Machining of bearing trunnions of rolls by heavy lathes in conditions of repair production

Viktor Vodzianskiy¹, Viktor Artiukh², Sergey Kargin¹, Elena Soloveva³

¹Pryazovskyi State Technical University, 7, str. Universytetska 87500, Mariupol, Ukraine
²Peter the Great St.Petersburg Polytechnic University, 29, str. Polytechnicheskiaya, 195251, St. Petersburg, Russia
³State University of Technologies and Management named after K.G.Razumovsky (Bashkir branch), Smolenskaya Street, 34, Meleuz, 453850, Russia

E-mail: artiukh@mail.ru

Abstract. Technology has been developed, tested on plants and theoretically justified for repair of precision bearing trunnions of oversized ‘raw’ rolls in which emphasis is done on use of unusual technique in machining of such details on heavy lathes essence of which is to regulate upper slides of lathe support taking into account distances between repairing trunnions. It is not always possible to obtain required surface parameters with roughness \( R_a = 0.8...0.4 \mu m \) as well as surface compressive residual stress since machining on lathe is carried out using cutting tool and especially in conditions of repair production. It is proposed to use additional device for grinding in order to solve this problem.

1. Introduction. Source analysis

Oversized rolls are rolls weighing more than 1 ton. They are used very widely, namely, in metallurgy, energy, lifting, transport and other industries (refer to Figure 1) [1-6].

![Figure 1. Work rolls of continuous wide strip hot rolling mill.](image-url)
Production and technological difficulties arise when repairing oversized rolls essence of which most often comes down to repairing the most worn surfaces (non-hardened bearing trunnions i.e. sliding supports) [7-10]. In this case quite high requirements are always imposed on rolls bearing trunnions in terms of quality of obtained surface, namely, surface roughness ($R_a = 0.08...0.16 \mu m$) with regard to geometric shape (difference in diameters of bearing trunnions over entire length of 0.02 mm) with bearing trunnions diameter of approximately 250 mm and length of around 300 mm and higher as well as residual stress [11-15]. These requirements in our case (rolls for metallurgical industry) can be achieved without special difficulties on circular grinding machines based on serial production (repair is single production) as well as dimensions ($D \approx 500 \text{ mm, } L \approx 4000 \text{ mm}$) of details to be repaired. But such circular grinding machines are not currently manufactured by industries of CIS countries, therefore such machining is compulsorily performed by heavy lathes which due to their design and precision characteristics can provide bearing trunnions size errors (diameters difference over entire length is up to 0.15 mm) as well as roughness ($R_a$ is not less than 1.6 $\mu m$) and presence of positive residual stress. Therefore, complexity of machining of rolls bearing trunnions with required quality parameters is very high [16-20]. Presence of stress in surface layer, its sign and depth when machining 'raw' rolls by cutting tool are quite important [21-23].

2. Purpose of this article
Main aim of this article is to provide required parameters of rolls fitting surfaces which need to be repaired in terms of accuracy, roughness and residual stresses with minimal metal removal. Following tasks need to be solved to achieve the aim:
1. All surfaces should be machined using principle of unity of bases (i.e. from one installation) to obtain the highest accuracy.
2. Use dimensional or kinematic chains that contain the smallest number of links to achieve the highest accuracy.
3. To ensure installation of additional device (with required accuracy and rigidity) on lathe.
4. To expand technological capabilities of used lathe.

3. Methods and results
Analysis of drawings dimensions of details to be repaired as well as passport data of investigated lathe model ‘1A660’ showed that length of bearing trunnions machining over the entire range of rolls to be repaired is less than stroke length of upper slides located on rotary part of support. This made it possible to exclude errors associated with movement of longitudinal support on housing and its fixation while feeding only with the upper support slide. In order to increase accuracy of machining of the bearing trunnions done by the lathe its slideways of the upper slide and the rotary part of the upper slide of the support were scraped. It resulted in deviation from straightness of the slide movements along entire length (500 mm) to be equal to 0.003...0.004 mm in one direction or another one depending on direction of movement. Symmetry of wear of rolls bearing trunnions in cross section (since it is not uniform in length) during their operation made it possible to develop technique for alignment of parallelism of the upper slides of the lathe center line directly along the roll bearing trunnion to be machined taking into account theory of dimensional chains.

Essence of this technique is as follows. Possible theoretical justification of fit method is being developed. Dimension chain is drawn up and shown on Figure 2.
Based on proposed three-link dimensional chain $\sigma_{A2} - \sigma_{A1} = \sigma_k$,

$$\Delta_k = \frac{\sigma_k}{2} + (\pm \Delta_{A2} \pm \Delta_{A1}) - (\pm \Delta_{A1} \pm \Delta_{A2}), \quad (1)$$

where $\Delta_k$ is correction to coordinate of tolerance zone of compensating link; $\Delta_{A1}$, $\Delta_{A2}$ are coordinates of midpoints of extended tolerance zones.

Coordinates of the midpoints of the tolerance zones can increase or decrease value of closing link $A_3$ of the three-link dimensional chain $A1 + A3 - A2 = 0$.

Then equation (1) can be written as

$$\Delta_k = \frac{\sigma_k}{2} + (\pm \Delta_{0A2} \pm \Delta_{0A1}) - (\pm \Delta_{dA1} \pm \Delta_{dA2}). \quad (2)$$

Equation (2) can be transformed taking into account algebraic sum of the tolerance zones midpoints coordinates of the indicated links, then

$$\Delta_k = \frac{\sigma_k}{2} + \left(\sum_{i=1}^{n} \Delta_{d1} \pm \sum_{n+1}^{m-1} \Delta_{d2}\right) - \left(\sum_{i=1}^{n} \Delta_{d1} \pm \sum_{n+1}^{m-1} \Delta_{d2}\right) \quad (3)$$

where $n$ is total number of increasing chain links; $m$ is total number of all chain links.

Analysis of equation (2) shows that with symmetry of tolerances i.e. $\Delta_{dA1} = 0$ and $\Delta_{dA2} = 0$ equation (3) has view $\Delta_k = \sigma_k/2$.

Practical part of described work was carried out on basis of proposed calculation method which confirmed theoretical assumptions made when considering provisions of dimensional chains theory.

Roll is installed on the lathe based on its center holes which ensures minimal radial runout of the bearing trunnions. Diameters of the bearing trunnions are measured by micrometer in its three sections, namely, in the middle and along edges at distance of 10 mm from its collar and butt. The lathe upper slides are installed in the middle position along guides length. Center of rotation of the support rotary part is set against middle of the roll bearing trunnion (refer to Figure 3) by moving the longitudinal support of the lathe.
Figure 3. Scheme of parallelism alignment of movement direction of the support upper slide of the lathe center line: 1 is longitudinal support; 2 is tool holder; 3 are upper slides of cross support.

Indicator for measuring linear displacements ‘MITUTOYO’ with scale interval of 0.01 mm and measuring range of 12.7 mm is mounted on the upper slide so that head of measuring rod in its initial position 𝐼 is on line perpendicular to center line and passing through middle of roll bearing trunnion and center of rotation of the support rotary part. Perpendicularity of tool holder moving along the upper slides of the center line will be ensured if the indicator set to zero in position 𝐼 in positions 𝐼𝐼 and 𝐼𝐼𝐼 shows values \( \frac{d_2 - d_1}{2} \) and \( \frac{d_3 - d_1}{2} \) with corresponding signs.

Machining of roll bearing trunnion after done alignment practically ensures required geometric shape, however, roughness remains the same \( (R_a > 1.6 \, \mu m) \). Similar operations are performed with other surfaces that need it.

To solve problems associated with ensuring the maximum surface quality in terms of residual stresses, their sign, occurrence depth and surface roughness additional studies and design developments were carried out that made it possible to solve the task comprehensively. Physical and mechanical properties of surface layer lying under machined surface determine performance of details of any equipment. These properties are highly important in our case of machining of ‘raw’ rolls. It is well known that sign and depth of residual stresses will be the most important indicators when cutting with blade tool. Residual stresses arising in surface layer are formed as a result of action of force field created by cutting forces and structural transformations. When machining soft materials tensile stresses are formed that negatively affects operational characteristics of surface. Magnitude, sign and depth of residual stresses depend on rake angle of tool, feed (thickness of cut layer), cutting speed and degree of wear of tool. Principal influence of feed \( S \), cutting speed \( V \), rake angle \( \gamma \) with specification of operating characteristics of cutting process on magnitude of stress and its depth \( \Delta \) is shown on Figure 4 a, b and c.
From presented graphs (refer to Figure 4) it can be seen that formation of surface layer is stabilized when machining specified ‘raw’ details with cutting speeds above $V \geq 150…170$ m/min i.e. they must be machined with $V \leq 120$ m/min. Rake angle of tool also greatly affects residual tensile stresses. It was found that rake angle should be $\gamma \geq -15^\circ$. Hardening is formed during cutting in addition to residual stress which in our case is positive phenomenon. Hardening of surface layer is mainly associated with deformation and hardening of ferrite phase of machined material. Depth of cut has little effect on hardening. In addition, hardening is significantly affected by increased wear of cutting tool.

In order to achieve required roughness a device has been developed for grinding the roll bearing trunnion by end of abrasive cup wheel according to scheme shown on Figure 5 due to impossibility of normal round grinding mode on the lathe. The device is installed in tool holder of the lathe (on the rotary part of the support) and clamped by strip fixed by two studs. Basis of the device is a high-precision spindle assembly with radial runout of base conical fitting surface of spindle equal to not more than 3 microns.

Grinding wheel is installed on cap that is installed on fit cone of the spindle assembly. Minimum runout of working surfaces of pulleys relative to axes of their rotation was provided by the final
machining of these surfaces being assembled. Flat rubberized cotton belt able to absorb possible vibrations was used to transmit rotational motion from the electric motor to the spindle. A series of studies revealed that in this case it is advisable to use grinding wheels of ‘cup wheel’ type ‘25CM1K56’ (description in CIS countries) which made it possible to obtain surface roughness of bearing trunnions equal to $R_a = 0.2 \mu m$ under accepted machining conditions. Grinding mode providing required quality of machined (repaired) surfaces is circular frequency of grinding wheel $n_c = 5000 \text{ rpm}$, circular frequency of detail $n_d = 40 \text{ rpm}$, longitudinal feed $S_{pr} = 1.68 \text{ mm/rev}$ ($V_c = 35...40 \text{ m/s}; \ V_d = 30 \text{ m/min}$). Grinding was carried out according to following technology: rotating grinding wheel was delivered to the bearing trunnion of the rotating roll until it touched the roll and a pass was made. The next pass was performed either without radial feed or similarly to the first one. In this case metal layer of 0.005...0.05 mm per side is removed during one pass. Required surface quality of the roll bearing trunnions ($R_a = 0.2...0.3 \mu m$) was obtained by two double strokes without implementation of radial feed after the first pass.

Developed by department ‘Mechanical Engineering Technology’ of State Higher Education Institution ‘Pryazovskiy State Technical University’ and department ‘Mechanics and Control Processes’ of Federal State Autonomous Higher Education Institution ‘Peter the Great St. Petersburg Polytechnic University’ described method of repairing rotors bearing trunnions of heavy compressor machines was tested at plants of international group of companies ‘Metinvest’ and made it possible to obtain required quality of rolls/shafts bearing trunnions at relatively low costs.

4. Conclusions
1. Developed method of repairing bearing trunnions or other precise surfaces of rolls/shafts of heavy equipment allows getting any required quality of repair.
2. Proposed method allows reducing labour intensity of repair by about 4...5 times.
3. Developed method significantly expands technological capabilities of heavy lathes which not always loaded.
4. Theoretical basis for selection of cutting conditions when machining by blade tool is developed.
5. Proposed method improves technological culture of production.

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