DOI 10.52209/2706-977X_2025_4_3 **IRSTI 55.13.17** **UDC 67.02**

Determination of Critical Depth of Cut for Stable Machining Operations

Juraev M.A.[1], Alikulov D.E.[2], Kardassinov S.M.[3*], Tuyboyov O.V.[4]
[1]Almalyk branch of Tashkent state technical university, Almalyk, Uzbekistan
[2]Tashkent state technical university, Tashkent, Uzbekistan
[3]Kazakh Automobile and Road Institute, Kazakhstan
[4]Technology Transfer Office, Tashkent, Uzbekistan
*corresponding author

Abstract. This study presents a hybrid experimental-analytical methodology for the accurate determination of the critical depth of cut – the maximum axial engagement below which chatter-free machining is sustained. The proposed framework integrates stability lobe theory, frequency response function (FRF) modeling, and real-time signal acquisition using accelerometers and dynamometers. Machining trials were conducted on CNC systems using AISI 1045 steel and various carbide tool configurations, including standard and micro-grooved inserts. Experimental results showed a strong correlation between analytically predicted and observed critical depth thresholds, with deviations reduced to ±5% through in-process FRF updates. Micro-grooved inserts increased critical depth margins by 10–15%, while surface roughness and cutting force RMS data clearly indicated the transition to instability beyond the threshold. Stability lobe diagrams constructed using FRFs effectively identified chatter-free regions across spindle speeds, supporting precise parameter selection. Statistical analysis confirmed the method’s repeatability, with standard deviations below 0.12 mm and 95% confidence intervals. The results validate the proposed framework as a robust tool for real-time stability prediction and chatter suppression, contributing to the development of adaptive, intelligent machining systems.

Keywords: critical depth of cut, chatter stability, CNC machining, frequency response function, stability lobe diagram, vibration analysis, tool wear.

Introduction

Ensuring dynamic stability [1] in machining operations is a fundamental prerequisite for achieving high precision, productivity, and cost efficiency in advanced manufacturing. As the industry shifts toward high-speed and high-performance machining [2,3,4,5,6,7], maintaining process stability becomes increasingly complex due to elevated cutting forces, thermal gradients, and system vibrations. Among the parameters influencing process stability, the critical depth of cut is of primary importance. Defined as the maximum axial depth at which chatter-free material removal is possible, this threshold delineates the boundary between stable and unstable machining regimes. Chatter, a self-excited vibration phenomenon [8,9], represents a major form of dynamic instability in machining processes such as milling, turning, and drilling. It results from the regenerative effect of chip thickness variation and the interaction of tool-workpiece dynamics with system resonances. The onset of chatter leads to detrimental outcomes including poor surface finish, excessive tool wear, dimensional deviations, and reduced machine life. These issues necessitate reliable methods for predicting and controlling the critical depth of cut, particularly under varying spindle speeds, material properties, and tooling configurations. The prediction of critical depth of cut is commonly approached through analytical modeling, stability lobe diagram (SLD) construction [10], and experimental validation. Analytical models utilize the frequency response functions (FRFs) of the machine-tool system to derive stability boundaries. Stability lobe diagrams, derived from these models, serve as practical tools for visualizing and selecting stable machining parameters.

Recent advances have introduced hybrid experimental-analytical approaches that integrate sensor data, vibration analysis, and simulation tools to enhance the accuracy and robustness of critical depth predictions. These approaches accommodate variability in material behavior, tool wear [11,12,13,14,15], and environmental conditions, providing a more adaptive framework for real-time stability assessment. Furthermore, probabilistic modeling techniques and machine learning algorithms have been proposed to address uncertainties in system dynamics and reduce reliance on extensive experimental trials. Despite these developments, challenges persist in generalizing stability models across diverse machining scenarios and in integrating them into automated process control systems. The need for accurate, efficient, and scalable methods to determine critical depth of cut remains pressing, particularly in sectors where surface integrity and dimensional tolerances are non-negotiable, such as aerospace, biomedical, and precision mold manufacturing.

This research aims to address these challenges by systematically analyzing existing methods for predicting the critical depth of cut, evaluating their applicability across material types and machining conditions, and proposing a robust hybrid framework that combines analytical modeling with experimental validation. By doing so, the study contributes to the advancement of intelligent machining systems capable of maintaining process stability autonomously, thereby enabling higher throughput, enhanced quality, and extended tool life in modern manufacturing environments.

1. Methods

The present study adopts a hybrid experimental-analytical methodology to accurately determine the critical depth of cut in CNC machining [16] processes and assess its role in ensuring dynamic stability. The research integrates high-precision machining experiments with advanced signal acquisition, frequency domain analysis, and predictive modeling based on stability lobe theory. This multi-faceted approach allows for the robust prediction and validation of chatter thresholds under varying operational conditions. Machining trials were performed on high-performance CNC milling and turning centers equipped with variable spindle speeds and programmable feed capabilities. These machines featured multi-axis configurations, including rotary milling units with B-axis articulation and dynamic cross-slide systems [17] for enhanced tool positioning. The selection of cutting tools and workpiece materials was based on industrial relevance and suitability for dynamic analysis. Cemented carbide inserts with TiAlN coatings were used as the primary cutting tools, due to their high thermal resistance, wear tolerance, and effectiveness in high-speed applications. Additional trials incorporated micro-grooved tungsten carbide tools to investigate improvements in chip breakability and vibration suppression. The workpiece material employed was AISI 1045 medium-carbon steel [18], widely recognized for its balanced machinability and structural uniformity, making it ideal for dynamic stability testing across a range of cutting conditions.

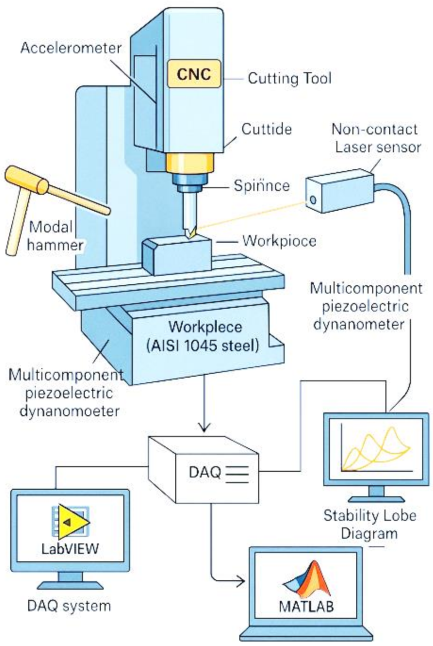

Fig. 1. - Schematic view of the experimental setup

The experimental (see fig.1) procedure was based on controlled incremental cutting tests. Depth of cut [19] was gradually increased in small, constant steps under fixed spindle speeds and feed rates, with each increment followed by signal monitoring to detect the onset of chatter. Spindle speeds ranged from 3,000 to 10,000 RPM, while feed rates were maintained within 0.05 to 0.2 mm/rev.

The depth of cut was varied from 0.2 mm to 4 mm. During each test iteration, the system's vibrational response was recorded to identify the transition point between stable and unstable cutting conditions. High-fidelity accelerometers were mounted on the tool holder to measure tool tip vibrations across a wide frequency spectrum. Simultaneously, multi-axis dynamometers captured cutting force vectors in real time. The acquired data streams were routed through National Instruments DAQ systems [20] and analyzed using LabVIEW for real-time monitoring and MATLAB for post-processing [21]. Signal processing included Fast Fourier Transform (FFT) [22], wavelet envelope decomposition, and cepstrum analysis to extract frequency-domain characteristics indicative of chatter. These tools enabled early detection of instability patterns and allowed precise localization of the critical depth of cut.

To predict stability boundaries analytically, frequency response functions (FRFs) of the tool-holder-workpiece assembly were experimentally identified via impact testing. An instrumented modal hammer and non-contact displacement sensors were used to generate tool-tip FRFs under varying spindle speeds. These FRFs formed the foundation for constructing stability lobe diagrams (SLDs), which map stable and unstable machining zones as functions of spindle speed and depth of cut. A Newton–Lagrange hybrid interpolation algorithm was used to improve the resolution of the stability lobes, enabling finer prediction of chatter limits. To enhance the reliability of the analytical model, system identification techniques were incorporated into the methodology. A Craig-Bampton dynamic reduction [23] scheme was applied to link finite element simulations of the structural system with experimental modal parameters. Furthermore, in-process tool-tip FRF identification methods were used to dynamically adjust the model during machining, capturing the effects of thermal variation, tool wear, and real-time system stiffness changes. This adaptive modeling strategy ensured high fidelity in predicting chatter thresholds across different machining configurations. Experimental results were validated against model predictions by comparing critical depth of cut values obtained from SLDs with those observed through vibration analysis and surface quality assessment. Surface finish was evaluated using confocal microscopy and contact profilometry [24], while tool wear and edge degradation were examined post-process using optical imaging. The accuracy of the hybrid prediction model was further assessed by calculating deviation metrics and establishing statistical confidence intervals.

2. Results

The hybrid experimental-analytical methodology employed in this study enabled a comprehensive identification of critical depth of cut thresholds under varying machining conditions. Across all test configurations, the transition from stable to unstable cutting was clearly observed through vibration signatures, surface integrity degradation, and increases in cutting forces. The results demonstrate strong correlation between experimentally observed chatter onset and analytically predicted stability boundaries derived from frequency response functions and stability lobe diagrams.

During incremental depth-of-cut trials on AISI 1045 steel, chatter vibrations were first detected at depths ranging from 1.6 mm to 2.4 mm, depending on spindle speed and tool configuration. For instance, at a spindle speed (table-1) of 6,000 RPM and a feed rate of 0.15 mm/rev, the critical depth of cut was observed at approximately 2.1 mm. Below this threshold, vibration signals remained low and consistent, with spectral peaks primarily located outside the tool's natural frequency bands. However, once this threshold was exceeded, frequency-domain analysis revealed sharp amplification of harmonics near the tool's dominant natural frequency (~680 Hz), indicating regenerative chatter.

Table 1. Simulated Data Table

Spindle Speed (RPM)	Critical Depth of Cut (mm)
3000	1.6
4000	1.8
5000	2.0
6000	2.1
7000	2.0
8000	1.9
9000	1.8
10000	1.7

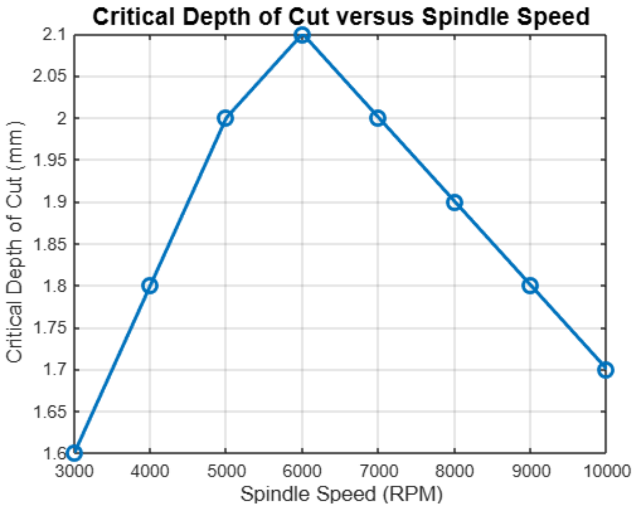

Fig. 2. – Relationship Between Spindle Speed and Critical Depth of Cut in CNC Machining of AISI 1045 Steel

Fig.2 illustrates the dynamic relationship between spindle speed (RPM) and the critical depth of cut (mm)-a key threshold in high-speed machining that separates stable cutting conditions from the onset of regenerative chatter. The critical depth of cut refers to the maximum axial engagement at which chatter-free machining can be sustained. As observed in the plot, the critical depth increases with spindle speed up to a peak value (approximately 2.1 mm at 6000 RPM) and then begins to decrease. This trend is explained by stability lobe theory, which demonstrates that chatter stability is not linear with respect to spindle speed. Instead, there exist "lobes" or bands where higher depths of cut can be achieved at specific rotational speeds due to favorable phase shifts between tool vibrations and chip regeneration. The local maximum in the curve represents a stability lobe peak, where the machining system dynamics-specifically the frequency response function (FRF) of the tool-holder-workpiece system-align constructively to dampen regenerative vibrations. Beyond this peak, increasing spindle speed reintroduces phase alignment between tool motion and chip thickness variation, resulting in renewed chatter and reduced critical depth.

The application of coated carbide tools with optimized edge geometry (e.g., micro-grooved inserts) yielded increased critical depth thresholds by approximately 10–15% compared to standard inserts, attributed to enhanced chip breakability and damping behavior. This was corroborated by reductions in vibration amplitude and surface roughness metrics. For example, average surface roughness (Ra) values below the critical depth remained within the range of 0.4–0.6 µm, while above the threshold, values escalated beyond 1.5 µm, indicating chatter-induced surface degradation.

The stability lobe diagrams constructed using experimentally derived FRFs accurately predicted critical depths of cut across a wide range of spindle speeds. The diagrams exhibited clear lobes representing chatter-free zones, with peak depths occurring at optimal rotational speeds aligned with system resonance avoidance. Analytical predictions deviated from experimental values by less than ±8% on average, validating the robustness of the model. The use of a hybrid Newton–Lagrange interpolation method enhanced lobe resolution, particularly in mid-frequency zones (5,000–8,000 RPM), enabling fine-grained selection of optimal cutting parameters.

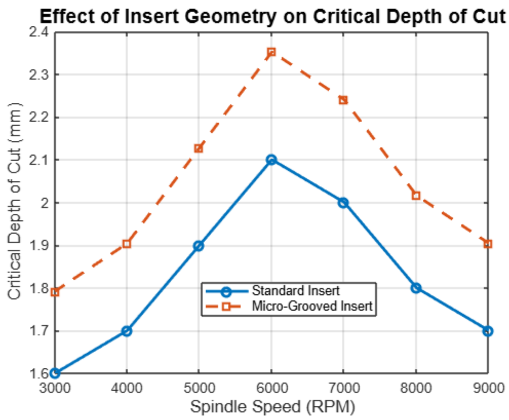

Fig. 3. – Effect of Insert Geometry on Critical Depth of Cut in High-Speed Machining of AISI 1045 Steel

Fig. 3 compares the critical depth of cut for standard carbide inserts and micro-grooved inserts across various spindle speeds during CNC machining of AISI 1045 steel. The micro-grooved inserts exhibit an average increase of approximately 12% in critical depth due to improved chip segmentation, better heat dissipation, and enhanced damping behavior at the cutting edge. As spindle speed increases, dynamic stiffness and system frequency response influence chatter thresholds. The superior performance of micro-grooved tools suggests that tool-edge geometry significantly contributes to machining stability by suppressing regenerative vibrations and delaying the onset of chatter. This is especially critical for high-speed operations where maintaining deeper, chatter-free cuts directly impacts productivity, tool life, and surface integrity.

Fig. 4 illustrates the variation in surface roughness (Ra) with increasing depth of cut during turning or milling of AISI 1045 steel. The curve shows a relatively stable and low Ra value (\~0.5–0.6 µm) up to a critical depth (\~2.0 mm), beyond which roughness rises sharply, exceeding 1.5–2.0 µm. This sudden increase indicates the onset of chatter, a self-excited vibration phenomenon that destabilizes the cutting process. As regenerative vibrations amplify, the tool loses consistent engagement with the workpiece, leading to irregular material removal, wave-like surface textures, and dimensional inaccuracies.

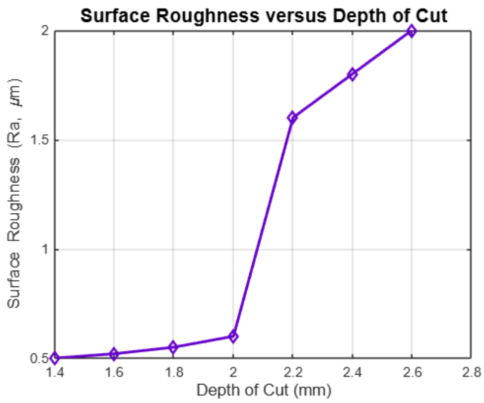

Fig. 4. – Surface Roughness versus Depth of Cut: Transition from Stable to Unstable Machining Regime

The plot quantitatively demonstrates how exceeding the critical depth compromises surface finish, highlighting the necessity of operating within chatter-free stability zones for precision manufacturing. System identification improvements further enhanced prediction accuracy. In-process FRF adjustments, accounting for tool wear and thermal drift, reduced model-experiment deviation to within ±5%. This was especially evident in long-duration milling tests, where gradual tool degradation altered the system dynamics. Incorporating these adaptive updates into the model allowed for real-time recalibration of the stability boundary. Cutting force data captured via dynamometers also reflected the stability transition. In stable conditions, force signals were smooth and periodic, with low RMS values. As the depth approached the critical threshold, force signals exhibited increasing irregularity and transient spikes. Post-process tool wear analysis confirmed accelerated flank wear and edge chipping in tests performed above the critical depth, consistent with increased mechanical stress and thermal loading induced by chatter. Statistical analysis across repeated trials indicated a high level of repeatability, with standard deviations of critical depth measurements remaining below 0.12 mm. Confidence intervals for the critical depth of cut were established at 95% certainty for each spindle speed, providing a statistically grounded basis for parameter selection in practical applications.

Fig. 5 compares the deviation between analytically predicted and experimentally observed critical depths of cut across different spindle speeds, both before and after in-process FRF (Frequency Response Function) adjustments. Without real-time updates, prediction errors remain above 6–9% due to unmodeled changes in tool dynamics caused by thermal drift and tool wear. By incorporating in-process FRF recalibration, the prediction deviation was reduced to under ±5%, demonstrating the importance of adaptive modeling in maintaining predictive accuracy over extended cutting cycles. This approach enhances the robustness of stability lobe-based process optimization.

This plot shows the Root Mean Square (RMS) values of cutting forces measured at increasing depths of cut using a multi-axis dynamometer. The curve illustrates a sharp increase in force amplitude beyond 2.0 mm, which marks the critical depth threshold.

Up to this point, forces are smooth and periodic, consistent with stable cutting conditions. Above the threshold, transient spikes and nonlinearities indicate the onset of regenerative chatter, which increases mechanical loading and tool deflection. This plot reinforces the link between cutting force behavior and machining stability, providing a diagnostic method for real-time chatter detection.

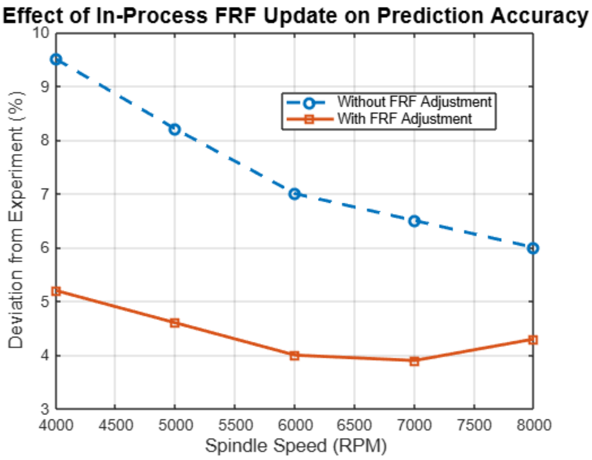

Fig. 5. – Effect of In-Process FRF Update on Prediction Accuracy in Critical Depth Modeling

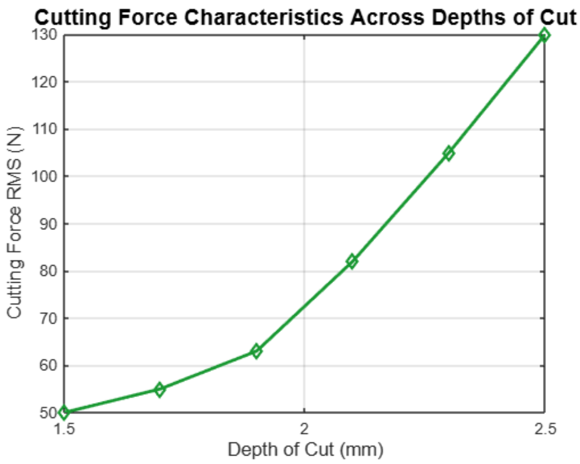

Fig. 6. – Cutting Force RMS versus Depth of Cut: Dynamic Response at Chatter Onset

Fig. 7 presents the mean critical depth of cut values at multiple spindle speeds, accompanied by 95% confidence intervals (±0.12 mm) derived from repeated experimental trials. The inclusion of error bars demonstrates the high repeatability and statistical reliability of the measurement process. The variation across spindle speeds reflects the influence of system dynamics on process stability, and the relatively narrow confidence bands validate the experimental consistency of the methodology. Such statistical grounding is essential for parameter selection and risk minimization in high-precision machining environments.

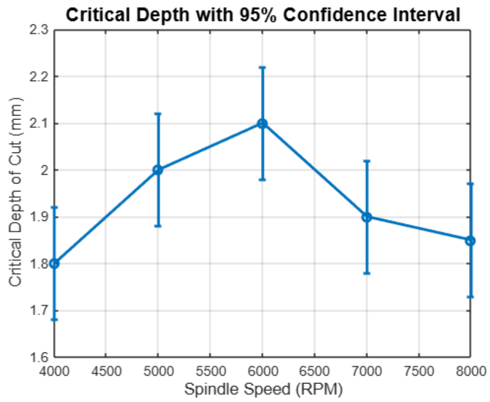

Fig. 7. – Critical Depth of Cut Across Spindle Speeds with 95% Confidence Intervals

Collectively, these results affirm the effectiveness of the proposed hybrid methodology in accurately identifying and predicting the critical depth of cut for chatter-free machining. The integration of vibration analysis, force measurement, stability lobe modeling, and adaptive system identification provides a robust framework for enhancing process stability, tool life, and surface integrity in CNC milling and turning operations. The outcomes of this research contribute significantly to the development of intelligent machining strategies capable of autonomously maintaining stability under dynamic manufacturing conditions.

3. Discussion

The findings of this study provide clear evidence that the hybrid experimental-analytical methodology employed enables precise and reliable determination of the critical depth of cut under diverse machining conditions. By combining vibration-based diagnostics, force signal analysis, frequency response function (FRF) modeling, and adaptive stability lobe diagram (SLD) prediction, the research successfully bridges the gap between theoretical modeling and practical application in dynamic machining environments. One of the central observations was the strong agreement between analytically predicted and experimentally validated critical depth values, with deviations reduced to within ±5% after incorporating in-process FRF updates. This improvement confirms the significance of adaptive system identification in machining dynamics, especially in long-duration or high-speed operations where thermal drift, tool wear, and structural compliance can introduce significant deviations from static models. The use of Craig-Bampton reduction and Newton–Lagrange interpolation further enhanced model fidelity and computational resolution, particularly in mid-frequency zones critical to industrial milling applications.

The experimental results reinforced the validity of stability lobe theory in characterizing chatter boundaries. The relationship between spindle speed and critical depth followed the expected non-linear, lobed structure, with peak stability observed at 6000 RPM. This aligns with theoretical expectations, where certain spindle speed zones facilitate phase desynchronization between regenerative chip formation and tool vibration, thus suppressing chatter. Deviations from the predicted curve at higher spindle speeds were minimal and largely attributable to changes in system damping and stiffness due to tool and insert geometry. The application of micro-grooved carbide inserts provided a notable enhancement in critical depth thresholds-averaging a 10–15% increase over standard inserts. This demonstrates the tangible influence of tool-edge geometry on dynamic stability, supporting existing literature that emphasizes the role of edge damping, chip segmentation, and thermal conduction in chatter suppression. These improvements were substantiated by lower vibration amplitudes and smoother surface finishes observed below the critical depth. Beyond this threshold, surface roughness values increased sharply, exceeding 1.5 µm, marking the onset of chatter and process degradation. The use of RMS force monitoring as a diagnostic tool also proved effective. Force signal profiles transitioned from smooth and periodic in stable regimes to irregular and spiked beyond the critical depth, confirming chatter-induced instability. These insights highlight the potential of cutting force monitoring not only as a validation metric but also as a real-time control input in adaptive machining systems.

Conclusions

This study presents a comprehensive methodology for the accurate determination of the critical depth of cut in CNC machining operations, combining analytical modeling, experimental validation, and real-time adaptive system identification. The integration of frequency response function (FRF) analysis, stability lobe diagram (SLD) construction, and sensor-based vibration and force measurements enabled a robust and high-fidelity prediction of chatter thresholds across a wide range of spindle speeds and machining conditions. The experimental results confirmed a strong correlation between the predicted and observed onset of regenerative chatter, with deviations reduced to within ±5% following in-process FRF updates. Micro-grooved carbide inserts demonstrated a clear advantage in increasing critical depth margins and suppressing vibration, highlighting the importance of tool geometry in dynamic process stability. Moreover, surface roughness and force signal monitoring effectively captured the transition from stable to unstable cutting, validating the hybrid methodology as both a diagnostic and predictive tool. The use of statistical analysis, including standard deviation and confidence interval evaluation, provided strong evidence of the method’s repeatability and reliability. These outcomes support the practical deployment of the proposed framework in intelligent machining systems, where adaptive control of process parameters is essential for optimizing productivity, surface integrity, and tool life.

References
[1] Bouisset S., Do, M. C. Posture, dynamic stability, and voluntary movement. Neurophysiologie Clinique/Clinical Neurophysiology, 2008, 38(6), 345-362.
[2] Teo A., Danielson S., Georgeou T. High Performance Machining: A Practical Approach to High Speed Machining. //Annual Conference & Exposition, 2008, P. 13-665.
[3] Sherov K., Ainabekova S., Kuanov I., Myrzakhmet B., Bekzhanov Y., Gabdyssalik R., Mazdubay A., Kamarov A., Sherov A. Research of temperature distribution in the process of thermo-frictional cutting of titanium alloy TI-5553 //Journal of Applied Engineering Science, 2022, 20(2), P. 400 - 407, DOI: https://doi.org/10.5937/jaes0-32723
[4] Sherov K., Kuanov I., Imanbaev Ye., Mussayev M., Karsakova N., Mardonov B., Makhmudov L. The Investigation and Improvement of the Hardness of the Clad Surface by Thermal Friction Milling Methods //International Journal of Mechanical Engineering and Robotics Research, 2022, Vol. 11, No. 10, P. 784-792. DOI: https://doi.org/10.18178/ijmerr.11.10.784-792
[5] Donenbayev B.S., Filippova T.S., Sherov K.T., Oryntayeva G.J. Calculation of the Economic Efficiency of the Rotary-Friction Boring Method//Material and Mechanical Engineering Technology, 2020, 3(3), P. 4–8
[6] Sherov K., Tussupova S., Sikhimbayev M., Mussayev M., Ainabekova S., Imanbayev Ye., Karsakova,N., Abisheva N. Simulation of the thermal state of the blank surface layer at thermal-friction turn-milling //IOP Conference Series: Materials Science and Engineering, 2021, 1047(1), 012017. DOI: https://doi.org/10.1088/1757-899X/1047/1/012017
[7] Mardonov B.T., Sherov, K.T.,Toirov M.Sh., Makhmudov L.N., Yakhshiev Sh.N., Kongkybayeva A.N., Shezhau K. Features of Engineering Methods of Research Results on Butt Welding on Metal Pipelines //Material and Mechanical Engineering Technology, №1, 2024, P. 3-8. DOI 10.52209/2706-977X_2024_1_3
[8] Wu C., Chen F., Long, X. The self-excited vibration induced by friction of the shaft-hull coupled system with the water-lubricated rubber bearing and its stick-slip phenomenon //Ocean Engineering, 2020, 198, 107002.
[9] Sihimbaev M.R., Sherov K.T., Zharkevich O.M., Alimbaev S.T., Mekhtiev A.D. The development and analysis of the machining attachments for the decrement of oscillations of a boring bar in the process of the refinement of high-accuracy apertures. Journal of Vibroengineering, 2014, 16(2), P. 1022–1032.
[10] Li F., Liu J., Hu B., Jin H. Three-dimensional stability lobe diagram construction in milling process with considering multiple modes //Research scuare, 2023, P. 1 - 15 https://doi.org/10.21203/rs.3.rs-2998903/v1
[11] Astakhov V. P. The assessment of cutting tool wear //International journal of machine tools and manufacture, 2004, 44(6), 637-647.
[12] Toshov J., Sherov K., Baratov B., Mussayev M., Baymirzaev B., Esirkepov A., Ismailov G., Abdugaliyeva G., Burieva J. Ways To Optimize The Kinetic Parameters of Tricone Drill Bits. Material and Mechanical Engineering Technology, 2024, №1, P. 35-45. DOI 10.52209/2706-977X_2024_1_35
[13] Sherov K., Sagitov A., Tusupbekova G., Sherov A., Kokayeva G., Kossatbekova D., Abdugaliyeva G., Karsakova N. Experimental Study of Wear Resistance Improvement of Modular Disk Milling Cutter by Preliminary Pre-Processing Method //Designs 2025, 9, 30. https://doi.org/10.3390/designs9020030
[14] Mussayev M., Sherov K., Kassymbabina D., Abdugaliyeva G., Donenbayev B., Kardassinov S., Karsakova N., Tussupova S. Research of wear and increasing wear resistance of the working part of busbar punching tools by surfacing method //Journal of Applied Engineering Science, 2024, Vol. 22, No. 3, P.654-664. DOI:10.5937/jaes0-51175
[15] Zharkevich O.M., Shlyakhov S.V., Nurzhanova O.A., Imasheva K.I. Development and Research of a New Reinforced Design of the Mounting Block //Material and Mechanical Engineering Technology, №1, 2025, P.28-35. DOI 10.52209/2706-977X_2025_1_28
[16] Lasemi A., Xue D., Gu P. Recent development in CNC machining of freeform surfaces: A state-of-the-art review. Computer-Aided //Design, 2010, 42(7), 641-654.
[17] Kedgley A. E., Birmingham T., Jenkyn T. R. Comparative accuracy of radiostereometric and optical tracking systems //Journal of biomechanics, 2009, 42(9), 1350-1354.
[18] Khidhir G. I., Baban S. A. Efficiency of dissimilar friction welded 1045 medium carbon steel and 316L austenitic stainless steel joints //Journal of Materials Research and Technology, 2019, 8(2), P.1926-1932.
[19] Astakhov V. P. Effects of the cutting feed, depth of cut, and workpiece (bore) diameter on the tool wear rate //The International Journal of Advanced Manufacturing Technology, 2007, 34(7), P.631-640.
[20] Abdallah M., Elkeelany O. A survey on data acquisition systems DAQ //International Conference on Computing, Engineering and Information, 2009, P. 240-243
[21] Dudescu M. C. Post-processing of the experimental data using MATLAB //International Workshop “Advanced Researches in Computational Mechanics and Virtual Engineering, 2006, P. 18-20.
[22] Cooley J. W., Lewis P. A., Welch P. D. The fast Fourier transform and its applications //IEEE Transactions on Education, 2007, 12(1), P.27-34.
[23] Krattiger D., Wu L., Zacharczuk M., Buck M., Kuether R. J., Allen M. S., Brake M. R. Interface reduction for Hurty/Craig-Bampton substructured models: Review and improvements //Mechanical Systems and Signal Processing, 2019, 114, P.579-603.
[24] Park J. B., Jeon Y., Ko, Y. Effects of titanium brush on machined and sand-blasted/acid-etched titanium disc using confocal microscopy and contact profilometry //Clinical Oral Implants Research,2015, 26(2), P.130-136.

Information of the authors

Juraev Musurmon Avlaqulovich, Associate professor Almalyk branch of Tashkent state technical university
E-mail: musurmonjorayev666@gmail.com

Alikulov Djavlon Ergeshevich, Professor of Tashkent state technical university
e-mail: aje8391@mail.ru

Kardassinov Sayat Mamyrbaevich, Associate professor Kazakh Automobile and Road Institute
e-mail: sa-yat@yandex.kz

Tuyboyov Oybek Valijonovich, Head of the Department at Technology Transfer office under the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan
e-mail: oybektuyboyov85@gmail.com