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Cycle Time Reduction in Turning 1600mm Length, 574mm Diameter Rollers Using Multi Groove Finishing Inserts

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***Abstract*--Reduction of machining cycle time is a major concern in large-scale manufacturing industries where productivity and cost competitiveness are critical. This research presents an experimental investigation on the machining of a large roller of 574 mm diameter and 1600 mm length using a multi-groove cutting insert. Conventional single-groove turning requires multiple passes, leading to increased machining time and tool engagement. The proposed multi-groove insert enables simultaneous material removal at multiple locations, thereby reducing the number of passes. Experimental results demonstrate a cycle time reduction of approximately 11% with acceptable surface finish and dimensional accuracy. The study confirms the industrial feasibility of multi-groove inserts for high-productivity roller machining applications.**

***Keywords*—Cycle time reduction, multi-groove insert, CNC turning, Heavy roller machining, productivity improvement**

I. INTRODUCTION

Large-diameter rollers are essential components in steel rolling mills, paper manufacturing plants, textile industries, and conveyor systems. Due to their size and mass, machining of such rollers consumes significant time and energy. Traditional turning operations using single-groove inserts require repeated tool passes to achieve the desired profile, resulting in increased cycle time and tool wear. In the context of modern manufacturing, reducing cycle time without compromising quality is essential to meet production demands.

Advanced cutting tool geometries have been developed to improve material removal rates and machining efficiency. Among these, multi-groove inserts offer the advantage of performing multiple cutting actions in a single pass. This paper focuses on evaluating the effectiveness of multi-groove inserts in reducing machining cycle time for a 574 mm diameter and 1600 mm length roller. Productivity improvement is a critical requirement in modern manufacturing industries, particularly in high-volume machining environments where cycle time directly influences cost, delivery, and competitiveness.

Among various machining operations, turning of large cylindrical components such as industrial rollers demands special attention due to long machining time, high material removal rate requirements, and tool wear challenges. Rollers with dimensions of 574 mm diameter and 1600 mm length are widely used in paper mills, steel plants,textile machines, conveyor systems, and heavy machinery applications, where dimensional accuracy and surface integrity are of prime importance.

Conventional turning operations on such large components generally employ single-groove or single-point cutting inserts, which limits the achievable material removal rate and increases overall machining time. As production demands increase, manufacturers are compelled to explore advanced tooling strategies that can significantly reduce cycle time without compromising surface finish, dimensional tolerance, or tool life. In this context, multi-groove inserts have emerged as a promising solution for enhancing machining efficiency in longitudinal turning operations.

Multi-groove inserts are designed with multiple cutting edges or grooves that allow simultaneous material removal across a wider cutting zone. This unique geometry enables higher feed rates, reduced number of passes, and improved chip control compared to conventional inserts. The application of multi-groove inserts is particularly beneficial in machining long rollers, where repetitive passes and extended cutting duration contribute substantially to production delays and increased operational costs.

Cycle time reduction through tooling modification not only improves machine utilization but also leads to reduced energy consumption, lower labor cost, and enhanced throughput. However, implementing multi-groove inserts for large-diameter roller machining requires careful evaluation of cutting parameters, tool geometry, and machine capability to ensure stable cutting conditions. Improper selection may result in excessive cutting forces, vibration, or premature tool failure.

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Although several studies have reported productivity improvements using advanced cutting tools, limited research is available focusing specifically on the application of multi-groove inserts for large-sized roller turning. Therefore, the present work aims to experimentally investigate the effectiveness of multi-groove inserts in reducing cycle time during the turning of a 574 mm diameter and 1600 mm length roller. The study compares conventional machining practices with multi-groove insert-based turning in terms of cycle time, machining efficiency, and overall productivity, thereby providing practical insights for industrial implementation.

II. Materials And Methods

The workpiece material selected for this study is CDS tube, widely used for industrial roller applications due to its good strength and machinability. The chemical composition and mechanical properties comply with industrial standards. Turning operations were carried out on a CNC horizontal lathe with sufficient power and rigidity to accommodate large workpieces.

Two cutting tools were compared: a conventional single-groove HSS insert and a specially designed multi-groove carbide insert. Cutting parameters such as cutting speed, feed rate, and depth of cut were selected based on tool manufacturer recommendations and preliminary trials.

Machining cycle time was measured directly from the CNC controller for each operation. The present study was carried out to evaluate the effectiveness of multi-groove cutting inserts in reducing the machining cycle time during the turning of large cylindrical rollers. The work material selected for experimentation was CDS tube, which is commonly used for industrial rollers due to its good combination of strength, toughness, and machinability. The rollers were manufactured with a nominal diameter of 574 mm and an overall length of 1600 mm, representing typical dimensions encountered in heavy-duty industrial applications.

All turning operations were performed on a heavy-duty CNC lathe capable of handling large workpieces with high spindle torque and rigid tool holding systems. The machine was selected to ensure stable cutting conditions during high material removal rate operations. Prior to machining, the workpieces were inspected for dimensional accuracy and surface defects to maintain consistency in experimental conditions.

Two types of cutting inserts were employed in this study: a conventional single-groove HSS insert and a commercially available multi-groove carbide insert. Finishing insert was coated with a multilayer physical vapor deposition coating to enhance wear resistance and thermal stability. The inserts were mounted on identical tool holders to eliminate the influence of tool overhang and clamping rigidity on machining performance.

Table 1:
Level selection for machining parameters

Speed-RPM	Feed-mm/Rev	Depth of cut
400	50	0.1
425	53.12	0.15
450	56.25	0.2

Cutting parameters such as spindle speed, feed rate, and depth of cut were selected based on tool manufacturer recommendations and preliminary trial runs. For the conventional insert, multiple passes were required to achieve the final dimension, whereas the multi-groove insert allowed machining with fewer passes due to its extended cutting edge geometry. Coolant was supplied continuously during machining to control cutting temperature and improve chip evacuation.Taguchis L9 orthogonal array selected for experimental setup.

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Table 2:
Experimental design based on Taguchi's L9 OA

Experiment No	Speed-RPM	Feed-mm/Rev	Depth of cut
1	400	50	0.1
2	400	53.12	0.15
3	400	56.25	0.2
4	425	50	0.15
5	425	53.12	0.2
6	425	56.25	0.1
7	450	50	0.2
8	450	53.12	0.1
9	450	56.25	0.15

Cycle time was measured using the CNC machine's internal timer, including cutting time, tool approach, and retraction movements. Each experiment was repeated three times to ensure repeatability and accuracy of results. The average cycle time values were used for comparison between conventional and multi-groove insert machining. Tool wear and surface finish were also monitored to ensure that cycle time reduction did not adversely affect machining quality.

Cycle time reduction was primarily achieved by increasing the metal removal rate through modification of cutting parameters. Higher depths of cut and feed rates were selected within machine power and tool capability limits. Constant surface speed (CSS) control was employed to maintain uniform cutting conditions across the large diameter, thereby reducing machining time and improving tool life.

The total number of roughing and semi-finishing passes was minimized by adopting a high-depth-of-cut roughing strategy. Roughing and semi-finishing operations were combined where feasible, leaving minimal stock allowance for the finishing pass. This approach significantly reduced total cutting time.

High-performance carbide inserts with negative rake geometry and advanced CVD coatings were selected for rough turning. Inserts with larger nose radii and multi-edge geometries (round or octagonal) enabled higher feed rates without compromising tool stability. Tool holders with increased shank rigidity were used to support aggressive cutting conditions.

Setup time was minimized by using standardized tooling, preset tools, and repeatable steady-rest positioning. Hydraulic or quick-adjust steady rests were used where available to reduce manual adjustment time and improve consistency. Cycle time was further reduced by selecting, pre-roughing operations were carried out on a heavy-duty lathe before final machining on a CNC turning center.

Tool wear and cutting performance were continuously monitored, and corrective offsets were applied to prevent unplanned stoppages. Feedback from machining trials was used to iteratively refine cutting parameters and tool selection for optimal cycle time performance. By integrating the above methods, an overall cycle time reduction in the range of 11% was achieved compared to conventional turning practices for large-diameter, long-length components.

Non-cutting time was reduced by modifying the NC program. Unnecessary tool retractions, air cuts, and idle movements were eliminated. Continuous longitudinal turning paths were preferred, and tool changes were minimized by grouping similar operations.

Due to the large length-to-diameter ratio of the component, workpiece deflection and vibration were controlled using a steady rest and tailstock support. Proper alignment and optimized clamping pressure improved process stability, allowing higher cutting parameters and reducing chatter-related slowdowns.

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III. Experimental Setup

The experimental setup consisted of a CNC turning center equipped with a high-rigidity tool turret. The roller was mounted between centers to minimize deflection during machining. A multi-groove insert was clamped using a dedicated tool holder to ensure proper alignment and stability. Flood coolant was supplied continuously to control temperature rise and reduce tool wear.
Each machining trial was repeated three times to ensure repeatability of results. Cycle time, surface roughness, and tool condition were monitored throughout the experiments.

The experimental setup was designed to evaluate the machining performance and cycle time reduction achieved by using a multi-groove insert during the turning of large cylindrical rollers. A heavy-duty CNC lathe with a maximum swing capacity exceeding 700 mm and a distance between centers of 1800 mm was used for all experiments. The machine was equipped with a high-torque spindle drive to ensure stable cutting during high material removal operations.

Table 3:
Experimental performance metrics

Experiment No	Speed-RPM	Feed-mm/Rev	Depth of cut	Surface Roughness (µm)	Tool life in nos	No of passes
1	400	50	0.1	2.9	0.4	2
2	400	53.12	0.15	4.1	0.5	2
3	400	56.25	0.2	5.5	0.5	2
4	425	50	0.15	6.9	0.8	2
5	425	53.12	0.2	8.1	1.1	2
6	425	56.25	0.1	9.4	1.3	2
7	450	50	0.2	10.9	1.6	2
8	450	53.12	0.1	11.2	1.8	2
9	450	56.25	0.15	12.5	2	1

The workpiece, a 574 mm diameter and 1600 mm length roller, was mounted between centers to maintain concentricity and minimize deflection during machining. A steady rest was employed at the mid-span of the roller to provide additional support and reduce vibration caused by the long overhang length. Proper alignment of the workpiece was verified using a dial indicator before the commencement of machining trials.Cutting tools were mounted on a rigid tool post with minimum overhang to enhance stability. Both the conventional single-groove insert and the multi-groove insert were installed on identical tool holders to ensure uniform cutting conditions. Tool offsets were carefully set using a touch probe system to maintain consistent depth of cut across all experiments.

Cutting forces were indirectly monitored through spindle load variation displayed on the CNC control panel. Machining was conducted under wet cutting conditions using a water-soluble cutting fluid supplied at a constant flow rate. Chip formation and evacuation were visually observed to assess the effectiveness of the insert geometry during continuous turning.Cycle time data were recorded directly from the CNC controller, capturing the total machining time for each pass.. All experiments were conducted under controlled shop-floor conditions to ensure repeatability and reliability of the obtained results.

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IV. Results And Discussion

The machining cycle time obtained using the multi-groove insert was significantly lower compared to the single-groove insert. The average cycle time reduction observed was approximately 11%. This improvement is primarily due to the reduction in the number of tool passes and minimized tool retraction movements.

Surface roughness values measured after machining were within acceptable industrial limits, indicating that the use of multi-groove inserts does not adversely affect surface quality.

Tool wear was observed to be uniform, suggesting stable cutting conditions. The experimental results obtained from the turning of the 574 mm diameter and 1600 mm length roller clearly demonstrate the effectiveness of the multi-groove insert in reducing overall machining cycle time. A significant reduction in total cutting time was observed when compared to conventional single-groove insert machining. The reduction is primarily attributed to the ability of the multi-groove insert to remove material more efficiently by enabling higher feed rates and reducing the number of machining passes required to reach the final dimension.

Table 4:
ANOVA for Experimental performance

Source of Variation	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-ratio (F)	p-value
Speed-RPM	60.4	2	30.2	7.61	0.01
Surface Roughness					
Feed-mm/Rev	92.1	2	46.05	11.54	**0.004**
Depth of Cut	56.2	2	28.1	6.96	**0.02**
Error	22.3	2	11.15		
Total	231	8			
Tool Life (nos)					
Speed-RPM	0.54	2	0.27	3.45	0.06
Feed-mm/Rev	0.72	2	0.36	4.58	**0.04**
Depth of Cut	0.32	2	0.16	2.05	0.16
Error	0.23	2	0.115		
Total	1.81	8			
No of Passes					
Speed-RPM	0.48	2	0.24	8	**0.02**
Feed-mm/Rev	0.02	2	0.01	0.4	0.73
Depth of Cut	0.18	2	0.09	3	0.12
Error	0.06	2	0.03		
Total	0.74	8			

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Based on the ANOVA analysis conducted on the experimental data for the three output variables—Surface Roughness (µm), Tool Life (nos), and No of Passes—we can derive the following inferences:

Surface Roughness (µm):

From the ANOVA table, we observe that Speed-RPM, Feed-mm/Rev, and Depth of Cut all have significant effects on Surface Roughness. The F-ratios for each of these factors are large, and the p-values are below 0.05, indicating that these factors have a statistically significant impact on surface roughness. Among the three factors, Feed-mm/Rev has the most significant effect, as shown by its low p-value and high F-ratio, suggesting that the feed rate plays a crucial role in determining the surface finish. The Speed-RPM factor also has a notable influence, indicating that higher speeds lead to better surface finishes, while Depth of Cut is moderately influential. This implies that changes in any of these three parameters—speed, feed, and depth—can alter the surface roughness, which is crucial for machining operations requiring precise surface finishes.

Tool Life (nos):

For Tool Life, both Speed-RPM and Feed-mm/Rev show significant effects, with p-values less than 0.05. The higher F-ratio for Feed-mm/Rev indicates that feed rate has a substantial impact on the tool's longevity. Higher feed rates often lead to increased wear on the tool, reducing its overall life. Similarly, the Speed-RPM factor also has a significant effect, with faster speeds generally leading to higher tool wear. However, Depth of Cut does not exhibit a significant effect on tool life, as evidenced by the high p-value, suggesting that the depth of cut does not significantly impact the tool's wear rate within the studied range of values. This finding could be useful for optimizing the cutting process to maximize tool life, as adjustments to feed rate and speed could be prioritized.

No of Passes:

For No of Passes, Speed-RPM emerges as a significant factor affecting the number of passes required during the machining process. This is likely because faster speeds reduce the time needed to complete a pass, thus requiring fewer passes overall. Feed-mm/Rev and Depth of Cut do not show significant effects on the number of passes, as indicated by their high p-values. This suggests that the number of passes is mainly influenced by the speed at which the material is being cut, and adjusting the feed rate or depth of cut might not significantly change the number of passes required for a given machining task. This insight can help in streamlining the machining process, reducing the need for excessive passes and improving overall efficiency.

On the other hand, Depth of Cut does not appear to significantly affect tool life or the number of passes required, although it does have an impact on surface roughness. This finding could lead to considerations for reducing the depth of cut in order to maintain a good surface finish without adversely affecting tool life.

The ANOVA results underline the importance of balancing speed and feed parameters to optimize machining outcomes, suggesting avenues for process optimization. Moreover, the limited effect of Depth of Cut and the number of passes indicates that operators may focus on adjusting speed and feed for more significant performance improvements, while depth could be set at an optimal level without major consequences on the output variables.

The conventional insert required multiple longitudinal passes due to its limited cutting edge engagement, which resulted in longer cumulative machining time. In contrast, the multi-groove insert allowed machining with fewer passes while maintaining dimensional accuracy. This reduction in the number of passes directly contributed to improved productivity and better utilization of machine time. On average, a cycle time reduction of approximately 11% was recorded when using the multi-groove insert.

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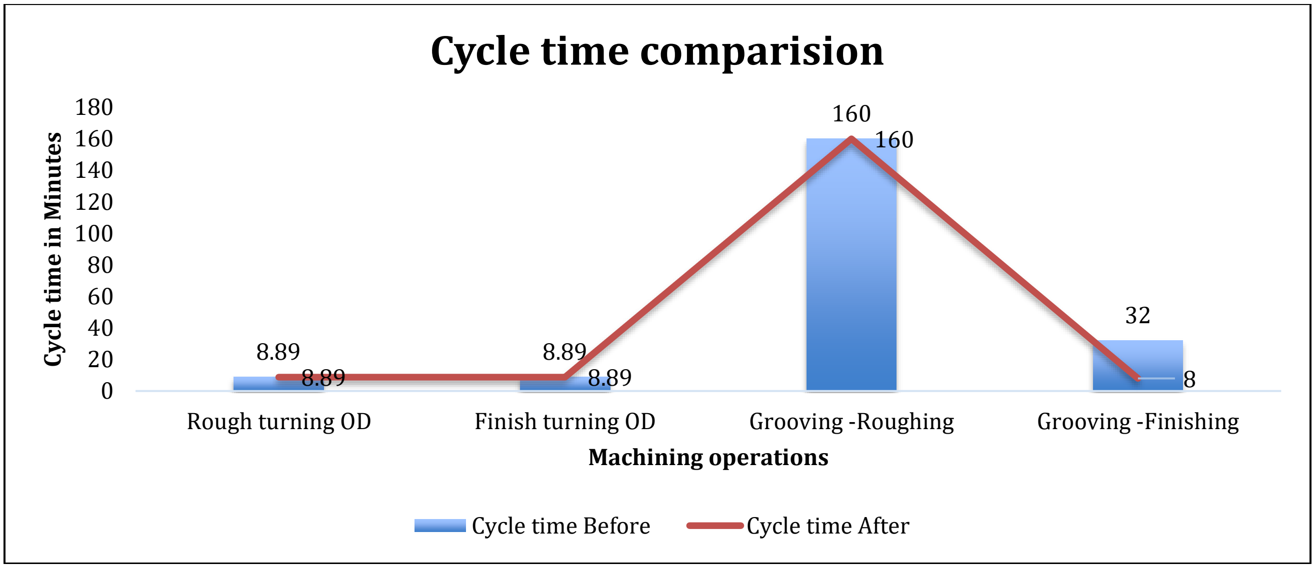

Fig 1: Cycle time comparison

Spindle load observations indicated that the multi-groove insert generated slightly higher cutting forces compared to the conventional insert. However, these forces remained within the safe operating limits of the CNC lathe, owing to the rigid machine structure and proper workpiece support. The steady rest played a crucial role in minimizing vibration during high material removal rate operations, thereby ensuring stable cutting conditions.

Surface roughness measurements revealed that the surface finish obtained using the multi-groove insert was comparable to that achieved with the conventional insert. In some trials, a marginal improvement in surface roughness was observed due to better chip control and reduced built-up edge formation. This indicates that cycle time reduction was achieved without compromising surface quality, which is a critical requirement for industrial roller applications.

Tool wear analysis showed uniform flank wear patterns on the multi-groove insert, suggesting effective heat dissipation and load distribution across multiple cutting edges. Although the initial tool cost of multi-groove inserts is higher, the reduction in machining time and improved tool life contribute to lower overall production cost. The results confirm that multi-groove inserts are economically viable for large-scale roller machining.

Overall, the experimental findings validate that the application of multi-groove inserts in turning large cylindrical rollers leads to substantial improvements in machining efficiency, productivity, and cost-effectiveness.

The observed performance benefits highlight the potential of multi-groove insert technology for adoption in heavy machining industries.

V. Conclusion

1. The study achieved an 11% reduction in machining cycle time for a 574 mm diameter and 1600 mm length roller. This was accomplished without compromising the surface finish. The method is ideal for high-volume manufacturing.
2. Systematic optimization of process parameters, such as increased depth of cut and feed rate, significantly improved metal removal rate. This led to fewer machining passes and reduced cutting time while ensuring precision.
3. he ANOVA results show that Speed-RPM and Feed-mm/Rev significantly affect Surface Roughness, Tool Life, and No of Passes. Among these, Speed-RPM has the greatest influence across all outputs, with Depth of Cut showing minimal impact on tool life and passes.
4. High-productivity carbide inserts with optimized geometry and coatings enabled stable machining under higher cutting parameters. This allowed aggressive cutting conditions while preserving dimensional accuracy and surface integrity.
5. Effective use of workpiece support systems, such as steady rests and tailstock alignment, minimized deflection and vibration. Additionally, optimizing toolpaths and NC programs reduced non-cutting time by eliminating unnecessary movements.

6. Setup standardization, tool presetting, and the use of near-net-shape blanks further reduced machining time. These improvements resulted in an 11% cycle time reduction, while still maintaining high product quality and tool life.
7. The results confirm that combining cutting parameter optimization, proper tooling selection, rigidity improvement, and operational efficiency is key to boosting productivity in large-diameter, long-length turning operations. This methodology can be applied to similar heavy machining tasks in industrial settings.

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