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The Mechanism of Formation of the Inner Surface of Pipes during Cold Rolling

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The requirements imposed on the surface microrelief of cold rolled pipes are viewed. The mechanism of forming the inner surface microrelief shape changing of pipes during cold rolling, as well as the dependence of the state of the internal surface of pipes from the stress-strain state of billet at its compressing in passes of cold rolling mill are analyzed. The information on the impact of technological lubricants on the resulting roughness of the inner surface of the of cold rolled pipes as well as the value of the contact surface in the hearth the pipe cold rolling mill are stated.

Keywords: COLD-ROLLED PIPES, SURFACE MICRORELIEF, PROCESSING METHODS

Introduction

The principal drawback of the existing technology is currently making cold-rolled pipes of responsible use of stainless steels, zirconium and titanium alloys is the formation on their inner surface of the longitudinally oriented defects in the form of local grooves and protrusions. Often, they are classified by the term "bloom" and believe that the prolonged use they can be potential causes of failure when exposed to elevated temperatures, pressures and corrosive environments.

For a long time it was felt that such defects are caused mostly by high value strain inherent in the cold rolling of pilgrim pipes [1]. A different solution is presented in [2], related to the technology of manufacturing of pipes of zirconium alloys, where in order to prevent the formation of defects and to ensure a favorable orientation of the hydrides it is recommended to apply a calibration factor Q, which is the ratio of wall thickness reduction in the mean diameter of the compression. It is suggested to form the route of rolling so that the Q was greater than 1, preferably equal to 2 or more and with a total strain of at least 50%. In general, it should be in the range 75-95%. Later, the principle of proportionality of strain on the diameter and wall thickness it was suggested to use proportional breakdowns in the calibration (PBC) recommended for the manufacture of stainless steel pipes [3]. In [4] it is proposed to improve the accuracy of the size and quality of the inner surface of the zirconia pipes, the stability of mechanical properties and reduce the number of defects on the inner surface of the proposed use of the calibration profile of the rolls and the mandrel, made in a uniform curve, based on mathematical calculations. It is based upon a determination of the curves of profiles that are the geometric position of the various nodes of spline functions. In calculating these curves use the coefficients that determine the physical and mechanical properties of the metal being rolled and cold-rolling modes which are used. In [5] provides a method to improve the quality of pipes, made from double-zirconium alloys with the following technological operations: the production of ingots, beta quenching, hot-forging at a temperature of 30-60 ° C above the transformation temperature of the alloy from the alpha + beta-phase beta-phase, the mechanical treatment and tempering at a temperature in the alpha phase. The subsequent cold deformation is recommended to produce an extract with a total of more than 100, while for intermediate sizes of pipes with a deformation of less than 50. It is reported that this technique is tested on Chepetsk mechanical plant. However, in the above patent information on the quantitative effect of improving the internal surface are not shown.

Performed literature and patent reviews on this topic gave grounds to conclude that there are significant contradictions caused by shortcomings of metrological support of research conducted. Fundamentally different regularities established in studies carried out using specialized measuringcomputer complex, which provided scan surfaces in a sequence of cross-sections located along the length of the deformation zone [1]. With the help of this technique large amounts of measurement data of high accuracy were collected, in a subsequent subjected to mathematical treatment using advanced algorithms. These results clearly showed that the inner surface of the tubes contains a set of macro and micro components, which are formed along the length of the deformation zone, including the end of the crimp and the beginning of a calibration plots. This conclusion is fundamentally changing the old idea of the regularities of formation of microrelief inner surface of pipes during the rolling process. These circumstances determined the necessity of rapid and reliable detection of origin of defects parts and their subsequent development during deformation. To solve this problem we developed a model of the rolling process control of pipes, which allows to determine with reasonable certainty regularities of formation of the inner surface to provide increased demands on its quality.

Results and Discussion

Cold pilgrim rolling of pipes is one of the most difficult types of plastic deformation of the metal. Frequency of feeding and turning blanks, uneven breakdowns in length and in cross sections, the consolidation of the metal complex of other technological factors make it difficult to create accurate models suitable for use in practical applications.

With a relatively small proportion of errors, this process can be regarded as a linear dynamical system consisting of a sequence of instantaneous deformation centers, each of which is a linear stochastic subsystem. In this case the input of each of the perturbing signal is applied as a moving outer profile and generates an output signal that reflects the coordinates of the cross section of the inner surface. In simplified form, this approach can be represented in the form of a flowchart shown in Figure 1. Here u (t) means the input signal, reflecting the movement of the outer surface of the corresponding cross-section of the deformation zone, y (t) the output signal representing the coordinates of the inner surface, and e (t) - the impact of noise associated with the uneven structure, mechanical properties of metal and other random factors. When specifying the coordinates of profiles in the polar parameter t is an argument. It is known [6] that complicated complex dynamical systems in continuous time can be described by the following equations:

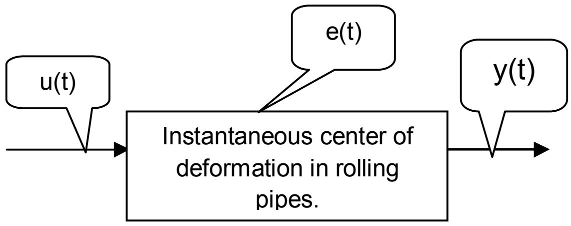

Figure 1. Flowchart of the instantaneous deformation zone

• stochastic differential form

$$\frac{d^n X(t)}{dt^n} + \alpha_{n-1}\frac{d^{n-1}X(t)}{dt^{n-1}} + \ldots + \alpha_0 X(t) = b_{n-1}\frac{d^{n-1}Z(t)}{dt^{n-1}} + \ldots + b_1\frac{dZ(t)}{dt} + Z(t)$$

• stochastic in finite differences

$$X_t + \varphi_1 X_{t-1} - \varphi_2 X_{t-2} - \ldots - \varphi_n X_{t-n} = a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \ldots - \theta_{n-1} a_{t-n+1}$$

In general, they can be represented by the following equation: y = Gy + He, where the output signal y (t) is the sum of the measured signal u (t) and the impact of the random component (noise) He. The symbol G denotes the dynamic properties of the system, defining how the input signal creates an output signal. For linear systems it is called the transfer function from input to output.

The symbol H characterizes the noise properties of the system. If the input and output signals are connected by the system linearly, their transformation can be written in the form of the equation

$$y(t) = \sum_{k=1}^{\infty} g_k u(t-k)$$

where u (t) - signal that influences the system, v (t) - signal generated by the system with impulse response function (impulse response) gk.

It is known that the ultimate goal of identifying a dynamic system is the selection of the model which in the best way describes the output signal based on the values of the input. Modern software allows to select the parameters of various models, including autoregression (ARX), autoregressive moving average (ARMAX), output error (OE) and the equation of the Box-Jenkins (BJ), and others. The most common methods used in the determination of these models is to find estimates of the amplitude-frequency characteristics and transfer functions.

Identification of complex systems using the finite difference equations is widely used in various fields of science and technology as well as economy. In the field of metal forming technology in general and in particular the manufacture of pipes, this approach has not yet found significant application.

Analysis of the dimensional structure of the inner surface of the microrelief is based on measurements of cross-sectional profiles deviations of pipes, details of the method are described in [7]. In each cross section up to 3500 deviations were measured, and then calculated their amplitude-frequency characteristics, and subsequently performed 3D-analysis. The measurement error was within ± 1.5 mm. Algorithm for processing measurement data included calculation of the autocorrelation function and power spectra of variations using the Welch and Hanning window. It was established that the dimensional structure of the cross-sectional profiles of the inner surface of cold rolled pipes differs the raised non-stationarity, the presence of trend and periodic components of different types. For their selection we designed digital filters, and then filtering the results of measurements was made in the required frequency bands. In some cases, wavelet analysis was used. On this basis, the following classification of the deviations of the surface was suggested: close to the period of deviation within 0.18-0.5 length of the perimeter cross-section tubes and micro-deflection within a period of 0.001-0.4 mm. It was established that periodic components of the inner surface of the pipes are in a limited frequency range. A different situation is characteristic of the micro deviations that complicate the valuation of length measurement and sampling step. To determine the mechanism of formation of the inner surface the relations between macro and micro components of deviations were analyzed.

The essence of the results is shown in **Figure 2**, where the rectangular coordinate system is a cross-sectional profile of the inner surface of cold rolled pipes size of 46 × 8 mm of steel ШХ15.

The solid dark line is the approximation of the deviations of the macro and micro-scale deviations from the selected set is displayed as gray dots. Nature of the approximated curve gives the conclusion that the deviation of the transverse profile of the macro associated with ovalisation during deformation. For the analysis of the formation of micro deviations in **Figure 2** is divided into three section 1, 2, 3 with the different character of the curvature of the cross-sectional profile. The measured values of deviations of micro profile on these sites are shown in **Figure 3**. Their comparison gives grounds to conclude that the plot № 1 is characterized by a smooth change in cross-section profile and relatively small values of the micro deviations. Fundamentally a different trend is inherent in the local areas 2 and 3, which is inherent in a sharp change in cross-section profile.

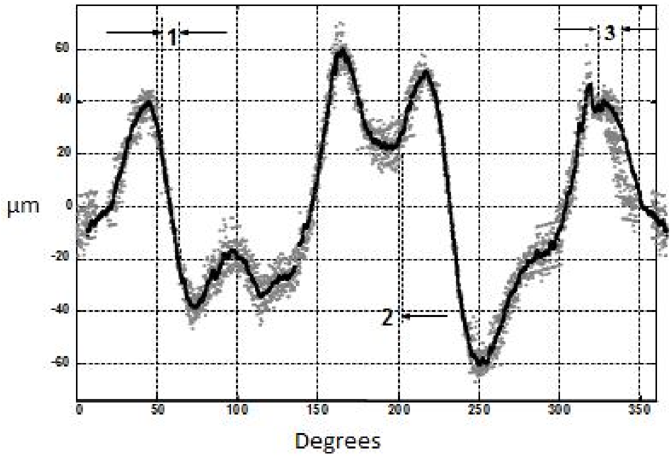

Figure 2. Cross-sectional profile of the inner surface of the pipe 46 × 8 mm, steel ШХ15: abscissa - the cross-sectional scan, degrees, ordinate - the deviation of the profile cross section, mm

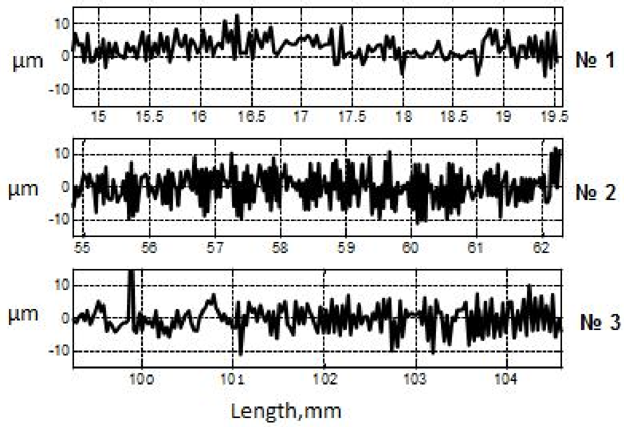

Figure 3. Micro deviations of the cross-sectional areas at the local inner surface, the pipe 46 × 8 mm, steel ШХ15: x-axis - the position of local areas in the cross section (mm), vertical axis - deviation of the profile (m)

The observed relationship between macro and micro cross-sectional profile deviations is the principal feature of the process, illustrating the validity of the conclusion that the formation of defects in the inner surface is primarily a consequence of the formation of macro biases that are inherently a deviation from roundness of the corresponding surface.

To analyze the fine structure of micro-sized components wavelet analysis was used. The need for this method which is widely spread in the last decade, is caused by the fact that the traditional Fourier transformation is not always able to adequately solve the problem of separating the time series into components. The results of analysis performed using a wavelet-type «sym» for four levels of decomposition showed that during the rolling process, the formation of local grooves and protrusions that could significantly affect the performance characteristics of tubes. This kind of dimensional anomaly is without a doubt will help to increase the absorption of gases, and thus may be potential sites of nucleation and subsequent corrosion cracking.

Interrelation of deviations of profiles of cross-sections the outer and inner surfaces of pipes

Within the framework of the research we established a close relationship between deviations of outer and inner surfaces. This trend is clearly seen when comparing the graphs shown in **Figure 4** and **5**. For the inner surface it is characterized by the imposition of a periodic component of the micro components.

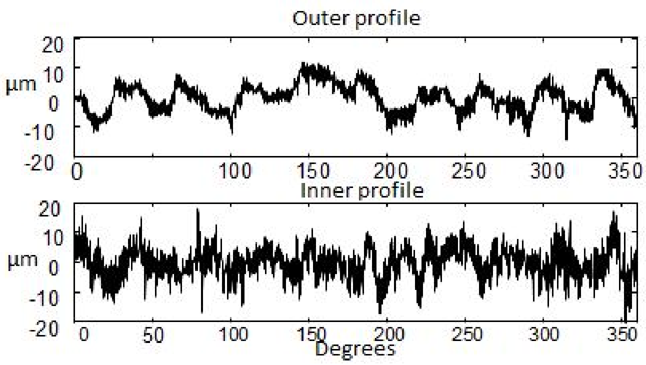

Figure 4. Cross sectional profiles of outer and inner surfaces: pipe size 35•5 mm, alloy Zr1Nb

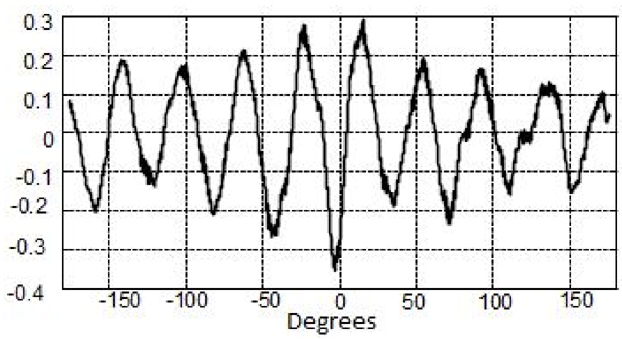

Figure 5. Deviations of the cross sectional profiles of outer and inner surfaces: pipe size 17 • 1.9 mm, alloy Zr1Nb, rolled along the route 30 • 4 mm → 17 mm • 1.9

The existence of a stable relationship shows cross-correlation function between the two profiles shown in **Figure 6**.

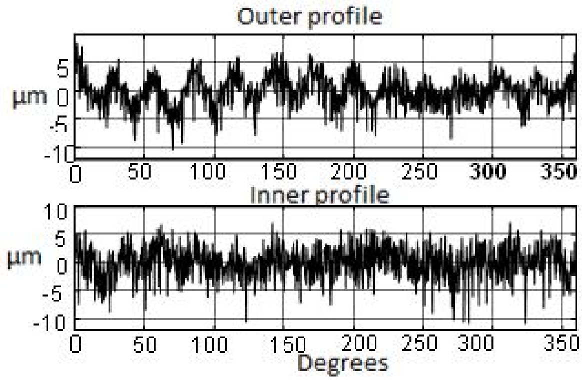

Figure 6. The mutual correlation function of the cross-sectional profiles of the outer and inner surfaces: pipe size 35 • 5 mm, the alloy Zr1Nb. The nature of this function indicates a relationship with a period of about 40°

The difference between quantitative cross-sectional profiles can be seen by comparing plots of histograms (**Figure 7**) and periodograms presented in a logarithmic scale (**Figure 8**).

V. The model parameters of the microrelief formation in the inner surface of the rolling process

To identify the model of a linear system describing the formation of the deviations of the inner surface of pipes during the rolling process, using the model fourth-order autoregressive moving average of A (q) y (t) = B (q) u (t) + e (t).

In the sampling step 32.1 microns for it found the following values of polynomials:

$A(q) = 1 - 4\ (\pm 0{,}0002293)\ q^{-1} + 6{,}002\ (\pm 0{,}0006876)\ q^{-2} - 4{,}004\ (\pm 0{,}0006875)\ q^{-3} + 1{,}002\ (\pm 0{,}0002292)\ q^{-4}$;

$B(q) = 0{,}001618\ (\pm 0{,}0005581)\ q^{-1} - 0{,}004706\ (\pm 0{,}001674)\ q^{-2} + 0{,}004556\ (\pm 0{,}001674)\ q^{-3} - 0{,}001468\ (\pm 0{,}0005582)\ q^{-4}$.

On their basis a form of simulated deviations of cross-sectional profile of the inner surface is defined. Measured and simulated deviations are shown in **Figure 9**.

The results obtained allow us to calculate the transfer function between the profiles and on its basis to determine the required level to reduce the value of macro deviations of outer surface to minimize the inner surface of the trace constituents

VI. The principle of control of formation inner surface of the cold rolled pipes

The established regularities were taken as the basis proposed in [8] the principle of diagnosing the inner surface of cold rolled pipes and control of its formation during cold rolling. Its essence is shown in a flowchart in **Figure 10** and provides the implementation of the proposed sequence of operations in a separate mode of time.

Thus it refers to the following terms: "control of the formation of the inner surface" - assessment of the internal surface with a consistent measure of deviations of cross sections of profiles to decide on the need to correct rolling modes. Under the influence of technological factors - the effect of the filing of deformation, the gaps between the rollers, the error of making gauges, and other options, potentially capable of forming cross-sectional contours of the deviation outer surface during cold rolling. Randomly assigned to the factors are non-uniformity of mechanical properties, thermal deformation modes other factors. At the same time we proceeded from the fact that their impact in the rolling process deviations of outer and inner surface is formed.

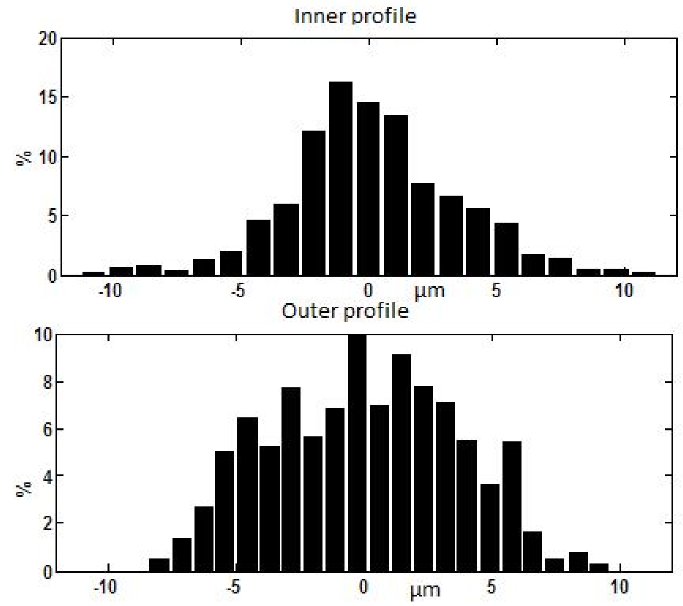

Figure 7. Histograms of deviations of the cross sectional profile outer and inner surfaces: the pipe size of 35 • 5 mm, the alloy Zr1Nb

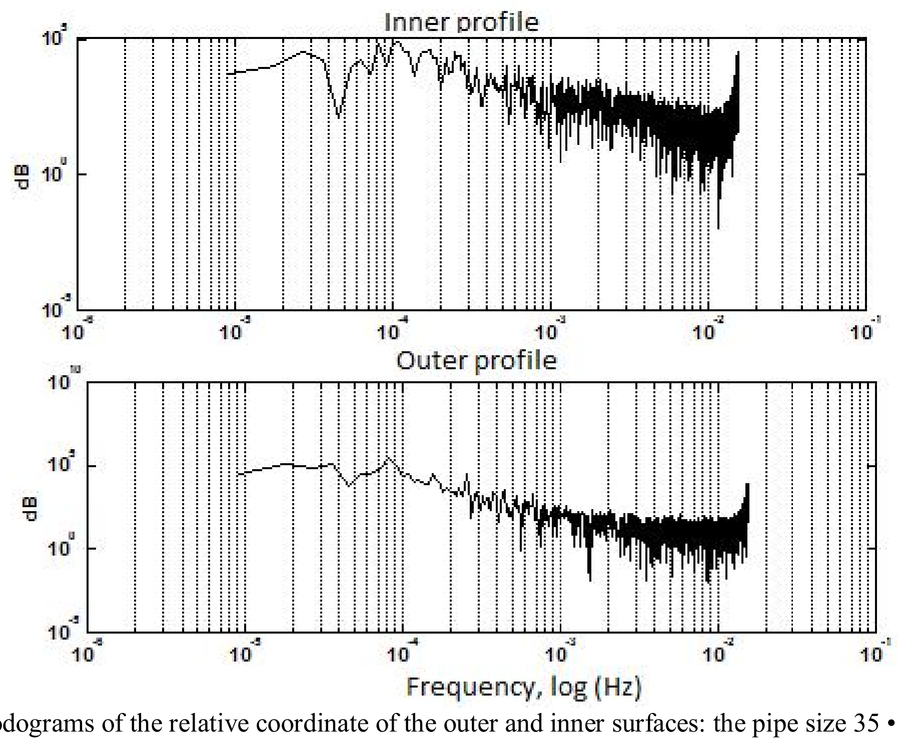

Figure 8. Periodograms of the relative coordinate of the outer and inner surfaces: the pipe size 35 • 5 mm in cross section, the alloy Zr1Nb (logarithmic scale)

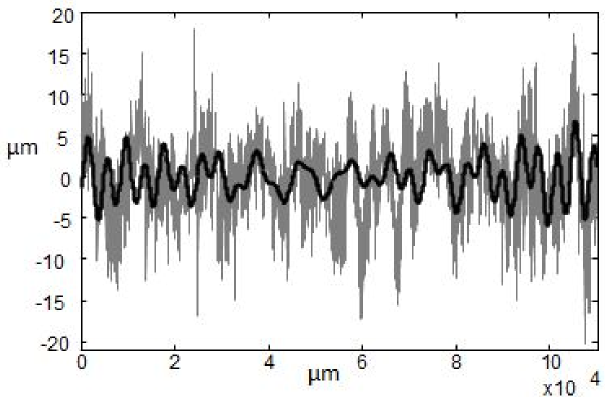

Figure 9. Measured (gray) and modeled deviations (black) of cross-sectional profile of the inner surface of the pipe 35 • 5 mm

The key point of "control" is to define the coordinates of the outer and inner surfaces. It can be done using continuous scanning of surfaces in a sequence of cross-sections of the working cone with minimal metrology errors. An important step is to determine the diagnostic procedure of coordinate surfaces. Given the longitudinal orientation of the inner surface of the cold rolled pipes, as shown in [9], a stage, "Measuring cross-sectional profiles deviations" in the deformation should be carried out by scanning the sequence of cross sections with the subsequent formation of three-dimensional matrices. It should pay particular attention to the metrological assurance of measurement accuracy.

The subsequent step is "Defining the transfer function between the profiles." It includes the processing of measurement results, the determination of estimates of statistical data, the calculation of the amplitude-frequency characteristics and other parameters, including the value of the transfer function, which is determined based on the need to change the deformation mode of rolling. This procedure allows determining the moment of origin defects of the inner surface and making appropriate adjustments of modes of deformation. Since operating life of power plants largely depends on the internal surface of pipes used, the proposed principle of diagnosis and management of the formation of the inner surface should be regarded as an indispensable element of the manufacturing technology of pipes of critical applications.

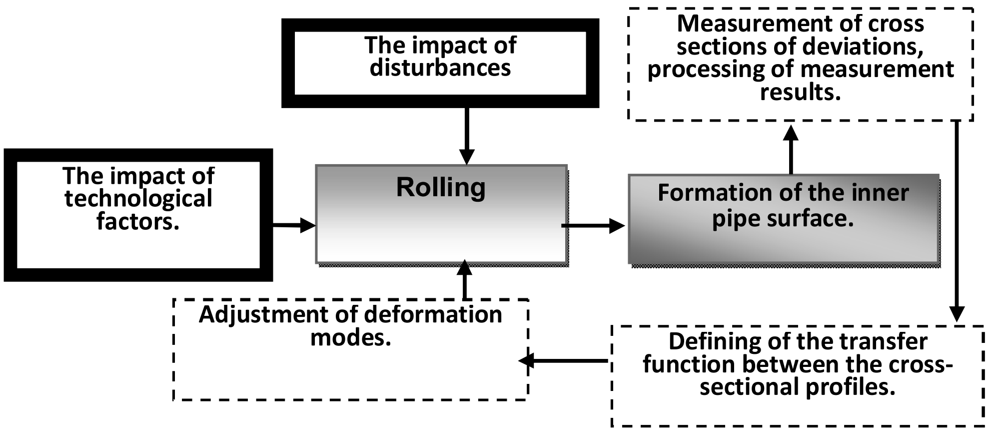

Figure 10. Flowchart of control of the formation of the inner surface of cold rolled pipes

References

1. Kuznetsov D.Ye. Metodicheskie osobennosti issledovaniya razmernykh kharakteristik vnutrennyeĭ poverkhnosti trub, Suchasni problemy metalurgii. Naukovi visti. Tom 8. Plastichna deformatsiya metaliv, Dnipropetrovs′k: Sistemní tekhnologii, 2005, P. 456–460. *

2. US Patent office № 3690850, patented Sept. 12, 1972. Zirconium alloy tube with zirconium hydride inclusions. John Olof Edsrom, Sven Eric Innerman, Bengt Henric Berg, and Brian Edward Mills, Sandviken, Sweden, assignors to Sandviken Jernverks Aktiobolag, Sandviken, Sweden.

3. Kholodnaya pilgernaya prokatka trub,V.F.Frolov, V.N.Danchenko, Ya.V.Frolov, Dnipropetrovsk: Porogi, 2005, P. 256.*

4. US Patent office № 6360575, patented March 26, 2002. Calibration of an instrument for the cold-rolling of tubes Zavodchikov; Inventors: Sergey Yurievich (Glazov, RU), Lositskiy; Anatoliy Frantsevich (Glazov, RU), Kotrekhov; Vladimir Andreevich (Glazov, RU), Komissarov; Vladimir Arsenievich (Glazov, RU), Safonov; Vladimir Nikolayevich (Glazov, RU), Krotkikh; Sergey Valerjevich (Glazov, RU), Devyatikh; Vasiliy Gennadjevich (Glazov, RU), Veretennikov; Vladimir Alekseevich (Glazov, RU), Bocharov; Oleg Viktorovich (Moscow, RU), Buchovtsev; Viktor Fedorovich (Moscow, RU), Shikov; Alexandr Konstantinovich (Moscow, RU). Assignee: Joint Stock Company

«Chepetsky Mechanical Plan» (RU).

5. US Patent office № 6368429, patented April 9, 2002. Method of manufacturing zirconium alloy tubes. Inventors: Zavodchikov; Sergei Jurievich (Glazov, RU), Aktuganova; Elena Nikolaevna (Glazov, RU), Bocharov; Oleg Viktorovich (Moscow, RU), Bukhovtsev; Viktor Fedorovich (Moscow, RU), Kotrekhov; Vladimir Andreevich (Glazov, RU), Lositsky; Anatoly Frantsevich (Glazov, RU), Shevnin; Jury Pavlovich (Glazov, RU), Nikulina; Antonina Vasilievna (Moscow, RU), Seliverstov; Vladimir Fedorovich (Glazov, RU). Assignee: Joint Stock Company «Chepetsky Mechanical Plan» (RU).

6. Dzhenkins G., Vatt•s D. Spektralnyi analiz i yego prilozheniya. Vyp. 1, M.: Mir, 1971, 317 p. *

7. Kuznetsov D.Ye. Metodiki otsenki sostoyaniya vnutrennyei poverkhnosti trub, Suchasní problemi metalurgii. Naukovi visti. Tom 11. Plastichna deformatsiya metaliv. Tyeoriya i tekhnologiya virobnitstva trub. Dnipropetrovsk, 2008, P. 305–312. *

8. Pat.15782 Ukraina, MPK (2006) V21V 21/00. Sposib vygotovlennya trub iz vysokolegovanikh stalyei i splaviv, Kuznetsov D.Ye., Vakhrusheva V.S, Kuznetsov Ye.D.; zayavitel′ i patentoderzhatel′ derzhavne pídpriemstvo «Naukovo-doslídnii ta konstruktorsko-tekhnologíchnii Institut trubnoíi promislovosti im. Ya.Yu. Osady», u 200600589; zayavl.23.01.2006; opubl. 17.07.2006, Byul. № 7. *

9. Kuznetsov D.Ye. Povyshenie tochnosti razmerov i kachestva poverkhnosti kholodnokatanykh trub,Stal′, 2005, № 10, P. 81–85.*

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Закономерности формирования микрорельефа внутренней поверхности труб при холодной прокатке

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Закономерности формирования микрорельефа внутренней поверхности труб при холодной прокатке

Дан обзор исследований, посвященных формированию внутренней поверхности труб холоднокатаных. Приведены результаты исследований, выполненных с использованием специализированного измерительно-вычислительного комплекса, установлены амплитудно-частотные характеристики отклонений наружной и внутренней поверхностей холоднокатаных труб. Предложен способ управления формированием внутренней поверхности труб из высоколегированных сталей и сплавов циркония в процессе холодной пилигримовой прокатки.