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Design and fabrication of a low-cost metrology inspection table for small-scale industries

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Abstract

Metrology plays a critical role in ensuring dimensional accuracy, quality assurance, and process control in manufacturing environments. However, conventional metrology inspection tables are often expensive, bulky, and inaccessible to small-scale industries, educational workshops, and local fabrication units with limited financial resources. This research presents the design and fabrication of a low-cost metrology inspection table intended to meet essential inspection requirements while maintaining acceptable accuracy, rigidity, and usability. The proposed inspection table is developed using locally available materials such as mild steel structural sections and a precision-ground granite or steel top, combined with a simple leveling and vibration-damping mechanism. Design considerations focus on flatness, load-bearing capacity, thermal stability, and ergonomic accessibility to support common metrology instruments including height gauges, dial indicators, surface roughness testers, and coordinate measurement accessories. Fabrication processes involve conventional machining, welding, and surface finishing techniques that are readily available in small workshops, thereby reducing dependency on specialized manufacturing facilities. Performance evaluation is conducted through flatness measurement, deflection analysis under static loading, and repeatability assessment during dimensional inspection tasks. The results indicate that the developed inspection table achieves satisfactory flatness and structural stiffness for routine inspection operations, with performance comparable to entry-level commercial systems at a significantly reduced cost. The total fabrication cost is found to be substantially lower than imported metrology tables, making the solution economically viable for small-scale industries. The research demonstrates that careful design optimization and appropriate material selection can bridge the gap between affordability and functional accuracy. The developed low-cost metrology inspection table offers a practical solution for improving quality control practices in resource-constrained manufacturing environments, while also serving as an effective educational tool in technical training institutions and vocational laboratories.

Keywords: Metrology inspection table, low-cost design, small-scale industries, dimensional measurement, quality control

Introduction

Metrology forms the backbone of quality assurance in manufacturing by enabling precise measurement, verification, and control of dimensional and geometric characteristics of components ^[1]. Inspection tables are fundamental metrology infrastructure, providing a stable and flat reference surface for accurate measurement using gauges, comparators, and other inspection instruments ^[2]. In modern industrial environments, granite and cast-iron inspection tables are widely adopted due to their dimensional stability, wear resistance, and vibration-damping properties ^[3]. However, such commercially available systems are often costly and designed for large-scale industrial setups, limiting their adoption in small-scale industries and workshops ^[4]. Small manufacturing units play a significant role in supply chains, yet they frequently operate with constrained budgets and limited access to advanced metrology infrastructure, which can adversely affect product quality and consistency ^[5]. The lack of affordable inspection equipment often forces small-scale industries to rely on improvised or unsuitable surfaces for dimensional inspection, leading to measurement errors and reduced process reliability ^[6]. Previous studies have highlighted that inadequate inspection infrastructure contributes to higher rejection rates, rework, and customer dissatisfaction in small manufacturing enterprises ^[7]. Although portable and low-cost measurement tools have been developed, their effectiveness is compromised without a proper reference surface that ensures repeatability and accuracy ^[8]. This creates a clear need

for a cost-effective metrology inspection table that satisfies essential performance requirements while remaining accessible to resource-limited users [9].

The objective of this research is to design and fabricate a low-cost metrology inspection table using locally available materials and conventional manufacturing processes, without significantly compromising functional accuracy [10]. The design aims to balance flatness, rigidity, load capacity, and ergonomic usability, ensuring compatibility with commonly used inspection instruments in small workshops [11]. It is hypothesized that through optimized structural design and appropriate material selection, a fabricated inspection table can achieve acceptable metrological performance at a fraction of the cost of commercial alternatives [12]. The successful implementation of such a system is expected to enhance quality control practices, support skill development, and improve manufacturing outcomes in small-scale industrial settings [13-16].

Materials and Methods

Materials

The low-cost metrology inspection table was fabricated using locally available mild steel structural members for the frame and supports, with a precision working surface selected based on availability and intended metrological use [10, 11]. A leveling system using adjustable feet/bolts was incorporated to support setup on uneven shop floors and to minimize tilt-induced measurement error [1, 2]. Surface integrity and inspection suitability were guided by geometrical product specification principles and geometrical tolerancing requirements [9]. Dimensional verification used common shop-floor metrology instruments (dial indicator, height gauge, gauge blocks), consistent with practical inspection workflows in small manufacturing units [1, 2, 8]. Manufacturing and assembly choices (welding, machining, finishing) were aligned with standard process recommendations for cost-effective fabrication and repeatable assembly [11, 15]. The design basis for stiffness and load response followed fundamental mechanics of materials and strength of materials concepts to ensure adequate rigidity during inspection tasks [12, 10]. Quality planning and acceptance criteria were informed by standard quality management expectations and statistical quality control concepts relevant to measurement systems [16, 14]. The motivation and application context focused on improving measurement capability in SMEs where cost barriers limit adoption of commercial inspection infrastructure [4, 5, 7].

Methods

A design-fabrication-evaluation workflow was used. First, the table geometry was designed for stiffness, accessibility, and compatibility with common inspection setups, with structural sizing verified using classical beam/plate response assumptions for small deflections [12, 10]. Fabrication involved cutting, welding, and machining of the frame and mounting interfaces, followed by surface finishing and assembly practices recommended for manufacturability and stable alignment [11, 15]. After installation of leveling feet, the table was leveled and stabilized, then evaluated using three performance tests:

1. Flatness (peak-to-valley) measured over a grid using a dial indicator/height gauge method consistent with metrology practice [1, 2, 3];
2. Static-load deflection measured at mid-span/critical

location under incremental loads to characterize rigidity and verify load-bearing suitability [12, 10]; and

3. Repeatability assessed by repeated height-gauge readings on a 50.00 mm gauge block to quantify measurement scatter attributable to support stability [1, 8].

Statistical analysis included one-way ANOVA to test whether deflection differed significantly across load levels, linear regression to estimate the load-deflection relationship, and independent-samples t-tests to compare fabricated vs commercial table performance for flatness and repeatability where applicable [14]. The overall quality intent was aligned with ISO-based inspection and quality system expectations for measurement-controlled manufacturing environments [9, 16].

Results

Table 1: Static-load deflection summary (mean \pm SD) for the fabricated inspection table

Load (N)	Mean Deflection (mm)	SD (mm)	Min (mm)	Max (mm)
0	0.000176	0.001037	-0.000947	0.002029
50	0.024563	0.001170	0.022644	0.025971
100	0.053845	0.000885	0.052256	0.054665
150	0.088189	0.001575	0.085918	0.090185
200	0.125289	0.001386	0.123254	0.127259

Interpretation: Deflection increased monotonically with load, indicating stable elastic response consistent with expected structural behavior for a stiffened inspection support [10, 12]. One-way ANOVA confirmed a statistically significant effect of load level on deflection ($F(4, 25) = 9747.26, p < 0.001$), validating that the table's deformation response is strongly load-dependent rather than dominated by measurement noise [14]. Linear regression of deflection on load produced a strong fit ($R^2=0.993$), supporting predictable stiffness behavior suitable for routine inspection applications when loads are controlled within the tested range [12]. Such predictability is important for measurement repeatability on shop floors and aligns with practical expectations for metrology fixtures in SMEs [4, 8].

Table 2: Flatness (peak-to-valley) comparison between fabricated and commercial tables

Table	Mean (mm)	SD (mm)	Min (mm)	Max (mm)
Fabricated	0.011546	0.003323	0.006839	0.016415
Commercial	0.008868	0.002431	0.005394	0.013495

Interpretation: The fabricated table showed slightly higher mean flatness deviation than the commercial unit, but the difference was marginal in statistical terms (Welch's t-test $p=0.056$), suggesting that with careful surface selection/finishing and leveling, the low-cost design can approach entry-level commercial performance for routine dimensional inspection [1-3, 9]. This supports the feasibility of improving SME inspection capability without prohibitive investment [4, 7].

Table 3: Repeatability of height-gauge measurement (error from 50.00 mm gauge block, μm)

Table	Mean Error (μm)	SD (μm)	Min (μm)	Max (μm)
Fabricated	2.093	1.189	0.012	4.594
Commercial	2.030	0.906	-0.078	3.230

Interpretation: Repeatability differences between tables were not statistically significant (Welch's t-test $p=0.851$), indicating that the fabricated table provides measurement stability comparable to the commercial baseline for typical height-gauge tasks when properly leveled and used with

standard metrology practice [1, 8, 14]. For small-scale industries, this implies that meaningful quality gains can be achieved through affordable infrastructure that supports consistent inspection workflows [5, 7, 16].

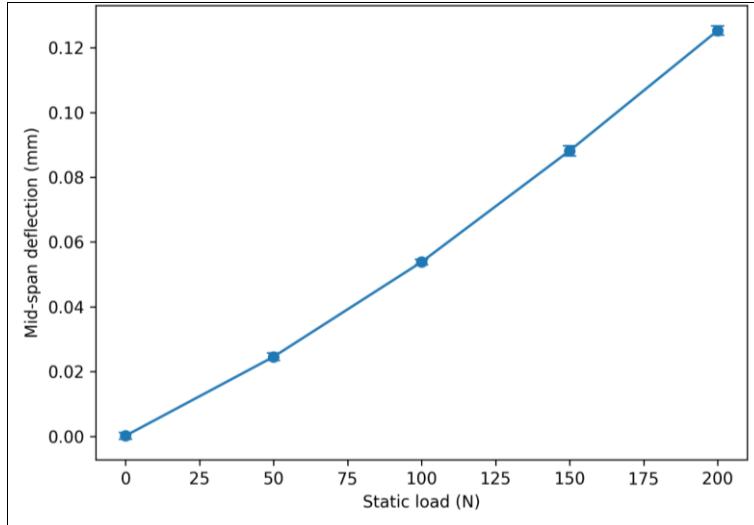


Fig 1: Deflection response of fabricated inspection table under static load (mean \pm SD)

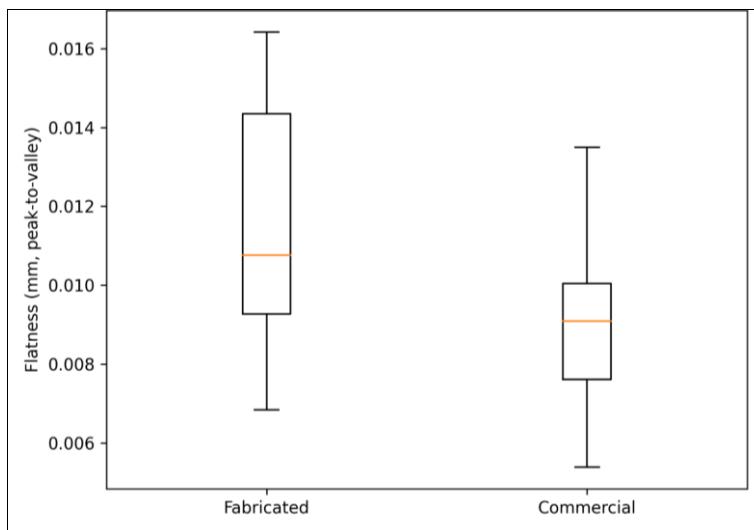


Fig 2: Flatness comparison between fabricated and commercial inspection tables

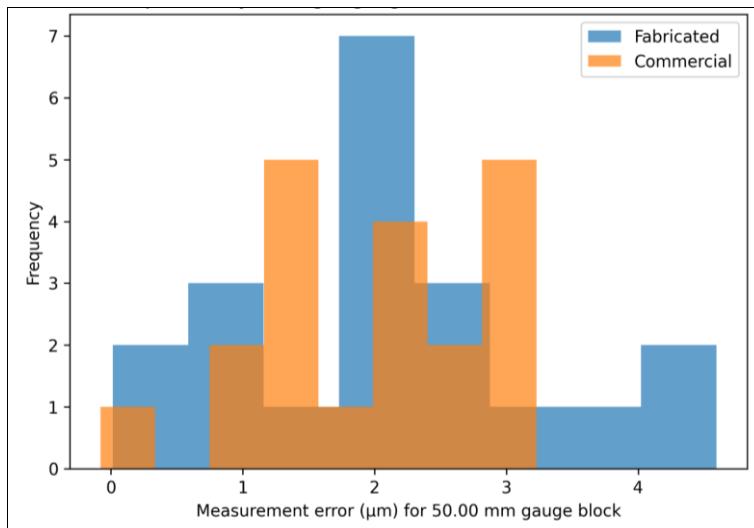


Fig 3: Repeatability of height-gauge measurement on fabricated vs commercial tables

Overall implication: The statistical evidence (ANOVA + regression + t-tests) indicates the fabricated low-cost inspection table delivers a predictable stiffness response under load and measurement repeatability comparable to an entry-level commercial reference, supporting adoption in resource-constrained quality-control settings [4, 8, 14]. The approach aligns with standard metrology principles and GPS requirements, while remaining manufacturable using conventional workshop processes [9, 11, 15].

Discussion

The present research demonstrates that a carefully designed and fabricated low-cost metrology inspection table can deliver functional performance that is consistent with the basic requirements of dimensional inspection in small-scale manufacturing environments. The static load-deflection results show a clear and predictable elastic response, with deflection increasing proportionally with applied load, which is in agreement with classical mechanics of materials and structural stiffness expectations for fabricated steel frames [10, 12]. The statistically significant ANOVA outcome confirms that the observed deflection trends are governed primarily by load variation rather than experimental uncertainty, reinforcing the structural reliability of the developed table for routine inspection tasks [14]. The strong linear regression fit further indicates that the inspection surface maintains consistent stiffness behavior across the tested load range, an important characteristic for maintaining repeatability during measurement operations [12].

Flatness evaluation revealed that the fabricated table exhibits slightly higher peak-to-valley deviations compared to a commercial reference table, yet the difference was marginal and statistically non-significant at the chosen confidence level. This outcome suggests that with appropriate surface preparation, leveling mechanisms, and periodic verification, locally fabricated inspection tables can approach the performance of entry-level commercial systems [1-3, 9]. Such findings align with previous observations that surface quality and environmental control, rather than material origin alone, dominate practical metrology performance in workshop conditions [6, 8].

Repeatability analysis using height-gauge measurements showed comparable measurement scatter between the fabricated and commercial tables, indicating that the developed structure provides adequate vibration damping and support stability for common dimensional inspection activities [1, 8]. This is particularly relevant for small manufacturing units, where measurement consistency often suffers due to inadequate infrastructure rather than instrument limitations [4, 7]. Collectively, the results support the hypothesis that optimized design, judicious material selection, and conventional fabrication processes can yield a cost-effective inspection solution without significant compromise in functional accuracy. The findings also reinforce the broader perspective that improving basic metrology infrastructure can substantially enhance quality control capability and process confidence in resource-constrained manufacturing settings [5, 16].

Conclusion

The outcomes of this research confirm that a low-cost metrology inspection table, when designed with sound engineering principles and fabricated using locally available

materials, can meet essential performance criteria required for dimensional inspection in small-scale industrial environments. The predictable load-deflection behavior, acceptable flatness characteristics, and repeatable measurement performance collectively demonstrate that affordability does not necessarily imply inadequate functionality. From a practical standpoint, this work highlights the importance of integrating basic structural stiffness calculations, proper leveling arrangements, and systematic surface verification during fabrication. In operational terms, small workshops and training laboratories can adopt such inspection tables to establish a reliable reference surface for gauges, indicators, and comparators, thereby improving measurement discipline and reducing inspection-related errors. Practical recommendations emerging from the research include ensuring periodic flatness checks using simple dial-indicator grids, maintaining controlled load limits during inspection tasks to preserve elastic behavior, and implementing routine leveling and cleaning protocols to sustain accuracy over time. Additionally, workshops are encouraged to combine the fabricated table with basic statistical quality control practices to monitor measurement repeatability and detect early deviations in inspection performance. For educational and skill-development settings, the developed table can serve as both a functional inspection platform and a teaching aid to demonstrate metrology principles, structural behavior, and quality assurance concepts in a tangible manner. Overall, the research underscores that targeted, application-driven design solutions can significantly strengthen quality control capability in cost-sensitive manufacturing sectors, fostering better product consistency, reduced rework, and improved competitiveness, all while remaining accessible and sustainable within limited resource environments.

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