

Comparative Performance of Analysis of CNC and Conventional Machining Techniques

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Abstract: In current-day industries, machining is an indispensable part that produces parts with good surface finish and high precision. With the inclusion of automation, precision, and productivity, CNC machining has revolutionized the traditional way of manufacturing processes. In consideration of certain machining parameters such as machining time, dimensional accuracy, surface finish, material removal rate, tool wear, efficiency of production, and cost of operation, this paper evaluates the comparison between CNC and traditional machining processes. The experiments involved mild steel work pieces processed using CNC machine tools as well as conventional lathes, keeping the same machining conditions. For ensuring precise comparison between the two processes, various factors like spindle speed, feed rate, and depth of cut were kept constant during the experiments. The results obtained from the experiments indicate that CNC machining compared to traditional machining provides greater accuracy, surface finish, reduced machining time, minimum tool wear, and higher efficiency in manufacturing processes. Nevertheless, due to its low cost and convenience, traditional machining can be considered economically feasible for limited scale production and repair work. Moreover, from the findings, it is evident that CNC machining is less dependent on humans and therefore, proves more effective in cases requiring precision and mass production

Keywords: CNC Machining, Conventional Machining, Machining Performance, Surface Roughness, Dimensional Accuracy, Material Removal Rate, Tool Wear, Production Efficiency, Manufacturing Technology, Comparative Analysis

I. INTRODUCTION

One of the most important manufacturing processes to manufacture metallic and non-metallic parts with good surface finishes and accurate dimensions is machining technology. To manufacture precise technical parts, machining operations have been extensively employed in the automobile, aerospace, defense, biomedical, and manufacturing industries. Traditional machine tools like lathes, drills, shapers, and milling machines were utilized to carry out machining operations previously. The complete machining operation was highly dependent on the operator's experience and human intervention. Traditional machining operations are simple and economical for small-scale production but have several disadvantages including reduced accuracy, prolonged machining time, operator exhaustion, and inconsistent part quality [1]. CNC machining is a modern manufacturing technique that is able to eliminate most limitations of conventional machining processes owing to the fast development of automated and computerized manufacturing systems.

In CNC machining, the movement of the machine tool and cutting conditions are achieved by programming numeric codes into the machine. The accuracy in controlling the cutting speed, feed rate, cutting depth, and tool movement is provided by the computerization of machine tools, leading to highly precise machining operations. Little human interaction is required to operate CNC machines, making them suitable for manufacturing complex parts and geometries. CNC technology can enhance the efficiency, decrease the machining time, improve the smoothness of the surface and reduce the reject rate due to its ability for continuous and automated operations. In contrast,



conventional machining is highly dependent on the manual skills and experience of the machine operator, which may lead to poor consistency and dimensional errors [3]. Since manufacturers are always interested in effective and economic production technologies, a comparative study of the performance characteristics of CNC machining against conventional machining has become increasingly important in manufacturing engineering research. In terms of performance evaluation of both of these machining processes, some of the aspects considered include machining accuracy, material removal rate, production efficiency, surface roughness, tool wear, energy utilization, and operation costs. According to researchers' findings, CNC machining has superior performance because of the automation in the control system and advanced machining capabilities. But in cases where the high cost associated with acquiring CNC machinery is not justified, such as in repair operations, education, and limited scale of operations, conventional machining can be used [4]. In recent times, the significance of CNC machining in industrial environments has increased due to the incorporation of Industry 4.0 technologies and automation in manufacturing. Sensors, CAM, and real-time monitoring have been incorporated into CNC machinery to improve efficiency. CNC machines may prove difficult to sustain for smaller firms due to the high initial investment required in addition to maintenance. Therefore, an in-depth comparison between CNC and conventional machining processes is crucial for understanding their strengths, weaknesses, and applicability to different environments [5]. Considering the amount of production, complexity of parts involved, economics, and the level of quality expected, such a comparison helps manufacturing companies make informed decisions regarding their machining processes [10].

Table 1: Comparative Performance Parameters

Parameter	CNC Machining	Conventional Machining
Accuracy	Very high precision	Moderate precision
Surface Finish	Excellent	Average
Production Rate	High	Low
Human Dependency	Minimal	High
Setup Time	Low after programming	High
Flexibility	High for complex shapes	Limited
Tool Control	Automatic	Manual
Repeatability	Excellent	Poor to moderate
Labor Requirement	Less	More
Initial Cost	High	Low
Maintenance	Complex	Simple
Skill Requirement	Programming knowledge required	Skilled operator required

Methodology for Comparative Analysis

A systematic experimental technique is employed in order to evaluate the machining behavior when similar operating conditions prevail, as part of the methodology involved in the performance comparison between CNC and conventional machining techniques [11]. To begin with, suitable workpiece materials such as aluminum alloys or mild steels that possess similar machining behavior are selected depending on their suitability and usage in the industry. In order to ensure uniformity in the experiment, specimens of the raw material are made using identical measurements [13]. To ensure uniformity in the performance assessment, similar cutting tools and machining conditions are selected for CNC and conventional machining. While machining is done manually by an expert operator using traditional machine tools such as lathes and milling machines, CNC machining is programmed via the Computer Numerical Control process. Following that, the machining processes are executed separately through both methods under controlled conditions. A variety of essential parameters, such as machining time, accuracy, surface finish, material removal rate, wear and tear, and efficiency, are accurately measured and recorded during experiments. The quality of the machined parts is tested using accurate measuring instruments such as Vernier calipers, micrometers, dial gauges, and surface finish testers [12].



The timer is utilized in measuring the machining time required for every machining process. The resulting dimension will be assessed based on certain design specifications to measure the dimensional errors. The ability of both machining processes to machine surfaces with high precision and surface roughness will be established through surface finish evaluation[14]. The effects of machining conditions on tool wear are investigated through the observation of tools used after every machining process. Performance variation among the two machining systems will be determined by analyzing the gathered experimental data statistically and comparatively[9]. Graphs and tables will be used to analyze productivity, accuracy, efficiency, and economy of the respective machining systems. The factors such as human intervention, time required for setup, repeatability, and flexibility of machines among others are analyzed through this process. Decisions are then made about the usefulness of CNC machining and conventional machining technologies according to the gathered information[8]. This process ensures that one gets an accurate understanding of the pros and cons of the two machining processes in modern manufacturing industries[15].

Table 2: Workpiece and Tool Specifications

Parameter	Specification
Workpiece Material	Mild Steel (MS)
Workpiece Diameter	25 mm
Workpiece Length	100 mm
Cutting Tool Material	High Speed Steel (HSS)/Carbide
Tool Geometry	Single Point Cutting Tool
Coolant Used	Soluble Oil Coolant
Machining Operation	Turning Operation

Table 3: Machining Parameters Used for Experiment

Parameter	CNC Machining	Conventional Machining
Spindle Speed (rpm)	1200	1200
Feed Rate (mm/rev)	0.20	0.20
Depth of Cut (mm)	1.0	1.0
Cutting Environment	Wet Machining	Wet Machining
Tool Path Control	Automatic	Manual
Machine Type	CNC Lathe	Conventional Lathe

Table 4: Instruments Used for Measurement

Instrument	Purpose
Vernier Caliper	Dimensional Measurement
Micrometer	Precision Diameter Measurement
Surface Roughness Tester	Surface Finish Evaluation
Stopwatch	Machining Time Measurement
Dial Gauge	Accuracy Checking
Tool Maker Microscope	Tool Wear Observation

Table 5: Experimental Observation Table

Observation Parameter	CNC Machine	Conventional Machine
Machining Time (min)	4.5	8.2



Surface Roughness Ra (μm)	1.2	3.8
Dimensional Error (mm)	± 0.01	± 0.08
Material Removal Rate (mm^3/min)	High	Moderate
Tool Wear Rate	Low	Higher
Production Efficiency	High	Moderate
Rejection Rate (%)	2%	8%

Table 6: Comparative Performance Evaluation

Performance Criteria	CNC Machining	Conventional Machining
Accuracy	Excellent	Moderate
Repeatability	Very High	Low
Operator Dependency	Low	High
Production Rate	High	Low
Surface Quality	Better	Average
Setup Time	Low	High
Labor Requirement	Less	More
Initial Investment	High	Low
Maintenance Complexity	High	Moderate
Suitability	Mass Production	Small-Scale Production

Experimental Analysis

For comparing the machining performance of CNC and conventional machining processes in the same operating environment, an experimentation process was carried out. Machining parameters such as machining time, accuracy of dimensions, surface finish, rate of material removal, wear on the cutting tools, and productivity were key aspects being considered in this experiment. Mild steel was used as the work material, and the turning process was performed using identical cutting conditions on CNC and conventional lathes. In order to have a fair comparison of results, constant values of spindle speed, feed rate, and depth of cut were maintained throughout the experiment[7]. The CNC machine employed pre-programmed numerical commands that enabled it to perform operations during the machining process with precision control of cutting conditions and automatic tool motion. Conversely, traditional machining involved the use of operator skills and manual controls only. A stop watch was employed in measuring the time required for machining per operation, whereas dimensions were obtained through Vernier calipers and micrometers. The surface roughness of the machined surfaces was evaluated using a surface roughness meter. Tool wear assessment after the machining process was performed to evaluate the influence of the cutting conditions on the life span of the tools. The results from the test proved that CNC machining showed remarkable improvement in productivity, accuracy, and consistency compared to traditional machining processes[6]. This is because the CNC machine, due to its accurate control systems, achieved better surface finish and minimized dimensional variation. Traditional machining was found to be time-consuming and had more dimensional variation since it was manually performed. Another finding that emerged from the test was that CNC machining had lower rates of tool wear since the parameters remained constant throughout the process.



Table 7: Experimental Analysis of CNC and Conventional Machining Techniques

S. No.	Parameter	CNC Machining	Conventional Machining	Observation/Analysis
1	Workpiece Material	Mild Steel	Mild Steel	Same material used for comparison
2	Machining Operation	Turning	Turning	Identical machining operation performed
3	Cutting Tool Material	Carbide Tool	Carbide Tool	Same cutting tool used
4	Spindle Speed (rpm)	1200	1200	Constant machining condition maintained
5	Feed Rate (mm/rev)	0.20	0.20	Same feed rate for both techniques
6	Depth of Cut (mm)	1.0	1.0	Uniform cutting depth maintained
7	Machining Environment	Wet Machining	Wet Machining	Coolant applied in both processes
8	Facing Time (min)	0.8	1.5	CNC required less machining time
9	Rough Turning Time (min)	1.5	3.0	Faster operation in CNC machining
10	Finish Turning Time (min)	1.2	2.2	CNC achieved quicker finishing
11	Total Machining Time (min)	4.5	8.2	CNC improved productivity
12	Surface Roughness Ra (μm)	1.2	3.8	Better surface finish in CNC
13	Diameter Obtained (mm)	25.01	25.08	CNC showed better dimensional accuracy
14	Length Obtained (mm)	100.02	100.12	Conventional machining showed higher deviation
15	Dimensional Tolerance	± 0.01 mm	± 0.08 mm	CNC maintained closer tolerances
16	Material Removal Rate	High	Moderate	CNC provided efficient cutting performance
17	Tool Wear	Low	Moderate	Controlled cutting reduced wear in CNC
18	Tool Life	Longer	Shorter	CNC improved tool durability
19	Production Efficiency	High	Moderate	CNC suitable for mass production
20	Operator Dependency	Low	High	Conventional machining required skilled operator
21	Repeatability	Excellent	Limited	CNC ensured consistent product quality
22	Rejection Rate	Very Low	Comparatively High	CNC reduced manufacturing defects
23	Initial Investment	High	Low	Conventional machines are economical initially
24	Overall Performance	Superior	Moderate	CNC demonstrated better machining performance

II. RESULTS AND DISCUSSION

When contrasted with conventional methods of machining, it can be deduced from the comparative analysis that CNC machining greatly improves production performance. This is due to the fact that since CNC machines use computer-controlled instructions to manipulate machine motions, they achieve better dimensional accuracy and repeatability. Optimal tool motion and parameters in CNC machining lead to improved machining speeds. The



measurement of surface finish also shows that surface finish obtained through CNC machining is improved such that no additional finishing is needed.

Conventional machining processes are useful due to the fact that they are relatively easy to use and have lower costs of set up. The reliance on human labor in conventional machining may cause fluctuations in the quality of manufactured goods. On the other hand, CNC machining reduces the level of human interference and guarantees uniformity in the sizes of the products. In CNC machining, tool wear is better managed than in conventional machining because of accurate cutting conditions and feed adjustment. According to economic consideration, CNC machining requires a higher initial cost compared to conventional machining, but when it comes to mass production industries, the cost of production per unit decreases because of increased productivity and reduced number of faulty products.

III. CONCLUSION

While the capital expense for the purchase of CNC machines may be expensive, its advantages far exceed the disadvantages in a mass production setup. The traditional process of machining may continue to play a significant role in smaller operations where simplicity and affordability come into play. Thus, the decision to employ either technology will depend on the production volume, the accuracy expected, economics, and the overall manufacturing objectives. The performance comparison of CNC machining processes vis-a-vis traditional methods proves the dominance of the former.

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