

Experimental Investigation of Optimizing Machining Parameters in CNC Machining

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Abstract—The automotive manufacturing industry requires high productivity, precision, and cost efficiency. CNC machining plays a critical role; however, improper parameter selection leads to increased cycle time, reduced productivity, and higher costs. This study presents an experimental investigation optimizing CNC machining parameters for a pipe union used in hydraulic and fuel line applications. Key parameters—spindle speed, feed rate, depth of cut, and tool path—were systematically optimized across facing, drilling, boring, undercutting, and back facing operations. Results indicate a cycle time reduction from 107 s to 79 s ($\approx 26\%$), with production rate increasing from 26 to 39 parts/hour ($\approx 47\%$ improvement). Component quality was maintained within specified tolerances throughout.

Index Terms—CNC machining, cycle time reduction, manufacturing, parameter optimization, production rate, tool wear.



Fig 1: pipe union

In the current scenario, the pipe union studied was produced with a cycle time of 107 seconds, yielding only 26–27 parts per hour—considerably below achievable capacity. This study was undertaken to identify optimal parameters, reduce cycle time, and improve resource utilization.

I. INTRODUCTION

The automotive manufacturing industry is among the most demanding sectors in modern engineering. Computer Numerical Control (CNC) machining has become fundamental due to its ability to produce complex geometries with tight tolerances and high repeatability. CNC machines are widely used for engine parts, transmission systems, and fluid line fittings.

Despite their advantages, CNC machine efficiency largely depends on the selection of machining parameters such as spindle speed, feed rate, depth of cut, and tool path strategy. Improper selection leads to increased machining time, excessive tool wear, poor surface finish, and higher production costs. Components like pipe unions used in hydraulic and fuel systems require high dimensional accuracy and leak-proof performance—even minor deviations can cause system failures and safety risks.

II. PROBLEM STATEMENT

In CNC machining of automotive components such as pipe unions, non-optimized machining parameters lead to higher cycle time, lower production rates, and inefficient resource utilization. In the existing process, a cycle time of 107 seconds resulted in limited output, affecting overall productivity. Increasing machining parameters without proper optimization can also impact tool life, surface finish, and dimensional accuracy, which are critical for hydraulic and fuel line applications. Therefore, there is a need to optimize machining parameters to reduce cycle time, improve production efficiency, and maintain product quality and reliability.

III. OBJECTIVES

The primary objective of this study is to optimize CNC machining parameters to improve productivity and efficiency in the manufacturing of an automotive pipe union component. The study aims to analyze the existing machining process in order to identify the factors responsible for higher cycle time and lower production rate. It focuses on evaluating the influence of key machining parameters such as spindle speed, feed rate, depth of cut, and tool path on overall

machining performance. Based on this analysis, the work seeks to optimize these parameters to achieve a reduction in cycle time without compromising product quality. In addition, the study aims to enhance production rate and machine utilization through systematic parameter adjustment while ensuring that tool life remains within acceptable limits. The optimized process is further validated through dimensional inspection, microstructural analysis, and functional leak testing to ensure reliability in practical applications. Finally, the study intends to quantify improvements in productivity, efficiency, and operational performance, and to establish a practical and scalable approach for CNC machining optimization in industrial environments.

IV. LITERATURE BACKGROUND

A. Cutting Parameter Optimization

Sharma et al. [1] demonstrated that systematic parameter selection can significantly minimize machining time without compromising quality. Kumar and Reddy [2] identified feed rate as critical, noting that excessively high rates reduce cycle time but degrade surface finish. Singh et al. [3] highlighted the trade-off between productivity and energy efficiency. Hassan et al. [4] confirmed that both spindle speed and feed rate significantly influence machining time and surface quality.

B. Statistical and Systematic Methods

Patel et al. [5] applied Design of Experiments (DoE) to optimize cycle time in automotive CNC components, quantifying the relative significance of each parameter. Ahmed et al. [6] used the Taguchi method, demonstrating efficient identification of optimal factor levels with minimal experiments. Zhang et al. [7] emphasized CNC program optimization in automotive mass production as a complementary strategy.

C. Tool Path, Fixture, and Idle Time Reduction

Li et al. [8] achieved significant machining time reduction through tool path optimization alone, without altering cutting parameters. Mehta and Rao [9] showed that optimized tool paths maintain or improve surface finish alongside reducing cycle time. Verma et al. [10] demonstrated that fixture design optimization reduces setup time and improves dimensional accuracy.

V. PROPOSED METHODOLOGY

A. Component and Raw Material

The selected component is a pipe union widely used in hydraulic and fuel line systems, demanding high dimensional accuracy and strict tolerance adherence. Raw material is first processed using Traub automation, producing semi-finished blanks with consistent initial dimensions before CNC transfer.



Fig 2: pipe union blanking

B. CNC Machining Operations

Five sequential operations were performed: (1) Facing—creates a flat reference surface; (2) Drilling—produces an axial hole for fluid flow; (3) Boring—enlarges and finishes the hole to precise dimensions; (4) Undercutting—creates relief grooves for assembly; (5) Back facing—finishes internal surfaces for proper seating.



Fig 3: CNC operation

C. Tooling Selection

Carbide inserts were selected for their wear resistance and thermal stability. TNMG 0.8 mm inserts (6 usable edges) were used for facing, providing approximately 600 components per edge. CCMT 0.8 mm inserts were used for undercutting and CCMT 0.4 mm for back facing, both yielding 200–250 components per edge. Tools were replaced proactively within these limits to maintain consistent quality.

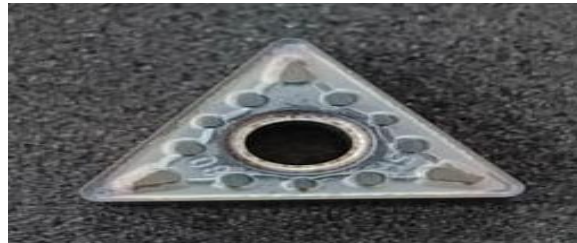


Fig 4: TNMG 0.8mm

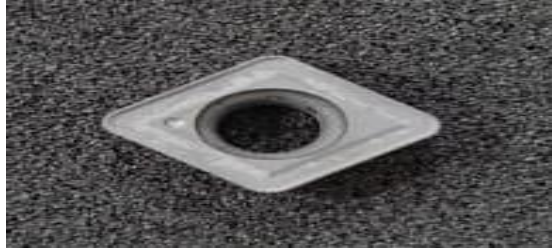


Fig 4: CCMT 0.8mm

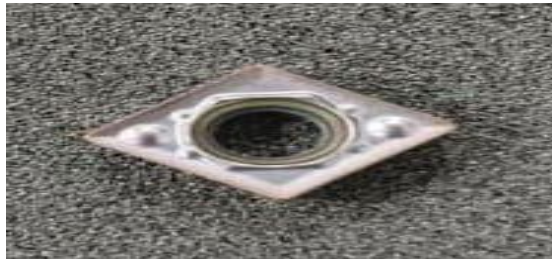


Fig 5: CCMT 0.4mm

D. Parameter Optimization

Spindle speeds were increased across all operations, and feed rates were optimized to reduce machining time while maintaining surface quality. The optimization strategy balanced productivity and quality by increasing feed rates within safe limits, adjusting spindle speeds, and improving tool path efficiency to reduce idle movement. Data was collected over 60 monitored hours.

TABLE I. Spindle RPM Comparison

Cycle Time	107 seconds	79 seconds
Operation	Spindle RPM (S)	Spindle RPM (S)
Facing	S2800	S3200
Drilling	S1000	S1800
Boring	S2500	S3500
Under cut	S2000	S3000
Back facing	S2000	S2500

TABLE 3.2 FEED RATE COMPARISON

Cycle Time	107 seconds	79 seconds	79 seconds
Operation	Feedrate (F)	Feedrate (F)	Secondary cut

Facing	F0.5	F0.25	-
Drilling	F0.06	F0.11	-
Boring	F0.15	F0.25	F0.27
Under cut	F0.16	F0.22	-
Back facing	F0.1	F0.17	-

VI. RESULTS AND DISCUSSION

A. Cycle Time Reduction

Cycle time was reduced from 107 s to 79 s—a reduction of 28 seconds (26.17%). In mass production, this reduction translates to substantial cumulative output gains. Over a monitored 30-hour window, output increased from 780 to 1,170 components, a net gain of 390 parts.

B. Production Rate and Efficiency

Production rate is calculated as 3600 / cycle time. Before optimization, theoretical output was 33 parts/hour with practical output of 26–27 parts/hour. After optimization, theoretical output reached 45 parts/hour with practical output of 38–40 parts/hour. Productivity improvement was approximately 44.4%, achieved without additional machinery or manpower.

C. Tool Wear Performance

Tool wear was monitored throughout to ensure increased parameters did not cause excessive wear. No sudden tool failure was observed; wear was gradual and predictable. TNMG inserts maintained ~600 parts per edge; CCMT inserts handled 200–250 parts per edge. Optimized parameters-maintained tool life within acceptable industrial limits.

D. Surface Finish and Dimensional Accuracy

Despite increased feed rates, no noticeable deterioration in surface finish was observed. All components fell within specified tolerance ranges with zero rejections due to dimensional deviation, confirming that higher productivity was achieved without sacrificing quality.

E. Microstructural and Functional Validation

Microstructural analysis (per ASM Handbook Volume 09-2004) confirmed no micro-cracks, no heat-affected zones, and uniform grain structure. All components successfully passed hydraulic leak testing under

pressure conditions, validating the suitability of optimized parameters for real-world applications.

VII. LIMITATIONS

This principle relies on the reliable readout of the tag, the accurate mapping of the recipe, and maintenance of the bin locking mechanism. Various environmental factors like metal surfaces, orientation of the tags, location of antennas, and radio frequency interference can influence RFID functionality. This is why pilot testing is needed before implementation. Bin design should also be user-friendly to avoid slowing down the process due to mistake-proofing.

One more constraint is the accuracy of the database. In case the master data of the recipe is inaccurate, the system could accurately perform the wrong command.

VIII. FUTURE SCOPE

Future work may explore Design of Experiments (DoE), AI-based optimization methods, automated loading/unloading systems, and energy-efficient machining practices. The methodology is scalable and applicable to other automotive components and machining environments.

IX. CONCLUSION

This study demonstrates that optimizing CNC machining parameters is a practical and effective method to enhance productivity in automotive component manufacturing. By reducing cycle time from 107 s to 79 s and increasing production rate by approximately 47%, significant gains were achieved purely through parameter refinement—without additional machinery or labour investment. Component quality, dimensional accuracy, surface finish, and tool life were all maintained within acceptable limits.

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REFERENCES

[1] P. Sharma, R. Kumar, and V. Singh, Optimization of CNC Turning Parameters for Cycle Time

Reduction, *Journal of Manufacturing Processes*, vol. 85, pp. 112-121, 2023.

- [2] S. Kumar and M. Reddy, Experimental Investigation on Feed Rate Optimization in CNC Milling, *Materials Today: Proceedings*, vol. 62, pp. 2450-2456, 2022.
- [3] A. Singh, P. Verma, and K. Rao, Influence of Cutting Parameters on Productivity and Energy Consumption in CNC Machining, *Journal of Cleaner Production*, vol. 276, p. 123456, 2020.
- [4] A. Hassan, K. Ibrahim, and M. Ali, Experimental Study on Spindle Speed and Feed Optimization in CNC Turning Operations, *Advances in Production Engineering & Management*, vol. 17, no. 2, pp. 215-226, 2022.
- [5] D. Patel, A. Joshi, and R. Mehta, Cycle Time Optimization in Automotive CNC Components Using Design of Experiments, *Procedia Manufacturing*, vol. 55, pp. 312-319, 2021.
- [6] T. Ahmed, M. Rahman, and M. Hassan, Optimization of CNC Milling Parameters Using Taguchi Method for Machining Time Reduction, in *Proc. Int. Conf. on Smart Manufacturing*, 2022, pp. 210-216.
- [7] L. Zhang, J. Wu, and Y. Liu, CNC Program Optimization for Automotive Mass Production Systems, *Robotics and Computer-Integrated Manufacturing*, vol. 80, p. 102456, 2023.
- [8] H. Li, Y. Zhang, and X. Chen, Reduction of Non-Productive Time in CNC Machining through Tool Path Optimization, *Int. Journal of Advanced Manufacturing Technology*, vol. 132, no. 3-4, pp. 1587-1598, 2024.
- [9] S. Mehta and P. Rao, Impact of Tool Path Strategies on Machining Time and Surface Quality in CNC Milling, *Manufacturing Letters*, vol. 29, pp. 45-50, 2021.
- [10] N. Verma, S. Gupta, and R. Khandelwal, Fixture Design Optimization for Improved CNC Machining Efficiency, *Journal of Manufacturing Systems*, vol. 73, pp. 98-110, 2024.