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Introduction to Theory of Transverse Centerless Grinding of Large Cylindrical Surfaces

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Abstract: The study presents a review of existing technical solutions in the sphere of restorative mechanical treatment of rolling surfaces of large rotating parts without their dismantling from a plant. Researchers emphasize comparison of an edge cutting and an abrasive method of surface treatment of large parts with variable rotation axes. A comparative analysis of the grinding methods known from the previous scientific works with indication of their advantages and disadvantages can be found here as well. There were considered the aspects of the theory of restorative treatment with use of transverse grinding. An operation scheme for abrasive tools at time of transverse grinding of tires was demonstrated. An operation scheme for abrasive belt grain was described and a model for calculation of its tension force was presented. The study contains recommendations for creation of a new technology and equipment for restorative surface treatment by means of transverse abrasive belt grinding. Conclusion and findings give information on perspective capabilities of automation of the offered restorative surface treatment technology.

Key words: Large rotating parts, mechanical treatment, form accuracy, transverse grinding, cutting theory, tire, rotating cement kiln, abrasive belt grinding, restoration, surface renewal

INTRODUCTION

The practice of restorative mechanical treatment of large parts of machines like cement kiln tires with no need of their dismantling amounts to quite a number of solutions based on use of the edge cutting and abrasive methods with employment of attachable machining modules. The majority of the existing machining schemes utilize a rotary technological movement of a tire which is being set into motion together with a kiln shell by an onboard drive as a principal motion.

As the works (Bondarenko *et al*., 2004a, b, 2006) state, all methods of machining of tires without disassembly are centerless since a processing capability fits the surface being machined. This results in occurrence of treatment errors which to a considerable extent are being copied from the surface being treated to the surface already machined. The existing inventions of the scientists from BGTU named after V.G. Shukhov, namely a floating slide by professor Pelipenko (2012), a dynamic self-aligning slide (Shrybchenko, 2000) by professor Shrubchenko and a tracking slide by assistant professor Sanin solve this problem to a certain degree but have some difficulties during practical realization for location error compensation takes place within one turn (transverse section) of a tire but a form of the machined surface may be distorted from turn to turn due to improper operation of the mentioned equipment.

Two treatment schemes are usually used for abrasive centerless machining. The first scheme involves use of abrasive stones fixed on a common carrying plate being pressed against the treated surface. A working motion of a part being treated is also used as a cutting motion. If the belt width is equal to the same of the part there is no necessity in transverse motion of the belt. In this case, a location surface is being constantly renovated. But direct copying of the form errors from the surface being treated to the surface already machined is observed.

The experience of treatment of cement kiln parts at OJSC “Belgorodskiy Tsement” (Bondarenko *et al*., 2006) showed that the scheme of longitudinal grinding does not have required rigidity and sufficient stability. As a result of considerable material removal an operational limit of a tire body thickness may be reached.

Lathing and grinding schemes with use of technological tire movement as a principal motion have a limited capacity. Thus, at time of workshop grinding a

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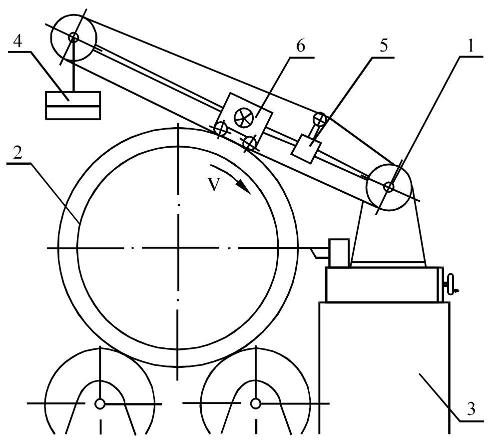

Fig. 1: The scheme of grinding of a ball mill spindle surface placed on rollers (Shrybchenko, 2000): 1 = belt feed drive; 2 = spindle; 3 = attachable machining module; 4 = ballast; 5 = belt tensioning device; 6 = holding down device

cutting speed of 25 m sec^{-1} and more may be reached whereas a standard motion speed of external surface of a tire makes (~20-40 m min^{-1}). In this contest, the edge cutting treatment has less strict requirements to the cutting speed since the needed capacity is being reached for the account of high cutting depth and the cutter feed per a part revolution.

Fedorenko (2009) pays a lot of attention to grinding of the working surfaces of the ball mill spindles without of their disassembly. He justifies the need of grinding by the necessity to create definite surface roughness and definite pattern of rough ridges distribution which could not be achieved by use of edge cutting tools only.

Fedorenko offers to use the already mentioned attachable machining modules with the belt grinding devices (Fig. 1) mounted on their longitudinal slides and having a principal motion drive as a grinding equipment.

The specified schemes use technological rotation of a treated part only as a rotary feed motion. This ensures high machining capacity. The schemes are characterized by the same grinding process instability and uncertainty of geometry generation along a linear generator of a part surface.

There is also a grinding scheme elaborated by Goncharov, Goncharov and Tulinov. This scheme is distinguished by use of a dynamic self-aligning slide as an element which stabilizes the cutting process as well as by a “contact” method of grinding. This scheme does not ensure significant advantages as compared to the devices described earlier in the literature and has almost all of their disadvantages.

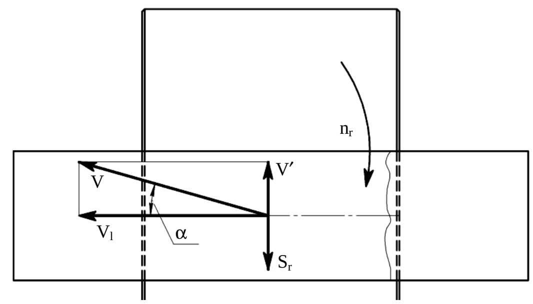

Fig. 2: The scheme of transverse grinding of the support roller: 1 = support roller surface, 2 = abrasive belt

MAIN PART

Use of a transverse grinding scheme as shown in Fig. 2 can be considered as an alternative of the schemes of mechanical centerless treatment of roller surfaces of tires described above. Principal ideas of this scheme are as follows: transverse grinding will allow to ensure proper geometry generation of the longitudinal generators of a tire surface at each point of a circular generator; abrasive band grinding with onboard principal motion drive will ensure the set capability, it will be possible to perform full treatment of a part in one revolution; proper orientation of a grinding belt is achieved by a floating locating pattern; accuracy of a circular form is ensured by removal solely prominences on the surface without copying the location surface errors; use of a special abrasive belt with elevated durability will allow to perform a tire treatment during a single installation of a portable machining device.

At time of roller 1 rotation with the frequency of n_r the points of its surface have the tangential velocity of s_r. Abrasive belt 2 pressed down against the support roller surface is moving towards direction perpendicular to the direction of the velocity vector s_r. In this case, each arbitrary grain M has a velocity equal to the velocity of the abrasive belt V_l and directed along the treated part axis. Relative to the moving surface of the support roller, the velocity of the abrasive grain M will be directed to the opposite and will be equal to $V' = -s_r$.

The calculation model (Fig. 2) shows a parallelogram of velocity vectors. The vector of the resulting velocity V of each abrasive grain in respect to the surface being treated will be directed at an angle (alpha) to the horizon:

$$\alpha = \mathrm{arctg}\left(\frac{s_r}{V_l}\right) \quad (1)$$

Taking into consideration that a great number of abrasive grains take part in the process of cutting simultaneously, the total of their velocity vectors will

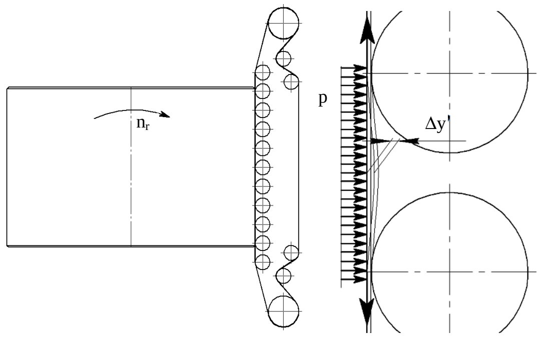

Fig. 3: The scheme of contact transverse grinding

represent some kind of a filed. Therefore a certain area of a part surface will be treated simultaneously, i.e., a cut surface confined by the surface edges at the right and at the left and inclined towards the horizon. Vertical dimension of the cut surface will change depending on a curvature of the surface being treated, a pressing force of the abrasive belt and an abrasive grit.

When the principal motion velocity makes 25 m sec^{-1} and the treated surface peripheral velocity makes 20 m min^{-1} an inclination angle of the resulting velocity vector will constitute:

$$\alpha = \mathrm{arctg}\left(\frac{20}{60 \cdot 25}\right) = 0°45'50'' \quad (2)$$

In order to ensure hardness in the cutting zone it is necessary to use a contact scheme of abrasive belt grinding (Fig. 3). For this purpose, the belt should be pressed against the cut surface by means of a roller system located at the belt reverse side. The rollers pitch should ensure minimum belt deflection in the zone of cutting and sufficient strain for compensation of the cutting force radial component.

The cutting force radial component may be presented as a product of the distributed pressure of the abrasive particles at the cut surface by the cut surface area:

$$P_y = p \cdot S_r \quad (3)$$

Pressure p is chosen depending on condition of cutting-in of the grains into the surface being treated at a definite depth (pressing force). In the general case, it should be equal to 10-20 kg/cm^2 or 1-2 MPa.

Let's calculate the belt tension force for ensuring its rigidity at the point equidistant from the two most proximate hold-down rollers. For this let's analyze a simple scheme below (Fig. 4).

The resulting R_T of the tension force T of the abrasive belt confronts the radial component of the cutting force P_y at the point equidistant from the extreme point of the belt contact with the hold-down rollers with the radius r. The resulting force R_T will be determined according to equation:

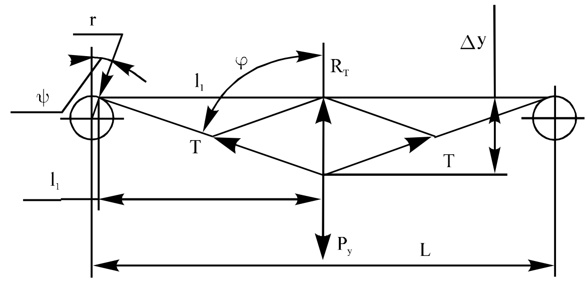

Fig. 4: The model for calculation of the belt deflection

$$R_T = 2T \cdot \cos\varphi \quad (4)$$

The angle (fi) may be determined on the basis of the calculation model shown on Fig. 4. If the distance from the extreme point of contact between the belt and the hold-down roller will be designated as l_1 then:

$$\mathrm{tg}\phi = \frac{l_1}{r \cdot \sin\varphi} \quad (5)$$

Being aware that:

$$l_1 = \frac{L}{2} - r \cdot \cos\varphi$$

We'll receive:

$$\mathrm{tg}\varphi = \frac{\frac{L}{2} - r \cdot \cos\varphi}{r \cdot \sin\varphi} \quad (6)$$

RESULTS

The offered method of centerless grinding treatment of large cylindrical parts is an elaboration of theoretical and practical solutions and is aimed at elimination of the principal defect typical for the already known methods of treatment, namely high probability of copying and reproduction of form errors. It can be achieved by locating of an operating device directly at the surface being treated by means of contact rollers with infinite curvature radius which theoretically should ensure absolute accuracy of a round shape of the treated surface.

Possible deviations from the circularity of the surfaces being treated in terms of value do not exceed elastic contact deformations at the location of the machine operating device at a part surface.

The offered technology of centerless mechanical treatment of the large cylindrical parts can be comparatively easily automated that's why the offered method will be in high demand among the heavy engineering enterprises.

CONCLUSION

Use of the method of transverse abrasive belt grinding will enable to enhance the process efficiency to the considerable extent since in this case the number of required treatment runs will be significantly reduced. Simultaneously, the mentioned efficiency increase can be reached by using a special design of cutting tools.

The transverse grinding requires special practices for orientation of the abrasive band plane against the treated surface since deviation of the band position from the normal one will result in change of the cutting depth, facet pattern occurrence and other defects. In this context a problem of combination of the abrasive tools with an adaptable or floating slide will be of great importance.

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