MACHINE SCIENCE

ISSN: 2227-6912
E-ISSN: 2790-0479

2024, № 2 Pages 35 – 41

# PRACTICAL APPLICABILITY OF MATRIX MODELS FOR ACCURACY IN MULTI-TOOL MACHINING ON AUTOMATIC LATHES

**Nizami YUSUBOV [1a], Heyran ABBASOVA[1b*]**

[1] *Department of Machine Building Technology, Azerbaijan Technical University, Baku, Azerbaijan*

*E-mail:[a]nizami.yusubov@aztu.edu.az, [b*] abbasova.heyran@aztu.edu.az*

*https://doi.org/10.61413/IBAL4228*

**Abstract:** Features and challenges of multi-tool turning operations are proposed: equipment for multi-tool turning; the level of utilization of the technological potential of multi-tool machining in mechanical engineering; achievable machining accuracy; statistics on machining parts with predominant dimensions; statistics on multi-tool configurations; dimensional-accuracy theory of multi-tool machining. Therefore, the objectives of developing a design theory for multi-tool machining, considering the capabilities of modern CNC machines, are substantiated. The article provides information on the development of matrix models for machining error in multi-tool setups with spatially arranged tools, taking into account the simultaneous effect of all cutting forces from all tools in the setup and the elastic deformations of the technological system in all coordinate directions. It is noted that these models were developed both for dimensional distortion models and scatter field models. The developed full-factorial dimensional distortion model for a dual-carriage setup allows consideration not only of planar-parallel movements of technological subsystems but also their angular displacements around reference points. The theoretical solutions obtained were tested and refined directly in the practice of machine-building plants across various industries. The results of this refinement included various methodological and regulatory recommendations, as well as the development of a methodology for determining the comprehensive compliance characteristics of the technological system — the coordinate compliance matrix and the angular compliance matrix.

***Keywords:*** *multi-tool machining, matrix accuracy models, CNC metal-cutting machines, automatic and semi-automatic lathes, operation concentration, achievable machining accuracy, multi-tool machining accuracy theory, comprehensive compliance characteristics of the technological system.*

## Introduction.

Equipment for Multi-Tool Turning Operations. One of the most important factors in improving the productivity of the technological process is the concentration of operations. The highest efficiency of operation concentration is achieved through its implementation in multi-tool setups [1-5]. A wide range of specialized equipment is currently being produced for organizing multi-tool setups. The most prominent in this regard is the group of turning machines, as turning operations offer the richest possibilities for organizing multi-tool setups.

The Utilization Level of the Technological Potential of Multi-Tool Machining in Machine Building. To determine the actual level of utilization of the potential capabilities of multi-tool automatic turning, N.D. Yusubov [2-4] conducted a special survey of 85 factories across 13 different branches of machine building. This survey was carried out through the “Manufacturing Technology” department of South Ural State University using documentation provided by the Central Bureau of Labor Standards of the Russian Federation (CBLS). It should be noted that this statistical data pertains to cam-controlled machines. Unfortunately, conducting a similar statistical survey for CNC machines was not feasible. The survey and subsequent analysis were conducted in two directions [2-4, 7-8]:

-the achievable level of operation concentration;

-the attainable machining accuracy.

Achievable machining accuracy. Statistics on machining accuracy on turret lathes (TL) for major types of work at leading machine-building plants [6] show a wide variation in the achievable accuracy on TLs. For example, when turning external grooves at the Volgograd Tractor Plant (VGTZ), the accuracy achieved is no higher than grade 13, while at the Minsk Automobile Plant (MAZ), the accuracy is grade 11.

The achievable accuracy level on turret lathes (TL) is limited to grade 11. However, the most common accuracy for nearly all types of work is grade 13-12.

As follows from the consolidated statistics on machining accuracy for the main types of automatic lathes across various branches of machine-building, turret lathes (TL) primarily operate within the range of grades 14-12. Grade 9 accuracy accounts for 1% of setups, and only the instrument-making industry provides 5% of setups for grade 9 accuracy. The chemical engineering industry, on the other hand, does not achieve accuracy higher than grade 12.

Figure 1 shows a diagram of the consolidated statistics on the achievable machining accuracy on turret lathes (TL).

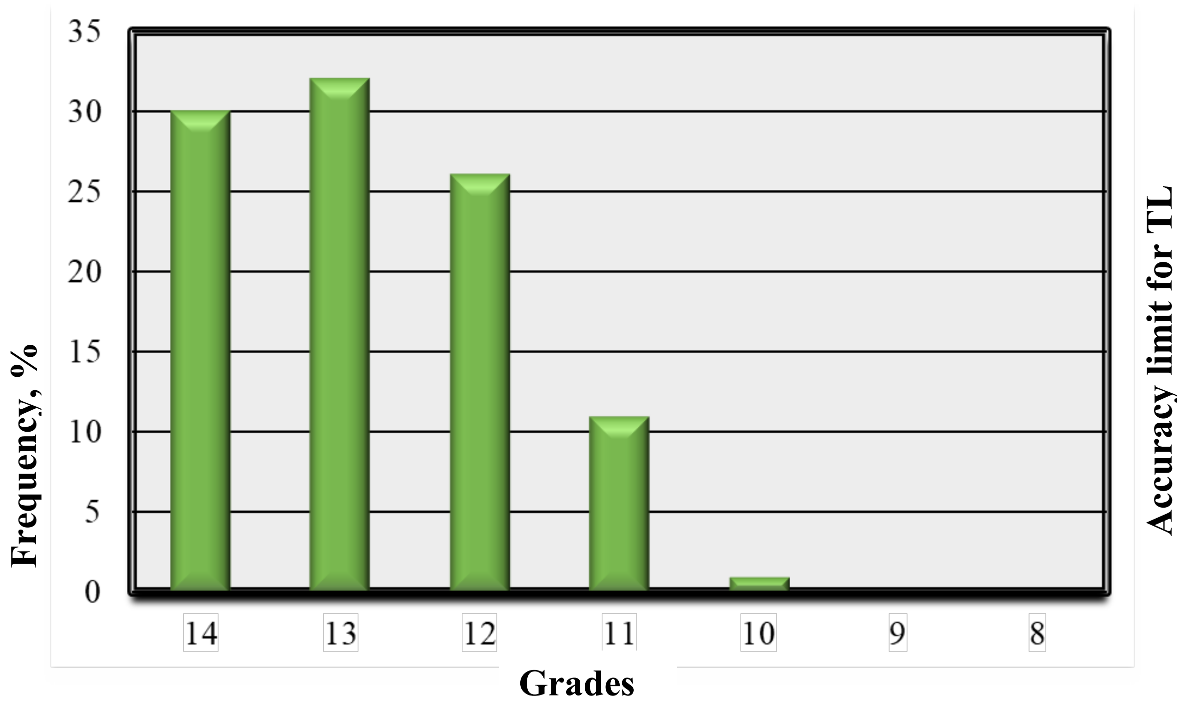


*Fig. 1. Consolidated Statistics on Machining Accuracy on Turret Lathes*

As can be seen from the diagram (Figure 1), turret lathes can typically achieve grade 10 accuracy, although the majority of the statistics fall within the 14-12 grade range. The analysis indicates that the potential capabilities of turret lathes are utilized to no more than half of their capacity.

Statistics on Machining Parts with Predominant Dimensions.

One of the tasks of the analysis was to determine the extent to which the capabilities of machining parts with predominant dimensions (L ≥3d) are utilized. Figure 2 presents the data from the statistical analysis of machining parts with different ratios of coordinate dimensions – lengths L and diameters D [2-4, 7-8].

The constructed diagrams show that machining parts with predominant dimensions is quite common, reaching up to 42% of cases (Figure 2) in turret lathe machining at leading machine-building plants and across major industries.

As can be seen from the diagrams, machining parts with predominant dimensions (L≥3d) is quite common. This is important for the formation of machining errors. In this case, even small rotational (angular) deformations of the part, which always occur during the cutting process, can cause noticeable distortions in the diametrical or linear dimensions.

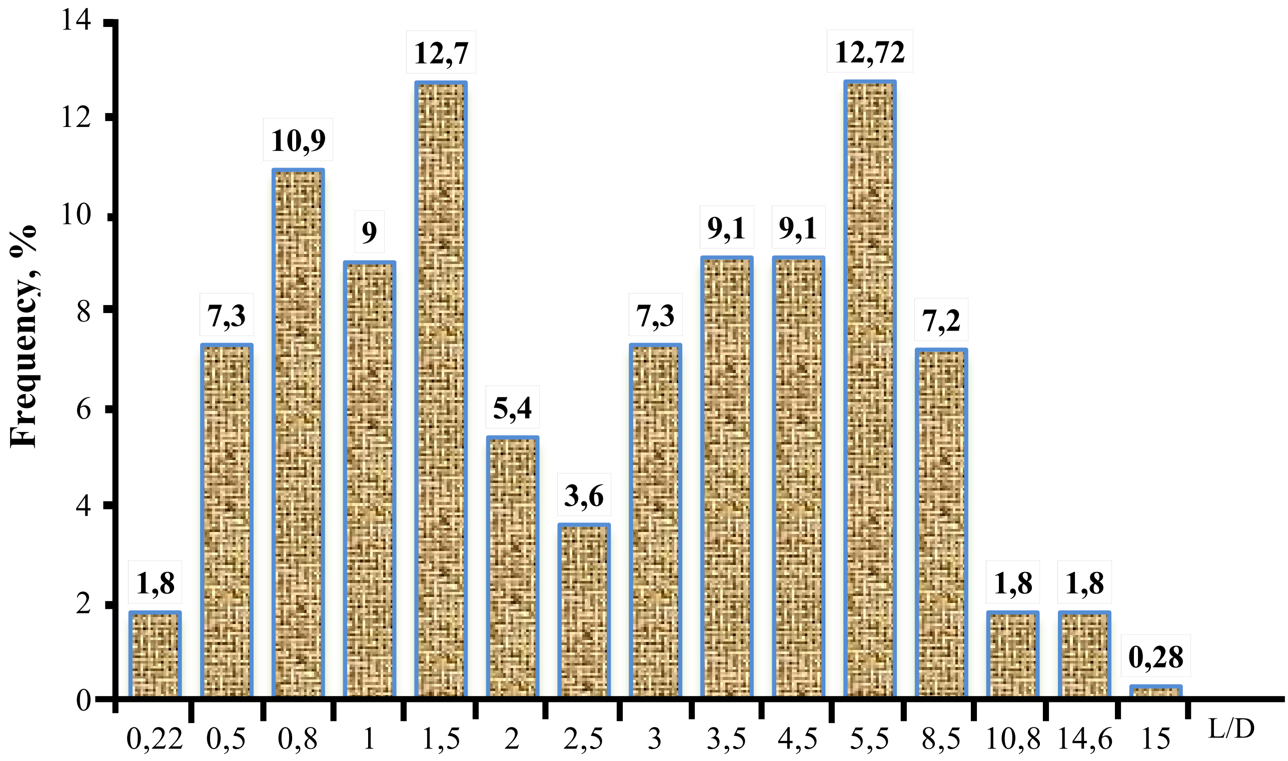


*Fig. 2. Relative Frequency of Machining Parts on Turret Lathes with Different Length-to-Diameter Ratios [2-4, 7-8]*

Statistics on multi-tooling. Multi-tool setups implemented on automatic and semi-automatic lathes can be divided into two types: single-carriage and dual-carriage setups [1-8].

In the first type of setup, several tools are positioned on a single carriage. In the second type of setup, one or more tools are placed on each position of the cross and longitudinal carriages.

When designing multi-tool setups, it is necessary to consider the organizational and force interactions between the tools in the setup. Modern cutting condition standards for turret lathe operations [9] take into account 11 types of multi-tool setups. However, in practice, there are many more types of multi-tool setups. As a result, most multi-tool setups are designed without regulatory support, based on subjective decisions. For scientifically substantiated design of multi-tool setups, it is necessary to include a comprehensive list of the types of multi-tool setups used in the cutting standards.

For this purpose, a statistical analysis of the frequency of using multi-tool setups was conducted. The analysis considered setups for single-spindle automatic lathes (of nearly all brands) across various machine building enterprises within the Commonwealth of Independent States (CIS). The analysis of the frequency of single-carriage multi-tool setups was performed on 978 single-carriage setups. Multi-tool setups accounted for 26%. Following the approach of A.A. Koshin [1], it is proposed to divide all single-carriage multi-tool setups into elementary and combined types. Elementary setups have two tools on the carriage, while combined setups have more than two tools. Among single-carriage multi-tool setups, the usage frequency of elementary setups is 98.4%, and combined setups account for 1.6%. A total of 38 types of elementary setups can be identified. Among combined single-carriage multi-tool setups, the following 19 types are frequently used. In the overall statistical analysis of multi-tool setups, dual-carriage setups accounted for 44%. Here as well, it is proposed to divide all dual-carriage setups into elementary and combined types. In elementary setups, one tool is placed on each carriage, while in combined setups, more than two tools are used. Among dual-carriage setups, the usage frequency of elementary setups was 74%, and combined setups accounted for 26%. Based on the analysis conducted, it is proposed to identify 49 types of elementary dual-carriage setups.

Thus, the analysis showed that machining parts with predominant dimensions is quite common, where the load from the cutting tool in the form of a moment of forces applied to the part becomes significant. For example, grooving on the end face with longitudinal feed or facing the end face with longitudinal feed. In such cases, the moment generated by the cutting force significantly affects the magnitude of the part's radial displacement.

Moreover, setups frequently involve the simultaneous operation of an axial tool and another cutting tool. The axial tool serves as an additional support, ultimately increasing the part's resistance to displacement. Therefore, the calculation model should account not only for coordinate stiffness but also for rotational stiffness.

Dimensional-accuracy theory of multi-tool machining: Turret lathes, semi-automatic lathes, and especially modern CNC machines possess significant technological potential, both in terms of transition concentration and machining accuracy. Machines with turret heads or tool magazines allow the concentration of up to 20 transitions within a single turret-lathe operation. Multi-spindle machines can increase the transition concentration level to 30. Modern CNC machines in multi-tool setups can achieve machining accuracy up to the 8th grade [2-4].

However, the analysis of the utilization level of the extensive technological capabilities of multi-tool turret lathes revealed that the actual usage level for transition concentration is 63%, with machining accuracy remaining at the 14th–12th grades, and the number of tools in a multi-tool setup not exceeding four [2-4].

An even more challenging situation is observed with modern CNC machines. Multi-tool machining is only found in setups designed by the machine manufacturer during its delivery [2-4].

The extremely low utilization of the technological potential of modern CNC equipment is due to the complete lack of normative guidelines for designing multi-tool setups and assigning cutting conditions for such setups on this equipment. The 1989 normative reference book on cutting conditions for multi-tool turret lathe machining [9], developed under the guidance of A.A. Koshin, covers only traditional cam-operated lathes. The general engineering normative cutting conditions for CNC machines published in 1990 [10], under the guidance of V.I. Guzeev, address only single-tool setups.

There are no regulatory guidelines for multi-tool machining on CNC machines. Currently, the design of multi-tool setups on CNC machines relies on the intuition of the setup operator, and technologists often avoid such complex setups, failing to utilize the vast technological potential of modern CNC machines.

Thus, the primary prerequisite for solving this issue is the development of a design theory for multi-tool machining that takes into account the capabilities of modern CNC machines.

The foundations of the theory for designing and optimizing multi-tool machining, based on accounting for the force interaction of tools in a multi-tool setup, were laid in the works of A.A. Koshin [1]. However, he only considered two classes of the simplest planar multi-tool setups implemented on cam-controlled automatic machines.

The design aspects of machining on CNC machines for contour trajectory machining are explored in the works of V.I. Guzeev [11]. However, these works are dedicated solely to single-tool machining.

The theory for designing multi-tool machining on modern multi-carriage and multi-spindle CNC machines must be based on balancing the force interactions of tools in the setup. This includes accounting for the possibility of tool movements along curved trajectories and the arbitrary spatial arrangement of tools in the setup. Thus, the development of error models for machining in multi-tool setups with spatial tool arrangements is crucial. These models must consider the simultaneous effects of all components of cutting forces from all tools in the setup and the elastic deformations of the technological system in all coordinate directions. For this purpose, the apparatus of analytical mechanics, which describes the elastic force interactions of a system of bodies in space and is based on matrix theory, proves to be convenient. Consequently, there is a need to develop a matrix theory of accuracy for multi-tool machining.

The development of a general theory of multi-tool machining is required, one that incorporates the setup structure at the level of initial data. It is this theory that should form the basis of the algorithmic support for technological design systems for modern CNC turning machines and their onboard computers.

To this end, a matrix theory of accuracy for multi-tool machining on modern multi-carriage and multi-spindle CNC turning machines has been developed, where for the first time a unified algorithmic model of machining errors has been created for the entire set of spatial multi-tool setups, taking into account the compliance of the technological system in all coordinate directions [2-4]. A unified generalized model has been proposed for distortions of performed dimensions, covering the entire range of multi-tool setups specified in the classification. A class of multi-tool setups is identified for scatter fields—homogeneous setups that allow an analytical representation of the model. For the first time, two different mechanisms for forming scatter fields within the class of homogeneous spatial multi-tool setups have been identified: opposite and co-positioned setups [2]. A full-factor model of dimensional distortion has been proposed for the first time, accounting for the compliance of the technological system across all six degrees of freedom, thereby enabling consideration of angular displacements in the technological system [2-4, 12-21]. For the first time, a stochastic simulation model of scatter fields in multi-carriage multi-tool machining has been proposed. This model reflects the probabilistic nature of error formation processes and encompasses the entire range of multi-tool setups, including non-homogeneous ones [2-4, 22]. Additionally, a comprehensive characteristic of the technological system's compliance has been introduced for the first time-each subsystem is represented by a set of two matrices [2-4, 23-24]:

- A coordinate compliance matrix, characterizing the subsystem's compliance along coordinate axes and their mutual influence;
- An angular compliance matrix, characterizing the resistance to rotations around coordinate axes and their mutual influence.

The description of a multi-tool setup using a system of loading vectors made it possible to define the structure of the setup at the level of the model's input data. This is fundamentally important for modern CNC machines, where the diversity of structures is difficult to classify.

**Conclusions.**

1. The foundation of the theory of accuracy in multi-tool machining consists of mathematical models of dimensional accuracy achieved by the tools in a multi-tool setup. Therefore, the current state of mathematical models for dimensional error formation in multi-tool setups is of particular interest.
2. Structural models of accuracy in multi-tool machining, reflecting the structure of the multi-tool setup and accounting for all major influencing factors, can serve as the foundation for a computational design theory of multi-tool machining.
3. Matrix models of accuracy in multi-tool machining on automatic lathes enable the prediction of machining accuracy under specified conditions (setup structure, properties of the technological system, machining conditions), thereby establishing a methodological basis for CAD systems in multi-tool turning operations.
4. The practical application of matrix models of accuracy in multi-tool machining on automatic lathes is reflected in the management and development of recommendations for cutting conditions, taking into account the setup structure for a range of standard multi-tool setups.

**Funding Acknowledgements.**

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

## REFERENCES

[1]. *Koshin* A.A. *The theory of accuracy and optimization of multi-tool turning operations*. Abstract of the dissertation Doctor of Technical Sciences, Chelyabinsk, 1997.

[2]. Yusubov N.D. *Improving the efficiency of multi-tool processing on automatic lathes*. Abstract of the dissertation Doctor of Technical Sciences, Baku, 2009.

[3]. Yusubov, N.D. *Multi-tool machining on automatic lathes (Matrix theory of multi-tool machining accuracy on modern CNC lathes).* AV Akademikerverlag Gmbh & Co. KG / LAP LAMBERT Academic Publishing, Saarbrücken, 2013.

[4]. Yusubov, N.D. *Fundamentals of matrix theory of accuracy of multi-tool turning. (Principles and structure of the theory, design and management of multi-tool machining processes).* AV Akademikerverlag Gmbh & Co. KG / LAP LAMBERT Academic Publishing, Saarbrücken, 2013.

[5]. Yusubov N.D. O*ptimization of multi-pass machining based on the productivity criterion.* Monograph. Omni Scriptum GmbH & Co. KG / LAP LAMBERT Academic Publishing, Saarbrücken, 2014.

[6]. Koshin A.A. *Computational design of optimal turning automatic operations* // Automated Design of Turning Automatic Operations. Restricted, Chelyabinsk, 1987.- pp. 14-16.

[7]. Yusubov N.D., Bogatenkov S.A., Badalova B.B. *Features and Challenges of Multi-Tool Turning*. Proceedings of the 2nd International Scientific and Technical Conference "Problems of Metallurgy and Materials Science", 28-30 November, 2017, Baku, AzTU, pp. 340 - 346.

[8]. Yusubov N.D., Bogatenkov S.A., Badalova B.B. *Study of Technological Capabilities of Multi-Tool Turning on CNC Lathes*. Proceedings of the International Scientific and Technical Conference on "Measurement and Quality: Problems and Perspectives". 2018, Baku, AzTU, November 21-23, pp. 128- 134.

[9]. *General engineering standards for cutting time and modes for automatic turning operations*. Part I-II., CBNT, Publishing House Economy, 1989.

[10]. *General engineering standards for cutting time and modes for standardizing work performed on universal and multi-purpose machines with numerical program control*. Part I-II. CBNT, Publishing House Economy, 1990.

[11]. Guzeev V.I. T*heory and methodology for calculating the productivity of contour machining of parts with various accuracies on CNC turning and milling machines*: Abstract of the dissertation … Doctor of Technical Sciences, Chelyabinsk, 1994.

[12]. Yusubov N.D. *Algorithmization of analytical model of dimensions stray field, executed in multi-tool multi-carriage adjustments.* Bulletin of Mechanical Engineering. 2008. No 2, pp. 54-56.

[13]. Yusubov N.D. *Matrix full-factor model of dimensional distortions in multi-tool setups*. Mechanical Engineering Technology, 2008, No 1, pp. 36-39.

[14]. Yusubov N.D., Abbasova H.M. *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", 28-30 November 2017, Baku, AzTU, pp. 375-380.

[15]. Yusubov N.D., Abbasova H.M. *The basic principles of the mechanism for the formation of scattering areas in the two-carriage adjustments*. / Machine science, Baku, 2018, vol. 7, No1, pp. 57-61

[16].Yusubov N.D., Abbasova H.M. *Generalized Segmented-Matrix Model of Multi-Tool Machining Accuracy*. Scientific works AzTU, No 4, 2018, pp. 16-22

[17]. Yusubov, N., & Abbasova, H. (2020). Models for Machining Accuracy in Multi-Tool Adjustment. International Journal of Automotive and Mechanical Engineering, 17(3), pp. 8067–8085. https://doi.org/10.15282/ijame.17.3.2020.01.0605

[18].S. A. Bogatenkov, N. S. Sazonova, V. I. Guzeev, N. D. Yusubov, and G. M. Abbasova. Increasing the Productivity of Multitool Machining on Automated Lathes by Optimizing the

Tool Positions. Russian Engineering Research, 2021, Vol. 41, No11, pp. 1075-1079.
[19]. Yusubov N.D., Abbasova H.M. Full-factor matrix model of accuracy of dimensions performed on multi-purpose CNC machines. Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) = Metal Working and Material Science, 2021, Vol. 23, No. 4, pp. 6-20. DOI: 10.17212/1994-6309-2021-23.4-6-20.
[20]. Nizami Yusubov, Heyran Abbasova. *Model of machining process control on multi-tool single-carriage adjustments*. Machine science, 2023, No 1, pp. 22-27
[21]. Nizami Yusubov, Heyran Abbasova. Models of cutting forces in the matrix theory of multitool machining accuracy. Key Engineering Materials, 2024, Vol. 979, pp. 27-38.
[22].Koshin A.A., Yusubov N.D. *Imitative stochastic model of fields of dissipation of the sizes executed in multi pockets of multi tool plate settings up adjustments*. Scientific works AzTU, 2007, No 1, pp. 32-35.
[23].Yusubov N.D. *Experimental determination of the static matrix characteristic of the compliance of a technological system*. Machine Builder, 2007, No 10, pp. 39-41.
[24].Yusubov N.D. *Statistical evaluation of the comprehensive compliance characteristic of a technological system*. Mechanical Engineering Technology, 2007, No 4, pp. 70-73.

**Received:** 27.10.2024
**Accepted:** 12.12.2024