Method of precision dimensional analysis in modelling of technological processes for shafts manufacturing

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Abstract. In this paper, we propose a method for conducting a dimensional-precision analysis of technological processes of making shafts using bench centers and consider the features of its application. A method for drawing up rotation error diagrams for processing shafts installed in the centers of lathes has developed, taking into account the principle of constancy of bases and the presence of an error in pre-centering the initial shaft workpiece.

1. Introduction
Ensuring the quality of manufacturing parts has always been and will be an urgent problem as long as there is industrial production. One of the main indicators of quality are: precision of dimensions of parts; relative positioning requirements, geometric precision and surface roughness of parts [1], [2], [3], [4]. In the conditions of automated production, with the automation of technological preparation of production (TPP) and with a constant increase of quality requirements for design solutions, the solving of the problem of formalization and algorithmization of the design process of mechanical processing TP becomes especially urgent, which in turn implies the further development of design theory and methodology, that determine the further development and improvement of the technical knowledge base [5].

One of the important stages of the TPP is to carry out dimensional-precision analysis in the design of route technologies [6], which allows to evaluate the precision of the main output parameters of the TP, as well as the precision of the TP overall [7]. Conducting dimensional-precision analysis allows designing reliable technologies that guarantee, when implemented, that they ensure the specified dimensional accuracy and technical requirements of the drawing. The thoroughness of the dimensional-precision analysis significantly affects the reduction of material and time costs for subsequent development and implementation of the designed technologies in production according to the results of experimental and installation batches [6], [8].

The dimensional-precision analysis (DPA) of route for TP for making parts such as bodies of rotation is based on the technique developed in North-West Technical University (St. Petersburg, Russia), which is described in detail in [9] and [10]. At the same time, some formulations used in [10] to describe this technique were refined in [9]. Therefore, in our further considerations, we will rely on the description of the DPA of TP flow technique presented in [9].

The objectives of the DPA are:

- Calculation (determination) of all operational sizes and machining allowances;
• Determination by analytical means of the possibility of fulfilling the design dimensions and technical requirements of the relative positions of the elements with a given precision automatically on the selected technological equipment when installing the workpiece either using truing or without truing.

2. Materials and methods
For parts of the "body of rotation" type, to which the shafts belong, according to the methodology presented in [9], the conduct of DPA TP has inextricably linked with the synthesis of the corresponding linear size and rotational errors diagram.

Schemes of linear dimensions have developed in order to determine by analytical method the possibility of ensuring the precision of the design dimensions, the calculation of linear operational dimensions and processing allowances. The objectives of developing rotational errors diagrams arising from the implementation of TP are:

• Checking the feasibility of fulfilling the technical relative position requirements (RPR) of rotation elements.
• Determination of uneven allowances.
• Calculation of diametrical operational dimensions and machining allowances.

If the DPA of TP of making shafts using bench centers for linear dimensions is no different from the general DPA technique described in [9], then for rotation elements, it has some features that have not covered in the literature. Let illustrate this with the example of TP of making the “Roller” part, using bench centers, whose drawing and operational systems (OS) are presented in figure 1. In the proposed TP for making the “Roller” part in operation 010, bases (center holes) are prepared for subsequent processing of the workpiece using bench centers in operations 015, 020, 025 and 030. At the same time, PRR surfaces (elements) of rotation, indicated in the drawing, has affected by operations 010, 015, 020, 025 and 030, and operation 035 does not.

First, we will develop a beat pattern (figure 2, a) in full accordance with the technique presented in [9], according to which all processed elements have their own unique number. Its first digit (the first two digits) corresponds to the element number in the structure of the T-system “Part” (TSP), and the last digit indicates its status in the T-system “Workpiece” (TSW).

In this technique, it has accepted that if the last digit of the element number is “zero”, then this corresponds to its final state. Therefore, the numbers 50 and 60 respectively indicates the left and right center holes on the rotational errors diagram.

Analyzing the presented rotational errors diagram, we see that when changing the processing side, the base changes. This is also confirmed by the beat equations of the machined rotation elements 12 and 42, arising in operations 015 and 020, respectively. According to the technique presented in [9], the rotating error of each processed rotation element is determined by the method of geometric summation of the tolerances of the component rotational error, since the sought and component rotational errors are vectors, and their nominal values are zero.

Therefore, the rotation error equations of the processed rotation elements 12 and 42, respectively, at operations 015 and 020 are:

\[ B_{12}^{15} = \sqrt{ (B_{60}^{15})^2 + (B_{60}^{10})^2 + (B_{21}^{10})^2 + (B_{21}^{05})^2 + (B_{12}^{05})^2 }, \]  

(1)

\[ B_{42}^{20} = \sqrt{ (B_{50}^{20})^2 + (B_{50}^{10})^2 + (B_{21}^{10})^2 + (B_{21}^{05})^2 + (B_{32}^{05})^2 }. \]  

(2)

In equation (1), as one of the components of the rotation error chain, the rotation error of the base surface 60 is used (figure 2, a) that occurs when the workpiece is set to operation 015, and in equation (2), as one of the components of the rotation error chain, the rotation error is used the base surface 50
that occurs when the workpiece is installed in operation 020, that is, the rotation error of another base surface located in the TSW structure on the other side of the workpiece.

Figure 1. Drawing for detail "Roller" and operating systems for its making using bench centers.

In fact, changing the machining side for rotation elements does not lead to a change of bases, since the base of the workpiece being machined is the axis of the centers, and the center chamfers when they are simultaneously prepared on a milling-and-centering machine, in fact, have a common axis, that is, in the case of making shafts using bench centers respected the basis constancy principle [3].
3. Results and Discussion

Thus, a contradiction arises: formally, there is a change of bases, but in fact, it does not exist. This contradiction can be eliminated by considering the center chamfers (holes) as a single element (for example, element number 50) (figure 2, b). In this case, half, the calculated values of which verify the possibility of fulfilling the relevant technical requirements of the drawing, reduce the number of vectors of technical RPR of rotation elements.

Further, analyzing the structure of the rotation errors that occur in operation 010 (figure 2, a), and the list of formulas given [11] in the section “Rules for calculating machining allowances”, as well as using the ratio of the surface rotation error and displacement known from [12] its axis ($B = 2e$) the conclusion suggests itself that the rotation error of the center holes (elements 50 and 60) after their drilling can be uniquely determined, such as:

$$ B_i^l = 2\Delta_x. $$  \hspace{1cm} (3)

Moreover, the total deviations $\Delta_x$ after drilling the hole, according to [8], are determined by the following formula:

$$ \Delta_x = \sqrt{(\Delta_{dd}l)^2 + C_{DAH}^2}, $$  \hspace{1cm} (4)

where: $\Delta_{dd}$ – drill drift value, microns per 1 mm; $l$ – is the length of the drilled hole, mm; $C_{DAH}$ – is the displacement of the axis of the hole, microns.

The drill run-off and the hole axis offset when machining with spiral and special drills are determined by reference data presented in [11]. However, if we compare the centering drill and the spiral drill with a cylindrical shank having the same diameter of the working part, from the point of view of their design, it becomes obvious that the centering drill has greater rigidity, since the length of its working part is much smaller and the diameter of the shank several times bigger. Therefore, the use of formulas (3) and (4), as well as reference data, is incorrect for this case.

Based on this, it follows that in the case under consideration we have a deadlock. However, it is not. This seeming impasse, firstly indirectly confirms the need to consider center chamfers as a single
element, and secondly, naturally leads to the idea that it is necessary to take into account the error in centering the workpiece.

With this in mind, the final version of the rotation error diagram was developed, which is presented in figure 2, b. Therefore, a rotation error vector of center bevels (a single element at number 50) relative to the base surface (element at number 21) appeared, which is designated as $2\Delta C$. That is, in such cases, taking into account the above ratio $B = 2e$, this rotation error vector is considered as a doubled displacement of the axis of the chamfers because of the error in centering the workpiece. Using the rotation error diagram, it can be defined as follows:

$$2\Delta C = \sqrt{(B_{50}^{15})^2 + (B_{21}^{10})^2}.$$  \hspace{1cm} (5)

Therefore:

$$(2\Delta C)^2 = (B_{50}^{15})^2 + (B_{21}^{10})^2. \hspace{1cm} (6)$$

In this case, the rotation error equations of the processed rotation elements 12 and 42, respectively, at operations 015 and 020 will look as follows:

$$B_{12}^{15} = \sqrt{(B_{50}^{15})^2 + (B_{21}^{10})^2 + (B_{21}^{10})^2 + (B_{12}^{15})^2} = \sqrt{(B_{50}^{15})^2 + (2\Delta C)^2 + (B_{21}^{15})^2 + (B_{12}^{15})^2},$$

$$B_{42}^{20} = \sqrt{(B_{50}^{20})^2 + (B_{21}^{10})^2 + (B_{21}^{10})^2 + (B_{42}^{20})^2} = \sqrt{(B_{50}^{20})^2 + (2\Delta C)^2 + (B_{21}^{20})^2 + (B_{42}^{20})^2}.$$  

Similarly:

$$B_{21}^{15} = \sqrt{(B_{50}^{15})^2 + (B_{21}^{10})^2 + (B_{21}^{10})^2} = \sqrt{(B_{50}^{15})^2 + (2\Delta C)^2}.$$  

According to [11], the centering error $\Delta C$ – the offset of the workpiece axis as a result of the centering error relative to the workpiece base used in centering, is determined by the following formula:

$$\Delta C = 0.25\sqrt{T^2 + 1}, \hspace{1cm} (7)$$

where $T$ – is the tolerance on the diametric size of the base of the workpiece used for centering, mm.

Thus, in the presence of a binding rotation error vector $\Delta \mu$ between the rotation error vectors of the base surface and center holes in the milling-centering operation and the possibility of determining its value by formula (7), there is no need to determine the values. That means, that in the case, when determining the composition of the rotation error chains, the closing links of which are the rotation errors of the machined surfaces of numbers 12 and 42 in operations 015 and 020, respectively, the transition from operation 015 or 020 to operation 005 through operation 010 is carried out directly through the connecting rotation error vector $\Delta C$.

The rotation error of the base surfaces when installing the workpiece in the centers is determined by the formula:

$$B_i = 2(a_3\sqrt{D + bL}), \hspace{1cm} (8)$$

where: $D$ – diameter of the center chamfer; $L$ – total length of the workpiece; $a_3$ and $b$ – coefficients depending on the accuracy of the installation: $a_3 = 0.006$ and $b = 0.00005$ – normal installation accuracy, $a_3 = 0.0018$ and $b = 0.000015$ – increased installation accuracy, $a_3 = 0.0009$ and $b = 0.00007$ – high precision installation.

For the considered TP of making the “Roller” part according to formula (8), the rotation errors of the center chamfers (a single element at number 50) are determined in operations 015, 020, 025 and 030 (figure 2, b).
Otherwise, the calculation of the values of the rotation errors of the elements of the initial workpiece, the rotation errors of the in-process and finished elements relative to the processing base and among themselves, the calculation of the unevenness of the allowances and checking the feasibility of performing technical RPR of the rotation elements with the selected basing systems and with the chosen devices, as well as the calculation of the intermediate diametrical sizes in accordance with the DPA routing TP methodology described in [9].

4. Conclusion
The aforementioned features of drawing up rotation error diagram and their calculation are the basis for formalizing the process of dimensional precision analysis of TP for making shafts using bench centers. The results obtained can be used to ensure the necessary degree of accuracy and dynamic stabilization [13], [14], [15], [16], [17] of the turning process.

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