Yusubov Nizami
Azerbaijan Technical University, Republic of Azerbaijan

Abbasova Heyran
Azerbaijan Technical University, Republic of Azerbaijan

Dadashov Ramil
Azerbaijan Technical University, Republic of Azerbaijan

ADEQUACY OF MACHINING ACCURACY MODELS IN MULTI-TOOL TWO-CARRIAGE SETUPS

Abstract. *The paper demonstrates the adequacy of the developed machining accuracy models in multi-tool two-carriage setups in relation to real machining processes. It is also shown that the developed models enable the prediction of machining accuracy under given conditions (setup structure, properties of the technological system, machining conditions), thereby forming a methodological basis for CAD systems of multi-tool two-carriage lathe machining.*

Introduction. Based on the analysis of multi-tool setups and their implementation methods [1-27], a set of mathematical models of dimensional errors has been developed [28–38]. This set of models covers practically the entire range of setups and methods for implementing multi-tool machining, both on conventional automatic and semi-automatic lathes with cam-controlled systems and on modern CNC multi-purpose lathes of the turning group.

Each model has its own domain of effective application. For instance, for models describing dimensional distortion, which are relatively simple in terms of error formation mechanisms, a set of standard analytical models has been developed for the main classes of multi-tool setups, oriented toward different groups of lathe automation equipment [39–88].

Mathematical models of dimensional distortion and dispersion fields in various types of setups take into account all major sources of machining errors: allowance (depth of cut, t) and its variations, Δt; stiffness of the technological system, e_0, e_i, e_{0i}, $i=1 \ldots n$ and its dispersion, Δe_0, Δe_i, Δe_{0i}, $i\text{-}1 \ldots n$; strength properties of the workpiece material (through relevant parameters C_x, C_y, C_z) and their instability v; cutting conditions such as feed (S) and cutting speed (V); cutting tools, material group, and type of machining (C_x, C_y, C_z, x_x, x_y, x_z).

Such a wide range of considered factors makes the developed models a powerful tool for analyzing and predicting machining accuracy.

The developed set of mathematical models of dimensional errors in multi-tool setups forms the basis of the theory of multi-tool machining accuracy [89–122]. Due to the significantly different levels of complexity of the developed models, the following scheme of their application is recommended:

– simpler standard models oriented to specific classes of multi-tool setups for particular machine groups are used in developing cutting regime standards;

– more complex generalized analytical models and especially the simulation stochastic model are used as a basis in CAD systems for corresponding operations with multi-tool setups of a general type.

However, before using these models, their validity must first be confirmed.

Main Content. Among the listed factors, the most significant are the depth of cut, its variation, and the instability of the technological system properties, since these are the primary sources of dispersion. Other factors influence the models through the dependence of cutting forces on machining regimes. Therefore, the first stage in assessing model adequacy should be verifying the correct accounting of these key factors[19–26].

The adequacy of the models was evaluated using simulation experiments conducted at two levels.

The first level involved laboratory model experiments. On universal equipment, the machining scheme was simulated, and the influence of cutting forces on dimensional distortion due to parallel and angular displacements of technological system elements was experimentally evaluated.

The second group of experiments was carried out directly under production conditions. Due to the practical impossibility of reconfiguring automatic machines for laboratory samples, this study was performed on real industrial technological processes. The research was based on statistical process control methodology.

The model experiments involved evaluating the influence of key technological factors on the dispersion field and comparing it with calculated values obtained from the developed models. Experimental dependencies were obtained by modeling the dispersion field caused by variations in system stiffness (due to machining workpieces of different diameters on different machines) and variations in cutting forces caused by fluctuations in allowance and material hardness.

To model the dispersion field, two groups of workpieces were manufactured—one with minimum and one with maximum dimensions. The first group had minimal allowance and minimal material hardness, while the second group had maximum allowance and hardness.

The first group was machined in a technological system with maximum stiffness, while the second group was machined under minimum stiffness conditions. Different stiffness levels were simulated by varying the workpiece overhang: 40 mm for the first group and 90 mm for the second group.

To obtain different hardness levels, the first group of workpieces was heat-treated (heated to 1000°C for three hours), while the second group was left without heat treatment. Experiments were conducted for three types of tools: turning tools, facing tools, and boring tools.

For workpieces from different groups processed under identical cutting conditions, the following were measured:

- for turning tools - external diameters;
- for facing tools - lengths;
- for boring tools - internal diameters.

The actual dispersion field was evaluated based on the differences in corresponding dimensions between the two groups.

Internal diameters were measured using dial indicators, while external diameters and lengths were measured using lever micrometers. Experiments were conducted on turret lathes (models 1B118, 1B125). Tool wear was monitored by measuring the flank wear land.

Table 1 presents the results of one such experiment.

Table 1

Comparison of calculated [19 ,20] and experimental dispersion fields of diameter (40X, HB 2.24 GPa; tool – turning, T15K6, $\gamma = 45°$, a = 1 mm; ITZ12; V = 160 m/min)

Initial diameter, mm	Cutting mode		Dispersion field, Δ_Σ μm		Deviation, %
	S, mm/rev	t, mm	Calculation	experiment	
40	0.26	2	152	145	-5
		4	210	204	-3
36	0.24	2	130	123	-5
		4	216	208	-4
32	0.22	2	103	94	-9
		4	192	204	-6

As shown in Table 1, the adequacy of the models with respect to the main factors of dispersion field formation is high. Therefore, these models can be used for predicting machining accuracy at the design stage.

However, for practical application, the model parameters must correspond to measurable quantities. For example, the model calculates the component of dispersion caused by elastic deformations, while in practice only the total dispersion can be measured. Similarly, instead of depth-of-cut variations, only workpiece dimensional deviations can be measured.

To relate these parameters, a known model of machining error can be used [6]. Its transformation for lathe machining is given as:

$$\Delta_{\Sigma} = \sqrt{(\Delta y)^2 + \Delta^2_{s} + \Delta^2_{t} + 3(\sum \Delta_{CT})^2 + 3(\sum \Delta_{T})^2} \quad (1)$$

where: Δ_{Σ} - total machining error; Δ_t - tool wear; $\Sigma\Delta_T$ - thermal deformations; $\Sigma\Delta_{CT}$ - geometric errors; Δ_s - setup errors; and Δ_y - elastic deformation errors.

In this model, the corresponding component is determined according to relationships given in [20, 26]. For the remaining components, which do not depend on cutting conditions and therefore can be considered constants under the conditions of the present problem, extensive statistical data are available in the reference literature. Based on these data and standard recommendations, a model can also be proposed for calculating variations in the depth of cut (Δt):

$$\Delta t = TZ + \Delta_s + \Delta_t + \Delta_{CT} \quad (2)$$

where TZ is the tolerance zone of the workpiece for the specified dimension.

With these additions, it becomes possible to perform accuracy analysis of real technological processes and to evaluate the adequacy of the developed dispersion field models under production conditions.

To evaluate real technological processes, statistical process control data from a manufacturing plant were used. The control system was implemented according to GOST 16.305-74.

At the Chelyabinsk Measuring Instruments Plant, setups were analyzed where the loading scheme corresponded to the developed models. Samples were taken at 30-minute intervals, and control charts ($\bar{X}$-R charts) were constructed. Statistical dispersion limits were compared with calculated values.

The analysis showed that measured dispersion values do not exceed calculated ones and remain within a 12% interval. With a confidence level of 0.95, the measured and calculated accuracies belong to the same statistical population.

Conclusion. Thus, the adequacy of the developed models to real machining processes has been confirmed. Consequently, the developed theory enables prediction of machining accuracy under given conditions (setup structure, technological system properties, machining conditions), forming a methodological basis for CAD systems in multi-tool lathe machining.

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

References:

1. 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.
2. 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.
3. Amirov, F. (2013). Developing Criterion and optimization of PAL system. Applied mechanics and materials, 379, 244-249.
4. 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.
5. Amirov, F. G., & Shiraliyev, I. T. (2025). External Wear of a Flush Pipe in a Drilling Rig. *Russian Engineering Research*, 45(5), 629-634.
6. 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.
7. Amirov, F. G. (2020). Some Features of Increasing the Productivity of Automatic Lines. *Proceedings of Higher Educational Institutions, Mechanical Engineering*, (9), 18-23.
8. 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.
9. 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.
10. 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.
11. Amirov F.G. (2013). Distinctive features of machining operation at positions. Vestnik mashinostroyeniya, (1), 49-51.
12. 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.
13. 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.
14. 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.
15. 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.
16. 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.
17. Amirov F. G., Mammadhuseynov A.R., Muradov F. R., Amirli S. F. (2025). Some features of production on automatic lines. *International Organization*.
18. 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.
19. 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.
20. Yusubov N.D., Movlazade V.Z., Abbasova H.M. (2022) Research of Sensitivity of Full-Factor Models of Scattering Fields of Dimensions Performed in Multi-Tool Machining. *Proceedings of the 8th International Conference on Control and Optimization with Industrial Applications (COIA 2022)*, Vol. 2, pp. 480–482.
21. Yusubov N. et. al. (2022) On the Matrix Generalization of the Theory of Machining Accuracy. *Machine Science*, Vol. 11, No. 2, pp. 23–36.
22. 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.
23. 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.
24. 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.
25. 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.
26. 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.
27. 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.
28. 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.
29. Rzayev, M. A., & Haziyev, A. R. (2025). Heat transfer and hydrodynamics in ship heat exchangers. In *Proceedings of the V International Scientific Conference "Bridging Disciplines for Scientific Progress"* (pp. 104–108). Marseille, France.
30. 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.
31. 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.
32. 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.
33. 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.
34. 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.
35. 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.
36. 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*, Bd. 85, S. 661–678.
37. 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.
38. 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.
39. 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.
40. 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.
41. 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.
42. Khankishiyev I., Amirli E., Huseynov Y. (2026) The process of technical supervision of a ship's propulsion complex elements in accordance with the rules of the classification society using the propulsion arrangement as an example. *Scientific Forum: Theory and Practice of Research*, Proceedings of the XI International Scientific and Theoretical Conference, March 13, San Francisco, pp.146–155. DOI: https://doi.org/10.36074/scientia-13.03.2026
43. 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.
44. 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.
45. 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.
46. 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.
47. 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.
48. 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.
49. 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.
50. Khankishiyev I., Mammadov E., Huseynov Y. (2026) Analysis of literary sources on the reliability and durability of ship machines and mechanisms operating under extreme conditions. *Scientific Forum: Theory and Practice of Research*, Proceedings of the XI International Scientific and Theoretical Conference, March 13, San Francisco,

pp.156–164.
51. Savin I.A. et al. (2025) Analysis of influence of various factors on fiber laser cutting technology. *ICTPE-2025 Conference*, pp. 95–102.
52. Khankishiyev, I., Majnunov, E., & Haziyev, A. (2026). *Improving the manufacturing technology of bimetallic bearings to enhance operational performance in marine engines. In:* Scientific Review of the Actual Events, Achievements and Problems*: Collection of Scientific Papers «SCIENTIA», Proceedings of the VI International Scientific and Theoretical Conference* (March 27, Berlin, Federal Republic of Germany). International Center of Scientific Research, pp. 95–102.
53. 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.
54. Simon S. et.al. (2024) Waterjet cutting of HARDOX-500 workpiece. *Russian Engineering Research*, vol. 44, no. 11, pp. 1572–1576.
55. Koshin A.A. et.al. (2009) Elements of matrix theory of multitool processing accuracy in three-dimensional setups. *Bulletin of mechanical engineering*, no. 9, pp. 13-17.
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., 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.
62. 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.
63. 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
64. 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.
65. 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.
66. 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.
67. 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.
68. 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.
69. Yusubov N., Abbasova H. (2020) Control of Processing at Multi-Tool Two-Support Setup. *Vestnik Mashinostroyeniya*, Vol. 3, pp. 67–73.
70. Koshin A.A. Obrabotka na tokarnykh stankakh: naladka, rezhimy rezaniya. *Spravochnik [Processing on lathes: adjustment, cutting conditions. Handbook]*. Chelyabinsk, Siti-Print, 2012. 744 p.
71. Abbasov I.T. et. al. (2022) Study on Reducing Energy Consumption in Rough Turning Operations. *Socar Proceedings*, Special Issue 1, pp. 23–28.
72. 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
73. 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
74. 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

75. 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.
76. Yusubov N.D. (2008) Matrix full-factor model of dimensional distortions in multi-tool setups. *Mechanical Engineering Technology*, No 1, pp. 36-39.
77. 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
78. 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.
79. 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.
80. 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.
81. Yusubov N.D., Abbasova H.M. (2018) Generalized Segmented-Matrix Model of Multi-Tool Machining Accuracy. *Scientific works*, No 4, pp. 16-22.
82. 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.
83. 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.
84. Yusubov N.D. (2009) Matrix models of working accuracy at single-cutter turning. *Tekhnologiya Mashinostroeniya*, no. 1, pp. 41-45.
85. 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.
86. 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.
87. 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.
88. 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.
89. 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.
90. Bogatenkov S.A. et.al. (2024) Digital twins for computer aided design on lathe operations. *Engineering Headway*, Vol. 7, pp.87-93.
91. 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.
92. 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.
93. 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
94. Aziz S. Sh. (2024) Improving surface quality in flat grinding operations using modern technological methods. *Machine science*, Vol. 13, Iss. 2, pp. 59–64.
95. 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.
96. 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.
97. Yusubov N. D., Ardashev D. V., Abbasova H. M. (2024) Integrated characterization of technological system compliance. *Machine science*, no. 1, pp. 4–10.
98. 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.
99. 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
100. 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.
101. 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.
102. 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.
103. 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.
104. 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.
105. 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.
106. Yusubov N., Abbasova H., Dadashov R. (2025) Modeling of machining accuracy of conical surfaces on CNC machine tools. *Proceedings*, vol. 2, pp. 59-67.
107. Zhukov A. et al. (2025) Scientific and methodological support for designing grinding operations using an acoustic indicator. *Machine Science*, Vol.2, pp.38–49.
108. Simon S. et al. (2025) Hardness of Surface Layers Obtained after Waterjet Cutting of Chromium–Nickel Steel Workpieces. *Russian Engineering Research,* 45, 1714–1718.
109. 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.
110. 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.
111. 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
112. 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.
113. 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
114. Yusubov N. (2009) Matrix Models of Accuracy in Multi-Tool Double-Toolplate Tunings. *Vestnik Mashinostroeniya*, No 3, 52–54.
115. 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
116. Aziz, S. Sh. (2020) Kinematic features of the lapping process and determination of its basic parameters. *Computational Nanotechnology*, № 3 (Vol.7), pp. 11–16.
117. 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.
118. 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.
119. Husseinov H. A., Bagirov S. A., Krehel' R., & Kočiško M. (2014) The increased production efficiency and optimization terms of stationarity by flat grinding with abrasive circle surface. *Advances in Materials Science and Engineering*, 2014, Article 108797.
120. Gusseinov G. (2012) Surfaces ground by standard wheels and wheels with graduated grain sizes. *Russian Engineering Research*, Vol. 32, No. 1, pp. 50–54.
121. 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.
122. 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.