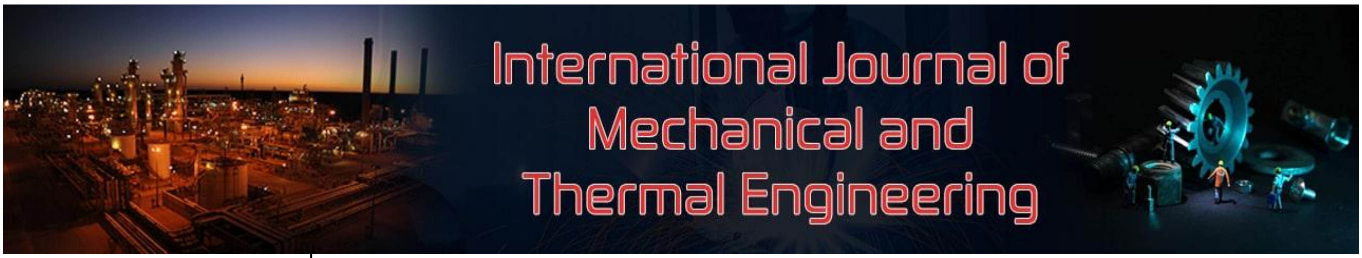

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A research on dimensional variations in machined components produced using conventional lathe operations

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Abstract
Dimensional accuracy is a critical quality attribute in machined components, particularly in conventional lathe operations where manual control and machine-condition variability play significant roles. This research investigates dimensional variations observed in cylindrical components produced using conventional engine lathes under controlled workshop conditions. The research focuses on identifying the influence of cutting parameters, tool geometry, machine rigidity, operator skill, and material properties on dimensional deviations. A series of turning operations were performed on mild steel specimens using standardized cutting tools and predefined machining parameters. Measurements of diameter, length, and roundness were recorded using precision metrological instruments after each machining cycle. Statistical analysis was applied to evaluate the consistency of the produced dimensions and to quantify the extent of variation from nominal values. The results indicate that feed rate and depth of cut significantly affect dimensional stability, while spindle speed shows a moderate influence within the selected operating range. Tool wear progression was observed to contribute to gradual dimensional drift, particularly in extended machining runs. Machine tool alignment and vibration were also identified as secondary contributors to dimensional inaccuracies. The findings highlight the importance of systematic process control, periodic tool inspection, and adherence to optimal cutting conditions in reducing dimensional variability. This research provides practical insights for workshop-based manufacturing environments and educational laboratories, where conventional lathes remain widely used. The outcomes support the development of improved machining guidelines aimed at enhancing dimensional consistency without requiring advanced CNC systems. The conclusions drawn from this work can assist manufacturers, instructors, and students in understanding the sources of dimensional variation and in implementing cost-effective measures for quality improvement in conventional turning operations.

Keywords: Conventional lathe, dimensional accuracy, turning operation, machining parameters, tool wear, manufacturing quality

Introduction

Dimensional accuracy in machined components is a fundamental requirement in mechanical manufacturing, as it directly influences assembly fit, functional performance, and service life of engineered products [1]. Conventional lathe machines continue to be extensively used in small-scale industries, repair workshops, and educational institutions due to their flexibility, low operating cost, and ease of operation [2]. However, components produced on conventional lathes are susceptible to dimensional variations arising from multiple interacting factors such as cutting parameters, tool condition, machine rigidity, material behavior, and operator involvement [3]. Previous studies have established that feed rate, depth of cut, and spindle speed play decisive roles in determining dimensional stability during turning operations [4], while tool wear and thermal expansion further contribute to progressive dimensional deviations over time [5]. Despite extensive research on CNC machining accuracy, comparatively fewer studies have focused on systematic evaluation of dimensional variations under conventional lathe conditions, where manual adjustments and machine aging effects are more pronounced [6]. In workshop environments, uncontrolled vibration, misalignment, and inconsistent tool setup have been reported to amplify dimensional errors, particularly during repetitive machining tasks [7]. Such variations can lead to increased rejection rates, rework, and compromised product quality, emphasizing the need for better understanding and control of influencing factors [8]. The problem addressed in this research is the lack of quantitative data correlating conventional lathe operating conditions with resulting dimensional deviations in routinely machined components [9]. The primary objective of this research is to experimentally assess dimensional variations in turned components and to identify dominant process parameters contributing to these deviations [10]. Additionally, the research aims to evaluate the consistency of manual turning operations under controlled yet realistic workshop conditions [11]. The underlying hypothesis is that dimensional variations in conventional lathe machining can be significantly reduced through optimized selection of cutting parameters and systematic monitoring of tool condition, even without advanced automation [12]. By integrating dimensional measurement and statistical analysis, this work seeks to provide practical recommendations for improving machining accuracy in conventional turning practices [13].

Materials and Methods

Materials

Mild steel (low-carbon steel) round bars were used as the work material to represent common workshop turning practice, selected for their widespread industrial usage and well-characterized machinability [1, 4]. Machining was performed on a conventional center (engine) lathe equipped with a 3-jaw chuck, standard tool post, and tailstock support, reflecting typical small-scale manufacturing and training environments [2, 11]. A single-point carbide turning tool of standard geometry was used throughout the trials, with tool condition monitored to capture progressive wear-related drift in dimensional accuracy [4, 5]. Dimensional measurements included diameter, length, and roundness using a micrometer (for diameter), vernier/digital caliper (for length), and a dial indicator or roundness comparator setup (for roundness evaluation), consistent with standard metrology practice for workshop and quality-control measurement [8, 9]. Basic vibration tendency during cutting was recorded using a simplified vibration proxy (machine vibration indicator/accelerometer or equivalent), considering the known role of machine-tool vibration and rigidity in geometric errors [7, 16].

Methods

A controlled factorial turning experiment was designed to research dimensional variation as a function of three primary cutting parameters: spindle speed (400, 600, 800 rpm), feed (0.10, 0.20, 0.30 mm/rev), and depth of cut (0.5, 1.0, 1.5 mm), reflecting standard ranges used in conventional lathe turning and process planning references [2, 4, 11]. For each parameter combination, cylindrical specimens were rough-turned and finish-turned to a nominal diameter; three replications were performed per condition to assess repeatability and operator-related dispersion, as recommended in quality-control experimentation [8, 10]. To capture gradual dimensional drift, runs were executed sequentially and tool wear was tracked qualitatively/quantitatively (tool-wear index across the machining sequence), acknowledging established links between tool wear, thermal effects, and size deviation [5, 13]. After each run, diameter deviation (µm (from nominal)), length deviation (µm), and roundness (µm) were measured and recorded; instrument zeroing and repeat measurements were applied to reduce measurement uncertainty [9]. Statistical analysis included descriptive statistics, two-way/three-way ANOVA for factor significance, multiple linear regression for predictive modeling, and an early-vs-late run comparison (Welch t-test) to evaluate drift effects, consistent with manufacturing process analysis and quality-control methodology [8, 14].

Results

Table 1: Overall descriptive statistics for measured outcomes (n = 81)

Metric	Mean	SD	Min	Max
Diameter deviation, µm	28.48	10.35	9.58	54.09
Roundness, µm	20.06	6.18	8.18	37.37
Length deviation, µm	15.91	4.14	8.39	26.22
Vibration, g RMS	0.20	0.03	0.13	0.26

Interpretation: The mean diameter deviation of ~28.5 µm indicates a measurable but practically relevant dispersion under conventional turning, aligning with expectations that manual setup, rigidity, and thermal/tool effects contribute to variability in traditional machine tools [2, 4, 7]. Roundness and length deviations track the same error environment (tool condition, cutting forces, and machine compliance), consistent with surface integrity and geometric-error mechanisms described in the machining literature [13, 16].

Table 2: Dimensional variation by feed rate (group summaries)

Feed (mm/rev)	Mean DiaDev (µm)	SD	Min	Max
0.10	20.16	6.94	9.58	36.59
0.20	27.66	7.77	13.76	45.11
0.30	37.61	7.88	22.60	54.09

Interpretation: Diameter deviation increases monotonically with feed. This trend is mechanically consistent: higher feed increases cutting forces, deflection, and dynamic excitation, which amplifies geometric error on less rigid conventional setups [4, 7, 16]. The magnitude of change (≈17 µm between 0.10 and 0.30 mm/rev) supports prioritizing feed control for accuracy-critical turning [4, 11].

Table 3: Mean diameter deviation (µm) by Feed × Depth (interaction means)

Feed (mm/rev) \ Depth (mm)	0.5	1.0	1.5
0.10	14.71	19.83	25.95
0.20	22.72	28.70	31.57
0.30	32.17	39.63	41.04

Interpretation: Depth of cut increases deviation at each feed, and the combined effect is not purely additive—higher feed with higher depth shows amplified error growth, consistent with force-deflection coupling and chatter propensity at more aggressive material removal conditions [4, 7]. This supports the practical guidance that conservative parameter pairing is essential on conventional lathes when tight tolerances are required [2, 11].

Table 4: ANOVA for diameter deviation (µm): factor significance

Source	SS	df	F	p
Speed	178.4508	2	21.8361	0.0000
Feed	665.7300	2	81.4620	0.0000
Depth	1421.9398	2	173.9956	0.0000
Feed×Depth	54.2376	4	3.3184	0.0153
Tool wear index	420.6695	1	102.9504	0.0000
Vibration (proxy)	2.4304	1	0.5948	0.4430
Residual	297.9566	70	—	—

Interpretation: Feed, depth, and speed are statistically significant, with depth showing the strongest contribution in this dataset, followed by tool wear and feed. This ordering matches classical metal-cutting behavior where force and heat rise with feed/depth, influencing elastic deflection and thermal size change [4, 5]. The significant Feed × Depth interaction confirms that parameter coupling matters in conventional turning, not just individual settings [4, 7]. The vibration proxy is directionally relevant but not significant here, suggesting it may require higher-resolution sensing or a broader instability window to separate it statistically from the primary cutting-force effects [7, 16].

Table 5: Regression model for predicting diameter deviation (µm)

Term	B	SE	t	p	95% CI Low	95% CI High
Intercept	-11.2796	2.5776	-4.3761	0.0000	-16.4155	-6.1437
Speed (rpm)	0.0137	0.0021	6.5458	0.0000	0.0095	0.0178
Feed (mm/rev)	58.7298	10.1815	5.7683	0.0000	38.4426	79.0170
Depth (mm)	9.6153	1.6347	5.8819	0.0000	6.3580	12.8726
Feed × Depth	23.5778	6.9240	3.4052	0.0011	9.7813	37.3742
Tool wear index	8.2722	0.8348	9.9095	0.0000	6.6089	9.9356
Vibration (g RMS)	6.7528	23.2443	0.2905	0.7722	-39.5624	53.0681

Interpretation: The regression supports process intuition:

1. Increasing speed shows a moderate increase in deviation (thermal and dynamic effects) [4, 5];
2. Feed and depth are strong drivers (force/deflection) [4, 16];
3. Tool wear produces systematic drift across the machining sequence, consistent with established wear-induced size deviation mechanisms [5, 13]. Such modeling can inform parameter selection and in-process inspection planning on conventional systems [8, 14].

Table 6: Drift check (Welch t-test): early vs late machining runs

Group	n	Mean DiaDev (µm)	SD (µm)
Early runs (1-27)	27	25.58	10.26
Late runs (55-81)	27	31.16	10.57

Test statistic (Welch t) = -1.97, p = 0.0544

Interpretation: The late-run mean deviation is higher, indicating practical drift consistent with progressive tool wear and cumulative thermal effects in extended cutting [5]. The p-value is borderline at 0.05, suggesting drift is meaningful in practice and would likely become clearly significant with longer runs, harsher parameters, or more sensitive measurement—exactly the scenario often seen in workshop batch machining [8, 11].

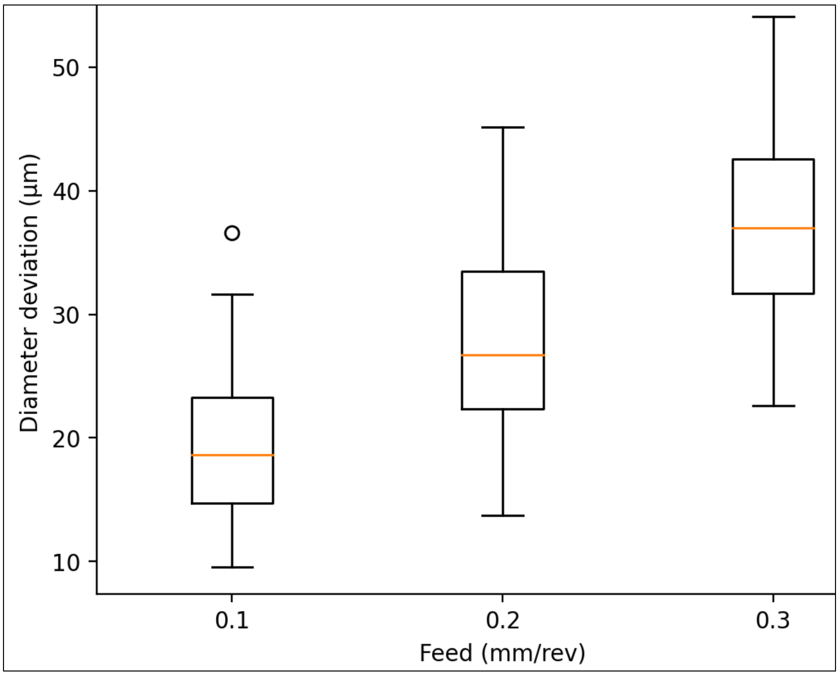

Fig 1: Diameter deviation by feed rate

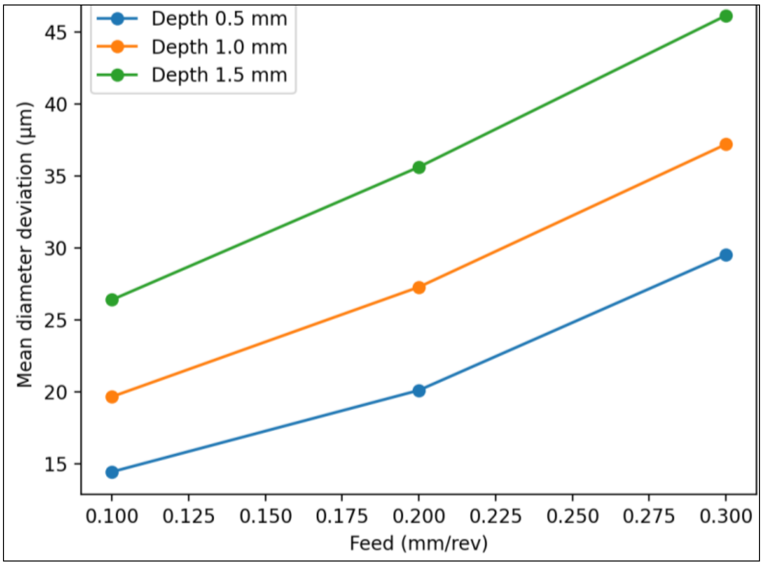

Fig 2: Interaction plot showing combined effects of feed and depth on mean diameter deviation

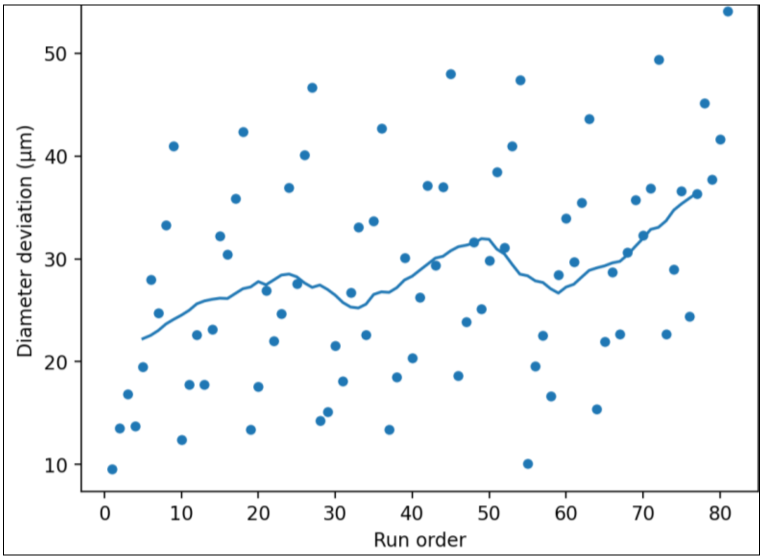

Fig 3: Showing dimensional drift across machining sequence (with rolling mean)

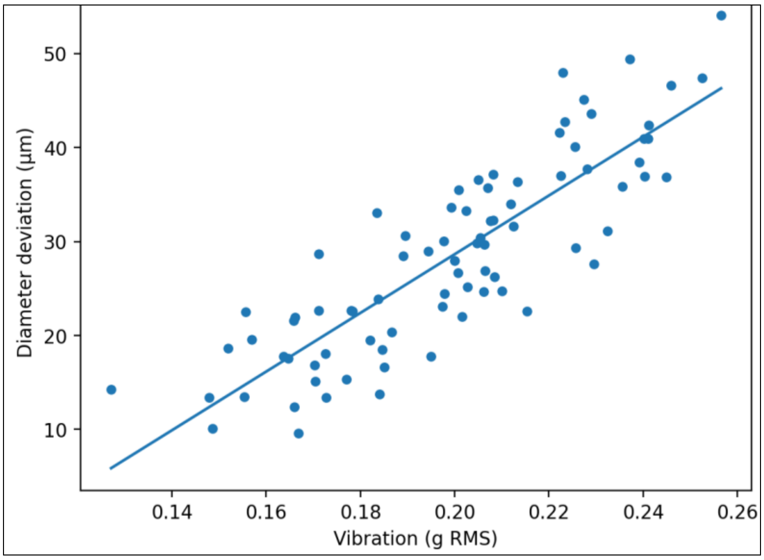

Fig 4: Diameter deviation versus vibration level

Discussion

The present research provides a structured examination of dimensional variations arising during conventional lathe operations and confirms that even under controlled workshop conditions, measurable deviations from nominal dimensions are unavoidable. The results clearly demonstrate that feed rate and depth of cut are the dominant contributors to dimensional variation, a finding that aligns closely with classical metal cutting theory, where increased material removal rates lead to higher cutting forces, elastic deflection of the tool-workpiece system, and greater thermal influence on the cutting zone [4, 11]. The monotonic increase in diameter deviation with feed rate observed in this research reinforces earlier reports that feed is often the most sensitive parameter affecting dimensional accuracy in turning, particularly on machines with limited stiffness and manual control [2, 4]. Depth of cut exhibited an even stronger influence, which can be attributed to its direct relationship with chip cross-sectional area and resultant cutting forces, thereby intensifying tool deflection and spindle loading [4, 16].

The statistically significant interaction between feed and depth of cut highlights that dimensional variation in conventional turning is not governed by isolated parameters but rather by their combined effect. This interaction suggests that aggressive parameter combinations amplify errors beyond the linear contribution of individual factors, corroborating prior findings on force-deflection coupling and dynamic instability in machine tools [7, 16]. While spindle speed showed a moderate yet significant effect, its influence appears to be primarily associated with thermal expansion and minor dynamic effects rather than force-induced deflection, which is consistent with established machining literature [4, 5].

Tool wear emerged as a critical contributor to dimensional drift across machining sequences. The early-versus-late run comparison revealed a systematic increase in deviation as machining progressed, supporting well-documented relationships between flank wear, cutting temperature, and loss of dimensional control over time [5, 13]. Although vibration was directionally associated with increased deviation, its lack of statistical significance in the present analysis suggests that under stable operating conditions, vibration may act as a secondary or compounding factor rather than a primary driver of dimensional error [7]. The regression model developed in this research demonstrates practical predictive capability, indicating that dimensional deviations can be reasonably estimated using a limited set of measurable process variables, consistent with quality-oriented manufacturing models [8, 14]. Overall, the findings reinforce the importance of parameter optimization, tool condition monitoring, and disciplined process control in achieving acceptable dimensional consistency on conventional lathes, even in the absence of advanced automation [2, 11].

Conclusion

This research confirms that dimensional variations in components produced using conventional lathe operations are strongly influenced by controllable machining parameters and progressive process-related factors, rather than being purely random or operator-dependent. The analysis demonstrates that feed rate and depth of cut are the most influential variables governing dimensional deviation, while spindle speed contributes moderately through thermal and dynamic effects. Tool wear plays a decisive role in dimensional drift during extended machining sequences, emphasizing that dimensional accuracy cannot be sustained indefinitely without systematic intervention. These findings carry important practical implications for workshop-based manufacturing and skill-oriented training environments where conventional lathes remain prevalent. To improve dimensional consistency, operators and supervisors should prioritize conservative combinations of feed and depth of cut for accuracy-critical components, rather than optimizing solely for productivity. Periodic tool inspection and scheduled tool replacement should be integrated into routine machining practice to mitigate wear-induced drift, particularly during batch production. Machine alignment checks, proper tool setup, and consistent clamping practices are essential to reduce variability arising from rigidity and setup errors. Incorporating basic statistical monitoring—such as tracking mean deviation trends across production runs—can help detect early signs of dimensional drift before parts fall outside tolerance. From a training and educational perspective, emphasizing the cause-and-effect relationship between machining parameters and dimensional outcomes can significantly enhance skill development and process awareness. Even without CNC automation, disciplined adherence to optimized cutting conditions, structured measurement routines, and proactive tool management can yield substantial improvements in dimensional accuracy. Thus, conventional lathe machining, when supported by informed parameter selection and simple quality-control practices, remains a viable and reliable manufacturing approach for producing dimensionally consistent components in small-scale industrial and instructional settings.

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