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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

INCREASE OF PRODUCTIVITY OF MULTI-TOOL MACHINING IN MODERN MULTI-PURPOSE CNC MACHINES

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GENERAL DESCRIPTION OF WORK

Relevance of the topic and degree of elaboration. Multi-purpose CNC machines have a high degree of automation and wide technological capabilities. Therefore, it turns out to be more efficient to use multi-tool machining on multi-purpose CNC machines of a new generation.

Analysis of the technological capabilities of multi-tool machining on multi-purpose CNC machines, as well as the studies carried out to determine the use of the potential of multi-purpose machines at machine-building plants of the Republic of Azerbaijan have shown that despite the presence of multi-tool machines and equipment at factories that allow multi-tool machining of several surfaces simultaneously, these possibilities are not used. Despite the fact that in world practice such adjustments make up a certain percentage (only 9% out of 400 theoretically possible adjustments), we can say that such adjustments are not used in the factories of Azerbaijan. Improving efficiency on multipurpose CNC machines consists in the rational coordination of the total speed of the spare spindle with the surface treatment of the workpiece. But practice shows that during the operation of multi-purpose CNC machines, despite the placement of tools on different carriages, two-tool two-carriage machining is mainly accompanied by sequential transitions.

The main reason for not using the possibilities of multi-tool parallel machining on modern multi-purpose CNC machines is the lack of recommendations for design schemes and, accordingly, adjustment schemes in this direction. Currently, there are recommendations for determining cutting conditions and time rates in the literature related to multi-purpose CNC machines. However, there is no information in this literature on multi-tool machining and on the determination of cutting conditions for such machining. For this reason, it is necessary to develop recommendations for the design and application of precisely multi-tool multi-carriage adjustments, which make it possible to use multi-tool parallel machining on multi-purpose CNC machines. The studies have shown that the real level of using the great technological capabilities of modern multi-purpose CNC machine tools does not exceed 11-13 grades in machining accuracy. However, as a result of the correct choice of adjustment and technological equipment, cutting conditions, the accuracy can be increased to 6-9 quality.

The basis for the development of recommendations for the design and use of multi-tool multi-carriage adjustments is the matrix theory of multi-tool machining accuracy, developed by N.D. Yusubov and taking into account the capabilities of modern CNC machines. Studies have shown that most of the machining error models developed on the basis of the matrix theory of the accuracy of multi-tool multi-carriage machining by N.D. Yusubov takes into account the rectilinear-parallel movements of the subsystems of the technological system. This approach to the process of forming machining errors is permissible for parts with equal overall designs along all coordinate axes. However, in practice, during turning, parts are also machined whose overall dimensions differ sharply in different directions. For example, parts such as long shafts (linear dimensions prevail), disks and flanges (diametric dimensions prevail). In such cases, rotations of the workpiece to be machined, and especially rotations in directions in which the overall dimensions prevail, will also affect the machining errors to a large extent.

Thus, on the basis of modeling the elastic displacements of the links of the technological system, taking into account the mutual influence of tools simultaneously working in setting up in connection with the use of multi-tool machining on modern multi-purpose CNC machines, the task of increasing the accuracy and productivity of multi-tool machining using the method of numerical determination of feeds is relevant and possesses both scientific and practical value.

The purpose and objectives of the research. The purpose of the research is to increase the accuracy and productivity of multi-tool machining based on modeling the elastic displacements of the links of the technological system, taking into account the mutual influence of simultaneously working in multi-tool setting on modern multi-purpose CNC machines.

To achieve this goal, the following research tasks are supposed to be solved:

1. Development of matrix mathematical models of errors in the dimensions performed during multi-tool machining in the adjustments of modern multi-purpose CNC machine tools.

2. Development of a methodology for the experimental determination of the full matrix characteristics of the rigidity of the technological system of multi-purpose CNC machine tools.

3. Development of a matrix model for controlling cutting conditions with the fulfillment of the requirements for dimensional accuracy in two-carriage multi-tool adjustments.

4. Development of a technique for the numerical determination of feed with the fulfillment of the requirements for dimensional accuracy.

Research methods. Theoretical studies were carried out on the basis of machine building technology, the theory of metal cutting, the theory of elastic-plastic deformations in a continuous medium, and the scientific foundations of analytical mechanics.

The correctness of theoretical conclusions has been confirmed by experiments in laboratory and industrial conditions.

The experimental data were processed by the methods of mathematical statistics with the evaluation of the results according to the Student's criterion and the Romanovsky criterion.

The numerical analysis of mathematical models was carried out using the Maple 2016 "Applied Software Package" on a computer.

The main provisions for the defense.

1. Algorithmic uniformity of precision models of multi-tool machining and piecewise-matrix models of precision of multi-tool machining satisfying the requirements for transparency of their structure.

2. Proof of the fidelity of the algorithm for searching for the extremum of the distortion function of the performed dimensions based on the basic principles of the mechanism for the formation of scattering fields of dimensions in two-carriage adjustments.

3. Full-factor matrix models of scattering fields of performed dimensions in multi-tool two-support adjustments.

4. Determination by numerical methods of coordinate matrices of rotation of subsystems of a technological system after their experi-

mental determination.

5. Matrix models for controlling cutting conditions with the fulfillment of the requirements for dimensional accuracy in two-carriage multi-tool adjustments.

6. Method for the numerical determination of feed with the fulfillment of the requirements for dimensional accuracy.

7. Design methodology for multi-tool machining on multi-purpose CNC machines.

Scientific novelty of the research.

1. Since the matrix theory of machining accuracy is primarily aimed at using computer technologies, a set of scalar equations in matrix form in n-dimensional hyperspace is proposed to meet the requirements of algorithmic similarity of precision models of multi-carriage machining on modern multi-purpose CNC machines and the transparency of their structures.

2. A piecewise-matrix apparatus that ensures the visibility of the generalized matrix model of the machining error was proposed, as well as a generalized piecewise-matrix model of machining accuracy for multi-carriage multi-tool adjustments.

3. On the basis of the basic principles of the mechanism of the formation of scattering fields of dimensions in two-carriage adjustments, the accuracy of the algorithm for searching for the extremum of the function of distortion of the performed dimensions was proved.

4. Full-factor matrix models have been developed that take into account not only the plane-parallel displacements of the subsystems of the technological system in the scattering fields of the dimensions in the multi-tool two-carriage adjustments of multi-purpose CNC machines, but also the angular displacements around the base points.

5. After the experimental determination of the same coordinate matrices of the rotary centers of the subsystems of the technological system, the possibility of their determination by a numerical method is shown.

6. On the basis of the developed mathematical models, a technique has been developed for the numerical determination of feed during machining on multi-purpose machines.

7. On the basis of modeling the elastic displacements of the sub-

subsystems of the technological system, taking into account the mutual influence of simultaneously operating tools in the multi-tool adjustment of modern multi-purpose CNC machine tools, using the method of numerical determination of feeds, a method for designing multi-tool machining has been developed, an increase in the accuracy and productivity of machining has been achieved.

Theoretical and practical significance of the research

1. The developed full-factor matrix models of scattering fields of the performed sizes for multi-tool two-carriage adjustments used on modern multi-purpose CNC machines, taking into account the complex characteristics of the technological system and the structure of the adjustments, makes it possible to determine by numerical methods the values of the scattering fields for the entire class of two-carriage rotated adjustments, using the principles of systematics of inhomogeneous adjustments, in the directions of the dimensions to be performed for opposed and combined adjustments, precision models in two special directions for homogeneous adjustments.

2. A calculation method is given for establishing the location of the turning center during the determination of the complex characteristics of the technological system.

3. The developed generalized fractional-matrix model of the accuracy of multi-tool machining, full-factor matrix models of distortion and scattering of the performed dimensions during multi-tool two-carriage machining make it possible to calculate the error values of each performed dimension at the design stage for various adjustment options and thereby create conditions for justifying the best option.

4. Models and methodology for modeling the machining accuracy make it possible, within the specified conditions, to predict the machining accuracy. Thus, conditions are created for the emergence of a methodological basis for an automated design system for multi-tool turning. Thus, the developed models can be used during the creation of mathematical support for the design of operations in computer-aided design systems for multi-carriage multi-tool machining performed on multi-purpose CNC machines.

5. On the basis of the developed mathematical models, a techni-

que has been developed for the numerical determination of feed during multi-tool two-carriage machining on multi-purpose machines.

6. A methodology for designing multi-tool multi-carriage machining on modern multi-purpose machines has been developed and proposed for use in factories as a technical guide material. It can be used in the educational process in bachelor's and master's graduation works, master's theses related to this topic, as well as in laboratory and practical classes.

7. The proposed models have independent practical value for solving individual technological design problems. For example, in verification calculations (during the determination of dimensional errors when assigning cutting dimensions and set-up structure).

8. The developed model of multi-tool machining distortion can be used to calculate the adjustment values of the adjustment dimensions in order to compensate for the error in the relative position of the part and the tool, which arises as a result of the influence of cutting forces from all the tools involved in the adjustment during the design of the operation.

Approbation and application. The results of the dissertation work were discussed at scientific conferences, seminars.

- ***International scientific-technical and scientific-practical conferences:***

VII International Scientific and Technical Conference "Information Technologies in Industry", Minsk, 2012; I international correspondence scientific and technical conference "Technological support of machine-building production", Chelyabinsk, 2014; International scientific and technical conference “Modern high technologies: development priorities and staff training”, Kazan, 2014; Engineer's Day, Senftenberg, 2014; 2nd International Scientific and Technical Conference on "Metallurgy and Problems of Materials Science", Baku, 2017; International Scientific and Technical Conference “Measurements and Quality: Problems, Prospects”, Baku, 2018; Engineer's Day, Kotbus, 2018; International Scientific and Technical Conference "The Role of Engineering in the Innovative Development of Azerbaijan: Goals and Prospects", Baku, 2019; I International Scientific and Technical Conference "Universities of Azerbaijan and

Turkey: education, science, technology", Baku, 2019.

- ***Republican scientific and scientific-technical conferences:***

XVIII Republican Scientific Conference of Doctoral Students and Young Researchers, Baku, 2013; Republican scientific and technical conference, students and young researchers on the theme "Youth and scientific and technological progress", dedicated to the 90th anniversary (Baku, 2013), 91th anniversary (Baku, 2014), 92th anniversary (Baku, 2015), 94th anniversary (Baku, 2017), 95th anniversary (Baku, 2018) and 96th anniversary (Baku, 2019).

- Scientific seminars of the Department of Mechanical Engineering Technology of the Azerbaijan Technical University.

On the topic of the dissertation, 26 scientific works have been published, including 10 articles and 16 abstracts of speeches at conferences. 3 articles from 10 and 5 reports from 16 abstracts of speeches at conferences were published without co-authorship, 4 articles were published in scientific periodicals included in the summarized and indexed international systems (bases) recommended by the Higher Attestation Commission, out of 16 published works based on the results of scientific events of the republican and international scale 5 published abroad. 17 works were published within the republic, 9 works abroad.

The results of the dissertation work are reflected in the reports with the State Registration of Scientific Research Works of the Azerbaijan Technical University. The author participated in these reports as a performer.

The guiding technical material "Designing multi-tool two-carriage machining on modern CNC machines" was adopted for use at the ALOV plant. When checking the experimental nature of the guiding technical material for 600 pieces of clamps of various diameters, the obtained conditional economic efficiency was 15132 AZN.

The materials presented in the dissertation work are used in lectures and practical classes, course projects and term papers at the undergraduate level at the Azerbaijan Technical University, as well as when performing graduate work.

The name of the organization in which the dissertation work was carried out. The dissertation work was carried out at the

“Department of Machine Building” at Azerbaijan Technical University.

Personal contribution of the applicant to ongoing research. The applicant shows the relevance of the research, the main goal and tasks set for their achievement, the directions of research are determined, the computer modeling of the theoretically obtained models is independently solved and the processing, systematization and discussion of the results are carried out. In general, the presented dissertation work is a complete scientific research work, covering the entire set of scientific and practical provisions and results, written personally by the applicant and put forward for defense.

The total volume of the thesis in signs indicating the volume of the structural sections of the thesis separately. The structure of the thesis is the title page (391 characters), content (7229 characters), introduction (17514 characters), 5 chapters (Chapter I -48107 characters, Chapter II -43407 characters, Chapter III -32586 characters, Chapter IV -47421 characters, Chapter V -16859 characters), conclusion (4517 characters), a list of used literature, additions and a list of abbreviations and conventional signs (98514 characters). The total volume of the dissertation work consists of 283 pages of text typed on a computer and includes 17 figures, 20 graphs, 31 tables, a bibliography of 166 titles and is 212658 characters, excluding figures, tables, graphs, additions and bibliography.

MAIN CONTENT OF THE WORK

The introduction substantiates the relevance of the topic and characterizes the degree of elaboration, the purpose and objectives of research are clearly expressed, research methods are described, the main provisions to be defended, the novelty of research, the theoretical and practical importance of research, testing and application, the name of the organization in which the dissertation work was carried out is determined. , the total volume of the thesis is indicated in signs indicating the volume of the structural sections of the thesis separately.

In the first chapter, in order to study the use of the potential of multi-purpose machine tools at the factories of the Republic of

Azerbaijan and analyze the technological capabilities of multi-tool machining on modern multi-purpose CNC machines, issues such as modern multi-purpose CNC machines, their advantages, study of the capabilities of modern multi-purpose CNC machines from the point of view of multi-tool processing are considered, examples of the technological capabilities of multi-tool machines in the form of multi-tool adjustments, features of the process of multi-tool multi-carriage machining (parallel multi-tool machining), dimensional-accuracy theory of multi-tool machining, mathematical modeling of technological processes of mechanical processing, full-factor size distortion model.

Based on the analysis of the design, 5 types of modern multi-purpose CNC machines were identified. The analysis of the capabilities of each of the design types of multipurpose machines is carried out and the possibilities of adjustment are considered.

As the results of the first chapter, the relevance of the dissertation work, the goals and objectives of the research given in the introduction are substantiated.

In the second chapter, it is deduced that the basis of the accuracy models of the performed dimensions in multi-tool adjustments are the elastic displacements of the tool tip, which forms the performed size relative to the processed surface of the workpiece in direction of the performed size, and these elastic displacements are a consequence of the final elasticity of the elements of the technological system, which perceives the general effect of cutting forces at the same time setting tools. It is noted that for multi-tool machining, especially for turning, the location of several cutting tools located on one, two and even three carriages of modern multi-tool machines and working simultaneously, in a rather complicated space. Therefore, during multi-tool machining, the system of forces acting on the technological system is a kind of common space. And therefore, it is natural to express the equations of distortion of the performed dimensions in multi-tool adjustments in vector form. Since the full elastic characteristic of the elements of the technological system for all degrees of freedom is reflected by the matrix, it is more advantageous to express the precision processing models in matrix form.

Then, according to the provisions of the matrix theory of machining accuracy, two matrix equations were written for a simple two-slide adjustment (the right facing cutter on the longitudinal carriage and the left facing cutter on the transverse carriage located in the opposite direction to the longitudinal carriage), in accordance with the cutting theory, using the coordinate components (P_x, P_y, P_z) of the cutting forces in the coordinate system of the machine from the matrix equations for all coordinate directions of the tops of the cutters, expressions for the relative elastic displacements are obtained. Due to the sufficient complexity of the obtained scalar equations from the point of view of research, even for simple setup, the need for the initial direction of precision models for use in computer technologies is noted. In this case, in connection with the emergence of the identity of algorithmic models and the requirements for the transparency of their structure in the first place, to ensure algorithmic identity, the set of scalar equations is presented in matrix form in six-dimensional hyper-space, to ensure accuracy, it is proposed to apply machining errors to the generalized matrix equation cell-matrix apparatus. For this, having selected a block of elements in the matrix equation that has an independent technological value, it is transformed into a cell-matrix model. In such a model, the elements of the matrix are themselves a matrix and, accordingly, the elements of vectors are vectors. As a result, the block vector of displacement consists of two components - the displacement vector on the longitudinal carriage and the displa-cement vector on the transverse carriage, that is, it has an extremely transparent structure. The situation is similar with the image of the power load. Thus, the use of cellular matrices significantly simplifies the multi-tool machining error model and makes it unlimitedly face-to-face. But the cellular elasticity matrix consists of two elements - matrices e_{01} and e_{02}. These matrices characterize the total elasticity of a complex consisting of two subsystems. It is more practical to work with the own characteristics of technological subsystems - e_1 and e_2. For this purpose, using the matrix theory, cell-matrix models are reduced to the canonical form. Here, on the example of multi-tool adjustments, the possibility of implementing conventional matrix models of the machining error by converting into the proposed schemes of block-matrix models is considered. For this purpose, in the second chapter of Appendix 5, in general for 6 different adjustments, cellular-matrix models are obtained and brought to the canonical form. Showing the creation of a cell-diagonal block matrix of carriages by the elastic matrices of the carriages, taking into account the transformation of the corresponding matrix to zero with the absolute rigidity of each of the subsystems, the model developed for the 6th setup (two carriages, two cutting tools on both carriages, the cutting tools are not rigid). Here, a decomposition for 7 subsystems is already necessary: a spindle, 2 carriages, 4 cutting tools. For each of these subsystems, an elasticity matrix is given: (e_0, e_{s1}, e_{11}, e_{12}, e_{s2}, e_{21}, e_{22}) is adopted as a generalized cell-matrix model of machining accuracy for multi-support multi-tool adjustment.

$$\begin{pmatrix} g_{11} \\ g_{12} \\ g_{21} \\ g_{22} \end{pmatrix} = e_0 K \cdot \begin{pmatrix} P_{11} \\ P_{12} \\ P_{21} \\ P_{22} \end{pmatrix} + \begin{pmatrix} e_{s1} & e_{s1} & 0 & 0 \\ e_{s1} & e_{s1} & 0 & 0 \\ 0 & 0 & e_{s2} & e_{s2} \\ 0 & 0 & e_{s2} & e_{s2} \end{pmatrix} \cdot \begin{pmatrix} P_{11} \\ P_{12} \\ P_{21} \\ P_{22} \end{pmatrix} + \begin{pmatrix} e_{11} & 0 & 0 & 0 \\ 0 & e_{12} & 0 & 0 \\ 0 & 0 & e_{21} & 0 \\ 0 & 0 & 0 & e_{22} \end{pmatrix} \cdot \begin{pmatrix} P_{11} \\ P_{12} \\ P_{21} \\ P_{22} \end{pmatrix}, \quad (1)$$

here g_{11}, g_{12} is the distortion of the emerging diametric dimension by two tools located on the longitudinal carriage, g_{21}, g_{22} is the distortion of the emerging linear dimension by two tools located on the transverse carriage and, accordingly, the first digit of the indices is the number of the carriage, the 2nd digit shows the tool number; $K = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$ is a square matrix of the corresponding composition, here P_{11}, P_{12}, P_{21} and P_{22} are the vectors of the cutting force of each cutting tool, respectively, the first digit of the index indicates the number of the carriage, the second number of the tool.

To construct full-factor matrix models of scattering fields of the performed dimensions in multi-tool two-carriage adjustments, the force by the nature of mutual influence in multi-tool adjustments is divided into two boundary cases (opposed and combined), it is noted that in the group of CNC lathes, both adjustments are used to the same extent, and having accepted in both cases the main factors affecting the occurrence of scattering fields of the performed dimensions are the change in the allowance ($t_F \in \left[t - \frac{\Delta t}{2}; t + \frac{\Delta t}{2} \right]$), the unevenness of the mechanical properties of workpieces within a batch (($C_F \in C_N \left[1 - \frac{\nu}{2}; 1 + \frac{\nu}{2} \right]$) and the scattering of the rigidity of machine tools ($j_F \in j_N \left[1 - \frac{\varepsilon}{2}; 1 + \frac{\varepsilon}{2} \right]$) from predetermined factors - the elasticity of technological subsystems (elasticity matrix) and coordinate components of the cutting force, a sequence is shown for calculating the scattering field of possible changes properties of the technological system. To determine the scattering fields of the performed dimensions, it is sufficient to find the limiting values (maximum and minimum) of the size distortion from the distortion dependences of the performed dimensions. Then, as a result of the study of all variants of the location of the scattering fields, a single model was formed and a unified model (2) of the scattering field was obtained in a two-carriage opposed adjustment, taking into account not only the plane-parallel displacements of the subsystems of the technological system of the scattering fields of the performed dimensions by the longitudinal carriage in the two-carriage opposed adjustments, but and angular displacements around base points. In a similar way, a scattering field model was obtained for the dimensions performed from a transverse carriage (opposed adjustment). Here, $\overline{\Delta w_1}$ and $\overline{\Delta w_2}$ are the scattering fields of the forming dimensions using the longitudinal and transverse carriages, respectively, taking into account the plane-parallel and angular displacements; auxiliary vectors $\overline{p_t^1}$ and $\overline{p_t^2}$, respectively, characterize the degree of influence of the depths of cut t_1 and t_2 ,auxiliary vectors $\overline{p_{\Delta t}^1}$ and $\overline{p_{\Delta t}^2}$, respectively, characterize the degree of influence changes in allowances of Δt_1 and Δt_2; e_0 and ξ_0 ,respecti-

$$
\Delta w_1 = \begin{cases}
if\ \ e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2} + (-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot t_1\overline{p_t^1}) + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2} \geq \\
\geq \dfrac{e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}}{2} + \dfrac{(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}}{2} \\
(here\ \ \ e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2} + (-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot t_1\overline{p_t^1}) + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2} \succ 0\ ) \\
\\
\omega\cdot\left[e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2}\right] + \left[e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}\right] + \omega\cdot\left[-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot t_1\overline{p_t^1} + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2}\right] + \\
+\left[-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}\right]; \\
\\
if\ \ -\dfrac{e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}}{2} - \dfrac{(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}}{2} \prec e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2} + \\
+(-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot t_1\overline{p_t^1}) + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2} \prec \dfrac{e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}}{2} + \\
+\dfrac{(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}}{2} \\
\\
\left(1+\dfrac{\omega}{2}\right)\cdot\left[e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}\right] + (1+\dfrac{\omega}{2})\cdot\left[(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}\right]; \\
\\
if\ \ e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2} + (-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot t_1\overline{p_t^1}) + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2} \leq \\
\leq -\dfrac{e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}}{2} - \dfrac{(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}}{2} \\
(here\ \ \ e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2} + (-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot t_1\overline{p_t^1}) + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2} \prec 0\ ) \\
\\
-\omega\cdot\left[e_{01}t_1\overline{p_t^1} - e_0 t_2\overline{p_t^2}\right] + \left[e_{01}\Delta t_1\overline{p^1_{\Delta t}} + e_0\Delta t_2\overline{p^2_{\Delta t}}\right] - \omega\cdot\left[-(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})t_1\overline{p_t^1} + a^0_{O_0}\xi_0 a^0_{O_0} t_2\overline{p_t^2}\right] + \\
+\left[(a^1_{O_1}\xi_1 a^1_{O_1} + a^0_{O_0}\xi_0 a^0_{O_0})\cdot\Delta t_1\overline{p^1_{\Delta t}} + a^0_{O_0}\xi_0 a^0_{O_0}\Delta t_2\overline{p^2_{\Delta t}}\right].
\end{cases} \qquad (2)
$$

vely, plane-parallel and angular matrix of the elasticity of the material body 0. e_{01} and e_{02} - total plane-parallel matrices of elasticities of contacting bodies (subsystems 0_1 and 0_2); ξ_0, ξ_1 and ξ_2 - angular matrices of elasticities of contacting material bodies; $\overline{P^1}$ and $\overline{P^2}$ - force vectors applied to bodies 1 and 2, respectively; $a^0_{0_0}$, $a^1_{0_1}$ and $a^2_{0_2}$

-matrices that make up the connecting vectors of the points of application of the forces $\overline{P^1}$ and $\overline{P^2}$ relative to the base points O_0, O_1 and O_2. Angular movements of contacting material bodies are made around these base points; ω - the total value of the dispersion of the properties of the technological system $\omega = \varepsilon + \nu$.

A similar problem was solved for the composite adjustment, and the corresponding matrix models of $\overline{\Delta w_1}$ and $\overline{\Delta w_2}$ for scattering fields were obtained.

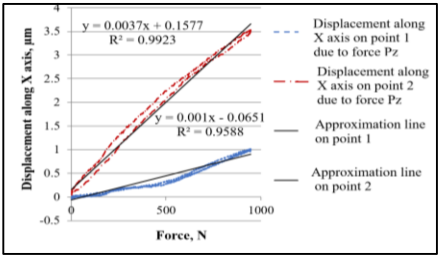
Thus, using the principle of systematics of neo-parental adjustments, it is possible to determine by calculation the values of the scattering field for the entire class of two-carriage adjustments in the direction for homogeneous adjustments, two special models: corresponding models for opposed and composite adjustments and in the direction of the performed dimensions.

In the third chapter, the experimental determination of the coordinate matrices e and the angular matrices of the ξ of the elasticity of subsystems in matrix formulas of accuracy is presented for the practical use of full-factor matrix models of distortion of the performed dimensions during multi-tool two-carriage machining and the developed accuracy models. To do this, first, a sample of the workpiece was made and placed in the machine spindle, thereby creating subsystem 0 - subsystem “part - spindle” and subsystem 1 - subsystem - “tool - turret”. Then, simulating a stepwise increasing variable load force arising on the cutting edge of a cutting tool with a machined surface in the technological system similarly to mechanical processing, displacements determined at two different points in separate subsystems along the corresponding coordinate axes of the machine (subsystem 0 - subsystem "part - spindle" and subsystem 1 - subsystem “tool - turret”) (at points 1 and 2). The removal of the load was carried out in the reverse order with the same values of the steps and, accordingly, the displacements were measured in the same order. Based on the obtained experimental data, a load-displacement diagram (hysteresis curve) was constructed with the indication of the displacement values in the direction of the corresponding coordinate axis, as a result of the load values in the direction of the axis, and in the direction of the loading axis. To determine the average elasticity of the subsystem, the load branch of the graph is straightened, that is, the experimental loading line is approximated by a linear dependence. Within the framework of the experiment, studies of the elasticity of the elements of the technological system of the INDEX V 160 CNC lathe in three directions were carried out. Measurements were carried out on an INDEX V 160 CNC lathe.

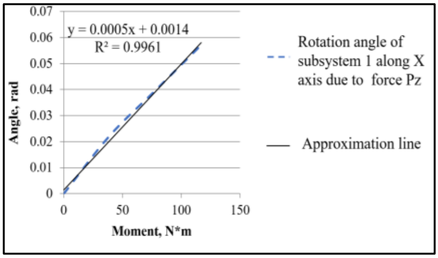
To determine the angular matrix ξ of elasticity under sequential loading, the moment created by the force is calculated, and the angular displacements are determined from the linear displacement of two points in the same plane. Based on the experimental results obtained, a graph was constructed showing the values of the moment arising as a result of the load force in the direction of the X axis, as well as the values of displacement in the direction of the corresponding axis as a result of loading in the direction of the Y axis. To determine the average angular elasticity of the subsystem, the graph is approximated by a linear relationship. The obtained values characterize the elasticity of the technological system in the corresponding coordinate directions and make it possible to determine the angular elasticity matrix. Graph 1 shows fragments of the results of experiments on determining the angular matrix of elasticity ξ characterizing their mutual influence and resistance to rotation around the coordinate axes of subsystems 1 and 0. Here, the regression equations and their fidelity (reality) are simultaneously given.

The third chapter also presents studies on determining the pivot centers of machine tool subsystems, experiments to assess the adequacy of the theoretical full-factorial model of dimensional distortion.

In the fourth chapter, the development of control matrix models of the cutting mode is carried out with the fulfillment of the requirements for dimensional accuracy in two-carriage multi-tool adjustments. It shows the methodology for assessing the adequacy of the theoretical full-factor model of distortion of dimensions, the sensitivity of full-factor models of distortion of the performed dimensions and during multi-tool machining and full-factor models of scattering fields, the possibility of designing and controlling multi-tool



a) displacement of subsystem 1 from P_z along the X axis



b) a graph of the average values of the angle of rotation along the X-axis of subsystem 1 from the P_z

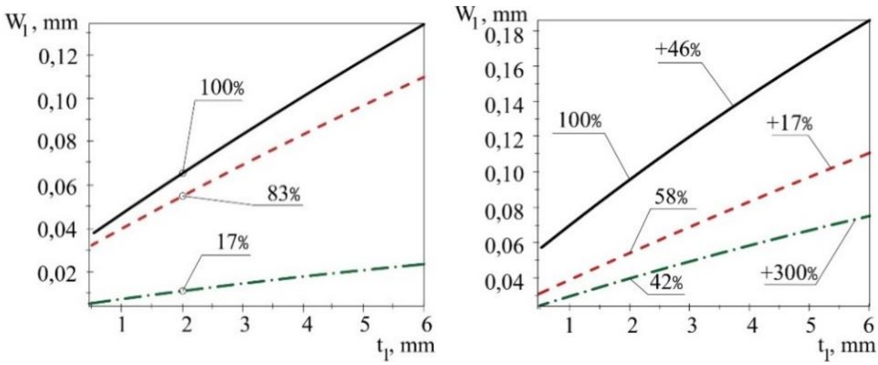
Graph 1. Fragments of the results of experiments carried out to determine the angular matrix of the ξ elasticity of subsystem 1

machining processes, calculation of limit values for the accuracy of cutting conditions.

To check the performance of the models, variants with different initial data that determine the action of the formula were calculated, that is, theoretical studies of machining accuracy were performed for various options. During theoretical studies in the model of distortion of the performed dimensions in a two-carriage setup, the dependences of both plane-parallel displacements and angular displacements of technological subsystems around base points on technological parameters were considered. To do this, first, adopting the basic version, in order to determine the effect on the value of the distortion of the diametrical size in various versions, depending on technological and design factors, plane-parallel displacements are first calculated, then angular displacements around base points and finally total displacements (in joint the case of linear and angular displacements) of the technological system and for various cases, graphs are plotted. The purpose of this approach is to show that the developed full-factor model fully reflects the process. The cutting forces for the accepted case (external turning on a longitudinal carriage, face turning on a transverse carriage) are calculated in the corresponding order. Calculations and graphs were performed using the Application

Package “Maple 2016”.

Graph 3 shows an example of the influence, depending on the technological and design parameters, of plane-parallel displacements



a) base variant b) $X_0 = 149{,}8$ mm

------linear ,-·-·-·- angular ,——— full

Graph 2. Influence of technological and design factors on the value of the distortion of the performed diametrical size in a two-slide adjustment, on plane-parallel displacements and angular displacements around the base points of the technological system at this value.

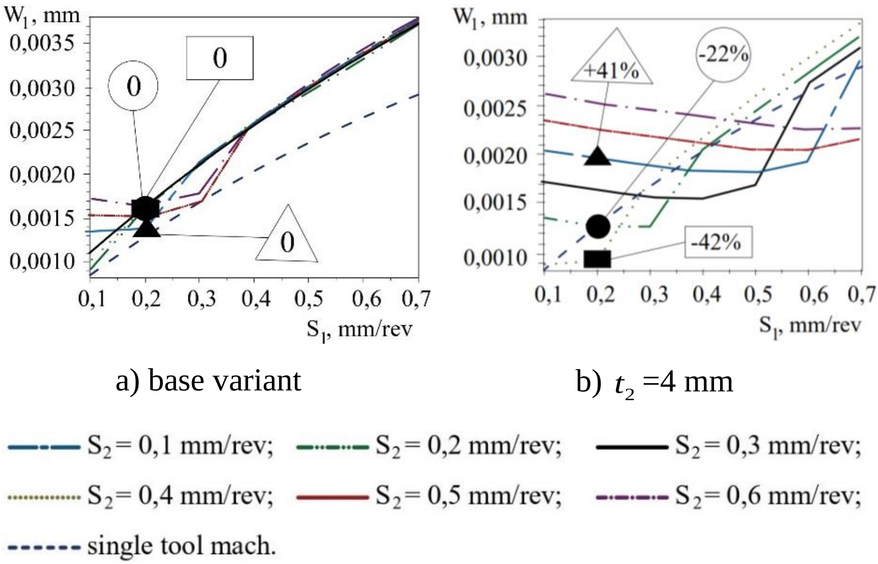
and angular displacements around the base points of the technological system with the value of the distortion of the diametrical dimension being performed in a two-carriage adjustment.

Base variant: steel 45, cutting insert - CNMG 120408 P04 4225 CoroKey: workpiece dimensions D=L=74,9 mm, accuracy grade of the workpiece -12, cutting speed $V_1 = V_2 = 200$ m/min, feed $s_1 = s_2 =$ 0,24 mm/rev, coordinates of the connecting vectors of the points of application of the forces $\overline{P^1}$ and $\overline{P^2}$ relative to the base points O_0 and O_1: $X_0 = 74{,}9$ mm, $Y_1 = 37{,}45$ mm, $X_1 = 136$ mm, $Y_1 = 130$ mm. Changes for another option are shown in Graph 3, along with the values of the distortions of the diametrical dimensions performed on the two-carriage adjustment for the case of 2 mm of the data of the basic version, but also the dependence of the plane-parallel displacements of the technological system and angular displacements around the base points formed by this value on technological and design parameters. The purpose here is to show in what relation plane-parallel displacements of the technological system and angular displacements around the base points are manifested with the values of the distortion of the performed dimensions in specific cases. If in the basic variant the total displacement is 17% of the angular, linear displacement is 83%, then these% change in other variants (graph 2a). So, for example, an increase in two times in relation to the basic version of the length of the workpiece leads to an increase in the values of angular displacements by 42% (linear displacements are, respectively, 58%, that is, in relation to the basic version, linear displacements decrease by 25%), the difference in these values of this variant in relation to the basic variant becomes the reason for their processing non-rigid parts, it is necessary to take into account the influence of angular displacements.

Graph 3 shows the effect of feeds and depths of cut of the longitudinal and transverse carriages on the value of the scattering field of the diameter size of the longitudinal carriage during multi-tool two-carriage machining on the machining error. The three anchor points are separated here as follows: ○ – s_1 = 0,2*mm/rev*, s_2 = 0,2 *mm/rev*; Δ - s_1 = 0,2 *mm/rev*, s_2 = 0,4 *mm/rev*; and □ - s_1 = 0,2 *mm/rev*, s_2 = 0,1 *mm/rev*. In the basic version, it is shown on which branches of the graph these points are located (graph 3a). And the signs of the appropriate form in other option indicate what benefit the change in machining conditions gives.

Multi-tool two-carriage machining can give less error in comparison with single-tool machining (graph 3b).

Studies have shown that by changing the feeds of the longitudinal and transverse carriage during multi-tool two-carriage machining, compared to single-tool machining, it is possible to provide greater accuracy. For example, during feed control and changes in other processing conditions, it is possible to significantly reduce or increase the processing error: for point □ - from 42%

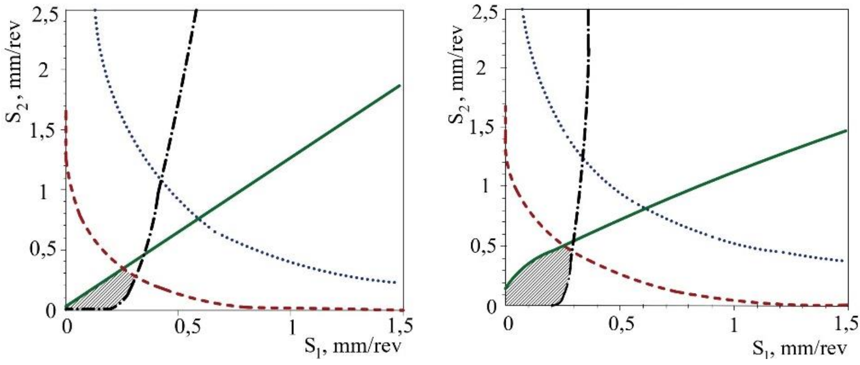


Graph 3. Influence of feed and other technological factors on the value of the scattering field of the performed diametrical dimension by the longitudinal carriage during multi-tool two-carriage machining.

to +250%, for point ○ - from -2014% to +38% , for the point Δ - from 2356% to +1602%.

A certain performance of the developed precision models and a set of factors taken into account make it possible to use them as the basis for a control model of multi-tool two-carriage machining. As a result, on the basis of these models, when designing various types of multi-tool setups, it is possible to solve the direct and inverse problems. Full-factor matrix models of scattering fields of the performed sizes in multi-tool two-carriage adjustments for various setup options make it possible to calculate the error value of each performed dimension at the design stage and thereby create conditions for justifying the best option. To use this model in a real technological process on a real part or workpiece, it is necessary to switch to a parameter whose value can be set or measured.

But in practice, the inverse problem is more relevant: to ensure the highest productivity for a given dimensional accuracy, determine the maximum permissible values of cutting conditions (and other control parameters). For this, during machining, taking into account the effect of feed on the components of the cutting force, taking feed (s) as the main control parameter during multi-tool machining, to develop a control model, the dependence of the feed (control factor) on the required accuracy in the developed precision models and other processing parameters was obtained. Taking into account the unequal feed for all setup tools in multi-tool two-carriage setup (two main control parameters - feed of the longitudinal carriage (s_1) and feed of the transverse carriage (s_2)), the multidimensional region of admissible feeds in terms of the accuracy of the dimensions performed is analytically set in the form of an inequality. This inequality limits the control parameters. So, the corresponding dependencies were obtained for the permissible range of feeds of composite adjustment and opposed adjustment for the dimensions performed by the carriages during two-carriage multi-tool machining, and these inequalities were called control models of technological parameters during two-carriage multi-tool processing. The developed inequalities are considered both as feed constraints for the accuracy of two-carriage multi-tool machining and as a control model of feeds for the criterion of the accuracy of the dimensions performed for two-carriage multi-tool machining. To find the feed with other specified machining parameters, the control models are solved with respect to the feed. For the algorithmic representation of the control model, a computer program was developed using the Application Package “Maple 2016”. This program makes it possible to calculate the permissible limiting values of feeds in terms of accuracy for any batch of other technological factors using a computer. The diagram of the intersection of the regions with two restrictions on the accuracy of the linear dimension performed on the transverse carriage and the diametric dimension performed on the longitudinal carriage is given in graph 4. Base variant: cutting depthes $t_1 = t_2 = 2$, $\omega = 0,2$, other conditions are the same as in graph 2 and changes are shown for other options.



a) base variant

b) $t_1 = 4\,mm, t_2 = 4\,mm, ITP_2 = 13$

Graph 4. Joint application of the area of permissible feeds while simultaneously ensuring the accuracy of the linear dimension with the transverse carriage and the diameter dimension with the longitudinal carriage during multi-tool two-carriage machining

The fifth chapter shows the practical use of the developed models and research results.

CONCLUSION

1. Fractional matrix models of multi-tool machining accuracy providing the requirements of algorithmic identity of multi-tool machining accuracy models and their structural transparency have been developed. Also obtained a generalized fractional-matrix model of machining accuracy for multi-carriage multi-tool adjustments [6, 16, 22, 26].

2. Using the principles of systematics of inhomogeneous adjustments in the direction of the performed dimensions and two special matrix models for inhomogeneous adjustments in the direction of the fidelity of the search for the algorithm for the extremum of the distortion function of the dimensions performed on the basis of the basic principles of the mechanism for the formation of scattering fields

of dimensions in two-carriage adjustments, it is proved by determining the calculated values of the scattering fields for all classes two-carriage adjustments [12, 15].

3. Full-factor matrix models have been developed that take into account both plane-parallel displacements and angular displacements around the base points of the subsystems of the technological system of scattering fields of the performed sizes of multi-tool two-carriage adjustments [5, 7-9, 13, 14, 17, 18, 22, 24, 26].

4. Full-factor matrix models of scattering fields of the performed dimensions in multi-tool two-carriage adjustments make it possible to determine the values of the scattering fields by calculation for the entire class of two-carriage rotated adjustments, using the principles of systematics of inhomogeneous adjustments in the directions of the dimensions performed for opposed and composite adjustments, taking into account the complex structure of the technological system adjustments and precision models in two special directions for homogeneous adjustments [7-9, 13, 14, 18, 22, 24, 26].

5. After the experimental determination of the coordinate matrices of the rotary centers of the subsystems of the technological system, the possibility of their determination by calculation is shown and the calculation method is given [10, 14, 18, 19, 22, 26].

6. The developed generalized cell-matrix model of the accuracy of multi-tool machining, full-factor matrix models of distortion and scattering of the performed sizes during multi-tool two-carriage machining make it possible to calculate the numerical values of the error of each performed dimension at the design stage for various setup options and thereby create conditions for justifying the best option [5-9, 13, 14, 16, 17, 18, 22, 24-26].

7. On the basis of the models, the degree of influence of complex technological factors on the machining accuracy was determined, including the structure of multi-tool adjustment, deformation properties and cutting modes of the subsystems of the technological system [7-9, 13, 14, 18, 24-26].

8. Models and methodology for modeling the machining accuracy make it possible to predict the machining accuracy within the specified conditions. Thus, conditions are created for the emergence

of a methodological base for computer-aided design systems for multi-tool turning [5-9, 13, 14, 16-18, 24-26].

9. On the basis of the developed mathematical models, a technique for the numerical determination of feed during machining on multi-purpose machines has been developed [11, 20, 21, 23, 25].

10. A methodology for designing multi-tool multi-carriage machining on modern multi-purpose machines has been developed.

11. The proposed models have independent practical applicability for solving individual problems in technological design [5-9, 13, 14, 16, 18, 24-26].

12. The developed models can be used to create mathematical support for the design of operations in CAD, created for multi-carriage multi-tool machining performed on multi-purpose machines.

13. The developed model of distortion of multi-tool machining can be used to calculate the correction values of the adjustment dimensions in order to compensate for the error in the relative position of the part and the tools that occur due to the influence of the cutting forces of all tools involved in the adjustment during the design operations. The adjustment dimension can be calculated for a through cutter $S_{dim} = \frac{d_{min}}{2} + w_y$ or for a facing cutter $S_{dim} = L_{min} + w_x$, boring cutter $S_{dim} = \frac{d_{max}}{2} - w_y$. Here, d_{min}, d_{max}, L_{min} - are the limiting values of the forming dimensions [5-9, 13, 14, 16, 18, 24, 26].

14. The guiding technical material “Design of two-carriage multi-tool machining on modern multi-purpose CNC machines” was developed and adopted for use at the “ALOV” plant. During the verification of the experimental nature of the technical guide material for 600 pieces of different diameters of the clamps, the economic benefit obtained was equal to 15132 AZN [23].

15. The materials presented in the dissertation work are used in lectures and practical classes at the bachelor's level of the Azerbaijan Technical University, as well as in the implementation of term projects and term papers, graduation works.

LIST OF PRINTED (PUBLISHED) WORKS ON THE DISSERTATION TOPIC

1. Юсубов, Н.Д., Багирова, Г.М. Многоинструментная обработка на многоцелевых станках // – Баку: Машиноведение, – 2012. №1, – s. 57-62.
2. Юсубов, Н.Д., Багирова, Г.М. Проектирование многоинструментной обработки на современных многоцелевых токарных станках с ЧПУ // Седьмая Международная научно-техническая конференция «Информационные технологии в промышленности», – Минск: ОИПИ НАН Беларуси, – 30 – 31 октября, – 2012, – с. 176-178.
3. Bağırova, H.M. Təkalətli emalda ölçülərin təhrif olunmasının tamfaktorlu modeli // Doktorantların və gənc tədqiqatçıların XVIII Respublika elmi konfransının materialları. I cild, – Bakı: Mütərcim, – 19 – 20 dekabr, – 2013, – s. 230-233.
4. Bağırova, H.M. Çoxalətli sazlamalar baxımından çoxməqsədli dəzgahların texnoloji imkanlarının araşdırılması // Azərbaycan xalqının Ümummilli lideri Heydər Əliyevin anadan olmasının 90 illiyinə həsr edilmiş gənc tədqiqatçıların I beynəlxalq elmi konfransının materialları, – Bakı: – 25 – 26 aprel, – 2013, – s. 370.
5. Yusubov, N.D., Bağırova, H.M. Çoxalətli ikisupportlu sazlamalarda ölçülərin təhrif olunmasının tamfaktorlu modeli // – Bakı: Maşınşünaslıq, – 2013. №3, – s. 43-48.
6. Кошин, А.А., Юсубов, Н.Д., Багирова, Г.М. Клеточно-матричные модели точности многоинструментной обработки // Сборник научных трудов I международной заочной научно-технической конференции «Технологическое обеспечение машиностроительных производств», – Челябинск: Издательский центр ЮУрГУ, – 16 – 17 декабря, – 2013, – с. 543-550.
7. Юсубов, Н.Д., Багирова, Г.М. Полнофакторные матричные модели полей рассеяния выполняемых размеров в многоинструментных двухсуппортных наладках // Современные наукоемкие технологии: приоритеты развития и подготовка кадров: Сборник статей международной научно-практической конференции, – Казань: Изд-во Казан. гос. техн. ун-та, – 22 мая, –2014,

– с. 132-137.

8. Yusubov, N.D., Abbasova, H.M. Full factorıal matrıx models of fıelds of dıspersıon of the carrıed out sızes ın multı-tool of two-carrıage adjustments // 1. Ingenieurtag 2014. Veranstaltung der Fakultät Ingenieurwissenschaften und Informatik der Brandenburgischen Technischen Universität Cottbus – Senftenberg, Campus Senftenberg, – Senftenberg, Deutschland: – 19 November, – 2014, – 4 s.

9. Bağırova, H.M., Yusubov, N.D. Müasir RPİ çoxməqsədli dəzgahlarında çoxalətli emal zamanı yerinə yetirilən ölçülərin dəqiqlik matris riyazi modellərinin işlənməsi // Azərbaycan xalqının ümummilli lideri H.Əliyevin anadan olmasının 91-ci ildönümünə həsr olunmuş "Gənclər və elmi-texniki tərəqqi" mövzusunda tələbə və gənc tədqiqatçıların respublika elmi-texniki konfransının materialları, –Bakı: AzTU, – 2014, – s. 378-380.

10. Abbasova, H.M., Yusubov, N.D. İNDEX V 160 RPİ torna dəzgahında texnoloji sistemin sərtliyinin kompleks xarakteristikasının eksperimental təyini // Azərbaycan xalqının ümummilli lideri Heydər Əliyevin 92-ci ildönümünə həsr olunmuş tələbə və gənc tədqiqatçıların "Gənclər və yeni texnologiyalar" mövzusunda Respublika elmi-texniki konfransının materialları, – Bakı: AzTU, – 2015, – s. 345-357.

11. Yusubov, N.D., Abbasova, H.M. Müasir RPİ çoxməqsədli dəzgahlarda çoxalətli ikisupportlu sazlamalar zamanı emal prosesinin idarə edilməsi // Azərbaycan xalqının ümummilli lideri Heydər Əliyevin 94-cü ildönümünə həsr olunmuş tələbə və gənc tədqiqatçıların "Gənclər və elmi innovasiyalar" mövzusunda Respublika elmi-texniki konfransının materialları, II hissə, – Bakı: AzTU, – 3 – 5 may, – 2017, – s. 24-27.

12. Юсубов, Н.Д., Аббасова, Х.М. Основные принципы механизма формирования поля рассеяния размеров в двухсуппортных наладках // Материалы 2-ой Международной научно-технической конференции «Проблемы металлургии и материаловедение», – Баку: АзТУ, – 28 – 30 ноябрь, –2017, – с. 375-380.

13. Abbasova, H.M., Yusubov, N.D. Ölçülərin təhrif olunması tamfaktorlu modelinin iş qabiliyyətinin yoxlanılması // Azərbaycan xalqının ümummilli lideri Heydər Əliyevin 95-cü ildönümünə həsr

olunmuş tələbə və gənc tədqiqatçıların “Gənclər və elmi innovasiyalar" mövzusunda Respublika elmi-texniki konfransının materialları. II hissə, – Bakı: AzTU, – 3 – 5 may, – 2018, – s. 115-117.

14. Юсубов, Н.Д., Аббасова, Г.М. Повышение производительности многоинструментной обработки на современных многоцелевых станках с ЧПУ // Материалы Международной научно-технической конференции «Измерения и качества: проблемы, перспективы», – Баку: АзТУ, – 21 – 23 ноябрь, – 2018, – с. 152-157.

15. Yusubov, N.D., Abbasova, H.M. İkisupportlu sazlamalarda ölçülərin səpələnmə sahələrinin formalaşması mexanizminin əsas prinsipləri // – Bakı: Maşınşünaslıq, – 2018. Cild 7, №1, –s. 57-61.

16. Yusubov, N.D., Abbasova H.M. Çoxalətli emalın dəqiqliyinin ümumiləşdirilmiş bölümlü-matris modeli // – Bakı: Elmi əsərlər, – 2018. №4, – s. 16-22.

17. Yusubov, N., Maemmaedov, A., Abbasova, H. Ein stochastisches Simulationsmodell der Streufelder der zu erfuellenden Masse fuer Mehrwerkzeuq - Mehrsupport - Einrichtungen bei der Drehbearbetung / Brandenburgische Technische Universitaet Cottbus - Senftenberg, 4. Ingenieurtag 2018 der Fakultaet Maschinenbau Elektro- und Energiesysteme und der Fakultaet Architektur, Bauingenieurwesen und Stadtplanung, NESEFF – Netzwerktreffen 2018. Tagungsband, – Cottbus, Deutschland: – 2019, – s. 115-124.

18. Юсубов, Н.Д., Аббасова, Х.М. Полнофакторные модели точности выполняемых размеров многоинструментной обработки на станках-автоматах токарной группы // – Челябинск: Вестник ЮУрГУ. Серия «Машиностроение», – 2019. Т. 19, №1, – с. 56-67.

19. Abbasova, H.M. RPİ çoxməqsədli dəzgahların texnoloji sisteminin elastikliyinin tam matris xarakteristikasının eksperimental təyini metodikasının işlənməsi // – Bakı: Maşınşünaslıq, – 2019. Cild 8, №1, – s. 45-50.

20. Abbasova, H.M. Ikisupportlu çoxalətli sazlamalarda ölçülərin dəqiqliyi üzrə tələbi yerinə yetirməklə verişin hesabi təyini metodikasının işlənməsi // Azərbaycan xalqının ümummilli lideri Heydər

Əliyevin 96-cı ildönümünə həsr olunmuş tələbə və gənc tədqiqatçıların «Gənclər və elmi innovasiyalar" mövzusunda Respublika elmi-texniki konfransının materialları. II hissə, – Bakı: AzTU, – 2 – 4 may, – 2019, – s. 511-513.

21. Abbasova, H.M. İkisupportlu çoxalətli sazlamalarda ölçülərin dəqiqliyi üzrə tələbi yerinə yetirməklə kəsmə rejimlərinin idarəetmə matris modelinin işlənməsi // "Azərbaycanın innovativ inkişafında mühəndisliyin rolu: hədəflər və perspektivlər" adlı beynəlxalq elmi-praktiki konfransın materialları, – Bakı: BMU, – 29 – 30 noyabr, – 2019, – s. 172-176.

22. Abbasova, H.M. RPİ çoxməqsədli dəzgahlarının texnoloji imkanlarının tam istifadə edilməsi zamanı çoxalətli emalin rolu // – Bakı: Elmi əsərlər, – 2019. №3, – s. 67-74.

23. Abbasova, H.M. Müasir RPİ çoxməqsədli dəzgahlarında ikisupportlu çoxalətli emalın layihələndirilməsi // Azərbaycan və Türkiyə Universitetləri: təhsil, elm, texnologiya" I Beynəlxalq elmi-praktiki konfransın materialları, III hissə, – Bakı: AzTU, – 18 – 20 dekabr, – 2019, – s. 219-224.

24. Аббасова, Г.М. Полнофакторная модель точности в многоинструментной двухсуппортной обработке // – Будапешт, Венгрия: The scientific heritage, – 2019. № 42, P.1 – с. 31-36.

25. Юсубов, Н.Д., Аббасова, Г.М. Управление обработкой при многоинструментной двухсуппортной наладке // – Москва: Вестник машиностроения, –2020. №3, – с. 67-73.

26. Yusubov, N.D., Abbasova, H.M. Models of Machining Accuracy in Multi-Tool Adjustments // - Pekan, Malaysia: International Journal of Automotive and Mechanical Engineering (IJAME), – 2020. 17(3), – p. 8067-8085.

Personal contribution of the applicant to published works.

Works [3, 4, 19, 20, 21, 22, 23, 24] were performed by the author independently.

In papers [1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 25, 26], the statement of research problems, theoretical research, processing of results, issuing recommendations, the formation of scientific provisions are made by the author. The rest of the parts are performed by the authors equally.

The works [3, 5] were written according to the recommendations of the scientific supervisor as a result of joint discussion of the authors in order to master the theoretical part of the problem.

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