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# Setup of a Mobile Robot Machine Tool for Large Annular Parts

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**Abstract**—Precise preliminary setup of a mobile robot machine tool for large annular workpieces—tires for rotary kilns (diameter up to 8300 mm, mass up to 120 t)—outside production shops is considered. The approach proposed is to measure the initial errors of the tire by means of the mobile robot and use the results in automatic adjustment of the tool trajectory.

**Keywords:** large workpieces, mobile robot machine tool, machine tool setup, shaping, abrasive belt, frameless technology, measurement, basing

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One challenge in machining is to produce large components for walking excavators, rotary cement kilns, and atomic reactor housings, and other machines used in the production of materials and energy, and in the supply and enrichment of minerals, for example, without using heavy stationary machine tools [1–5]. It is very important to develop optimal production technology ensuring high precision and quality of large products, especially in frameless machining [1, 3–8].

The use of mobile robot machine tools was proposed for machining large immobile annular workpieces (diameter up to 8000 mm and weight 60 t or more) in [1, 6]. The bases were guiderails forming a closed circle around the workpiece, which was mounted on a baseplate (Fig. 1).

In the present work, we consider the setup of a mobile robot machine tool for large annular workpieces so as to ensure specified machining precision and surface quality [9–13]. As an example, we consider the tire of a rotary cement kiln.

## FORMULATION OF THE PROBLEM

In the mobile robot machine tool, most operations associated with its use in the surface machining of large annular workpieces are automated. In particular, after installing the workpiece on the platform, preliminary setup of the machine tool is required, with the option of adjusting the setup automatically in the course of machining.

## METHODS

In the initial setup of the mobile robot machine tool, the goal is to ensure the correct trajectory of the machining head and tool relative to the workpiece, regardless of the instantaneous relative position of the workpiece and machine tool. For the large workpieces here considered, traditional basing theory is inapplicable, since additional factors produce errors in the mutual position of the tool and workpiece [2, 10, 11].

To ensure a circular drive surface of the rotary-kiln tire, as for the end surfaces, the tool must move over a circular trajectory around some imaginary axis coinciding with the workpiece axis.

We assume that the workpiece axis is associated with its primary basing surface, which is the hole surface. Correspondingly, in machining the hole, the tool

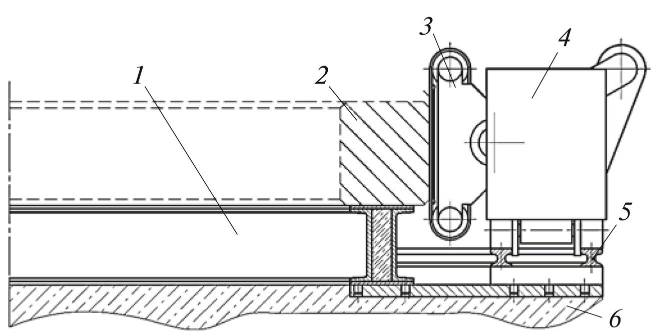


**Fig. 1.** Mobile robot system for machining large annular workpieces: (*1*) platform; (*2*) workpiece; (*3*) cutting tool; (*4*) robot machine tool; (*5*) guiderails; (*6*) base plate.

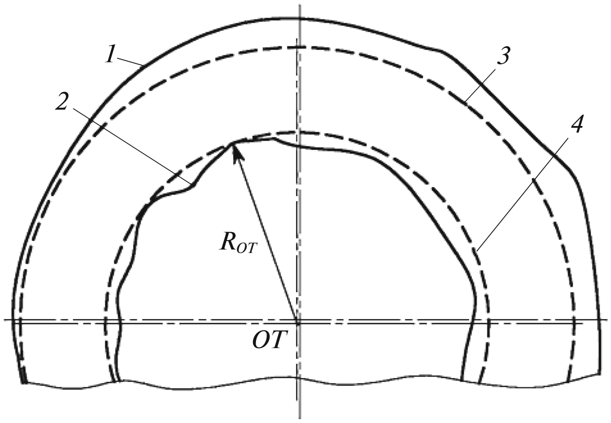


**Fig. 2.** Inscribing the tool trajectory in the large annular workpiece: (*1*, *2*) external and internal surface profiles before machining; (*3*, *4*) inscribed and circumscribed trajectories.

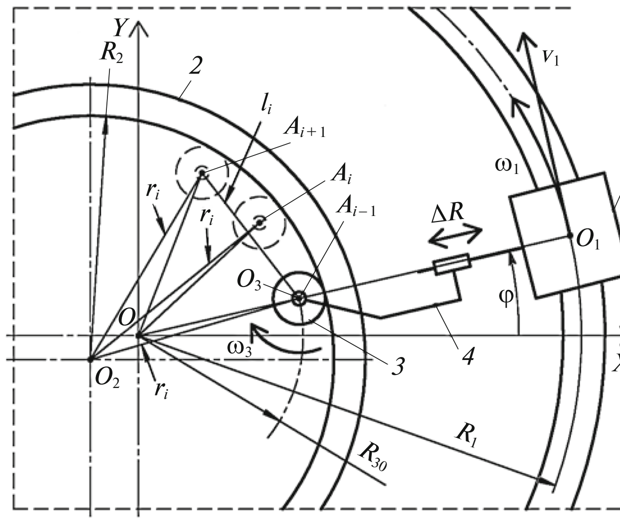


**Fig. 3.** System for radial measurement: (*1*) mobile robot machine tool; (*2*) large annular workpiece; (*3*) measuring sensor; (*4*) machining head.

must move over a circular trajectory [1, 8, 9]. These trajectories must be coaxial, differing only in their radius of curvature, or else the roller's drive surface and hole will be eccentric.

The control program for the mobile robot machine tool is generated automatically, on the basis of preliminary coordinate measurements for points on the basing surface of the large workpiece.

The position of the hole axis for the rotary-kiln tire is determined by successive probing of the hole surface using a special sensor as the machine tool moves uniformly along the guiderails. The number of points in probing must be sufficient to ensure acceptable error.

On the basis of the known coordinates of points on the hole surface, the coordinates of the cylinder axis are calculated by the method described, for example, in [4, 12, 13]. The actual hole contour of the tire will differ from an ideal cylinder, with both transverse error (elliptical distortion, displacement of the half-rings, faceting) and longitudinal error (barrel, cone, or saddle shape). The combination of these errors may also give rise to local defects (troughs or projections). Hence, some margin must be specified in machining the tire hole along with machining of the external drive surface.

Thus, an ideal cylinder (within the tire) must be circumscribed by a contour of diameter somewhat greater than that of the actual hole in the tire (Fig. 2).

The coordinates of points on the hole surface and external surface of the large workpieces in the machine-tool coordinate system *XOY* may be determined by a method based on calculating the difference in surface radii at various points of the profile (Fig. 3).

We assume that the robot machine tool *1* (Fig. 3) moves over the guiderails at constant angular velocity $\omega_1$ relative to some center *O*. Mounted at the end of the machining head *4*, which is directed to the center of the circular trajectory, a measurement module records the change $\Delta R$ in tool overhang and the kinematic characteristics of the drive roller *3* (acceleration, speed, displacement, etc.).

The drive roller of the measurement module is in contact with the hole surface of workpiece *2* (radius $R_2$). The frictional forces between the immobile workpiece and the surface of the drive roller apply rotation to the roller in the opposite direction to the motion of its axis. We may assume negligible slip between the roller and workpiece surfaces.

As already noted, the hole surface and the external drive surface of the roller may be noncircular. Therefore, in general, the profile of the measured surface may be described by the model in [4]. In that case, the profile is divided into arcs of limited length, each of which passes through three measuring points $A_{i-1}$, $A_i$, and $A_{i+1}$, where $A_i$ is a specific point of the profile.

The coordinates of a point of the profile in the coordinate system *XOY* may be measured by means of sensors recording the change in tool overhang. If $R_1$ is the radius vector determining the position of the initial point of the robot, while φ is its angle of rotation in the system *XOY*, it follows from Fig. 3 that $R_{30i}$, corresponding to the position of point $A_i$ (the axis of roller rotation), will be

$$R_{30i} = R_1 - \Delta R_i.$$

The coordinates of the point's current position $O_3 \equiv A_i$ will be

$$X_{Ai} = R_{30i}\cos(\varphi); \quad Y_{Ai} = R_{30i}\sin(\varphi).$$

Thus, we solve the following system of equations to calculate the current coordinates of the center of the arc $OT_i\,(X_{OTi}, Y_{OTi})$ and its current radius of curvature $r_i$

$$\begin{cases} (X_{Ai-1} - X_{OTi})^2 + (Y_{Ai-1} - Y_{OTi})^2 = r_i^2; \\ (X_{Ai} - X_{OTi})^2 + (Y_{Ai} - Y_{OTi})^2 = r_i^2; \\ (X_{Ai+1} - X_{OTi})^2 + (Y_{Ai+1} - Y_{OTi})^2 = r_i^2. \end{cases}$$

The coordinates of the centers of curvature of the hole surface are measured for the maximum number $n$ of robot positions along its circular trajectory. The number of points $n$ should be limited only by the microprocessor's ability to store and rapidly process information in the measurement system.

The coordinate set obtained in the measurements is used to calculate the coordinates of their group center, through which will pass the axis of the circular tool trajectory in machining the surfaces of large workpieces. The coordinates of the group center are calculated as the means of the corresponding coordinate sets $X_{OTi}$ and $Y_{OTi}$

$$X_{OT} = \sum_{i=1}^{n} X_{OTi}; \quad Y_{OT} = \sum_{i=1}^{n} Y_{OTi}.$$

In the general case, the radius of curvature $R_{OT}$ of the tool trajectory (Fig. 2) is determined as the distance between this center $OT\,(X_{OT}; Y_{OT})$ and the most remote point *2* of the actual hole profile.

In machining the hole surface, the radial tool position and hence the cutting depth is then automatically regulated at each point of the trajectory by means of the cutter overhang. The cutting depth is determined by the margin at a specific point and the technological capabilities of the system (including its rigidity and the cutting properties of the tool).

The tool trajectory for machining external surface *1* of the large workpiece is the circle *3*, which is concentric with trajectory *4* for machining hole *2* and passes through the point of minimum radius on the external surface. To determine the point of minimum radius, the procedure for measuring the profile coordinates is repeated for the external surface.

## CONCLUSIONS

1. The proposed approach to machining large solids of revolution should be of great value to the manufacture of heavy machinery since it considerably decreases labor and material costs.

2. The control program for the machining of rotary-kiln tires is based on two concentric circles of the external and internal kiln diameters, which provide virtual standards for the formulation of the machining process.

3. Coordinate measurement, calculation of the center position of the standard circles, and setup of the robot machine tool are automatic or semiautomatic processes. That reduces the setup time, increases the productivity, and lowers the cost in machining large workpieces.

4. An important benefit of the proposed approach is that the smallest possible metal layer is removed to ensure the required circularity and machining precision.

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## CONFLICT OF INTEREST

The authors declare that they has no conflict of interest.

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