SECTION 11.

SYSTEM ANALYSIS, MODELING AND OPTIMIZATION

Yusubov Nizami
Azerbaijan Technical University, Republic of Azerbaijan

Abbasova Heyran
Azerbaijan Technical University, Republic of Azerbaijan

Dadashov Ramil
Azerbaijan Technical University, Republic of Azerbaijan

A FULL-FACTOR ANALYTICAL MODEL OF DIMENSIONAL DISTORTION IN SINGLE-TOOL MACHINING SETUPS CONSIDERING TRANSLATIONAL AND ANGULAR DISPLACEMENTS

Abstract. *This paper presents a full-factor analytical model for dimensional distortion in single-tool machining setups, taking into account both translational and angular displacements of the technological system subsystems. It is shown that in machining operations involving workpieces with significantly anisotropic dimensions, angular displacements induced by cutting forces can substantially affect the overall machining accuracy. Unlike previously proposed models, which are limited in scope and often inconsistent with the general principles of the mechanics of elastically deformable systems, the developed model is based on a rigorous matrix formulation of compliance characteristics. The model incorporates both translational and rotational compliance matrices, as well as coordinate transformation matrices associated with the point of force application. A generalized expression for dimensional distortion is derived as a combination of translational and angular components, reflecting the full set of six degrees of freedom. The resulting full-factor model provides a unified and physically consistent framework for analyzing machining errors in single-tool setups.mThe proposed model can serve as a theoretical basis for improving accuracy prediction, technological process design, and further development of computer-aided manufacturing systems.*

Introduction. In practice, there are frequent cases where workpieces with significantly different overall dimensions in different directions are machined in turning operations. In such cases, rotations of the workpiece can make a substantial contribution to machining errors, especially along the directions of dominant overall dimensions [1-25]. The necessity of accounting for angular displacements of the workpiece under cutting forces was already emphasized in the several works. They proposed even simple analytical relationships for calculating such angular displacements [26-68].

However, all these relationships are of a particular nature and include parameters whose determination in practice is associated with significant difficulties [69-114]. For example, the spindle rotation center is a virtual object that cannot be directly measured. Most importantly, these models are not consistent with the general laws of mechanics of elastically deformable systems. Therefore, they cannot be used to construct a unified theory of machining accuracy that accounts for possible angular displacements of technological system subsystems.

The fixation of a rigid body in space is achieved by imposing constraints on each degree of freedom. Three constraints limit translational motion along the coordinate axes, while three constraints limit rotational motion about these axes. The degree of motion restriction introduced by a constraint is characterized by its stiffness or, inversely, its compliance. In the contact interaction model of a two-body system (Fig. 1), considering only translational (planar) movements, the transformation into a full-factor model is carried out as follows:

For the first body [72-80]:

$$\overline{u_1} = (e_1 - a^{1}_{0_1}\xi_1 a^{1}_{0_1})\overline{P_1} \qquad (1)$$

For the second body [72-80]:

$$\overline{u_2} = (e_2 - a^{2}_{0_2}\xi_2 a^{2}_{0_1})\overline{P_2} \qquad (2)$$

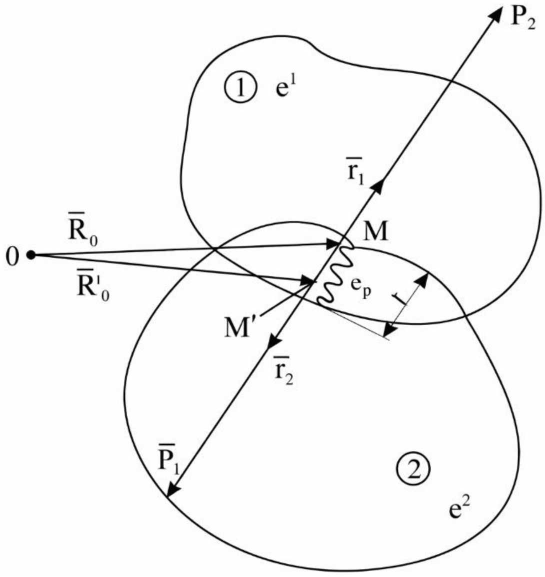

Fig. 1. **Schematic diagram of force interaction in a two-body system. Notation: $\overline{P_1}$ – force exerted by body 1 on body 2; $\overline{P_2}$ – force exerted by body 2 on body 1; $\overline{r_1}$ – elastic displacement of body 1; $\overline{r_2}$ – elastic displacement of body 2; t – parameter defining the level of force interaction; e^1 – compliance characteristic of body 1; e^2 – compliance characteristic of body 2.**

Here, the following notation is used [72–75]:

- e_1 and e_2 matrices of translational compliance of bodies 1 and 2, respectively;
- ξ_1 and ξ_2 matrices of rotational compliance of bodies 1 and 2, respectively;
- $a^1_{O_1}$ and $a^2_{O_2}$ matrices defining coordinate vectors of the force application point for bodies 1 and 2;
- $O_1\left(x^1_0, y^1_0, z^1_0\right)$ and $O_2\left(x^2_0, y^2_0, z^2_0\right)$ base points of bodies 1 and 2 (reference points for angular displacements).

For each contacting body, its coordinate vector is defined as:

$$\overline{R_1} = \overline{O_1A} = \left\{x^1 - x^1_0; y^1 - y^1_0; z^1 - z^1_0\right\} \tag{3}$$

$$\overline{R_2} = \overline{O_2A} = \left\{x^2 - x^2_0; y^2 - y^2_0; z^2 - z^2_0\right\} \tag{4}$$

The vector $\overline{M^1M^2}$ (Fig. 1), representing the displacement of the contact point due to elastic interaction (where M is the initial contact position, M^1 and M^2 and are the positions of the point on bodies 1 and 2 in the deformed state), is determined as the difference of partial displacement vectors of each body:

$$\overline{M^1M^2} = \overline{w} = \overline{u_2} - \overline{u_1} \tag{5}$$

Since the vectors $\overline{u_1}$ and $\overline{u_2}$ represent the total displacements of the force application point on each body, the vector $\overline{w}$ characterizes the displacement of the contact point, i.e., the total dimensional distortion caused by both translational and angular displacements of the deformable bodies. Taking into account expressions (1), (2), and the relationship, equation (5) takes the form:

$$\overline{w} = \left[\left(e_1 - a^1_{O_1}\xi_1 a^1_{O_1}\right) + \left(e_2 - a^2_{O_2}\xi_2 a^2_{O_2}\right)\right]\overline{P} \tag{6}$$

where $\overline{P}$ *is the cutting force.*

For translational displacements, the concept of a unified compliance matrix was previously introduced $e_{12} = e_1 + e_2$ [3, 4]. However, from equation (6), it follows that for the full consideration of all six degrees of freedom, it is not possible to define a single unified compliance matrix, since the effective angular compliance matrices for given points of each body are products of three matrices. Therefore, only the previously introduced unified compliance matrix for translational displacements can be used. With its application, equation (6) is transformed into:

$$\overline{w} = \left[e_{12} - \left(a^1_{O_1}\xi_1 a^1_{O_1} + a^2_{O_2}\xi_2 a^2_{O_2}\right)\right]\overline{P} \tag{7}$$

Analysis of the full-factor dimensional distortion model (7) shows that, in accordance with the structure of the total displacement of a point in a body, a translational component can be distinguished:

$$\overline{u} = e_{12}\overline{P} \tag{8}$$

and a component due to angular displacements of the contacting bodies around their base points:

$$\overline{\delta} = -\left(a^{1}_{O_1}\xi_1 a^{1}_{O_1} + a^{2}_{O_2}\xi_2 a^{2}_{O_2}\right)\overline{P} \tag{9}$$

Clearly, the angular component of dimensional distortion is also defined as the difference in angular displacements of the contact point on each contacting body:

$$\overline{\delta} = \overline{\rho_2} - \overline{\rho_1} \tag{10}$$

Thus, the full-factor model of dimensional distortion in a single-tool setup can be represented structurally as:

$$\overline{w} = \overline{u} + \overline{\delta} \tag{11}$$

Therefore, model (11) forms the basis for modeling dimensional distortion in single-tool setups, taking into account not only translational displacements of technological subsystems but also their angular displacements about base points.

Conclusion. A full-factor model of dimensional distortion in single-tool setups has been developed, accounting for both translational and angular displacements of interacting bodies within the technological system. In contrast to existing approaches, the proposed model is consistent with the fundamental principles of mechanics of elastic systems and does not rely on poorly measurable or virtual parameters.

The analysis has shown that dimensional distortion can be represented as the sum of two components: one caused by translational displacements and the other by angular displacements of the contacting bodies relative to their base points. This decomposition allows for a more accurate description of the physical nature of machining errors.

The developed model forms a unified analytical framework that can be applied to a wide range of machining conditions, particularly in cases where angular effects are significant. It can be used for improving the accuracy of machining process modeling, as well as for the development of advanced methodologies in process planning and computer-aided manufacturing systems.

This work was supported by the Azerbaijan Science Foundation – **Grant № AEF-MGC-2024-2(50)-16/01/1-M-01**

References:

1. Yusubov N., Abbasova H., Dadashov R. (2026) Full factorial model of dimensional distortion in multi-tool dual-carriage setups. *Scientia: Collection of Scientific Papers with the Proceedings of the X International Scientific and Theoretical Conference "Current Issues of Science, Prospects and Challenges"*, Sydney, Australia, pp. 127–136.
2. Yusubov N. et. al. (2022) On the Matrix Generalization of the Theory of Machining Accuracy. *Machine Science*, Vol. 11, No. 2, pp. 23–36.
3. Bogatenkov S. et. al. (2025) Productivity of Technological Operations and Artificial Intelligence: Surface Treatment Plans. *Reliability: Theory & Applications*, Vol. 20, SI 10 (88), pp. 348–355.
4. Orucov F.S., Ismayılov N.Ş., Məmmədov E.D. et al. (2020) Specifics of Obtaining Powdered Die Steel Alloys for Cold Forming and Higher Mouldability. *IOP Conference Series: Materials Science and Engineering*, Vol. 988, 012115.
5. Yusubov N. et. al. (2025) The Influence of Cutting Conditions and Tool Wear on Machining Efficiency in CNC Machine Tools. Machine Science, No. 1, pp. 4–19.
6. Khabarova D. et. al. (2025) Fluid Flow Modeling in the Spool and Sleeve of an Electro-Hydraulic Power Amplifier. *Reliability: Theory & Applications*, Vol. 20, SI 7 (83), pp. 281–287.
7. Amirov, F. G., & Shiraliyev, I. T. (2025). External Wear of a Flush Pipe in a Drilling Rig. *Russian Engineering Research*, 45(5), 629-634.
8. Fraňa, K., Neubert, C., Simon, S., Mammadov, A., & Amirov, F. (2020, December). A Flow Study in the Cyclone with Particle Separations. *In International Conference on Computational & Experimental Engineering and Sciences* (pp. 52-59). Cham: Springer International Publishing.
9. Amirov, F. G. (2020). Some Features of Increasing the Productivity of Automatic Lines. *Proceedings of Higher Educational Institutions, Mechanical Engineering*, (9), 18-23.
10. Amirov, F. G. (2020). Combination of tool blocks in the position of mechanical processing of alloys with directed crystallization of eutectic structures on multi-threaded automatic lines. *Vestnik Mashinostroeniya*, (10), 79-81.
11. Abbasov, V., Amirov, F., & Karimov, A. (2025). Wear properties of camshaft cams and improvement of their wear resistance. *Reliability: Theory & Applications*, 20(SI 7 (83)), 297-303.
12. Amirov, F. G., Simon, S., Steffen, W., Amirli, S. F., & Frana, K. (2021). Determining the accuracy of water pressure processing using 3D scanning. *Herald of Azerbaijan Engineering Academy*, 13(3), 38-44.
13. Amirov, F. G. (2020). Unification of instrumental units in the position of mechanical processing of alloys with directional crystallization of eutecnic structures on multi-stream automatic lines. Vestnik mashinostroeneniya, (10), 79-81.
14. Amirov F.G. (2013). Distinctive features of machining operation at positions. Vestnik mashinostroyeniya, (1), 49-51.
15. Amirov F.G. The Classification of Components for Adjustable or Configurable Automatic Production Lines Using CNC Machine Tools. *Energy Efficiency in Construction and Mechanical Engineering*, 7-11.
16. Amirov F., Shiraliyev, I. (2024, May). Top drive wash pipe surface wearing. *In International Symposium on Unmanned Systems and The Defense Industry* (pp. 264-269). Cham: Springer Nature Switzerland.
17. Abbasov, V., Amirov, F., Amirli, S., Hasanli, S., & Frana, K. (2024). Formation of shaft accuracy during mechanical processing on CNC machines. *Advances in Science and Technology*, 148, 81-86.
18. Amirov, F. (2013). Developing Criterion and optimization of PAL system. Applied mechanics and materials, 379, 244-249.
19. Bashirov, R. J., & Amirov, F. G. (2022). Method for determining the thermal state of the cylinder sleeve during centrifugal induction sintering. *Izvestiya vysshikh uchebnykh zavedeniy. Mashinostroenie*, 33-41.
20. Amirov F. G., Mammadhuseynov A.R., Muradov F. R., Amirli S. F. (2025). Some features of production on automatic lines. *International Organization*.
21. Amirov F. G., Abbasov V. A., Kerimov A. F., Rzayeva V.H. (2025). Design Features of New Camshaft. *Russian Engineering Research*, 45(9), 1244-1247.
22. Yusubov N., Abbasova H. (2024) Practical Applicability of Matrix Models for Accuracy in Multi-Tool Machining on Automatic Lathes. *Machine Science*, Vol. 13, No. 2, pp. 35–41.
23. Gafarov A.M., Khankishiyev I.A., Sadigov V.B. (2019) Analysis of causes of failures of high-precision parts of ship machinery and mechanisms. *Proceedings of Azerbaijan State Marine Academy*, No. 1, pp. 12–16.
24. Sharifov Z.Z., Khankishiyev I.A. (2016) Corrosion behaviour of welded joints of RSD32 and RSD32SH steels in Caspian seawater. *Water Transport: Collection of Scientific Papers*, No. 2(25), pp. 37–44.
25. Abbasov V., Amirov, F., Karimov, A. (2024, May). Features of the New Design of the Camshaft of Internal Combustion Engines. *In International Symposium on Unmanned Systems and The Defense Industry* (pp. 282 288).

Cham: Springer Nature Switzerland.

26. Amirli S. F., Fritsche P., Abbasov I. T., Wichmann S., Simon S., Amirov F. G., Mammadov A. S. (2022). The impact of high speed mechanical processing efficiency on the production process. *Herald of Azerbaijan Engineering Academy*, 14(1), pp.41-51.
27. Amirov F., Shiraliyev I. (2025, October). Top Drive Wash Pipe Surface Wearing. *In Research and Updates on the Use of Artificial Intelligence in Drone Technology: Proceedings of the 2024 International Symposium on Unmanned Systems: AI, Design and Efficiency* (p. 264). Springer Nature.
28. Gafarzade H.V., Gafarov A.M., Khankishiyev I.A. (2023) The Analysis of Information Processing Methods to Assess Reliability of Machines and Equipment. *Hearld of Azerbaijan Engineering Academy*, No. 2, pp. 29–41.
29. Yusubov N.D., Abbasova H.M. et al. (2021) Development of a planning theory for multi-tool machining with the possibilities of modern CNC machine tools. *Forschung im Ingenieurwesen*, Vol. 85, pp. 661–678.
30. Gafarov A., Khankishiyev I., Haziyev A., Abbasova I. (2025) Study of dynamic characteristics of the rotary honing process in the processing of non-rigid thin-walled parts. *Reliability: Theory and Applications*, Vol. 20, pp. 350–357.
31. Savin I.A., et al. (2025) Innovative robotic solutions for stamping equipment repair using advanced laser cleaning and hardening techniques. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, No. 1, pp. 253–261.
32. Gafarov A.M., Khankishiyev I.A., Pashazada S.G. (2023) Honing the External Surface of High-Precision Thin-Walled Cylinders for Marine Mechanisms: Kinematic Aspects. *Russian Engineering Research*, Vol. 43, No. 8, pp. 948–951.
33. Savin I.A. et al. (2025) Innovative solid-state laser method for environmentally safe reconditioning of cemented carbide tools. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, No. 4, pp. 315–323.
34. Mammadov A.T., Ismayilov N.S., Huseynov M.C. et al. (2023) Features of obtaining special oil and gas drilling pipes. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, No. 3, pp. 270–275.
35. Haziyev, A. R., Hasanov, V. H., & Bayramova, F. I. (2025). Effect of desalination in vacuum on heat transfer parameters. *Scientific Works of the Azerbaijan State Maritime Academy*, 1, 204–208.
36. Mamedov A.T., Abbasov E.O. et al. (2021) Analytical solution of diffusion equations in multicomponent systems during application of diffusion coatings. *Mechanical Engineering Bulletin*, No. 8, pp. 3–9.
37. Yusubov N.D., Khankishiyev I.A., Abbasova H.M. (2023) Matrix models of machining errors in multi-tool multi-carriage adjustments. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, No. 3, pp. 309–315.
38. Savin I.A. et al. (2024) Application method of laser ablation of worn surfaces for spot restoration of stamps. *ICTPE-2024 Conference*, pp. 234–240.
39. Yusubov N., Abbasova H., Dadashov R. (2026) Full factorial model of dimensional distortion in multi-pass turning. *Scientia: Collection of Scientific Papers with the Proceedings of the X International Scientific and Theoretical Conference "Current Issues of Science, Prospects and Challenges"*, Sydney, Australia, pp. 120–126.
40. Yusubov N.D., Abbasova H.M. et al. (2021) Entwicklung einer Projektierungstheorie für die Mehrwerkzeugbearbeitung mit den Möglichkeiten der modernen CNC-Werkzeugmaschinen. *Forschung im Ingenieurwesen*, 85, pp. 661–678.
41. Yusubov N., Abbasova, H. (2024) Models of Cutting Forces in The Matrix Theory of Multitool Machining Accuracy. *Key Engineering Materials*, 979, pp. 27–38. DOI: 10.4028/p-bW48Sb
42. Bogatenkov S.A. et. al. (2022) Decision-Making in the Conditions of Introduction of Automated Design Systems of Technological Processes. *Socar Proceedings*, Special Issue 1, pp. 006–010.
43. Bogatenkov S. et. al. (2021) Increasing the Productivity of Multi-Tool Machining on Automatic Lathes by Optimizing the Method of Tool Replacement. *"Machine-building and Energy: New Concepts and Technologies" International Scientific-Practical Conference*, AzTU, Baku, Azerbaijan, pp. 59–61.
44. Yusubov N., Abbasova H., Dadashov R. (2023) Theoretical basis for the development of an algorithmic unified complex of mathematical models of cutting forces. *Machine science*, N1, pp. 55-60.
45. Yusubov N., Abbasova H. (2023) Model of Machining Process Control on Multi-Tool Single-Carriage Adjustments. *Machine Science*, Vol. 1, No. 1, pp. 22–27.
46. Movlazade V.Z., Abbasova H.M. (2021) Experimental Determination of Full Matrix Characteristics of Elasticity of Technological System on CNC Machines. *"Machine-building and Energy: New Concepts and Technologies" International Scientific-Practical Conference*, December 2–3, 2021, Azerbaijan Technical University, Baku, Azerbaijan, pp. 71–73.
47. Savin I.A. et al. (2025) Preparation for reconditioning of cemented carbide axial tools by removing wear-resistant coating using a solid-state laser. *ICTPE-2025 Conference*, pp. 109–116.
48. Savin I.A. et al. (2025) Comprehensive study of thermal, optical and material factors influencing fiber laser cutting efficiency. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, No. 4, pp. 351–359.
49. Savin I.A., Avvakumov I.I., Movlazade V.Z. et al. (2024) Standardized work and microelement rationing as a

method of increasing operational efficiency. *ICTPE-2024 Conference*, pp. 241–248.

50. Savin I.A., Shaparev A. et al. (2024) Punches and Matrices Recovery for Hot Punching by Electric Arc Hardfacing. *Advances in Science and Technology*, Vol. 148, pp. 65–71.
51. Gafarov A.M., Gafarzade H.V. et al. (2025) Analysis of the Features of Application of Multi-Factor Planning Methods in Carrying out Experimental Studies. *Herald of Azerbaijan Engineering Academy*, No. 1, pp. 25–36.
52. Savin I.A., Avvakumov I.I., Movlazade V.Z. et al. (2025) Optimizing production processes in machine-building enterprises: a case study on microelement rationing and operational excellence. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, No. 1, pp. 262–269.
53. Savin I., Khankishiyev I., Mirzayev A. et al. (2025) Processing of High Speed Steels by Pulsed Laser Radiation. *Reliability: Theory and Applications*, Vol. 20, Special Issue 7(83), pp. 304–309.
54. Yusubov N. D. (2008) Algorithmization of analytical model of dimensions stray field, executed in multi-tool multi-carriage adjustments. *Vestnik Mashinostroyeniya*, no. 2, pp. 54–56.
55. Simon S. et.al. (2024) Waterjet cutting of HARDOX-500 workpiece. *Russian Engineering Research*, vol. 44, no. 11, pp. 1572–1576.
56. Simon S. et. al. (2024) Formation of geometric parameters of the surfaces of cylindrical parts during waterjet cutting. *Advances in Science and Technology*, vol. 148, pp. 59–64.
57. Yusubov N. D. (2009) Practical applicability of matrix model of precision processing. *Mashinostroite*l, no. 2, pp. 37–40.
58. Bogatenkov S.A., Yusubov N.D. (2019) Planning of Personal Trajectors of Development: Systems of Automated Design. *Bulletin of the South Ural State University. Ser. Computer Technologies, Automatic Control, Radio Electronics*, vol. 19, no. 1, pp.139–145.
59. Yusubov N. D. (2013) Matrix models of processing accuracy in multitool turning. *Mechanical Engineering Technology*, no. 1, pp. 57–63.
60. Yusubov N. D., Abbasova H. M. (2019) Full factorial models of dimensional accuracy of multi-tool machining on automatic turning machines. *Bulletin of the South Ural State University. Series Mechanical Engineering Industry*, vol. 19, no. 1, pp. 56–67.
61. Yusubov N., Abbasova H. (2020) Control of Processing at Multi-Tool Two-Support Setup. *Vestnik Mashinostroyeniya*, Vol. 3, pp. 67–73.
62. Koshin A.A. Obrabotka na tokarnykh stankakh: naladka, rezhimy rezaniya. *Spravochnik [Processing on lathes: adjustment, cutting conditions. Handbook]*. Chelyabinsk, Siti-Print, 2012. 744 p.
63. Abbasov I.T. et. al. (2022) Study on Reducing Energy Consumption in Rough Turning Operations. *Socar Proceedings*, Special Issue 1, pp. 23–28.
64. Ardashev D. et.al. (2021) Research on chrome plating quality of the internal surfaces in the hydraulic drives with hydrostatic guideways. *Materials Science Forum*, 1037 MSF, pp. 417–422. DOI: 10.4028/www.scientific.net/MSF.1037.417
65. Ardashev D. et.al. (2020) Development of environmental protection system for installation of chrome plating of the internal surfaces of hydraulic drives with hydrostatic guideways. *E3s Web of Conferences*, 193, pp.02015. DOI: 10.1051/e3sconf/202019302015
66. Yusubov N., Abbasova H. (2021) Full-factor matrix model of accuracy of dimensions performed on multi-purpose CNC machines. *Obrabotka Metallov*, 23(4), pp. 6–20. DOI: 10.17212/1994-6309-2021-23.4-6-20
67. Simon S. et.al. (2025) Surface Roughness of Chromonickel Steel after Water Jet Machining: A Full Factorial Experiment. *Russian Engineering Research*, 45(3), pp. 341–345.
68. Yusubov N.D. (2008) Matrix full-factor model of dimensional distortions in multi-tool setups. *Mechanical Engineering Technology*, No 1, pp. 36-39.
69. Yusubov N.D. (2009) Matrix models of the accuracy in multitool two-support setup. *Russian Engineering Research*, 29(3), pp. 268–271. DOI: 10.3103/S1068798X09030125
70. Bogatenkov S.A. et.al. (2021) Increasing the Productivity of Multitool Machining on Automated Lathes by Optimizing the Tool Positions. *Russian Engineering Research*, 41(11), pp. 1075–1079. DOI: 10.3103/S1068798X21110058
71. Yusubov N.D., Abbasova H.M. (2017) The fundamental principles of the mechanism for forming the scatter field of dimensions in dual-support setups. *Proceedings of the 2nd International Scientific and Technical Conference "Problems of Metallurgy and Materials Science"*, pp. 375-380.
72. Yusubov N.D., Abbasova H.M. (2018) The basic principles of the mechanism for the formation of scattering areas in the two-carriage adjustments. *Machine science*, vol. 7, No1, pp. 57-61.
73. Yusubov N.D., Abbasova H.M. (2018) Generalized Segmented-Matrix Model of Multi-Tool Machining Accuracy. *Scientific works*, No 4, pp. 16-22.
74. Dadashov R.Y., Yusubov N.D., Abbasova H.M. (2023) Modeli sil rezaniya pri mekhanicheskoy obrabotke na sovremennykh stankakh tokarnoy gruppy (Models of Cutting Forces During Mechanical Machining on Modern Machines of Turning Group). *Proceedings of the All-Russian Forum of Young Researchers – 2023*, pp. 236–246.
75. Bogatenkov S.A. et.al. (2021) Increasing the Productivity of Multitool Machining on Automated Lathes by Optimizing the Machining Plan. *Russian Engineering Research*, 41(11), pp. 1071–1074.

76. Yusubov N.D. (2009) Matrix models of working accuracy at single-cutter turning. *Tekhnologiya Mashinostroeniya*, no. 1, pp. 41-45.
77. Balabanov I. et. al. (2025) Development of a Parametric Model for Calculating Cutting Forces in External Cylindrical Turning of 20CRMN Steel (1.7147) Using an SNMG 15 06 16-pr 4425 Insert. *Reliability: Theory and Applications*, Vol. 20, Issue 7, pp. 335-342.
78. Khankishiyev I., Majnunov E., Haziyev A. (2026) Improving the manufacturing technology of bimetallic bearings to enhance operational performance in marine engines. *Scientia: Collection of Scientific Papers with the Proceedings of the VI International Scientific and Theoretical ConferenceScientific Review of theActual Events, Achievementsand Problems"*, Berlin; Federal Republic of Germany, pp. 95-102.
79. Yusubov N., Abbasova H., Dadashov R. (2025) Matrix Model of Accuracy in Machining Conical Surfaces on CNC Lathes. *Reliability Theory and Applications*, Vol. 20, Iss. 7, pp. 393-400.
80. Yusubov N.D., Movlazade V.Z., Abbasova H.M. (2022) Accuracy Models of Machining in Multi-Tool Adjustments. *Proceedings of the 8th International Conference on Control and Optimization with Industrial Applications (COIA 2022)*, Vol. 2, pp. 477–479.
81. Simon S., Yusubov N. D., Amirli S. F. (2025) Investigation of surface roughness in hydroabrasive machining depending on changes in abrasive grain size and pressure. *Reliability: Theory & Applications*, vol. 20, no. SI 7 (83), pp. 239–245.
82. Bogatenkov S.A. et.al. (2024) Digital twins for computer aided design on lathe operations. *Engineering Headway*, Vol. 7, pp.87-93.
83. Aziz, S. Sh. (2020) Theoretical studies of the dynamic characteristics of the internal lapping process. *Vestnik of Nosov Magnitogorsk State Technical University*, № 2 (Vol.18), pp. 30–37.
84. Aziz S. Sh., Jafarli G., Sivanesan S. (2025) Increasing processing efficiency in finefinishing technology of internal cylindrical surfaces by technological methods. *Reliability: Theory & Applications*, Vol. 20 Iss. SI 10 (88), pp. 307–314.
85. Aziz S. Sh. The general regularity of surface layer work hardening in the honing operation of medium carbon steels. *Reliability: Theory & Applications*, 20 (SI 7 (83)), pp.372–378
86. Aziz S. Sh. (2024) Improving surface quality in flat grinding operations using modern technological methods. *Machine science*, Vol. 13, Iss. 2, pp. 59–64.
87. Aziz S. Sh. (2021) Technology procure of multple launch rocket system directions reliability. *The XVII İnternational Scientific Symposium - "Karabakh Way to Victory"*, pp. 300-306.
88. Korobatov D., Baturin A., Ardashev D. V., Abbasova H. M. (2024) Requirements definition, modeling, and simulation of control units of an electrohydraulic power amplifier. *Advances in Science and Technology*, vol. 148, pp. 179–186.
89. Yusubov N. D., Ardashev D. V., Abbasova H. M. (2024) Integrated characterization of technological system compliance. *Machine science*, no. 1, pp. 4–10.
90. Dubrovin V., Kulakov B., Karpinsky A., Ardashev D., Degtyareva-Kashutina A., Dadashov R. (2025) Modeling and simulation of ductile-iron blank casting processes for an electrohydraulic power amplifier body. *Reliability: Theory & Applications*, vol. 20, no. SI 7 (83), pp. 274–280.
91. Savin I.A. et. al. (2026) Enhancing the efficiency of the die casting process in metal molds. *Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) = Metal Working and Material Science*, vol. 28, no. 1, pp. 101–113. DOI: 10.17212/1994-6309-2026-28.1-101-113
92. Yusubov N., Abbasova H., Dadashov R. (2026) Multi-tool dual-carriage single-coordinate setups. *Scientia: Collection of Scientific papers with the proceedings of the XI International Scientific and Theoretical Conference "Scientific Forum: Theory and Practice of Research"*, San Francisco, USA, pp. 220–228.
93. Yusubov N., Abbasova H., Dadashov R. (2026) Multi-tool double-carriage two-coordinate setups. *Scientia: Collection of Scientific papers with the proceedings of the XI International Scientific and Theoretical Conference "Scientific Forum: Theory and Practice of Research",* San Francisco, USA, pp. 211–219.
94. Yusubov N., Abbasova H., Dadashov R. (2026) Analysis of multi-tool multi-carriage single-coordinate machining configurations. *Collection of Scientific papers with the proceedings of the XI International Scientific and Theoretical Conference "Scientific Forum: Theory and Practice of Research"*, San Francisco, USA, pp. 202–210.
95. Hasanov Y.N. et. al. (2025) Application aspects of international quantum standarts in electrical measurements. *Proceedings of Azerbaijan State Marine Academy*, No 2, pp.198-203.
96. Hasanov Y.N., Shirvan A.S., Agayev A.R. (2026) Analysis of the technological characteristics of the honing operation of 32CrMoV12-10 steels used under severe friction conditions. *Scientia: Collection of Scientific Papers with the Proceedings of the X International Scientific and Theoretical Conference "Current Issues of Science, Prospects and Challenges"*, Sydney, Australia, pp. 88-97.
97. Movla-Zade V., Mamedov A., Aliyev R., & Tirfie S. (2006) Improving tool-grinding conditions by variation in process kinematics. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, Vol. 220, No. 6, pp. 847–855.
98. Yusubov N., Abbasova H., Dadashov R. (2025) Modeling of machining accuracy of conical surfaces on CNC machine tools. *Proceedings*, vol. 2, pp. 59-67.

99. Zhukov A. et al. (2025) Scientific and methodological support for designing grinding operations using an acoustic indicator. *Machine Science*, Vol.2, pp.38–49.
100. Simon S. et al. (2025) Hardness of Surface Layers Obtained after Waterjet Cutting of Chromium–Nickel Steel Workpieces. *Russian Engineering Research,* 45, 1714–1718. DOI: 10.3103/S1068798X25703198
101. Simon S. et al. (2025) Hardness of surface layers of blanks made of chromium-nickel alloys at hydroabrasive machining. *Vestnik Mashinostroyeniya,* Vol.104, No 10, 873–877. DOI: 10.36652/0042-4633-2025-104-10-873-877
102. Simon S. et al. (2024) Research of the Dependence of Microhardness on Cutting Modes during Waterjet Treatment of Hardox-500 Chrome-Nickel Steel. *Herald of Azerbaijan Engineering Academy*, Vol.16, No 4, 27–33.
103. Simon S. et al. (2024) Planning of Full Factorial Experiments for the Investigation of Roughness in Hydroabrasive Waterjet Cutting of Hardox-500 Steel. *Pakistan Journal of Life & Social Sciences*, Vol.22, No 2, 21590. DOI: 10.57239/PJLSS-2024-22.2.001526
104. Yusubov N., Abbasova H., Dadashov R. (2026) Predicting and controlling machining accuracy in multi-tool setups using matrix theory. *Scientia: Collection of Scientific Papers with the Proceedings of the VII International Scientific and Theoretical Conference "Modern Tools and Methodsof Scientific Investigations"*, Antwerp; Kingdom of Belgium, pp. 189–197.
105. Aziz, S. Sh. (2020) Kinematic features of the lapping process and determination of its basic parameters. *Computational Nanotechnology*, № 3 (Vol.7), pp. 11–16.
106. Aziz S., Agayev A. (2025) Modern technological methods of formation and reduction of residual stresses in aluminum alloys. *Machine science*, No 1, pp. 74–79.
107. Aziz S.Sh. (2020) Accuracy and regularity of its formation at processing with lapping surface of machine details. *Machines, units and processes. Design, creation and modernization*, No 3, pp.30-35.
108. Pashkov M., Avvakumov I., Abbasova H., Shabiyev E., Abbasova I. (2024) Analysis of Errors Occurring during Tooth Milling Operations and Technological System Factors Affecting the Accuracy of Tooth Processing. *Machine Science*, No 1, 36–45.
109. Guzeev V. et al. (2024) Optimization of the Number of Machining Stages Workpieces for Mechanical Engineering Parts. *Machine Science*, No 2, 4–12. DOI: 10.61413/VZRV4922
110. Yusubov N. (2009) Matrix Models of Accuracy in Multi-Tool Double-Toolplate Tunings. *Vestnik Mashinostroeniya*, No 3, 52–54.
111. Aziz S. Sh. (2023) Characteristics of quality formation in processing of 32CrMoV12-10 steel by honing. *2nd International Scientific-Practical Conference "Machine Building and Energy: New Concepts and Technologies"*, December 4-5, AzTU, Baku, Azerbaijan
112. Amirov F.G., Muradov F.R., Mammadhuseynov A.R., Amirli S. F. (2025) Technological and structural features of automatic lines for modern manufacturing systems. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, Vol. 17, No. 4 (Issue 65), pp. 389–396.
113. Khankishiyev I., Mammadov E., Aliyev A., Babayev L. (2026) Factors affecting surface quality andwear resistance in high-precision parts ofship machinery and mechanisms. *Scientia: Collection of Scientific Papers with the Proceedings of the VII International Scientific and Theoretical Conference "Modern Tools and Methodsof Scientific Investigations"*, Antwerp; Kingdom of Belgium, pp. 180–188.
114. Yusubov N.D., Abbasova H.M. (2024) Systematics of multi-tool setup on lathe group machines. Obrabotka metallov (tekhnologiya,oborudovanie, instrumenty) = Metal Working and Material Science, vol. 26, no. 4, pp. 92–111. DOI: 10.17212/1994-6309-2024-26.4-92-111.