and 4, 5 and 7 stages of rolling, the average value of the maximum deformation in the inner cavity of the workpiece of the rolling piston is, while in 1, 2 and 6 stages, $e_m = 0.475$ this value is equal to 0.42.

Circumferential (tangential) deformations on the inner surface of the cavity of the piston workpiece change during rolling in the above stages within the following limits: $e_\varphi = -0.07$, to $e_\varphi = -0.3$. The average value of the circumferential deformation $e_\varphi$ reaches 3, 4, 5 and 7 stages $e_\varphi = -0.28$, while at 1, 2, and 6 this value is equal to $e_\varphi = -0.19$.

This circumstance is due to the different initial hardness of the piston blanks. In fig. In Fig. 4 shows the change in the initial hardness of the piston blanks from the sample number. Thus, samples 1, 2 and 6 were subjected $m_1 = 0.24$, $m_2 = 0.51$ and $m_6 = 0.63$ to rolling parameters, and had a hardness of $(HV)_1 = 230$ MPa, $(HV)_2 = 234$ MPa i $(HV)_6 = 233$ MPa, respectively, and samples 3, 4, 5 and 7 were subjected $m_3 = 0.64$, $m_4 = 0.65$ $m_5 = 0.62$ and $m_7 = 0.49$ to rolling parameters, and had a hardness of $(HV)_3 = 211$ MPa, $(HV)_4 = 206$ MPa, $(HV)_5 = 218$ MPa i $(HV)_7 = 212$ MPa.

For the whole deformation process, this fact means that a harder material when rolled shows less deformation in the axial and circumferential directions than a softer one. The flow limit, for example of a material having a hardness $(HV)_0$ = 206 ÷ 212 MPa is in the range $\sigma_{0.2}$ = 62 ÷ 64.5MPa. The flow limit of a material having a hardness $(HV)_0$ = 218 ÷ 234MPa is in the range $\sigma_{0.2}$ = 65 ÷ 70MPa. The maximum divergence of the flow boundary is about 13%. This discrepancy leads to the instability of the geometry of the piston and connecting rod blanks during their rolling.

The stress state during rolling was determined according to the method described in [7]. It involves determining the intensity of stress and strain by hardness using the engineering method [6]. When rolling the piston-rod, the dangerous area of deformation is the outer area in the vicinity of the action of the sunset roller. At the dangerous points, the contact stresses, the components of the stress tensor, the accumulated intensity of deformation, as well as the stress index were calculated.

$$\eta = \frac{\sigma_1 + \sigma_2 + \sigma_3}{\sigma_u}, \quad (7)$$

where $\sigma_1$, $\sigma_2$, $\sigma_3$, - main stresses, $\sigma_u$ - stress intensity.

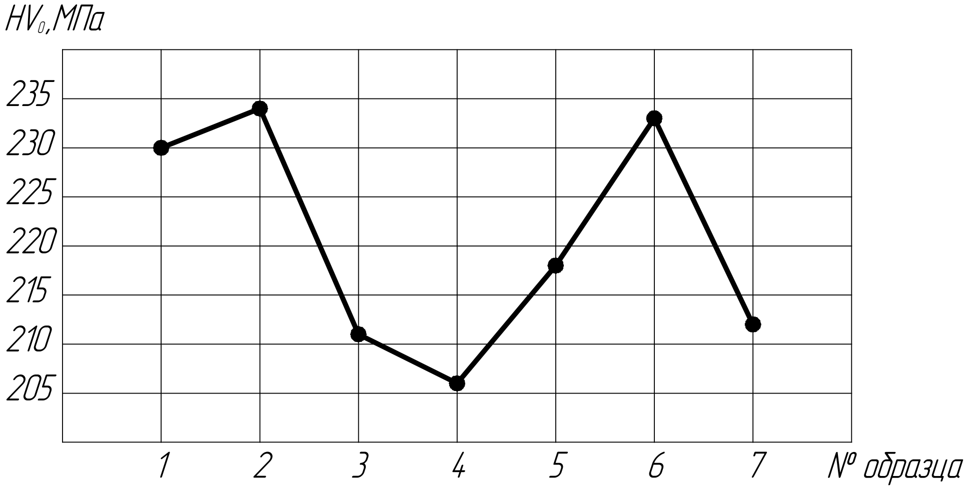


**Fig. 5. The dependence of the initial hardness HV0 of the piston blanks on the sample number**

For the investigated material (steel 38Х2МЮА) the diagram of plasticity in coordinates $e_p = f(\eta)$, is $e_p$ - constructed, where is the accumulated intensity of deformations up to the moment of fracture.

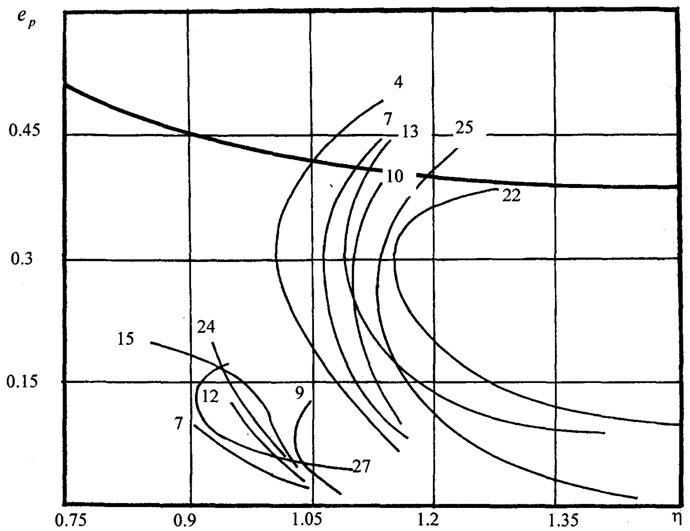


**Fig. 6. Ways of deformation of dangerous points in the process of rolling the piston-connecting rod pair and the diagram of plasticity of steel 38Х2МЮА**

In Fig. 6 shows part of the diagram of plasticity within the change of the index η 1.5 ≥ η ≥ 0.25, in the same figure for the dangerous points of the plastic region shows the ways of deformation of material particles during rolling in the coordinates $e_p = f(\eta)$. Each of the ways of deformation has its own curvature, so to determine the used resource of plasticity used phenomenological criterion of failure, which takes into account the rate of change of the stress state $d_\eta / de_u$ [8].

The criterion has the form

$$\psi = \int_0^{\bar{e}_u^*} \left(1 + a \cdot arctg \frac{d\eta}{de_u}\right) \frac{\bar{e}_u^{\,a \cdot arctg \frac{d_u}{de_u}}}{\left[e_p(\eta)\right]^{1 + a \cdot arctg \frac{d\eta}{de_u}}} \le 1, \quad (8)$$

where the constant *a*=0.2, $\frac{d\eta}{de_u}$ - "direction of deformation", $e_p(\eta)$ - diagram of plasticity, $\overline{e_u}$ - accumulated intensity of deformation, $\bar{e}_u^*$ - ultimate deformation, which corresponds to the used resource of plasticity $\psi = 1$.

The results of the calculation of the value of $\Psi$ using criterion (8) are given in table 2, from which it follows that at dangerous points on the outer surface, the plasticity resource $\Psi$ is close to unity. On the inner surface of the piston plane, the value of the used plasticity resource is significantly less than one (0,44 ≥ $\psi$ ≥0,22).

**Table 2**

**The value of the used resource of plasticity in the most dangerous areas of deformation**

| Punctum | 6 | 9 | 12 | 15 | 24 | 27 |
|---|---|---|---|---|---|---|
| $\psi$ | 1,1 | 1,05 | 0,95 | 0,98 | 0,97 | 1,04 |
| Punctum | 4 | 7 | 10 | 13 | 22 | 25 |
| $\psi$ | 0,22 | 0,3 | 0,32 | 0,4 | 0,44 | 0,42 |

**Conclusions**.

1. The kinematics of deformation during the operation of rolling a pair of piston-rod workpieces is studied. Using the dividing grid, all components of the logarithmic deformation tensor in the inner cavity of the piston blank at different stages of shape change, as well as on its outer surface, are calculated.

2. It is shown that at the increased hardness of the steel piston workpiece 38Х2МЮА (after heat treatment) the circumferential and meridional deformations in the inner cavity of the piston are smaller in comparison with the deformations in the workpieces made of softer steel. Deviation of maximum deformations: respectively circumferential by 20%, meridional by 13% for mild and hard steel (their hardness differed by 13%) leads to unstable filling of the piston cavity, which causes an increase in the gap between the connecting rod head and the piston.

3. To eliminate the defect associated with the deviation from the regulated gap between the workpieces of the piston and connecting rod when they are rolled, it is necessary to discard the workpieces of the piston and connecting rod on hardness. At the set regulated or reduced numbers of hardness of preparations of the piston the stable backlash is guaranteed at observance of other modes of deformation. In case of increase in number of hardness of preparations of the piston it is necessary to carry out process of rolling by a roller which geometry differs from the set.

4. The process of rolling the piston-rod blanks is carried out in the "hard" area of change of the stress state. On the outer surface of the piston workpiece used plasticity resource close to unity, on the inner

surface of the cavity of the piston workpiece plasticity resource $\Psi$ less than one, which provides a margin of plasticity in this operation.

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## ИССЛЕДОВАНИЕ ДЕФОРМИРОВАННОГО СОСТОЯНИЯ СОЕДИНЕНИЯ ПОРШНЯ С ШАТУНОМ НЕРЕГУЛИРУЕМОГО ПОРШНЕВОГО НАСОСА

В работе рассмотрены технологические процессы холодной раскатки прецизионных заготовок и кольцевых деталей, обкатывание труб, закатывание пары поршень-шатун аксиально-роторного поршневого насоса, которые представляют собой разновидность обработки металлов давлением и содержат изменение формы заготовок в соответствии с необходимыми очертаниями изделия путем периодического обжатия рабочими органами, осуществляющими относительно оси заготовки радиальное вращательное движение. Заготовка при этом может оставаться неподвижной, или делать вращательное движение.

Показано, что с помощью технологического процесса обкатывание труб, раскатки заготовок получают различные пустые осесимметричного метизы, указанные процессы сочетающие механизмы деформации, а именно: в них реализуется две деформации сжатия и одна - растяжения. Такая механическая схема деформации создает благоприятные условия для пластической деформации, так как затрудняются межкристалличные сдвиги, приводящие к нарушению механических связей и пластическая деформация протекает в основном за счет внутрикристаллических оползней.

Показано, что в процессе соединения пары поршень-шатун при соблюдении параметров процесса (выходное давление подачи, скорость подачи, время выхаживания) величина указанного зазора или превышает максимальную величину, либо уменьшается до значения, при котором в следующей работы пары поршень-шатун происходит заклинивания.

В работе изучено деформированное состояние в технологической операции закатывания пары поршень-шатун на разных стадиях формоизменения, выявлен механизм управления процессом, который предотвращает недостаток в виде отклонения от регламентированного зазора после закатывания между поршнем и шатуном.

Рассчитан использованый ресурс пластичности на различных стадиях закатывания, проведена оценка деформируемости заготовки поршня в процессе закатывания.

***Ключевые слова**: технологичний процесс, поршень-шатун, деформированное состояние, использованный ресурс пластичности*

## ДОСЛІДЖЕННЯ ДЕФОРМОВАНОГО СТАНУ З'ЄДНАННЯ ПОРШНЯ З ШАТУНОМ НЕРЕГУЛЬОВАНОГО ПОРШНЕВОГО НАСОСА

В роботі розглянуто технологічні процеси холодного розкочування прецизійних заготовок і кільцевих деталей, обкочування труб, закочування пари поршень-шатун аксіально-роторного поршневого насоса, які являють собою різновид обробки металів тиском і містять зміни форми заготовок відповідно до необхідних обрисів виробу шляхом періодичного обтиснення робочими органами, здійснюючими щодо осі заготовки радіальний обертальний рух. Заготовка при цьому може залишатися нерухомою, або робити обертальний рух.

Показано, що за допомогою технологічного процесу обкочування труб, розкочування заготовок одержують різні

порожні осесимметричні металовироби, зазначені процеси поєднує механізм деформації, а саме: у них реалізується дві деформації стиску і одна – розтягу. Така механічна схема деформації створює сприятливі умови для пластичної деформації, тому що утрудняються міжкристалічні зсуви, що приводять до порушення механічних зв'язків, і пластична деформація протікає в основному за рахунок внутрішньокристалічних зсувів.

Показано, що у процесі з'єднання пари поршень-шатун при дотриманні параметрів процесу (вихідний тиск подачі, швидкість подачі, час виходжування) величина зазначеного зазору або перевищує максимальну величину, або зменшується до значення, при якій у наступній роботі пари поршень-шатун відбувається заклинення.

В роботі вивчено деформований стан в технологічній операції закочування пари поршень-шатун на різних стадіях формозміни, виявлено механізм керування процесом, що запобігає брак у виді відхилення від регламентованого зазору після закочування між поршнем і шатуном.

Розраховано використаний ресурс пластичності на різних стадіях закочування, проведена оцінка деформуємості заготовки поршня в процесі закочування.

***Ключові слова:*** *технологічний процес, поршень-шатун, деформований стан, використаний ресурс пластичності*

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