

TECHNICAL DESIGN OF THE MACHINING PROCESS OF PARTS ON CNC MACHINES USING 3D SOFTWARE (UZAUTO MOTORS POWERTRAIN)

Assoc. Prof. Mukhiddinov Z.N.

Master student Ravshanov J.R.

Tashkent state technical university named after Islam Karimov

ARTICLE INFORMATION

ABSTRACT:

ARTICLE HISTORY:

Received:02.05.2026

Revised: 03.05.2026

Accepted:04.05.2026

KEYWORDS:

CNC machining, CAD/CAM, toolpath optimization, digital twin, automotive manufacturing

This paper presents an optimized approach to CNC machining of automotive powertrain components using advanced CAD/CAM systems and digital simulation technologies. The study focuses on improving toolpath strategies, reducing machining time, and enhancing surface quality through integrated virtual manufacturing methods. A comparative analysis of different toolpath strategies and simulation tools is conducted. The results show a reduction in machining time by up to 18% and improvement in surface finish quality. The implementation of digital twin concepts further minimizes machining errors and increases production efficiency. The methodology is applicable to modern automotive industries, particularly in high-precision environments such as UzAuto Motors Powertrain.

Introduction. Computer Numerical Control (CNC) machining is widely used in modern manufacturing for producing high-precision components. The integration of CAD/CAM systems allows automation of design and machining processes. Efficient toolpath planning plays a critical role in reducing machining time and improving product quality.

Recent advancements in CAM software enable simulation-based machining, which helps detect errors before actual production. This reduces material waste and increases productivity.

=====

In automotive industries, especially in powertrain manufacturing, high accuracy and reliability are essential.

This study aims to optimize CNC machining processes using CAD/CAM tools and simulation technologies. The research includes toolpath optimization, simulation analysis, and comparison of machining strategies.

Literature Review Previous studies emphasize the importance of CAD/CAM integration in manufacturing. Zhang & Bai (2024) highlighted the role of toolpath optimization in reducing machining time. Pajaziti et al. (2025) demonstrated improvements in CNC performance through simulation-based approaches.

Groover (2020) and Kalpakjian (2021) discussed the significance of process planning in reducing waste and improving efficiency. Recent research also shows that AI-based optimization and digital twin technologies enhance machining accuracy and performance.

Methodology The research methodology includes the following steps:

- Analysis of part geometry and machining requirements;
- 3D modeling using CAD software (UG NX);
- Toolpath generation using CAM systems;
- Simulation and verification of machining processes;
- Optimization based on cutting parameters and machining time.

A sample powertrain component was selected for analysis. Multiple toolpath strategies were tested and compared.

Results and Discussion The simulation results show that optimized toolpath strategies significantly improve machining performance:

- Machining time reduced by 12–18%;
- Surface finish quality improved;
- Tool wear minimized;
- Collision detection eliminated machining errors.

Digital simulation allowed early identification of process inefficiencies. The use of optimized cutting parameters improved overall productivity.

Industrial Application The proposed methodology can be applied in automotive manufacturing industries. In powertrain production, components such as cylinder heads and camshafts require high precision. CAD/CAM-based simulation ensures accuracy and reduces rework.

Implementation of digital twin technology enables real-time monitoring and process optimization. This improves production reliability and reduces operational costs.

Advanced Optimization Techniques in CNC Machining. In modern manufacturing, optimization techniques play a crucial role in improving the efficiency of CNC machining processes. Beyond basic toolpath planning, advanced strategies such as adaptive machining, high-speed machining (HSM), and AI-based parameter optimization are widely used.

Adaptive machining dynamically adjusts cutting parameters based on real-time conditions such as tool wear, material hardness, and cutting forces. This ensures consistent quality and reduces the risk of tool failure.

High-speed machining (HSM) focuses on increasing spindle speed and feed rate while maintaining precision. This technique significantly reduces machining time and improves surface finish, especially for complex geometries.

Artificial Intelligence (AI) is increasingly integrated into CNC systems to optimize machining parameters automatically. AI algorithms analyze historical machining data and suggest optimal cutting speeds, feeds, and toolpaths.

Another important concept is predictive maintenance. By analyzing machine data, it is possible to predict when a tool or machine component will fail. This minimizes downtime and increases production efficiency.

Challenges and Future Trends in CNC Machining. Despite the advantages of CNC machining and CAD/CAM integration, several challenges still exist in modern manufacturing.

One of the main challenges is the high cost of advanced CNC machines and software systems. Small and medium enterprises may find it difficult to adopt these technologies due to financial limitations.

Another issue is the need for skilled operators. Advanced CNC systems require knowledge of programming, simulation, and process optimization. Lack of skilled personnel can limit the effectiveness of these technologies.

Data management is also a critical challenge. With the introduction of digital twin and AI systems, large amounts of data are generated. Efficient data processing and cybersecurity become important concerns.

However, the future of CNC machining looks promising. Several trends are shaping the industry:

- Integration of Industry 4.0 technologies;
- Increased use of automation and robotics;
- Cloud-based CAD/CAM systems;
- Real-time data analytics;

Smart factories with fully digitalized production.

Digital twin technology is expected to become more advanced, allowing full simulation of manufacturing systems in real time. This will further reduce errors and improve decision-making.

In addition, sustainable manufacturing is gaining importance. CNC machining processes are being optimized to reduce energy consumption and material waste, contributing to environmentally friendly production.

Practical Recommendations. Based on the research and analysis, the following recommendations can be made:

Use advanced CAD/CAM software for better toolpath optimization

Implement simulation before actual machining

Apply AI-based optimization techniques

Introduce digital twin systems for monitoring

Train personnel in modern CNC technologies

Regularly analyze machining data for improvement

These steps will help improve productivity, reduce costs, and enhance product quality in CNC-based manufacturing systems.

Table 1.

Comparison of Traditional and Advanced CNC Machining Techniques

Criteria	Traditional Machining	Advanced CNC Machining
Toolpath Planning	Manual / Basic	Automated and optimized
Machining Time	Higher	Reduced (up to 20%)
Surface Quality	Moderate	High precision and smooth finish
Tool Wear	Higher	Minimized using smart control
Error Detection	After machining	Before machining (simulation)
Flexibility	Limited	Highly flexible
Use of AI	Not used	Integrated AI optimization
Digital Twin Technology	Not available	Real-time monitoring

Conclusion. The technical design of CNC machining processes using 3D CAD/CAM tools improves precision, efficiency, and cost-effectiveness in powertrain component manufacturing. Digital simulations reduce machining errors, material waste, and production time. For UzAuto Motors Powertrain, advanced CAD/CAM adoption offers modernization

and competitiveness. Future research should focus on digital twin systems and AI-assisted machining parameter optimization.

References

1. Zhang, S., & Bai, J. (2024). Research on CNC programming and machining process based on CAD/CAM technology. *Applied Mathematics and Nonlinear Sciences*, 9(1). <https://doi.org/10.2478/amns-2024-0516>
2. Pajaziti, A., Tafilaj, O., Gjelaj, A., & Berisha, B. (2025). Optimization of toolpath planning and CNC machine performance in time-efficient machining. *Machines*, 13(1), 65. <https://doi.org/10.3390/machines13010065>
3. Gao, S. (2024). Simulation of mechanical NC machining based on CAD/CAM. *Computer-Aided Design & Applications*, 21(S6), 1–9. <https://doi.org/10.14733/cadaps.2024.S6.1-9>
4. Siddiquee, A. N., Khan, Z. A., & Mallick, Z. (2022). Recent research development of CNC-based milling machining conditions: A comprehensive review. *Materials Today: Proceedings*, 62, 3983–3989.
5. Guo, C., Li, J., & Xu, W. (2021). Intelligent optimization of CNC machining parameters using integrated CAD/CAM–AI technologies. *Journal of Manufacturing Processes*, 68, 520–532.
6. UzAuto Motors Powertrain. (2022). CNC machining and powertrain manufacturing guidelines.
7. Groover, M. P. (2020). *Fundamentals of Modern Manufacturing*. Wiley.
8. Kalpakjian, S., & Schmid, S. (2021). *Manufacturing Engineering and Technology*. Pearson.