STUDY OF THE AXIAL FORCE IN A THREE-ROLL HELICAL ROLLING

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Abstract
In previous works, this authors developed the idea of obtaining subultrafine metal structure by implementing a combination of processes helical rolling and ECAP in one continuous process. A key factor in this combination is the axial force at the helical rolling, which should be enough for continuous extrusion mill after standing in the matrix. The study can also be useful in improving the process of piercing tube bars.

The study was made on a three-roll helical rolling mill with conical rolls with diameter 71 mm. For measurement of the maximum axial rolling force, which in essence is the reserve of friction forces, was applied strain measurement (tensometrical) equipment. It was been designed and manufactured like a measuring instrument with 2 working strain gage connected by the scheme provides temperature compensation.

The instrument was calibrated on a hydraulic tensile testing machine. Standard error of measurement, relative to the value of the instrument measuring range (40 kN) on the results of 42 tests was 0.2%.

Experimental measurements of force were carried out in 3 series by 8 tests is each. The force was measured for conditions of the hot rolling of ordinary steel bars, diameters 16 mm, 20 mm and 25 mm with a diameter reduction of 6 %; temperature 1000 °C. Values of force was 15-38 kN for different diameters. The results were statistically processed. In addition, the graph data was obtained and to generalize about the nature of change in the axial force by the time.

Keywords: helical rolling, axial force, tensometry, strain measurement, strain gage

INTRODUCTION
In previous works, these authors developed the idea of obtaining subultrafine metal structure by implementing a combination of processes helical rolling and ECAP in one continuous process [1]. A key factor in this combination is the axial force at the helical rolling, which should be enough for continuous extrusion mill after standing in the matrix. Because of helical rolling difficulty in both practical and theoretical ways, experimental study of axial force in the process of three-roll helical piercing tube bar rolling process is well-grounded. Therefore, the aim of this experiment is to define typical axial force values and their distribution along the rolling mill.

1. EXPERIMENT SET UP. EQUIPMENT AND MATERIALS.
In order to carry experimental study of maximum axial value occurring at holding the metal bar during the helical rolling process (which basically is reserve of frictional forces) strain measurement study devices and methods were used. Strain measurement studies of helical rolling process were carried out [2-4]. In these named works pipe bar piercing force measurements were done. In the general case, strain gages sensor (measuring cell) was placed under mandrel axial bearing.

Presently available to us three-roll helical rolling mill РСП «10-30» of National University of Science and Technology “MISIS” project [5-6] is not designed for pipe piercing and accordingly does not have a mandrel. The mill is designed for tube bars with severe plastic deformation with high cross angles. Therefore,
measurement structure design was chosen according to constructional features of this mill. Basic measurement scheme is shown at the figure 1.

![Measurement scheme](image)

1 – tube bar; 2 – rolls; 3 – gauge strip; 4 – brackets; 5 – front frame; 6 – adjustment bolts; 7 – strain gages

**Fig. 1** Measurement scheme

The tube bar (1) is going out of rolls (2) and thrusts against the middle of gauge strip (3) which is freely standing in brackets (4). Brackets’ back is pressed to the back side of stand’s front frame (5) with the help of adjustment bolts (6). Strip edges are pressed by the moving tube bar to the brackets and the strip is bending, becoming a typical beam. The change of tensed-deformed condition of the strip influences the resistance on strain gages (7) which are attached to it and is recorded by a strain-gauge station in a form of voltage change diagram. Received diagram according to calibration is transformed into force change diagram. Beam-type measurement scheme was chosen because of highest measurement linearity, lowest dependence on the point of impact [7], higher protection of strain gages from both temperature and mechanical damage, simplicity and ease of implementation. The material for the gauge strip is heat-treated 5XB2C steel (by GOST) [8]. Strip size is calculated under the condition of getting the deformation equal to
maximum possible strain gage’s deformation (2 %) with force of 100 kN in the place of strain gages’ attachment.

Therefore, measurement beam-type equipment with two measuring and two compensating strain gages assembled into a full Wheatstone bridge circuit providing thermal compensation was developed and created. Strain gages ТКФО1-2-200 (constantan detecting element with 2 mm base and 200 Ohm resistance on phenolic mountain film by “ETMS” CJSC, Russia) and single-component quick-setting adhesive Z70 by HBM, Germany were used. Pasting and connection scheme is shown at the figure 2. Strain gages are symmetrically glued in the middle of the distance between the strip centre and bearing carriers. Measuring (active) strain gages (R_A) are glued along the strip, compensating ones (R_K) are glued across it, thus receiving only temperature disturbances. In a bridge circuit measuring (R_A) and compensating (R_K) elements alternate with each other, i.e. compensating ones are present on both sides of bridge measuring lever, and vice versa. This kind of connection provides increase of scheme responsivity, protecting it from temperature disturbances [7]. The scheme gets DC 5V.

A) – tensoresistors attachment scheme; B) – strain gages connection scheme (E – bridge power; e_0 – output voltage)

Fig. 2 Measuring equipment strain gages attachment and connection scheme

Brackets are angle-enforced thick parts with M8 bolt in the front bottom part. The bolt is necessary for clamping and holding the bracket on the front frame and providing free position of the gauge strip which lies on the bolts. The latter point is important because it eliminates the possibility of edges jamming in the process of gauge strip bending, thus properly implementing beam deformation and imitating conditions identical to calibrating ones. Besides, free position of gauge strip eliminates preliminary tension level subtracting operation (like in use of measuring cells in stand chocks), which makes measurement process more exact and convenient. Since significant rolling torque is a part of helical rolling, in order to eliminate the possibility of gauge strip rotation and its slipping out of brackets the connection is held by wire rings. Gauge strip as a tool was calibrated on hydraulic torsion-tearing device МИ-40КУ (Ukraine) in compression test mode using hysteresis impact minimizing method. Use of hydraulic torsion-tearing device makes it possible to generate significant force (35 – 40 kN) with accurate and reliable value recording. The change of tensed-deformed condition of the strip on load causes deformation and linear change of attached strain gages resistance. The main point of calibrating is to create a dependence binding circuit voltage and force applied to gauge strip. The dependence should be linear.
In calibrating process strip was consequently getting force from zero to 35 kN (with increase step of 5 kN). Respective voltage values in circuit on load and off load were recorded. For the purpose of hysteresis decreasing and accuracy increasing three passes within given range were done – up, down, up – or 42 measurements in total.

The information received during calibrating process was statistically treated, according to it regression equation binding the force \( F_i \) (N) applied to the tool to the voltage \( U_i \) (mV) in the circuit was established. The equation look the following way:
\[
F_i = -3631.2 \times U_i + 10122.
\]
Determination coefficient \( R^2 = 0.99998 \); standard error of measurement correlated to the tool measurement values range (40 kN) after 42 measurement tests is less than 0.2%. Calibrating diagram is shown at figure 3. Received information was recorded into ZET-017-T8 strain-gauge station measurements recording and handling software (“ETMS” CJSC, Moscow, Russia) in order to record the signal in form of force diagram. After the experiment several random check loads were done, which error was not higher than given above; this confirmed measuring device accuracy and reliability in the process of experiment.

2. EXPERIMENTAL PART

Because of common three-roll helical rolling difficulty, and also for the purpose of collecting statistic data it was decided to carry out the experiment with one influential factor – ratio of rolls diameter \( (D_v) \) to bar diameter \( (D_0) \) in three series, using three different factor values accordingly. For taking experimental axial force measurements 16 mm, 20 mm and 25 mm input profiles were chosen, as the most common for РСП «10-30» rolling mill (15 – 30 mm bar diameter). Round hot-rolled bars Круглые горячекатаные заготовки GOST 2590-88 of ordinary steel 0.3 % carbon Ст 3 (by GOST [8]) grade were heated to 1000 °C temperature in tube-type furnace Nabetherm R120/1000/13 (Germany) in batches of 2-4 pieces with 16-30 minutes time exposure, depending on bars square area and position. Reduction rate \( (\varepsilon, \%) \) was considered constant in all cases - 6 % of diameter. Ratio of conical rolls diameter (71 mm) to bar diameter \( (D_v/D_0) \), and also input \( (D_0) \) and output sizes \( (D_1) \) of bars in experiment series are shown in table 1. The choice of \( D_v/D_0 \) ratio as a factor is determined by intention to get engineering information on axial force during three-roll helical rolling mill with conical rolls in the range profiles rolled on the rolling mill without making the task more complicated by calculation and measurement of contact area.
Bar going out of rolls thrusted against the tool, elastically deformed it, and the result was recorded in form of force diagram with temporal resolution of signal recording 1 kHz. Distance from deformation point to gauge strip corresponded to supposed distance to matrix in combined process and was equal to 100 mm. Rolling mill drives synchronously were stopping at the moment of noticeable bar bending, so it was possible to take it out of stand without changing mill settings. The moment of drives stop can be distinctly seen at charts as short overshooting disturbance, which also gives some information for analysis. 8 experiments were done in each series, thus total amount of measurements was 24. Experiments were marked with ordinal numbers within each series (series number – hyphen – experiment number). Most part of experiments went in a standard way, measuring device showed itself in the best light. No device disadvantages were found.

3. RESULTS AND ITS DISCUSSION

Force charts recorded by strain-gauge station are similar in common and have identical fragments. As a demonstration, II-6 experiment charts are shown at figure 4. In the first part there is a rapid (approximately 0,15 s) increase of force with a little slowing down closer to the peak point. At this stage gauge strip is bending because of bar axial movement and bar front end is slightly deformed. Graph at this place is similar to parable. Then bar bending occurs, accompanied by symmetrical force decrease by one-third and smooth flattening of force decrease, apparently connected to start of rolls slipping. It should be noted that at the last stage the bar is thrusted against not only the strip, but also part of the front frame, because as a rule it is greatly bent. As the experiments show, the moment of drives switch-off (after the peak point) does not have any impact neither on qualitative nor on quantitative side of force change. As the experiment value, the peak of force was recorded.
Results of each experiment series were checked for rude errors according to t-test, then for each series the following statistical characteristics were calculated: arithmetic average ($F_{ср}$), maximum ($F_{max}$) and minimum ($F_{min}$) values, standard deviation ($F_{st}$). These listed characteristics are shown in table 2. Force values for all experiments are summarized in chart at figure 5.

### Table 2 Statistical characteristics of experiments

<table>
<thead>
<tr>
<th>Statistical parameter</th>
<th>Experiment series / ($D_v/D_0$)</th>
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<tbody>
<tr>
<td></td>
<td>I / 2.8</td>
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<tr>
<td></td>
<td>II / 3.6</td>
</tr>
<tr>
<td></td>
<td>III / 4.4</td>
</tr>
<tr>
<td>$F_{ср}, H$</td>
<td>35 541</td>
</tr>
<tr>
<td>$F_{max}, H$</td>
<td>39 394</td>
</tr>
<tr>
<td>$F_{min}, H$</td>
<td>31 077</td>
</tr>
<tr>
<td>$F_{st}, H$</td>
<td>31 077</td>
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</tbody>
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Fig. 4 Force charts for II-3 experiments
CONCLUSION

From the given information a conclusion can be made that at thicker profiles rolling significantly greater force values’ scattering is seen, which probably can be explained by increase of the role of other factors in this case. This can be billet internal and contact friction peculiarities, its rheology, deforming device calibration peculiarities.

Measured axial force values themselves (up to 38 kN) show possibility of combined extrolling at high (140°-150°) values of ECA matrix channel connection angles process implementation in principle. According to study data, the main danger in this case is not lack of force but chance of billet bending between rolls and matrix. Besides, force value can be slightly increased by using ragged roll at maximum reduction. Received results can be compared to results of similar profiles three-roll mills piercing force study [2-4].

This study results also can be used for pipe billet piercing process optimization as they contain information about force (friction) reserve of helical rolling.

REFERENCES


