Experimental studies of rotatory rolling of long thin-wall pipes

A M Lavrentiev
Lecturer, Kamysordin Technological Institute (branch) of the Volgograd State Technical University, str. Lenina 6A, Kamysdin 403874, Russia
E-mail: Lamvstu@gmail.com

Abstract. The article considers the application of rotatory rolling of the external surface of a long thin-wall pipe. The author studied the possibility of correcting the form of a thin-wall pipe outer diameter by means of rotatory rolling with cylindrical rollers having a rectilinear generator and set for a self-tightening angle with a simultaneous decrease of the processed surface roughness. Further, the author provides a photo of the measuring device used to define the circular deviation of a thin-wall pipe surface. A polar diagram of the pipe surface as-delivered and its profile record were made. The article provides a photo showing the adjustment process of a rotatory reeling machine with three deformation rollers for treating long thin-wall pipes in the system of a general purpose lathe. The experiment results are presented in the form of a polar diagram and the treated surface profile record. It is shown that after rotatory rolling the circular deviation decreases to 0.1 mm while the surface roughness decreased from Ra 1.83 µm to Ra 0.23 µm.

1. Introduction
The industry produces a large number of products (household carts and baby carriages, shopping carts, stacks, furniture pieces, curtain rods, stair railing and balustrades, hand rails, etc.) the structural parts of which are nickel coated long thin-wall pipes with the diameters 16–50 mm and wall thickness 0.5–3 mm made in compliance with the 14th accuracy degree and circular deviation within 0.1 mm, the surface roughness Ra 0.12–0.16 µm [1].

As workpieces for such pipes seamless cold-deformed pipes are generally used. As compared with electrically welded pipes seamless cold-deformed ones have smaller circular deviations: in the as-delivered state such pipes have an external surface profile deviation within 0.3% of their diameter. Consequently, to get ready products of these pipes, one can simply use centerless grinding with the purpose of eliminating the defect layer with light gauge and subsequent polishing. However, the cost of seamless cold-deformed pipes is higher than the cost of longitudinal electrically welded pipes, thus, it is more reasonable to use a longitudinal electrically welded pipe as a workpiece.

When manufacturing longitudinal electrically welded pipes, their geometrical form and cross-section are subject to deviations, scale is formed on the surface while at their transportation and storage one can also observe rust formation. All the listed defects must be eliminated in the process of pipe machining. The key operations of the machining industrial process for small diameter pipes (16–50 mm) are the following: defect layer elimination, provision of the accuracy of diameter dimensions and external surface form and required elevation parameters for surface roughness up to the value Ra 0.16 µm [2]. However, abrasive machining is a labour-intensive and low-productive machining...
method resulting abrasive dust generation. Breathing in such dust oftentimes leads to such professional diseases as asthma, flint disease, mechanic bronchitis, etc.

Therefore, the main task at the machining of an external cylindrical surface of thin-wall pipes is the selection of more advanced and high-productive machining methods providing for successive performance of the following operations: defect layer elimination, geometrical form correction and decrease of the treated surface roughness. One of such method can be combined processing of thin-wall pipes with rolling and wire brushing.

Theoretical research conducted in the previous papers \[3, 4, 5\] on rolling in the planned range necessary for solving the set tasks allowed obtaining theoretical dependencies to define the parameters of the contact zone and stress state in contact between deformed reeling machine rollers and the rolled pipe surface. The analysis of the obtained theoretical dependencies for the definition of efficient structural, power and process-dependent parameters of a rotatory reeling machine providing for a required deformation source in compliance with diametric dimensions of the machined pipe and its wall thickness as well as rolling process engineering support allowed developing technical documents, manufacturing a pre-production prototype of a rotatory reeling machine and conducting experimental studies.

Experimental studies of the impact the deforming rollers design parameters and machining modes have were conducted with the help of a specially developed and manufactured reeling machine installed on a turning lathe which provides for a wide range of planned process-dependent mode parameters. Previously, the design parameters of deformed rollers were studied at an upgraded mount \[6\] alongside with their penetration depth and self-tightening angle.

The process of improving the outside diameter form accuracy in thin-wall pipes by means of rotatory rolling is influenced by a vast number of factors which is why it is necessary to conduct experimental research complementing and specifying theoretical research.

On the basis of theoretical research conducted \[6\] and the mathematical dependencies obtained it is established that the penetration depth of a cylindrical deforming roller into the machined surface of a thin-wall pipe depends on the strain force and the angle of its installation in relation to the machine part axis (self-feeding angle). One should define the law of contact stress distribution along the contact area and, in its turn, obtain the contact zone form and dimensions. The intensity and distribution law of occurring contact stresses in the contact area influences the value of the pipe wall deflection and its elastic recovery.

At the rolling of a thin-wall pipe with a cylindrical deforming roller having a rectilinear generator the depth of its penetration into the machine part surface in compliance with the dimensions of the deformed part itself is one of the factors defining the machining results. In this paper it has a particular significance as the author are developing and studying a new design of a reeling machine which has not been applied yet in manufacturing practice \[7\].

According to the results of theoretical research, average pressure in the contact area (which is an ellipsis) depends on its geometrical parameters changing in compliance with the deformed part dimensions, thin-wall pipe outside diameter, self-feed angle and increases pro rata with the deformed part depth of penetration into the surface. In connection with the aforementioned in this paper the author studied the impact of the surface penetration depth of a deforming part in the form of a cylindrical roller with a rectilinear generator at the work with a thin-wall pipe as well as the self-feed angle impact on the rotatory rolling parameters.

2. **Research materials and methods**

At planning and preparation of experimental studies the author selected a necessary number of measurements at a set error with the use of a certain measurement method and specific device \[8,9\].

For conducting the experimental research of the rotatory rolling the pipe diameters were assumed as delivered. In this case the pipe diameter was assumed to be equal to 33.5 mm.

Before conducting rotatory rolling the author has made a polar diagram of the pipe external surface by means of measuring the surface profile polar ray. Changing the polar ray value was performed at
the measurement device (Figure 1) consisting of a control device 1, dial test indicator 3 installed inside a magnetic display rack 2. The external surface profile in a cross-section was defined by polar ray measurement at the rotation of the pipe 4 in the centers installed in the front and rear tailstocks 5 and 6 correspondingly. The value measured at this device showed the deviation from a set parameter which is defined by a polar ray vibrations of the measured surface, its shift in relation to centers and deviation from turning motion. This method has significant drawbacks as in fact one measures radial motion variation by which it is impossible to judge on the measured surface form. In addition, it does not take into account the deviation from turning motion. Also, it is likely that the total of the form error and turning motion uncertainty can result in zero radial motion variation due to similar values but different digits. The main factor decreasing the accuracy of this method measurement is the deviation of actual motion of a part from the turning one. In this case it is reduced to minimum.

![Figure 1](image1.png)

**Figure 1.** The measurement device for defining the circular deviation of the pipe external surface.

Further, the author measured the part profile and put the values in the table. However, the representation of data in a graphical form shows the profile deviation more clearly. Polar diagrams are most frequently used to show the circular surface form.

Making up the pipe surface polar diagrams as-delivered (Figure 2a) was performed as follows: in the region limited by the curve (which is actually a profile) the author selected the O center from which the rays were drawn. The values of the polar ray module were marked on these rays in the required scale. As a result a figure in the form of a closed curve was obtained. In a similar way the author made a polar diagram for the pipe surface after rotatory rolling (Figure 2b).

![Figure 2](image2.png)

**Figure 2.** Pipe polar diagrams: a) as-delivered b) after rolling process.

Experimental studies were conducted at a screw-cutting lathe with the application of a reeling machine Figure 3.
The reeling machine for rotatory rolling of thin-wall pipes is installed on the turning lathe toolhead and consists of the bottom 1 on which one fixes the body 2 with uniformly and circumferentially distributed inserts 3 with the possibility of motion in a radial direction and a purpose of adjusting the penetration depth of rollers into the machined pipe surface 4 as well as the adjustment of the reeling machine for processing pipe diameters (16–35 mm) and the use of deformed rollers with various diameters. Each deformed roller is installed on two road wheels which in their turn are installed on conical axial bearings.

Before machining the pipe is placed between three deforming rollers, and the diameter of the circumference made by the rollers is smaller than the outside diameter by a set depth of roller penetration into the pipe surface.

The adjustment of a necessary penetration depth is conducted with the help of 4 screws 5, two screws allows performing the body release while the other two screws compress the body in a radial direction. For this purpose a longitudinal through groove is made inside the body.

3. Results and Discussion

The polar diagram of the pipe external surface machined at the rotatory reeling machine is given in Figure 2b.

The obtained results of experimental studies show that the circular deviation of the thin-wall pipe external surface decreased to 0,1 mm after machining which complies with the requirements set to the pipes used as structural components of the aforementioned products.

The machined surface roughness decreased from Ra 1,83 um to Ra 0,23 um. Figure 4a shows the crossing line between a non-treated (right) and rolled (left) surfaces. The profile diagrams of the surface before and after machining at the reeling machine are presented in Figure4b and Figure 4c correspondingly.

In compliance with the conducted experiments it is established that the maximum feed angle of deformed rollers should not exceed 30° while the penetration depth should not be more than 0,15 mm.

4. Conclusion

As a result of the conducted theoretical and experimental studies the author proved that the industrial process of rotatory rolling has significant advantages over abrasive machining as there is no necessity to apply labour-consuming polishing, and the set parameters in terms of circular accuracy and roughness can be obtained. Circular deviation decrease occurs simultaneously with the decrease of the machined surface roughness.

The conducted theoretical and experimental studies allowed one to follow them to its logical end, develop recommendations on selecting reasonable structural parameters of rotatory rolling for thin-wall pipes with 16–35 mm diameters at wall thicknesses 1,5–3,5 mm.
Figure 4. Results of experimental research: a) crossing line of a non-machined (right) and rolled (left) surfaces, b) profile diagram of the pipe surface as-delivered, c) profile diagram of the pipe surface after rotatory rolling.

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