Modeling elastic deformations of the rotary dividing table faceplate under the action of the workpiece weight

B A Tsarfin
Jig-boring machine plant ZAO «Stan-Samara», 22 Partsjezda 7a, Samara, Russia
legirovanniy@mail.ru

Abstract. The article discusses the problem of determining elastic deformations of the rotary indexing table faceplate that arise when installing maximum allowable weight workpiece. A numerical analysis of the stress-strain state of the faceplate under loading with the same weight of its different sections consisting of concentric zones into which the faceplates was conditionally divided was performed. It has been established that the deformations under study can have a significant effect on the accuracy of the workpiece base. All calculations were performed in the CAE ANSYS finite element modeling software package. Based on the calculation results, the proposal was developed to modernize the design of the faceplate, which reduces elastic deformations.

1. Introduction
The constant intensification of production in mechanical engineering is inextricably linked with the technical re-equipment and modernization of machines based on the use of the latest scientific and technological achievements, including the development and implementation of technological equipment. In mechanical engineering, in the total amount of technological equipment, approximately 50% are machine tools [1].

Rotary indexing tables are universal and non-adjustment devices for coordinate-boring and coordinate-grinding machines of particularly high precision (class A) and special accuracy (class C).

However, the use of additional machine tools to expand the technological capabilities of the machine, namely to process the workpiece from five sides without reinstalling it; to process in the polar coordinate system; increase labor productivity; to stably provide high quality workpiece processing [2], may be accompanied by additional errors associated with the installation of the workpiece on the table plate.

2. Component errors of the workpiece installation
In the General case, the error in the installation of the workpiece on the rotary table consists of the errors of basing and fixing and is determined by the following components:

$$\varepsilon_{\text{inst}} = f(\varepsilon_{\text{geom}}, \varepsilon_{\text{ed}}, \varepsilon_{\text{mb}}, \varepsilon_{\text{just}}, \varepsilon_{\text{sfix}}),$$

where $\varepsilon_{\text{geom}}$ – the error in the shape and location of the base table surfaces. Depends on build quality.

In any case, all components of this error should not exceed the values established by the standard;
\( \varepsilon_{ed} \) – the error caused by elastic deformations of the rotary table structural elements under the action of the workpieces weight. These deformations disappear after unloading;

\( \varepsilon_{mb} \) – error due to mismatch of installation and measuring bases. The general methodology for its calculation is to determine the position of any point of the part in the device coordinate system [7];

\( \varepsilon_{fas} \) – the error of fixing the workpiece on the table. This is a random error, it is a consequence of the part shifts under the action of the clamping force aimed at maintaining the workpiece position, as well as the deformations of various elements of the chain setting element - part - device;

\( \varepsilon_{sf} \) – the error introduced by the faceplate fixation system. The forces arising from the operation of the faceplate fixation system against rotation can have a significant effect on the faceplate itself, causing changes in its shape.

Thus, the creation of a precision rotary dividing table is possible only when analyzing the formation of each of these components and developing measures to minimize them.

This article investigates the influence of the stress-strain state of the rotary dividing table SP 100 faceplate on the error. The SP 100 table was designed in 2005 and is still being manufactured and is used when working on coordinate boring machines for boring, drilling, finishing milling of high-precision parts of the aviation and space industry, as well as measuring stands.

According to GOST 16163-90 [5], the table must provide high geometric accuracy (class C) with a maximum allowable weight \( H_{\text{max}} \) of the part installed on it - 20,000 N [3]. Under its action, the table plate experiences elastic deformations, which increase the error in the base of the part. Figure 1a shows the installation diagram of the workpiece or under study part 2 on a SP 100 single-axis table with faceplate 1 with a diameter of 1000 mm, where \( T \) – is the distance from the table base to an arbitrary point on the surface of the part along the Z axis - without taking into account the error \( \varepsilon_{ed} \). Figure 1b: \( T_{ed} = T - \Delta_{ed} \), where \( T_{ed} \) – distance along the Z axis from the base of the table to an arbitrary point on the surface of the part, taking into account \( \varepsilon_{ed} \), \( \Delta_{ed} \) - error value of \( \varepsilon_{ed} \).

Figure 1. The scheme for installing parts on the rotary table SP 100.

The entire load from the weight of the faceplate and the part is transferred to the table casing 3 via an axial-radial device 4. Considering the effects of static forces, we can neglect the reactions of the other rotary table systems (worm drive and others), since their deformation mainly occurs when the angle of the faceplate changes and are the subject of separate studies. Also, as part of our study, we will consider the frame and axial radial device to be absolutely rigid provided \( H_{\text{max}} \leq 20000 \text{ N} \).
3. Modeling the faceplate loading process

To simulate the loading of the faceplate by the finite element method, the CAE ANSYS program was used, which is currently one of the world leaders in the finite element analysis field [4]. Since the rotary table can serve as a universal fixture for machines or as an independent stand, in practice the objects installed on it can have different weights and areas of basing surfaces, and also not be axisymmetric bodies. Therefore, we have introduced the following restrictions:

− the parts are bodies of revolution and are mounted coaxially to the faceplate;
− all parts have a weight of 20,000N;
− the contact between the faceplate and the part is assumed to be perfect, roughness and waviness are not taken into account;
− the base surface of the parts is inextricable, is a circle or ring in shape.

The rotary table was conditionally divided into 7 zones bounded by concentric circles with a pitch of 125 mm in diameter (Figure 2). To carry out calculations from these zones, 13 sections of the faceplate surface were obtained: $S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8 = \sum_{i=1}^{2} S_i$, $S_9 = \sum_{i=3}^{4} S_i$, $S_{10} = \sum_{i=5}^{6} S_i$, $S_{11} = \sum_{i=7}^{8} S_i$, $S_{12} = \sum_{i=9}^{10} S_i$, $S_{13} = \sum_{i=11}^{12} S_i$.

To the supporting surface of the faceplate, mating with the radial-axial device, the boundary condition of hard sealing (fixed support) is applied, as shown in Figure 3. Simulating the part weight equal to 20,000 N, a force (Force) $F$ is applied perpendicularly to a given portion of the faceplate surface (Figure 3).

Figure 2. Faceplate surface areas.

Figure 3. Rigid termination and application of force to the table faceplate.
In the case where the table SP 100 is a fixture for machines of particularly high precision, such as, for example, mod. 2B470, the value of $\Delta_{ed}$ will significantly affect the processing of the part when $\Delta_{ed} \geq 0.5\Delta_{mov}$, where $\Delta_{mov}$ – linear displacement error of the working body. For coordinate boring machine mod. 2B470, equipped with SP 100, $0.5\Delta_{mov} = 3 \, \mu m$ [6]. If the table SP 100 is used as an element of a special measuring stand, the purpose and accuracy of which are unknown to us, then in this case we will also consider significant $\Delta_{ed} \geq 3 \, \mu m$. When solving for each of the given sections in ANSYS, we obtained both the maximum modulus values of the deformation and the distribution patterns of the deformations values over the faceplate entire surface. Figure 4 shows the solutions for the sections $S_1$ and $S_7$, where $\Delta_{ed} \geq 3 \, \mu m$.

![Figure 4. Simulation solutions for the sections $S_1$ and $S_7$.](image)

In Figure 5 shown a graph of the elastic deformation maximum modulus $\Delta_{ed}$ of the table faceplate, depending on the area to which the force $F$ was applied, simulating the weight of the part. Graph points that are above a straight line of 3 microns match sections $S_1$ and $S_7$, as mentioned above.

![Figure 5. The graph of the elastic strains values $\Delta_{ed}$ in the loading sections.](image)
4. Measures to reduce the elastic deformation of the faceplate

Analyzing the results of modeling the impact of workpieces of maximum weight on different rotary table faceplate surface parts, we can draw the following conclusions:

- the smallest elastic strains are observed in the section $S_4$, located directly above the supporting surface $P$ (figure 6), which interfaces with an axial-radial device. Therefore, the best area for installing the workpiece is a “ring” with a small diameter of 540 mm and a large diameter of 652 mm;
- the greatest errors $\varepsilon_{ed}$ are observed in the areas farthest from the surface $P$ in the radial direction sections $S_1$ and $S_7$;
- using the obtained solutions, it is possible to introduce an adjustment of the size $T$ (figure 1), thereby increasing the accuracy of machining on the machine or measurement on the stand. To reduce the values of elastic strains, 2 variants of the path are proposed:
  1) Search for modern materials for the faceplate manufacture. At the moment, this may be economically disadvantageous due to their high cost. In addition, cast iron is convenient for manual scrapping, without which it is difficult to obtain high geometric characteristics of class C tables.
  2) Increasing the rigidity of the faceplate by changing its design.

The simplest way is a “superstructure” of 10 mm of size $B$ over the entire plane of the faceplate while maintaining size $K$, as shown in Figure 6. At the same time, the weight of the faceplate will increase by 496.2 N, which will increase the load on the radial-axial device. Therefore, to maintain the rotary table design rigidity, it is recommended to reduce the maximum weight of the workpiece to $H_{\text{max}} = 19503.8$ N. In Figure 7 there is a graph showing the results of modeling the loading of the faceplate (all conditions and parameters are similar to the previous experiment) after the applied improvements in its design.
5. Findings

Based on the results of modeling in the CAE ANSYS software package loading of rotary table SP 100 faceplate different sections with a force equivalent to the maximum weight of the workpiece, elastic strains were found that significantly affect the workpiece positioning accuracy.

When analyzing the results obtained, recommendations were developed on modifying the design of the faceplate to reduce the elastic deformation amount. If it is impossible to change the design of the faceplate, it is proposed to use the values obtained from computer calculations to compensate for the error in the part base.

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