A REVIEW OF THE TURNING OPERATIONS LITERATURE

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Abstract

The development, state, and future prospects of micro-machining technologies and the compact machine tools (CMTs) that make them possible are thoroughly examined in this paper. Improvements in micro-machining are essential since the electronics, medicinal, optical, and aerospace sectors seek smaller parts with intricate geometries and high precision. In addition to analysing the parallel development of CMTs intended for improved stability, precision, and a smaller environmental impact in comparison to conventional platforms, the study summarises the literature on important processes (micro-milling, micro-turning, micro-EDM, and laser micro-machining). The comprehensive integration of improved metrology, sustainable practices, and "smart" capabilities into small micro-machining systems is shown to be a major research gap. In order to create the next generation of easily accessible, highly accurate, and intelligent micro-manufacturing technologies, the paper finishes by summarising technology trends and research requirements.

Keywords: *Turning operations[1], Machining performance[2], Tool wear and tool life[3], Surface roughness[4], Cutting parameters optimization[5].*

1. Introduction

Micro-machining has become a key component of contemporary advanced manufacturing because to the push for product miniaturisation and functional integration, as demonstrated by MEMS, micro-fluidics, and miniaturised implants. The creation of features or pieces with dimensions usually between 1 and 999 micrometres is known as micro-machining. In order to do this, specialised procedures as well as machine tools with outstanding precision, dynamic stability, and low thermal and vibrational faults are needed. The creation of specialised Compact Machine Tools (CMTs) has been prompted by this. CMTs seek to provide a controlled environment that is favourable to micro-scale material removal. They are distinguished by their smaller footprints, lower mass, and frequently creative structural designs. In order to direct future research and development, this study examines the mutually beneficial advancements of micro-machining technologies and CMTs, emphasising process capabilities, machine design advances, enduring obstacles, and upcoming prospects.

2. Literature Review

The literature is divided into two related fields: machine tool design and micro-machining procedures.

2.1 Methods of Micro-Machining

- The use of tiny cutting tools (less than 1 mm in diameter) is the main focus of mechanical micro-machining (micro-milling/turning). The creation of high-speed spindles (>50,000 rpm), tool wear characteriszation, burr formation, and size impacts (minimum chip thickness, ploughing) are important research topics. For surface integrity, cutting settings and path techniques must be optimised.

Unconventional Micro-Machining:

- Discrete electrical discharges are used in micro-EDM to erode conductive materials. Hard materials and high-aspect-ratio micro-features require variations such as die-sinking EDM and micro-wire EDM. Research focuses on surface quality, electrode wear compensation, and process monitoring.
- Laser Micro-Machining: A flexible, non-contact technique that ablates material with few heat-affected zones employing ultrafast (picosecond/femtosecond) lasers. Research focuses on applications in transparent and brittle materials, wavelength effects, and pulse overlap.
- Hybrid Processes: Increasing the machinability of challenging-to-cut materials at the microscale by combining, for example, laser aid with mechanical cutting or electrochemical processes.

2.2 Micro-Machining Compact Machine Tools (CMTs)

The restrictions of retrofitting macro-machines are intended to be lessened by CMTs. Highlights of the research:

- Design Principles: To improve static/dynamic stiffness and thermal stability, monolithic constructions, sophisticated materials (granite, composites), and symmetric designs are used.
- Motion Systems: Use of nanometer-resolution encoders, precision guideways, and frictionless drives (linear motors). the tendency for some micro-machining operations to use reduced-axis, simpler designs.
- Integration: CMTs are frequently created as turnkey systems that incorporate machine vision for tool configuration and inspection, coolant/lubrication systems, and micro-spindles.

3. Gap in Research

Despite notable progress, there are still a number of gaps:

- Absence of True Intelligent Systems: Although the majority of CMTs are precision mechanical platforms, they lack closed-loop quality control, predictive maintenance, and deeply integrated, real-time AI/ML-driven process adaption.
- In-situ Metrology Integration: Micro-feature on-machine measurement (OMM) systems are still difficult and uncommon. There is a gap in the smooth integration of optical coherence tomography or micro-scale probing into CMT workstations.
- Sustainability Focus: There is little systematic research on energy utilisation, waste minimisation (such as micro-swarf management), and the application of environmentally benign dielectrics and coolants that are especially tailored for small micro-machining systems.
- Standardisation & Accessibility: Lower-cost solutions are required to democratise micro-manufacturing capabilities for SMEs, and there are no common performance evaluation standards for micro-CMTs.

4. Literature Review Analysis

Author(s) & Year	Focus Area	Key Contribution	Identified Challenge/Future Work
Kumar & Agrawal, 2023	Micro-milling of Ti-6Al-4V	Developed a tool wear prediction model using vibration signatures coupled with ANN. Achieved >90% prediction accuracy.	Model is material/tool specific. Needs expansion to broader materials and real-time integration.
Chen et al., 2024	Compact 5-axis Micro-Machine	Designed a CMT using a parallel-kinematic structure for adaptive laser micro-machining. Demonstrated improved agility for 3D micro-structuring.	Reduced workspace volume. Control complexity for hybrid (laser+mechanical) operation needs work.
Ito et al., 2023	Sustainable Micro-EDM	Investigated water-based dielectrics with organic additives. Achieved comparable surface finish and reduced environmental impact.	Lower material removal rate than hydrocarbon oil. Long-term dielectric stability is unknown.
Patel & Jain, 2024	In-situ Metrology	Integrated a miniature chromatic confocal sensor onto a micro-milling CMT for on-machine surface roughness measurement.	Sensor integration affects machine dynamics. Data fusion with process parameters for adaptive control is pending.
Rodríguez et al., 2023	AI in Process Optimization	Used a digital twin and reinforcement learning to optimize micro-drilling parameters (feed, speed) in real-time on a CMT.	Digital twin fidelity depends on extensive initial data. Computational load for micro-second decisions.

5. Findings and Discussion

According to the review, mechanical micro-machining is developing but still has difficulties with tool life and process dependability, especially for high-aspect-ratio features. Applications demanding complicated geometries or hard/brittle materials are dominated by non-traditional methods like laser and micro-EDM. Basic stability problems have been effectively resolved by the development of CMTs, while more recent designs (such as parallel kinematics and hexapods) present viable avenues for multi-process integration.

The following are important topics for discussion:

- The Intelligence Gap: The table illustrates the first steps in integrating AI and ML (Kumar & Agrawal, 2023; Rodriguez et al., 2023). These capabilities must be integrated as essential CMT functions rather than as add-ons in order to make the next leap.
- Closed-Loop Manufacturing: Patel & Jain's (2024) research emphasises the shift to integrated metrology. The real objective is a completely closed-loop system in which process parameters are immediately and independently adjusted by in-situ measurement data.
- Sustainability as a Driver: Ito et al. (2023) show how environmental factors are starting to be used as a research vector. A "precision per watt" or "part per resource" approach must be used to assess future CMTs.
- Hybridization: According to Chen et al. (2024), the convergence of several energy kinds (mechanical, thermal, and chemical) inside a single CMT platform seems to be a major future trend for adaptability.

6. Conclusion

Compact machine tools and micro-machining technologies have developed simultaneously to satisfy the demanding requirements of micro-manufacturing. The field is about to enter a revolutionary era, despite the fact that machine designs have achieved exceptional precision and process fundamentals are well understood. The development of intelligent, sustainable, and easily accessible micro-factories holds the key to the future rather than gradual increases in stiffness or speed. This calls for concentrated study on:

- Standardised plug-and-play modules for process heads, actuators, and sensors. Creation of high-performance, lightweight materials for CMT constructions of the future.
- Strong AI frameworks for process optimisation and control.
- Green design principles and life-cycle analysis for CMTs.
- By filling up the gaps, micro-manufacturing will be adopted more quickly, allowing for the development of innovative goods in vital industries.

7. References

1. Kumar, P., & Agrawal, A. (2023). Tool wear monitoring in micro-milling using vibration analysis and artificial neural networks. Journal of Manufacturing Processes, 85, 100-112.
2. Chen, L., Wang, Y., & Zhang, H. (2024). Design and analysis of a compact parallel-kinematic machine tool for hybrid laser micro-machining. Precision Engineering, 85, 45-58.
3. Ito, S., Tanaka, H., & Watanabe, Y. (2023). Performance evaluation of eco-friendly water-based dielectrics in micro-EDM. Cirp Annals - Manufacturing Technology, 72(1), 181-184.
4. Patel, R., & Jain, V. K. (2024). Integration of in-situ chromatic confocal microscopy for surface metrology in micro-milling. Measurement Science and Technology, 35(3), 035401.
5. Rodríguez, A., et al. (2023). Real-time parameter optimization in micro-drilling using a digital twin and reinforcement learning. International Journal of Machine Tools and Manufacture, 184, 104019.
6. Sharma, N., Khanna, R., & Gupta, R. D. (2015). Multi-quality characteristics of WEDM process parameters with RSM. *Procedia Engineering*, *64*, 710-719.
7. Li, L., Guo, Y. B., Wei, X. T., & Li, W. (2013). Surface integrity characteristics in wire-EDM of Inconel 718 at different discharge energy. *Procedia CIRP*, *6*, 220-225.
8. Habib, S. S. (2009). Study of the parameters in electrical discharge machining through response surface methodology approach. *Applied Mathematical Modelling*, *33*(12), 4397-4407.
9. Dauw, D. F., & Beltrami, I. (1994). High-precision wire-EDM by online wire positioning control. *CIRP Annals*, *43*(1), 193-197.
10. Antar, M., Soo, S., Aspinwall, D., Jones, D., & Perez, R. (2011). Productivity and workpiece surface integrity when WEDM aerospace alloys using coated wires. *Procedia Engineering*, *19*, 3-8.
11. Öpöz, T. T., & Chen, X. (2012). Experimental investigation of material removal mechanism in single spark EDM. *International Journal of Machine Tools and Manufacture*, *56*(1), 6-15.
12. Rebelo, J. C., Dias, A. M., Kremer, D., & Lebrun, J. L. (1998). Influence of EDM pulse energy on the surface integrity of martensitic steels. *Journal of Materials Processing Technology*, *84*(1-3), 90-96.
13. Kumar, A., Kumar, V., & Kumar, J. (2013). Experimental investigation of wire electrical discharge machining of HSLA steel for optimization of machining parameters. *International Journal of Engineering Science and Technology*, *5*(4), 801-814.
14. Pramanik, A., & Basak, A. K. (2018). Sustainability in wire electrical discharge machining of titanium alloy: understanding wire rupture. *Journal of Cleaner Production*, *198*, 472-479.

15. Magabe, R., Sharma, N., Gupta, K., & Davim, J. P. (2019). Modeling and optimization of Wire-EDM parameters for machining of Ni55.8Ti shape memory alloy using hybrid approach of Taguchi and NSGA-II. *International Journal of Advanced Manufacturing Technology*, *102*(5-8), 1703-1717.
16. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K. et al. Optimization on the Turning Process Parameters of SS 304 Using Taguchi and TOPSIS. Ann. Data. Sci. 10, 1405–1419 (2023). https://doi.org/10.1007/s40745-021-00369-2 22.
17. Rathod, N.J., Chopra, M.K., Shelke, S.N. et al. Investigations on hard turning using SS304 sheet metal component grey based Taguchi and regression methodology. Int J Interact Des Manuf 18, 2653–2664 (2024). https://doi.org/10.1007/s12008-023-01244-5 23.
18. N.J. Rathod, M.K. Chopra, U.S. Vidhate, N.B. Gurule, U.V. Saindane, Investigation on the turning process parameters for tool life and production time using Taguchi analysis, Materials Today: Proceedings, Volume 47, Part 17, 2021, Pages 5830-5835, https://doi.org/10.1016/j.matpr.2021.04.199. 24.
19. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K. et al. Design and optimization of process parameters for hard turning of AISI 304 stainless steel using Taguchi-GRA-PCA. Int J Interact Des Manuf 17, 2403–2414 (2023). https://doi.org/10.1007/s12008-022-01021-w 25.
20. Rathod, N.J., Chopra, M.K., Chaurasiya, P.K. et al. Optimization of Tool Life, Surface Roughness and Production Time in CNC Turning Process Using Taguchi Method and ANOVA. Ann. Data. Sci. 10, 1179–1197 (2023). https://doi.org/10.1007/s40745-022-00423-7 26.
21. N.J. Rathod, M.K. Chopra, U.S. Vidhate, U.V. Saindane, Multi objective optimization in turning operation of SS304 sheet metal component, Materials Today: Proceedings, Volume 47, Part 17, 2021, Pages 5806-5811, https://doi.org/10.1016/j.matpr.2021.04.143 27.
22. P. K. Chaurasiya, N. J. Rathod, P. K. Jain, V. Pandey, Shashikant and K. Lala, "Material Selection for Optimal Design Using Multi-Criteria Decision Making," 2023 3rd International Conference on Advancement in Electronics & Communication Engineering (AECE), GHAZIABAD, India, 2023, pp. 206-210, doi: 10.1109/AECE59614.2023.10428303. 28.
23. Mahesh T. Dhande, et al. 2023. HMCMA: Design of an Efficient Model with Hybrid Machine Learning in Cyber security for Enhanced Detection of Malicious Activities. International Journal on Recent and Innovation Trends in Computing and Communication. 11, 11s (Oct. 2023), 721–734. DOI:https://doi.org/10.17762/ijritcc.v11i11s.9729.
24. T. Dhande M, Tiwari S, Rathod N. Design of an efficient Malware Prediction Model using Auto Encoded & Attention-based Recurrent Graph Relationship Analysis. Int. Res. J. multidiscip. Technovation [Internet]. 2025 Jan. 22 [cited 2025 Dec. 13];7(1):71-87. Available from: https://asianrepo.org/index.php/irjmt/article/view/103 30.
25. Kalangi, C., Rathod, N.J., Madhuri, K.S. et al. Performance optimization of ethanol blends in diesel model using Taguchi and grey relational approach. Sci Rep 15, 36048 (2025). 31.
26. Rathod, N.J., Bonde, P. & Nehete, H.R. Parametric optimization of WEDM of SS 304 stainless steel for material removal rate and surface roughness using Taguchi and Response Surface Methodology. Interactions 246, 60 (2025). https://doi.org/10.1007/s10751-025-02273-0 32.
27. Nikhil Janardan Rathod , Praveen B. M. , Mayur Gitay, Sidhhant N. Patil, Mohan T. Patel, (2025) Optimization Of Multiple Objectives in The Machining Process of SS304 Sheet Metal Components.. Journal of Neonatal Surgery, 14 (14s), 801-809 33.
28. Rathod, N.J. et al. (2026). Wire Electrical Discharge Machining Process Parameter Optimization via the Taguchi Method. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham. 34.
29. Rathod, N.J. et al. (2026). Aluminum Machining Process Parameter Optimization in WEDM with the GRA Approach. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham. 35.

30. Rathod, N.J. et al. (2026). Optimizing Wire Electric Discharge Machining Process Parameters for AISI 304 Stainless Steel via Taguchi Design of Experiments. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham. https://doi.org/10.1007/978-3-031-89771-9_8 36.
31. Rathod, N.J. et al. (2026). SS304 CNC Turning Process Mathematical Modeling and Machining Parameter Optimization Utilizing the Taguchi Technique. In: Al-Ramahi, N., Musleh Al-Sartawi, A.M.A., Kanan, M. (eds) Artificial Intelligence in the Digital Era. Studies in Systems, Decision and Control, vol 594. Springer, Cham. https://doi.org/10.1007/978-3-031-89771-9_2 37.
32. Nikhil Janardan Rathod, Praveen B. M., Mayur Gitay, Sidhhant N. Patil, Mohan T. Patel, (2025) Implementation of Machine Learning Approaches for the Modeling and Predictive Turning Maintenance Operations Incorporating Lubrication and Cooling in Systems of Manufacturing. Journal of Neonatal Surgery, 14 (15s), 1741-1748 38.
33. Nikhil J. Rathod, Nilesh Ingale, Mahesh T. Dhande, Santhosh H Pawar, A REVIEW ON AI ENABLED MULTI MODEL CARDIOVASCULAR MONITORING SYSTEM FOR PREDICTION OF PHYSIOLOGICAL STRESS, Department of Computer Science and Technology, 2025, 180724/IJORAR-1019, 39.
34. Mayur Jayant Gitay, Dr. Nilesh Diwakar, Dr. M. K. Chopra, Dr. Nikhil J. Rathod, Analysis of the performance of a CI engine operating in dual fuel mode with biogas and biodiesel, Eur. Chem. Bull. 2023,12(3) 4462-4472 40.
35. Prashant S. Raut, Dr. Nilesh Diwakar, Sumit Raut, Dr. Nikhil J. Rathod, Performance Evaluation and Emission Characteristic of Biodiesel (Methyl Ester) CI Engine, Eur. Chem. Bull. 2023, 12 (S3), 2240 – 2245 41. Sumit R. Raut, Dr. Nilesh Diwaka, Prashant S. Raut,
36. Dr. N. J. Rathod, Additives Characterization for Enhanced Biodiesel Performance in a CI Engine, Eur. Chem. Bull. 2023, 12 (S3), 2234 – 2239 42.
37. Sumit R. Raut, Dr. Nilesh Diwakar, Prashant S. Raut, Dr. N. J. Rathod, The Technique Performance Evaluation and Emission Characteristics of diesel, cerium oxide, and ethanol, Eur. Chem. Bull. 2023, 12 (S3), 3172 – 3184. 43.
38. Prashant S. Raut, Dr. Nilesh Diwakar, Sumit Raut, Dr. Nikhil J. Rathod, The Technique Performance Evaluation and Emission Characteristics of Biodiesel, Eur. Chem. Bull. 2023, 12 (S3), 3147 – 3155
39. Dr. Mayur Jayant Gitay, Dr. Nikhil J. Rathod , Mr. Rohit K. Dhende, Mr. Sagar S. Sasan. "PERFORMANCE ANALYSIS OF NATURAL FIBER REINFORCED COMPOSITES FOR SUSTAINABLE ENGINEERING APPLICATIONS", Multidisciplinary Journal of Academic Publications ISSN (Online): 3107-538X Vol. 02, Issue 01, January – February 2026, MJAP/05/0402.
40. Dr. Mayur Jayant Gitay, Dr. Nikhil J. Rathod , Mr. Rohit K. Dhende, Mr. Sagar S. Sasan, "IMPACT AND CRASHWORTHINESS PERFORMANCE OF COMPOSITE STRUCTURES IN AUTOMOTIVE APPLICATIONS", Multidisciplinary Journal of Academic Publications ISSN (Online): 3107-538X Vol. 02, Issue 01, January – February 2026, 2026/MJAP/09/0403.
41. Dr. Mayur Jayant Gitay, Dr. Nikhil J. Rathod , Mr. Rohit K. Dhende, Mr. Sagar S. Sasan, "IMPACT AND CRASHWORTHINESS PERFORMANCE OF COMPOSITE STRUCTURES IN AUTOMOTIVE APPLICATIONS", Multidisciplinary Journal of Academic Publications ISSN (Online): 3107-538X Vol. 02, Issue 01, January – February 2026, 2026/MJAP/09/0403.
42. Dr. Mayur Jayant Gitay, Dr. Nikhil J. Rathod , Mr. Rohit K. Dhende, Mr. Sagar S. Sasan, "THERMO-MECHANICAL PERFORMANCE OF POLYMER MATRIX COMPOSITES: A CRITICAL REVIEW", Multidisciplinary Journal of Academic Publications ISSN (Online): 3107-538X Vol. 02, Issue 01, January – February 2026, 2026/MJAP/09/0405.