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NEW TECHNOLOGIES IN MECHANICAL ENGINEERING

Processing of a Large-Sized Cement Kiln Bandage by a Robotic Machine

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Abstract—In this paper, we describe the concept of setting the base of large-sized parts with a diameter of up to 8300 mm and a mass of up to 120 tons, such as a bandage of a rotating cement kiln during machining using a mobile robotic machine. The issue of controlled cutting to ensure accurate shaping of a large-sized part with a thickness of the removed metal layer up to 6 mm is considered. Processing is conducted by the method of power grinding using a special tool: an abrasive belt. Rigidity in the "part—tool" system is ensured by the local method of rigid support.

Keywords: large-sized part, rigidity, mobile robotic machine, shaping and accuracy, abrasive belt, welded structure, frameless technology

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ANALYSIS OF THE CURRENT STATE OF THE PROBLEM CONSIDERED

Many industrial units in Russia were created earlier and are now being created according to the following principle: the larger, the higher the productivity. Such large-sized units find their application in the nuclear, mining, and building materials industries. Their production and operation are associated with significant costs. Therefore, one of the most important and topical issues in heavy engineering is the development of optimal production technologies and methods for restoring worn parts [1–8].

For example, the processing time for the bandage of a rotating cement kiln (RCK) with a diameter of 6300 mm and mass of 62000 tons under stationary conditions is more than 600 machine-tool hours. The price of the RCK bandage is more than 15 million rubles. The drive gear for a standard cement kiln with a length of 180000 mm is over 42 million rubles.

The technological possibilities for the manufacture of new large-sized parts or restoration of worn out ones, such as bodies of revolution, the dimensions of which exceed 4000 mm using small mobile machines, were considered in [9–11]. However, not enough attention was paid to the issues of setting the base of large-sized parts in the process of their production and machining.

Purpose of this paper. The authors aim to acquaint the reader with their existing developments in the field of mechanical processing of large-sized parts using frameless technology.

STATEMENT OF THE PROBLEM

The creation and use of a mobile robotic machine [12, 13] contributes to a significant expansion of the technological equipment of enterprises, including enterprises of mining and nuclear engineering and the industry of building materials. For successful application of the means of frameless technology, it is necessary to ensure the correct base of the large-sized products processed, as well as to ensure the possibility of compensating for uncertainty in the position of the cutting tool relative to the machined surface of the large-sized part.

STATEMENT OF THE ESSENCE OF THE SOLUTION TO THE PROBLEM

Mechanical processing of the outer surfaces of VCK bandages at the factory [14] is carried out using a base scheme (Fig. 1) that includes a mounting base, one of the end surfaces of the bandage, and a center-

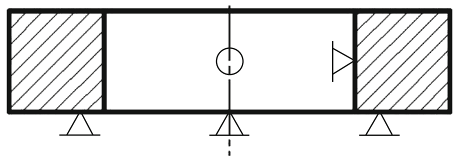

Fig. 1. Diagram of the ring-shaped part of the base.

ing base, the surface of the bandage hole. This is a typical layout for ring-type parts used for both small and medium-sized and large parts.

Using a typical base scheme, it is possible to exclude the effect of gravity on the shape distortions of the treated surface of the bandage due to the fact that the stiffness of the bandage section in the transverse direction is an order of magnitude higher and the bandage weight is uniformly distributed along its circular generatrix. Thus, it is the typical base scheme that allows obtaining the highest accuracy of the dimensions, shape, and relative position of the surfaces of the machined large ring-shaped parts. Therefore, it should be used in the machining of the surfaces of the VCK bandages.

The use of a typical base scheme can be accompanied by two methods of shaping. The first method of shaping assumes a stationary placement of the RCK bandage on a certain supporting surface of the device. In this case, the cutting tool must move along a circular generatrix relative to the rotation axis of the RCK bandage, as occurs, for example, when boring holes or during rotary milling of cylindrical surfaces.

The second method of shaping assumes the possibility of rotation of the bandage itself similarly to how it happens in a shop, for example, on the faceplate of a boring lathe.

The main requirement when deciding on the applied shaping method is the mobility of the tools used. We consider the first method of shaping and the technological solutions possible within its framework.

The RCK bandage must be installed motionlessly on the supporting surfaces of a special device. The device can be constructed as follows:

(a) Made in the form of a prefabricated metal structure, which

• is moved by vehicles to the operation place together with a mobile robotic machine, deployed, mounted on a previously prepared site of a cement plant, checked by level, etc.;

• is manufactured in advance for the needs of the cement plant, stored on its territory, and mounted on a previously prepared site of the cement plant permanently or during periods of the plant's need for new or repaired bandages;

(b) Made of reinforced concrete in the form of a stationary building structure, reinforced with steel sheets and equipped with the necessary structural elements for the base of the RCK bandage blank (like a plaza), and can

• be in the open air or under a canopy (capital, removable, inflatable, etc.);

• be used during overhaul periods for the economic purposes of the cement plant that are other than the direct purpose of setting the base of the RCK bandages.

For the purposes of manufacturing or mechanical processing of bandages, the cement plant will need to prepare a special reinforced concrete platform of the required area aligned horizontally and having sufficient strength (with a thickness of at least 600–800 mm), with built-in steel elements under the supports. With some stretch, this site can be called a base plate or plaza by analogy with plazas used in heavy engineering. The platform can be rectangular or round. The diameter of the inscribed circle of the platform must be at least twice the diameter of the RCK bandages being processed.

The RCK bandages have limited rigidity in the radial direction and slightly more in the axial direction. When setting the base of the workpiece of the bandage on the faceplate of the turning-boring machine with its butt end, it comes into contact with the supporting surface of the faceplate of the machine at many points of its surface; therefore, the low rigidity of the bandage structure does not play a significant role in the cutting process.

However, in the field, the insufficient rigidity of the bandage structure should be taken into account when machining. The best option from the viewpoint of ensuring the accuracy of the bandage shape would be to create on the slab surface a solid ring-shaped support made of concrete or steel (Figs. 2, 3).

Elevation *3* above the base plate should provide the cutting tool with access along the entire length of the generating lines to the outer rolling surface, to the free end, and to the surface of the hole in the RCK bandage without the need to reinstall since each bandage reinstallation is a laborious process associated

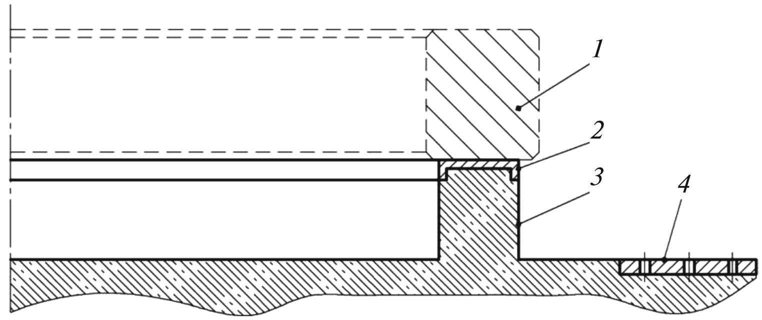

Fig. 2. Diagram of the base plate device for performing machining of the RCK bandages outside the machine shop conditions: (*1*) RCK bandage, (*2*) steel protective strip, (*3*) base of the reinforced concrete plate with an elevation, and (*4*) mounting plates.

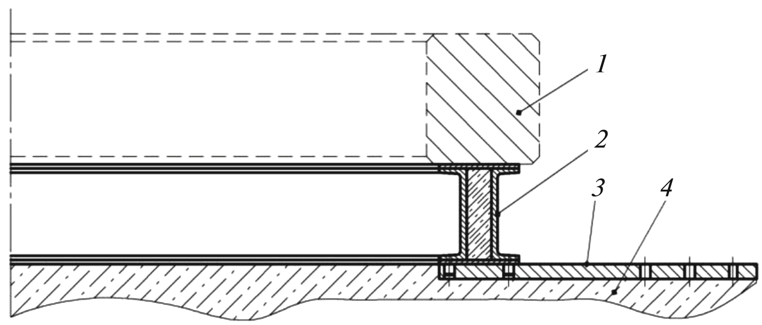

Fig. 3. Scheme of installation of the RCK bandages on the base plate with a removable annular elevation: (*1*) RCK bandage, (*2*) elevation from profile rolled products, (*3*) mounting plates, and (*4*) base plate.

with risks of serious injury to people, destruction of buildings and equipment, and deformation of the bandage itself.

If the elevation structure is made removable, for example, from a steel profile (Fig. 3), then for the subsequent precise installation of this elevation, it will be necessary to provide support surfaces in the base plate in the form of plates *4* embedded in concrete with holes including threaded holes (Fig. 3) or with fingers.

On the other hand, the presence of a solid ring-shaped support is not a rational solution because the bandage workpiece may be defective in the form of a significant deviation from the parallelism of its ends, deviation from the flatness of the ends, eccentricity of the hole relative to the outer surface, ovality, etc. Furthermore, the base slab can become distorted over time, and if geological surveys are not performed correctly, the slab can tilt and obtain an asymmetric draft or displacement. As a result, it may be necessary to perform a complex of construction and installation works to level the slab, correct the support sites, or change the bandage position on the support to install it level.

In any case, the correct solution would be to install the bandage not on a monolithic elevation, but on a system of adjustable supports (Fig. 4). Three supports are not enough, and additional supports located between the three main ones must be provided. Thus, the total number of supports should be at least six [14], and it is better if their number reaches nine or even twelve to distribute the load from the installed part between them.

The choice of a design option for supports for the installation of an RCK bandage requires deep economic analysis and a complex design. However, it seems necessary to preliminarily formulate the following requirements for the supports: (1) the support is attached to the base with anchor bolts; (2) the lifting capacity of one support must be sufficient to hold half of the total weight of the bandage (in case of uneven loading of the supports when installing the bandage with a crane); (3) supports must be adjustable in height and have a controlled drive (hydraulic or electric); (4) the supports should be able to move radially to correct their position taking into account the diameter of the workpiece being installed due to the longitudinal grooves on the support sole; (5) supports must have built-in elements of the measurement sys-

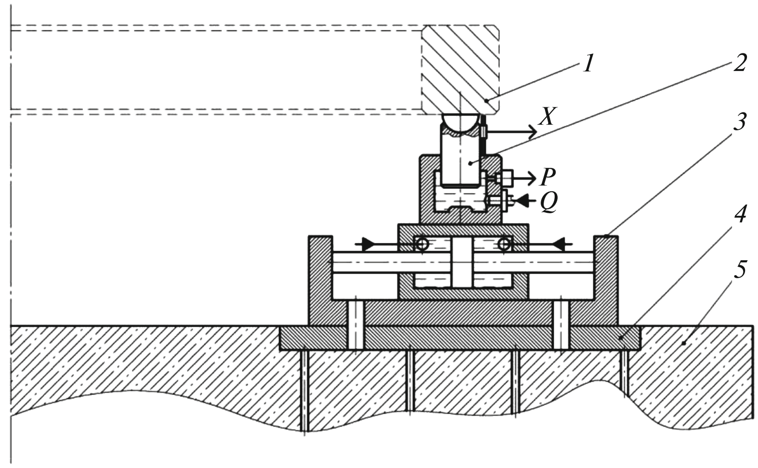

Fig. 4. Scheme of installation of RCK bandages on the base plate with adjustable supports: (*1*) RCK bandage, (*2*) adjustable self-aligning support with built-in sensors, (*3*) radial movement mechanism, (*4*) mounting plate, and (*5*) base plate.

tem: level, load value, and displacement limits to automate the process of aligning the position of the installed bandage; (6) the operating surfaces of the supports should have a flat platform (possibly with corrugations) with the possibility of self-installation (to ensure the largest contact area with the base end of the bandage); (7) supports should be easy to mount and dismantle.

The removable support structure has the following positive properties: (1) removable supports can be stored in a special warehouse or transported together with a mobile robotic machine from one cement plant to another (it is enough to have one main set and one spare and not to make a set for each plant); (2) increasing the reliability and maintainability of the base system; (3) on the territory of the cement plant outside the period of repair or construction, a special site can be used for storage of materials or other economic purposes and will not contain unnecessary elevations; (4) there is no need for additional means to protect high-tech supports from weathering and pollution, it is enough to protect the supporting surfaces of the base plate; (5) when using various standard sizes of RCKs at a cement plant, as is the case at the Belgorod cement plant, it is enough to move the removable supports closer to the center of the site or further from it and not build an additional site for another standard size of bandages.

As can be seen in a typical locating scheme (Fig. 1), besides a mounting base, ring-type parts require a centering base. In the case of bases on supporting surfaces (Figs. 2–4), it is not possible to distinguish the contact centering technological base. We can only talk about the use of a tuning technological base, which can be either a hole in the bandage or its outer surface.

If the central hole of the RCK bandage is considered as the tuning technological base, then the principle of the unity of the bases in terms of coincidence with the design base of the part will be observed: with its hole, the bandage is installed on the surface of the RCK shell (welded or centered and fixed by a system of shoes).

The issue of the base the RCK bandage should be considered in conjunction with the issue of ensuring the accuracy of the trajectories of the cutting tool relative to the selected reference surfaces.

The trajectory of the cutting tool, whatever it may be (cutter, milling cutter, abrasive belt) [15, 16], should be a regular circle with the center coinciding with the center of the hole in the bandage. Under frameless processing conditions, the solution of this issue has always turned out to be the most laborious and difficult to implement. However, simple technological methods [1, 2, 4, 6] were replaced by modern digital technologies of control and management.

In this regard, the issue of ensuring the accuracy of the dimensions and shape of the processed bandage is largely assigned to the mobile robotic machine and its automatic control system [13]. In other words, there is no need for a very precise installation of the bandage on the supports, and there is no need for a very precise installation of the guides of a mobile robotic machine or very high rigidity of its structure. The issue of ensuring the accuracy of shaping is solved in the “bandage–tool” system. Therefore, it is very important to ensure the accuracy of the trajectory of the cutting tool in relation to the bandage processed. This task is entrusted to the robotic machine itself due to the technological capabilities, design features, and information algorithms provided for in its design.

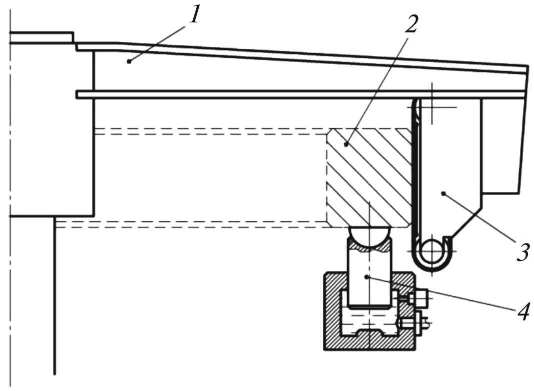

Fig. 5. Option of console placement of the mobile robotic machine: (*1*) console of the mobile robotic machine, (*2*) processed RCK bandage, (*3*) cutting tool module, and (*4*) support.

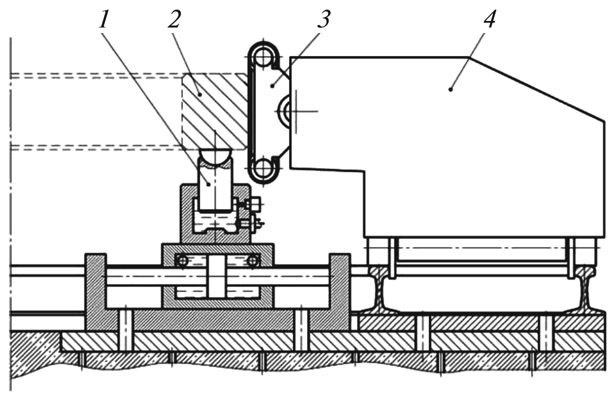

Fig. 6. Option of placing a mobile robotic machine on rail guides: (*1*) support, (*2*) processed RCK bandage, (*3*) cutting tool module, and (*4*) mobile robotic machine.

In order for the mobile robotic machine to move the cutting tool along a circular path relative to the machined surfaces of the RCK bandage, the robotic machine itself must have a corresponding circular or quasi-circular motion path. This is ensured by placing the mobile robotic machine on a console rotating relative to the center of the bandage (Fig. 5) and placing the mobile robotic machine on circular rail guides.

The use of a console arrangement of a mobile robotic machine has a number of limiting disadvantages: (1) the robotic machine is presumably heavy, and therefore, the console, the length of which may exceed 3 m, and its bearings will be subject to high loads from holding the robotic machine weight, as well as from cutting forces; (2) the power supply is required through the console using a sliding contact, which can be very unreliable and cause electromagnetic interference with the control system; (3) when installing the bandage on the supporting surface of an elevation, the machine tool console must be dismantled or folded (adjust the overhang, deflect or raise the robotic machine itself); and (4) the rigidity of the technological system can decrease due to the large length of the console.

The advantage of console placement is the precise centering of the robotic machine itself.

Placing a mobile robotic machine on rail guides presumes a high manufacturing accuracy of the guides themselves and a relatively high accuracy of their installation to ensure a circular (or quasi-circular) trajectory of the cutting tool. The rail guides are placed in a circle outside the ring of the bandage to be machined on the base plate (Fig. 6).

Among the disadvantages of using rail guides are the following: (1) if power is supplied through the center console, sliding contacts also have to be used; (2) there is a high complexity and laboriousness of installation and alignment of rail guides relative to the horizon and center; (3) the rail guides are supposed to be transported by the same means as the mobile robotic machine, and they will take up a lot of space while having a large weight of their own.

The advantages of placing the robotic machine on rail guides are (1) the ability to supply power through the rails; (2) high rigidity of the guides placed on the base plate; (3) a small overhang of the robotic machine relative to the rail guides and, as a result, reduced loads from its weight and increased rigidity of the technological system; and (4) that the robotic machine does not interfere with the installation of the bandage on the supports.

Comparing the advantages and disadvantages of the options for installing a mobile robotic machine, we conclude that the advantages of the rail option prevail. In this case, electricity should be supplied through the rails, and the laboriousness of installing the rail guides should be minimized due to optimal design solutions. Alignment errors of rail guides, along with other errors, will have to be compensated for by the mobile robotic machine itself controlled by an intelligent digital system.

CONCLUSIONS

Based on the authors' practical experience and developments in the field of frameless technology, the proposed technological solution concerning the machining of large parts using small robotic machines is economically justified, relevant, and feasible and opens up broad prospects for application in Russia. The proposed concept of machining large-sized parts allows removing restrictions on their overall dimensions and weight and eliminates the need for separate production of elements of one part, their transportation over long distances, assembly at the site of operation, and subsequent laborious revision or alignment.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest. Professor N.A. Pelipenko is the official scientific adviser of the doctoral student S.N. Sanin.

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