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Design and Development of a Low-Cost Pneumatic Leak Testing Machine for Casting Components

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Abstract: Leak testing is a critical non-destructive quality assurance process in casting industries, where defects such as porosity and micro-cracks can compromise component performance and reliability. This study presents the design and development of a low-cost pneumatic leak testing machine for casting components, aimed at providing an efficient in-house alternative to expensive third-party testing methods.The developed system is based on the water immersion (bubble) testing principle, in which pressurized air at 1 bar is introduced into the component and leakage is detected through visual observation of air bubbles during submersion. The machine incorporates a dual-station configuration, enabling simultaneous testing of two components, along with a custom-designed fixture to ensure proper sealing of complex geometries. A pneumatic actuation mechanism is employed to achieve controlled and repeatable immersion, improving consistency and reducing manual effort.Experimental validation was carried out on 50 casting components, including 40 known defect-free parts and 10 defective samples. The system successfully identified all defective components and correctly classified leak-free parts, demonstrating reliable detection capability for visible defects in the approximate range of 0.2–0.5 mm. Repeatability of operation was confirmed through multiple testing cycles under stable pressure conditions.The implementation of the developed machine eliminated dependency on third-party leak testing, reducing testing costs from ₹90 per component to an estimated ₹5 per component. With a fabrication cost of approximately ₹60,000 and a production rate of 100 components per week, the system achieves a payback period of about two months, making it highly suitable for small and medium-scale manufacturing units.The proposed system offers a practical, economical, and efficient solution for leak testing of casting components, contributing to improved quality control and faster defect identification in industrial environments.

Keywords: Leak testing, water immersion, casting components, pneumatic system, fixture design, non-destructive testing, SME manufacturing.

I. INTRODUCTION

In modern manufacturing industries, ensuring the integrity and reliability of components is essential for maintaining product quality and operational safety. Casting components, particularly those used in fluid handling and pressure-based applications, are highly susceptible to defects such as porosity, micro-cracks, and improper sealing surfaces. These defects can lead to leakage, resulting in system failure, reduced efficiency, and potential safety hazards. Therefore, leak testing has become a critical non-destructive testing (NDT) technique in quality assurance processes.

Conventional leak testing methods include pressure decay testing, vacuum testing, tracer gas techniques, and water immersion (bubble) testing. Among these, water immersion testing is widely preferred in small and medium-scale industries due to its simplicity, low cost, and ability to visually localize defects through bubble formation. However, many small and medium enterprises (SMEs) rely on third-party testing services due to the high cost and complexity of commercial leak testing equipment. This dependency increases operational costs, extends production lead times, and limits immediate feedback for process improvement.

To address these challenges, there is a growing need for cost-effective, in-house leak testing solutions that are simple, reliable, and adaptable to specific component geometries. In particular, investment cast components with multiple ports and complex shapes require customized fixtures and controlled testing environments to ensure accurate and repeatable results.

This research presents the design and development of a low-cost pneumatic leak testing machine specifically intended for casting components. The system utilizes a water immersion bubble testing method, where compressed air is introduced into the component at a regulated pressure of 1 bar, and leakage is detected through visual observation of air bubbles during submersion. The proposed machine integrates a dual-station configuration that enables simultaneous testing of two components, thereby improving throughput and operational efficiency.

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A key feature of the developed system is the use of a pneumatic actuation mechanism to automate the immersion and retraction of the testing setup, ensuring consistency and reducing manual effort. Additionally, a custom-designed fixture is implemented to securely hold and seal multi-port casting components during testing, minimizing the chances of false leakage detection.

The developed machine was fabricated and implemented in an industrial environment, where it was validated using production casting components. The system demonstrated reliable leak detection capability for visible defects and enabled complete elimination of third-party testing dependency. The low fabrication cost and short payback period further establish the feasibility of the system for SME applications.

This study contributes to the field of manufacturing and quality assurance by providing a practical and economical solution for leak testing of casting components, bridging the gap between high-cost industrial systems and manual testing methods.

II. LITERATURE REVIEW

Leak testing is an essential non-destructive testing (NDT) method widely used in manufacturing industries to ensure the integrity of components subjected to fluid or pressure conditions. Various techniques have been developed over time, including pressure decay testing, vacuum testing, tracer gas methods, and water immersion (bubble) testing, each offering different levels of sensitivity, cost, and complexity.

Pressure decay testing is one of the most commonly used industrial methods due to its ability to quantify leakage rates with high precision. However, it requires sophisticated sensors, data acquisition systems, and strict sealing conditions, making it expensive and less suitable for small-scale industries. Tracer gas methods, such as helium leak detection, provide extremely high sensitivity for detecting micro-leaks but involve high operational costs and specialized equipment, limiting their practical use in cost-sensitive environments.

Water immersion testing, also known as bubble testing, is a simple and cost-effective technique in which a pressurized component is submerged in water, and leakage is identified through the formation of air bubbles. This method is particularly advantageous in small and medium enterprises (SMEs) due to its low setup cost, ease of implementation, and ability to visually localize defects. However, traditional bubble testing setups are often manual, lack repeatability, and are not optimized for high-throughput industrial applications.

Recent studies have emphasized the need for developing low-cost, semi-automated leak testing systems that can bridge the gap between manual methods and expensive commercial equipment. Researchers have explored the use of pneumatic systems for automation, customized fixtures for complex geometries, and multi-station testing to improve productivity. These approaches aim to enhance consistency, reduce human error, and increase testing efficiency while maintaining affordability.

Despite these advancements, there remains a significant gap in the availability of compact, low-cost, and application-specific leak testing machines suitable for investment cast components with complex geometries. The present work addresses this gap by developing a pneumatic, dual-station water immersion leak testing system with a custom-designed fixture, providing an effective and economical solution for industrial applications.

III. METHODOLOGY AND SYSTEM DESIGN

The developed leak testing system is based on the water immersion (bubble) testing principle, which is a widely accepted non-destructive testing method for identifying leakage in pressurized components. The methodology involves introducing compressed air into the test component and observing the formation of air bubbles when the component is submerged in water. The presence of bubbles indicates leakage, while the absence of bubbles confirms the integrity of the component.

The system was designed to operate at a regulated pressure of 1 bar, supplied through a pneumatic setup consisting of a compressor, pressure regulator, and an analog pressure gauge for monitoring. The regulated air is introduced into the casting component through a sealed connection, ensuring that all internal cavities are pressurized uniformly. The use of an analog pressure gauge allows the operator to verify the applied pressure before initiating the test cycle, ensuring consistency across multiple tests.

A key feature of the system is the integration of a pneumatic actuation mechanism that enables controlled immersion and retraction of the test components into a water tank. This semi-automated approach reduces manual intervention and improves repeatability compared to conventional manual testing methods. The pneumatic system ensures smooth and consistent motion during the immersion process, minimizing disturbances that could affect bubble observation.

To accommodate the complex geometry of investment cast components, a custom-designed fixture was developed. The fixture is capable of securely holding and sealing multiple ports of the casting, preventing unintended air leakage during testing.

Proper sealing is critical to avoid false indications and to ensure that any observed leakage originates from actual defects within the component. The fixture design also supports a dual-station configuration, allowing two components to be tested simultaneously within a single cycle, thereby improving productivity and reducing overall testing time.

The testing procedure involves placing the components in the fixture, applying compressed air at 1 bar, and immersing the assembly into the water tank for a duration of 30 seconds. During this period, the operator visually inspects the component for bubble formation. After completion of the test cycle, the components are retracted using the pneumatic mechanism and depressurized before removal. The cycle time was experimentally evaluated through multiple trials, confirming consistent operation under identical conditions.

The overall system was designed with a focus on simplicity, cost-effectiveness, and ease of operation, making it suitable for small and medium-scale industrial applications. By combining pneumatic automation, dual-component testing capability, and a customized fixture, the developed machine provides a practical and efficient solution for leak testing of casting components.

IV. RESULTS AND DISCUSSION

The performance of the developed leak testing machine was evaluated through experimental validation under industrial conditions. A total of 50 SS316 investment cast manifolds were tested, comprising 40 known defect-free components and 10 intentionally identified defective samples. The primary objective of the validation was to assess the reliability, repeatability, and practical applicability of the system for in-house leak detection.

The system successfully classified all 40 defect-free components as leak-free and correctly identified all 10 defective components through visible bubble formation during immersion. This resulted in an observed detection accuracy of 100% for the given dataset. The defective samples exhibited clear and consistent bubble generation at the defect locations, enabling precise visual localization of leakage points. The defects were primarily estimated to be within the range of approximately 0.2–0.5 mm, based on observed casting imperfections.

The testing process was conducted at a regulated pressure of 1 bar with a fixed immersion duration of 30 seconds. The pressure was monitored using an analog gauge prior to each test cycle and remained stable throughout the testing duration. No significant pressure fluctuations were observed that could affect the reliability of the test results. The use of a controlled pneumatic system ensured uniform pressurization and consistent testing conditions across all samples.

Repeatability of the system was evaluated through multiple cycle-time trials. Three independent trials were conducted, each involving simultaneous testing of two components. The results indicated consistent cycle performance with no variation in detection outcome or operational behavior. The dual-station configuration demonstrated improved throughput by enabling parallel testing, effectively reducing the overall inspection time compared to single-component testing methods.

From an operational perspective, the system proved to be efficient and easy to use within an industrial environment. The pneumatic actuation mechanism provided smooth and controlled immersion, minimizing manual handling and reducing the possibility of operator-induced variability. The custom-designed fixture effectively sealed the components, eliminating false leakage indications and ensuring that observed bubbles corresponded to actual defects.

A significant advantage of the developed system is its economic feasibility. The implementation of the in-house leak testing machine eliminated the need for third-party testing services, which previously incurred a cost of ₹90 per component. With an estimated in-house operating cost of approximately ₹5 per component, the system achieves substantial cost savings. Considering a production rate of 100 components per week and a fabrication cost of approximately ₹60,000, the payback period is estimated to be around two months. This highlights the suitability of the system for small and medium-scale manufacturing units where cost constraints are critical.

Despite its advantages, the system is primarily limited to qualitative leak detection based on visual observation. While it effectively identifies visible leaks and enables defect localization, it does not provide quantitative leakage rates or calibrated detection of micro-scale defects. Future improvements may include integration of pressure sensors or automated bubble detection systems to enhance sensitivity and enable quantitative analysis.

Overall, the results demonstrate that the developed machine provides a reliable, repeatable, and cost-effective solution for leak testing of casting components, with strong potential for industrial adoption in SME environments.

V. CONCLUSION

This study presented the design and development of a low-cost pneumatic leak testing machine for casting components, with a focus on practical industrial application in small and medium-scale manufacturing environments.

The developed system utilizes the water immersion bubble testing method combined with pneumatic actuation to provide a simple, reliable, and repeatable leak detection solution.

The machine incorporates a dual-station testing configuration and a custom-designed fixture, enabling simultaneous testing of two components while ensuring proper sealing and accurate defect identification. Experimental validation conducted on 50 casting components demonstrated consistent performance, with successful identification of all defective samples and correct classification of leak-free components. The system effectively detects visible leakage defects and allows precise localization through bubble observation.

In addition to its technical performance, the system offers significant economic advantages. By eliminating dependency on third-party leak testing services, the developed machine reduces operational costs substantially and achieves a short payback period, making it highly suitable for SME applications. The simplicity of design, ease of operation, and low fabrication cost further enhance its industrial feasibility.

Although the current system is limited to qualitative leak detection, it provides a strong foundation for future enhancements such as integration of sensors and automation for quantitative analysis. Overall, the developed machine successfully addresses the need for an economical and efficient in-house leak testing solution, contributing to improved quality control and productivity in casting industries.

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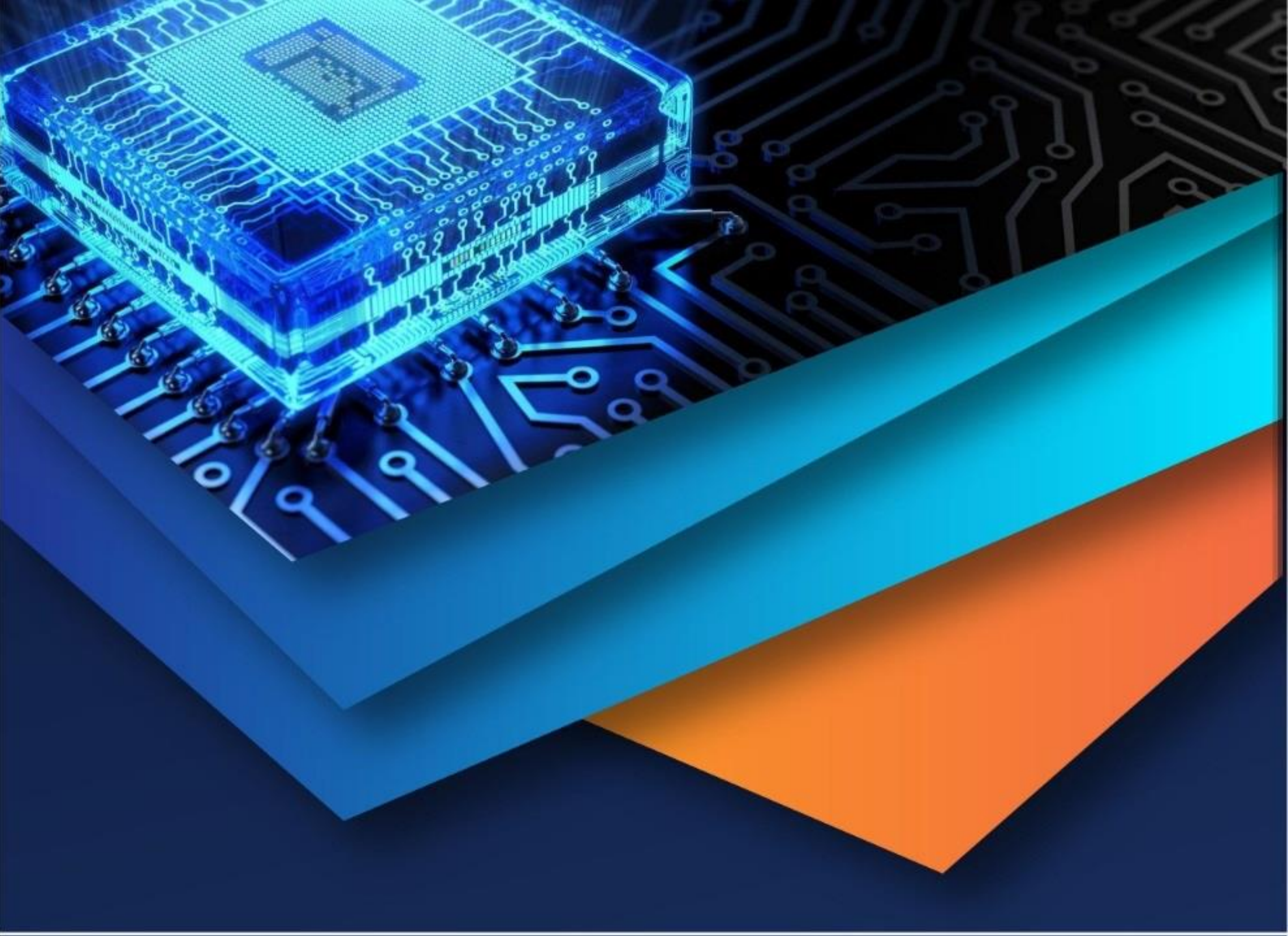

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