Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

# Development of Bore Gauge System for Bearing Inspection with integration of IOT

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***Abstract: - This paper describes the design and development of Automatic Bore Gauge (ABG) Testing Machine for precision inspection of electric vehicle (EV) motor bearing bores. Dimensional accuracy of bearing bores is one of the key factors influencing Noise, Vibration and Harshness (NVH) performance in EV drivetrains. With the low noise floor of an EV, dimensional deviations at the micron level can be noticeable. Conventional manual bore gauges are not sufficiently repeatable for tight EV bearing tolerances, with operator-dependent repeatability in the range of ±5 µm. The proposed interdisciplinary system includes a cast iron***

***structural frame, a precision spindle assembly with angular contact bearings, a double action pneumatic linear actuator for controlled probe insertion, an RM RV 3115 recirculating ball linear guide rail, and an LVDT (Linear Variable Differential Transformer) displacement sensor as the main measurement element. Pneumatic actuation is controlled by a solenoid directional control valve coupled to a motor controlled pressure regulator interfaced to a Programmable Logic Controller (PLC) and a NEMA 17 stepper motor with DRV8825 driver provides an accurate 360° rotational sweep of the bearing under test. The embedded control system collects LVDT data for the entire circumferential sweep and determines the minimum diameter (Dmin), maximum diameter (Dmax),***
***average diameter (Davg), and***
***ovality (Δ = Dmax - Dmin). Each bearing is categorized as Good, Rework, or Scrap. The pneumatic actuator force validation results in a safety margin of greater than 7:1 on the carriage operating load.Use of guide rail is less than 1.5% of rated dynamic capacity. The system provides***

***better measurement repeatability to ±1 µm, reduces inspection time from ~25 s (manual) to 6s and eliminates operator induced variation. The system architecture encompasses a provision for IoT based real time data monitoring and traceability.***

## 1.INTRODUCTION

Electric vehicles (EVs) are becoming popular worldwide as they are highly energy efficient, have zero direct emissions and are quiet. Unlike traditional internal combustion engine vehicles, the acoustic environment of an EV drivetrain is inherently low noise and therefore the noise and vibration produced by the mechanical components are much more noticeable to the vehicle occupants. Of all mechanical elements in an EV motor, rolling element bearings are one of the most critical determinants of NVH (Noise, Vibration and Harshness) performance, load-carrying capacity and service life.

The accuracy of the bearing bore diameter directly dictates the interference fit between the inner race of the bearing and the motor shaft. Even sub-micron geometric deviations like bore diameter variation, ovality and waviness induce cyclic vibration excitation forces that manifest as audible noise and high vibration amplitudes in the assembled motor. Research has shown that micron level bore inaccuracies have disproportionately large NVH effects due to the cyclic nature of rolling contact loading [8]–[10].
Dial bore gauges, telescopic gauges, and inside micrometers are commonly employed as conventional manual bore inspection tools due to their low cost, but they are fundamentally limited by reliance on the operator, inconsistent contact force, and susceptibility to misalignment. The typical

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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repeatability of ±5 µm is not adequate for the tight bore tolerances required for EV motor bearing applications [1], [2]. Industrial-grade automated inspection systems are capable of reaching sub-micron accuracy but are prohibitively expensive due to capital costs, infrastructure demands, and the need for skilled operation, thereby making them unavailable to academic institutions, research laboratories, and small-scale businesses.

This paper fills this gap by presenting the design and development of an inexpensive laboratory scale Automatic Bore Gauge (ABG) Testing Machine that combines precision mechanical engineering design with embedded electronics and control system. The proposed system combines a rigid cast iron mechanical structure, pneumatic linear actuation, LVDT displacement sensing, PLC driven automation and provision for IoT connectivity into a single coherent inspection platform. The system provides ±1 µm measurement accuracy, automatic classification of Good/Rework/ Scrap.

## 2.KEYWORDS

- Automated Bore Gauge
- Precision Bearing Inspection
- LVDT
- Stepper Motor Control
- PLC / Embedded Control System
- Industrial Automation
- Dimensional Measurement
- Mechatronics System

## 3. METHODOLOGY

*Fig 3.0 Methodology*

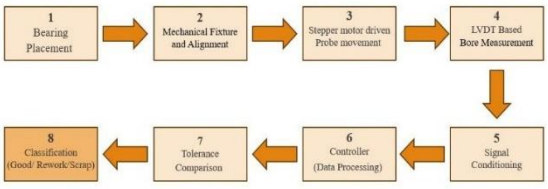


*Fig 3.0 Methodology*

### A. Bearing Placement and Fixture Alignment

The bearing under test is placed on the spindle fixture and clamped in a precisely aligned position. The spindle fixture is designed to ensure that the bore axis of the bearing is coaxial with the spindle rotational axis, eliminating misalignment error that would introduce systematic offset in the LVDT measurement.

### B. Pneumatic Probe Insertion

Upon inspection cycle initiation via the HMI, the PLC energies the solenoid directional control valve to supply regulated compressed air to the cap-end of the double-acting pneumatic cylinder. The actuator rod extends, lowering the measuring head carriage along the RM RV 3115 linear guide rail until the LVDT probe tips engage the bore surface at the designated measurement depth. End-position reed switches confirm probe engagement and signal the PLC to commence the rotational sweep. Supply pressure is regulated to 4–6 bar, yielding a theoretical actuator thrust of approximately 157 N—providing a force safety margin exceeding 7:1 over the 21 N carriage weight.

### C. LVDT-Based Bore Measurement

The NEMA 17 stepper motor rotates the spindle through a full 360° sweep at controlled speed via PWM step pulses. The LVDT sensor, integrated into the measuring head, continuously monitors dimensional variation as the bore surface is traversed. Any bore diameter deviation displaces the LVDT ferromagnetic core proportionally, inducing a differential output voltage in the secondary coils of the sensor. This analog signal is amplified, filtered, and transmitted to the PLC analog input module

### D. Signal Conditioning and Data Processing

The conditioned LVDT analog signal is digitized by the PLC ADC and processed to compute: minimum bore diameter D

min, maximum bore diameter Dmax, mean diameter Davg = (Dmax + Dmin)/2, and ovality Δ = Dmax − Dmin. These parameters are displayed in real time on the HMI panel and stored digitally for traceabi

### E. Tolerance Comparison and Classification

The measured values are compared against predefined tolerance limits stored in the PLC program. The system generates one of three classification outputs: Good (all parameters within tolerance), Rework (marginally outside tolerance), or Scrap (significantly outside tolerance or ovality exceeding limit). The classification result is output to indicator lights, displayed on the HMI, and logged for quality records.

### F. Probe Retraction and Reset

After classification, the PLC energies the retract solenoid, withdrawing the pneumatic actuator to the fully retracted position. The system resets and awaits the next bearing for inspection.

## 4. WORKING PRINCIPLE

The Automatic Bore Gauge Testing Machine operates on the principle of precise displacement measurement combined with controlled mechanical automation. In this system, the bearing is first placed in a rigid and accurately aligned fixture to ensure stable positioning and eliminate misalignment errors. A stepper motor–driven linear actuation mechanism then inserts the probe into the bearing bore in a controlled and repeatable manner. The use of stepper motor control ensures consistent probe positioning and uniform contact force, thereby

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ISSN: 2278-0181
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eliminating variations caused by manual handling. When the probe comes into contact with the internal surface of the bore, any dimensional deviation results in a small mechanical displacement.
This displacement is detected by a Linear Variable Differential Transformer (LVDT), which works on the principle of electromagnetic induction. The movement of the ferromagnetic core inside the LVDT changes the induced voltage in the

secondary coils, producing an output voltage proportional to the displacement. The analog signal generated by the LVDT is then amplified and conditioned to remove noise and improve stability. The processed signal is fed into an Arduino-based embedded control system, where it is converted into a digital value, calibrated, and translated into bore diameter deviation in microns.

The measured value is automatically compared with predefined tolerance limits suitable for EV motor bearing applications. Based on this comparison, the system classifies the bearing into Good, Rework (undersize or oversize), or Scrap categories. The entire process is automated, reducing inspection time and eliminating operator-dependent errors. By combining rigid mechanical design, controlled probe insertion, high-sensitivity sensing, and embedded data processing, the system achieves high accuracy, repeatability, and reliable classification, making it suitable for precision EV bearing inspection and quality control applications.

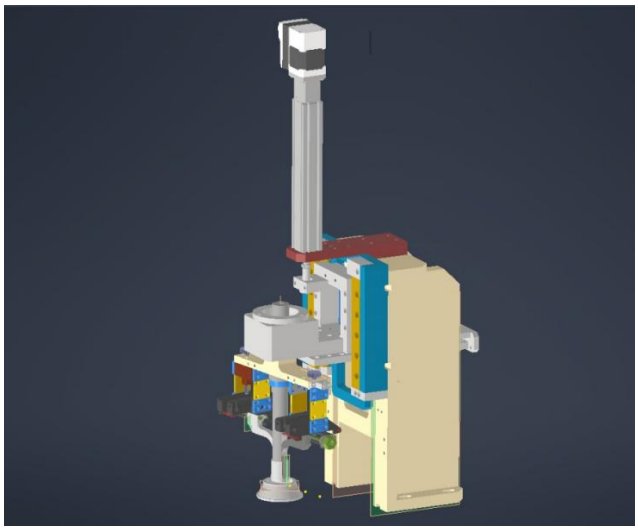

*Fig 4.0 Structure of The Frame*

**Information Of Components Used for Integration**

**1. AC to DC control panel:**

- Power conditioning
- Rectification
- Control relays/contactors

I. Input AC Protection & Filtering Stage: Protect circuit and give stable AC
Function:

- Suppress voltage spikes
- Reduce switching noise
- Protect components

II. AC to DC Conversion:


*Fig 4.1: Rectifier Stage*

Working:

1. Bridge Rectifier (Diodes):
Converts AC → Pulsating DC (unidirectional)
2. Filter Capacitor: Smoothens ripple → gives stable DC

III. Switched Mode Power Supply (SMPS):

After Rectification


*Fig 4.2 SMPS Circuit*

Working: Provides constant voltage
Used for:
1.Relay coils
2.Control PCB

IV. Control Section:


*Fig 4.3 Relay and Contactor Working*

Working:
1. A low-voltage control signal is given to the relay coil.
2. Relay gets energized → its contacts close
3. This allows current to flow to the contactor coil .
4. Contactor coil energizes → main contacts close
5. High-power supply is given to the load (device)

Final Block Diagram:

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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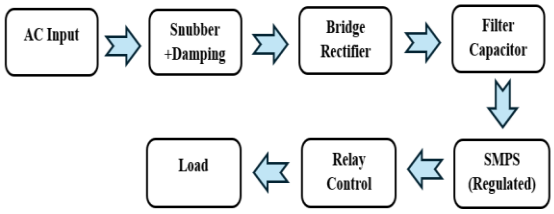


*Fig 4.4 Circuit final methodology*

## 5. HARDWARE SPECIFICATIONS

### A. Material Selection

Material selection for major structural and functional components was governed by requirements of mechanical rigidity, vibration damping, dimensional stability, wear resistance, and cost. Table I summarizes the selected materials.

| Component | Material | Key Properties |
|---|---|---|
| Structural Frame | Grey Cast Iron | High stiffness, damping, thermal stability |
| Spindle / Shaft | EN31 Alloy Steel (HT) | High strength, hardness, wear resistance |
| Measuring Assembly | EN31 Alloy Steel (HT) | Dimensional stability, fatigue resistance |
| Linear Guide Rail | Stainless Steel 440C | Corrosion resistance, high hardness |
| Pneumatic Cylinder Body | Anodised Aluminium Alloy | Lightweight, corrosion resistant |
| Probe Contact Tips | Tungsten Carbide | Very high hardness, high compressive strength |

*Table 5.1 Selection of the Materials*

Grey cast iron was selected for the frame primarily for its high material damping ratio, which attenuates vibrations from pneumatic actuation and motor operation—a critical requirement in a precision measurement instrument. EN31 steel, after hardening and tempering, provides the required surface hardness and fatigue strength for the spindle shaft and measuring assembly components.

### B. Structural Frame and Tower

The structural frame is cast in grey cast iron and machined into an L-configuration comprising a vertical tower column and a horizontal base plate. The tower column provides mounting surfaces for the linear guide rail, pneumatic actuator brackets, and motor assembly. The base plate houses the spindle assembly and bearing fixture. CNC milling is applied to all critical mounting surfaces to achieve the required flatness and perpendicularity tolerances, ensuring correct probe-to-bore-axis alignment. Misalignment angle θ introduces a cosine error defined by: Measured Length = Actual Length × cos(θ), making surface parallelism fundamental to measurement accuracy.

**C. Spindle Assembly and Angular Contact Bearings** : The spindle assembly holds and rotates the bearing under test through the 360° measurement sweep. The EN31 steel spindle shaft is supported within an aluminium housing by a pair of angular contact bearings arranged in back-to-back (DB) configuration and axially preloaded. Angular contact bearings are selected in preference to deep groove bearings due to their higher combined load capacity, greater stiffness, and ability to be preloaded to eliminate internal backlash—a prerequisite for accurate circumferential bore measurement. Bearing journals are ground to H6/g6 tolerance to achieve the required concentricity and minimal runout. Rotational drive is transmitted through a synchronous belt-and-pulley system from the NEMA 17 stepper motor.

### D. Pneumatic Linear Actuator

A double-acting pneumatic cylinder is employed for vertical probe insertion, replacing electromechanical drives to eliminate backlash, reduce mechanical complexity, and provide fast, consistent stroke motion. Table II presents the actuator specifications.

| Parameter | Specification |
|---|---|
| Type | Double-Acting Pneumatic Cylinder |
| Bore Diameter | 20 mm |
| Stroke Length | 100–150 mm (adjustable) |
| Operating Pressure | 4–6 bar (regulated) |
| Theoretical Thrust (at 5 bar) | $F = P \times A = 5\times10^5 \times \frac{\pi}{4} \times (0.02^2) \simeq 157\,\text{N}$ |
| Actuation | Solenoid valve + motor-controlled pressure regulator |
| End-Position Sensing | Magnetic reed switches |
| Body Material | Anodised aluminium alloy |

*Table 5.2 Pneumatic Linear Actuator*

The carriage and measuring head assembly weighs approximately 2.1 kg (≈21 N). At 5 bar operating pressure, the actuator delivers approximately 157 N thrust, providing a force safety margin of 7.5:1. Flow control valves on both supply lines regulate extension and retraction speed to ensure gentle probe engagement and prevent mechanical shock that could damage the LVDT sensor or bearing surface.

Table III presents a comparative evaluation of pneumatic actuation versus an electromechanical ball-screw drive for this application, justifying the pneumatic selection.

| Parameter | Pneumatic Actuator | Ball Screw Drive |
|---|---|---|
| Backlash | None | Very low (with preload) |
| Actuation Speed | Very fast | Moderate |
| Vertical-Axis Motor Required | No | Yes (stepper motor) |
| Positional Control | End-position (reed switches) | Continuous (step-based) |
| Maintenance | Minimal | Periodic (nut wear, alignment) |
| System Complexity | Low | Moderate |
| Relative Cost | Lower | Higher |

*Table 5.2 Comparison Table*

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### E. Linear Guide Rail System

The RM RV 3115 recirculating ball-type linear guide rail (15 mm rail width) constrains the measuring carriage to move exclusively along the vertical axis, preventing lateral displacement, tilting, and rotational deviation. The applied carriage load is approximately 60 N. With a dynamic load rating of 5,000–8,000 N and a static load rating of 8,000–12,000 N, guide rail utilization is below 1.5% of rated dynamic capacity, ensuring negligible stress, zero deformation, and an indefinite service life under operating conditions.

### F. Measuring Head and LVDT Integration

The measuring head assembly consists of a low-mass aluminum body housing two symmetrically opposed contact fingers with tungsten carbide probe tips. The contact fingers make simultaneous contact with diametrically opposite points on the bore inner surface. The LVDT sensor is integrated into the measuring head body with micrometric zero-position adjustment capability. Probe guide holes are reamed to fine tolerances ensuring smooth, low-friction probe movement without stick-slip behavior. Adjustment screws on the probe holding structure permit calibration of the probe tip positions relative to the nominal bore diameter.

### 1. XY- LPWM:

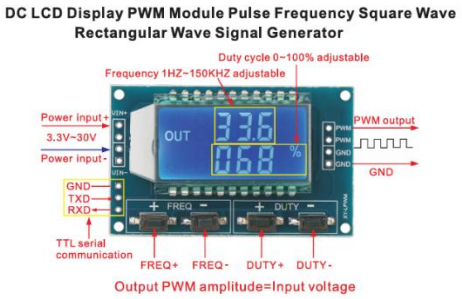


*Fig 5.0 Pulse Generator*

**Specifications:**

1.Working voltage: 3.3 ~ 30V;
2. Frequency range: 1Hz ~ 150KHz;
3. Frequency accuracy: the accuracy in each range is about2%;
4. Signal load capacity: the output current can be about530ma
5. Output amplitude: PWM amplitude equal to the supply voltage;
6.Ambient temperature: -20 ~ +70 °C.

### 2. TB6600 Stepper Driver:

*Fig 5.1 Stepper Driver*

**Specification**

1.Input Current: 0–5.0A
2.Output Current: 0.5–4.0A
3.Power (MAX): 160W
4.Micro Step: 1, 2/A, 2/B, 4, 8, 16,
5. Temperature: -10 ~ 45°C
6. Humidity: No Condensation
7. Weight: 0.2 kg
8. Dimensions: 96 × 56 × 33 mm

### 3. NEMA 17 - Stepper Motor

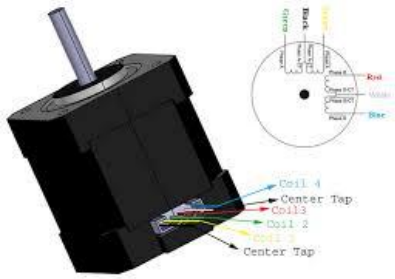


*Fig 5.2 Stepper Motor*

**Specifications:**

1.Step Angle: 1.8° (200 steps/revolution)
2.Current Rating: ~1A to 2A per phase
3.Voltage: ~2V to 4V

1. Holding Torque: ~0.25 to 0.55 Nm
2. Frame Size: 42 × 42 mm
3. Shaft Diameter: 5 mm
4. Motor Length: 34–48 mm
5. Step Modes (with driver): Full, 1/2, 1/4, 1/8, 1/16, 1/32

### 4. LVDT Probe Sensor :

*Fig 5.3 Linear Variable Differential Transformer*

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**Specifications:**

1. Measurement Range: ±1 mm to ±250 mm
2. Excitation Voltage: 1V to 10V AC
3. Excitation Frequency: 50 Hz to 10 kHz
4. Output: Differential AC voltage
5. Sensitivity: 1–10 mV/V/mm
6. Linearity: ±0.25% to ±0.5% of full scale
7. Accuracy: up to ±0.5%
8. Resolution: Infinite (very high precision)
9. Repeatability: Very high (≈ ±0.01%)
10. Hysteresis: Negligible
11. Operating Temperature: −25°C to +85°C

## 6. STRUCTURE ANALYSIS

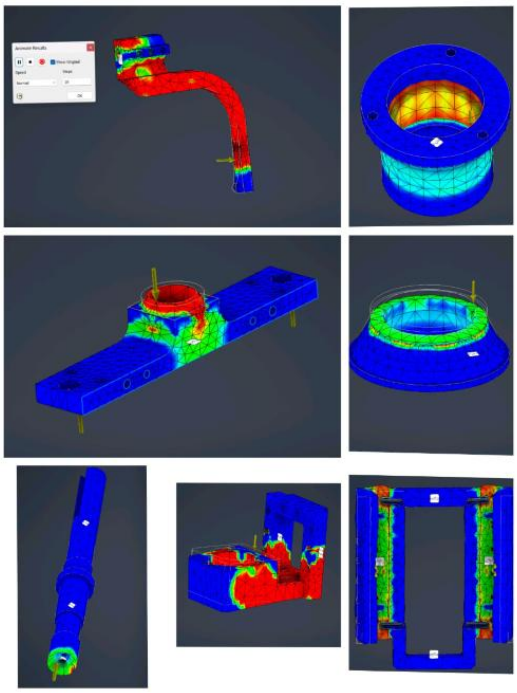

*Fig 6.0 Structure Analysis*

**1. Bearing Holder Shaft**
Loading & Direction: Subjected to a dual-vector axial load along the vertical axis, simulating bearing press-fit forces.

Safety & Stability: Peak stress (1.109 MPa) is localized at the flange radius; an exceptionally high Factor of Safety ensures zero fatigue failure and maintains critical bearing concentricity.

**2. Conical Ring Support**
Loading & Direction: Experiences a vertical compressive point load on the upper rim, dissipated through the tapered conical geometry.

Stress & Integrity: Peak stress (0.003 MPa) is negligible; the geometry ensures uniform strain distribution and provides the high structural stiffness required for metrological stability.

**3. Measuring Head Main Bracket**
Loading & Direction: Undergoes a central vertical compressive load simulating the combined mass and pneumatic actuation force of the probe assembly.

Safety & Stability: Maximum stress (0.03 MPa) occurs at the cylinder-to-plate transition; the high Factor of Safety guarantees a rigid reference plane for precision measurement.

**4. Measurement Finger (RHS)**
Loading & Direction: Subjected to a lateral contact force at the distal tip, inducing a localized cantilever-style bending moment.

Stress & Integrity: Stress concentrations (0.03 MPa) are managed by the upper mounting block to prevent permanent deformation, ensuring the finger returns to a consistent null position.

Mechanical Stress Analysis: Center Shaft
Loading & Stress: Subjected to torsional and transverse loading, the shaft exhibits a peak Von Mises stress of 0.0047 MPa localized at the stepped transition zone.

Safety & Stability: With a Factor of Safety exceeding 50,000, the design ensures negligible elastic strain and high rotational accuracy, prioritizing structural stiffness for precision transmission applications.

**5. Measuring Head Carriage**
Loading & Stress: A vertical Y-axis point load induces a peak Von Mises stress of $8.45 \times 10^{-3}$ MPa, with concentrations efficiently dissipated through the lower vertical ribs and horizontal base.

Precision & Safety: The extreme Factor of Safety (>30,000) and negligible elastic strain ensure zero functional deformation, providing the high-metrological stiffness and vibration damping required for precision repeatability.

**6. Linear Guide Rail & Carriage**
Loading & Stress Distribution: Under a vertical Z-axis compressive load, the assembly exhibits a peak Von Mises stress of 5 MPa localized at fastener interfaces and inner carriage radii.
Structural Performance: With a Factor of Safety > 50, the design prioritizes structural rigidity and vibration damping over weight, ensuring negligible strain and maintaining critical axial alignment for high-precision metrology.

## 7. CIRCUIT DIAGRAM

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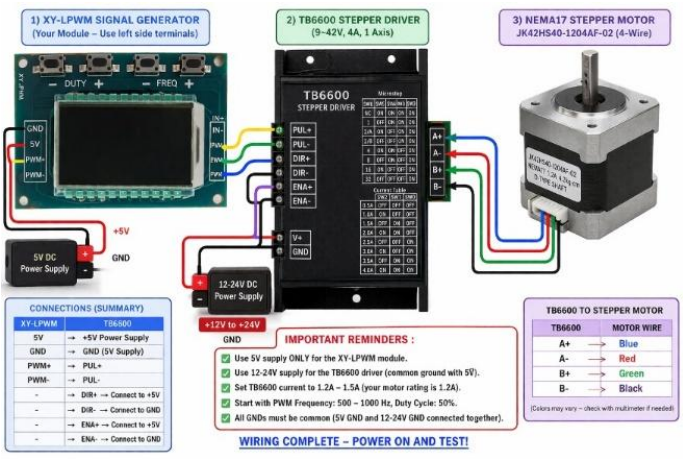


*Fig 6.0 Module 1*

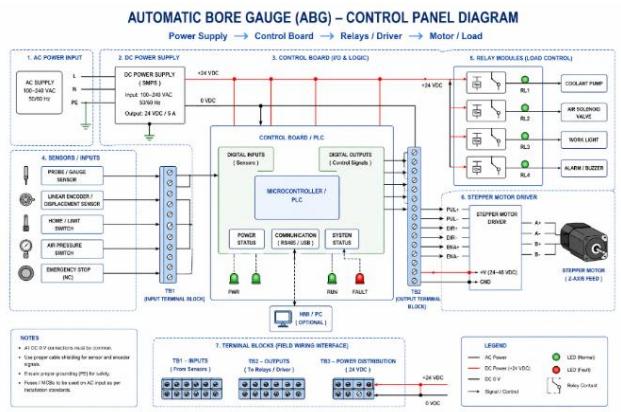


*Fig 6.1 AC to DC Control*

## 8. AUTOMATION PANEL SETUP

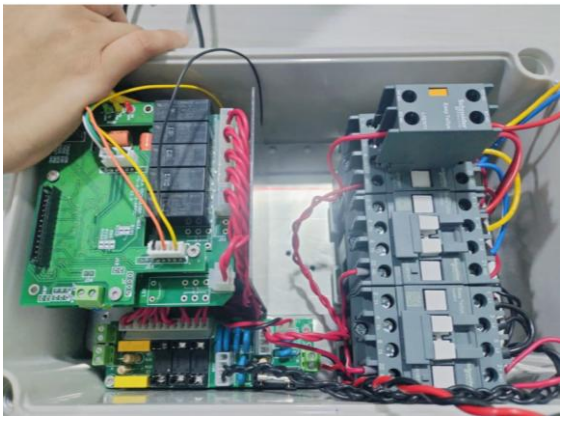

*Fig 7.0 Rectification Unit*

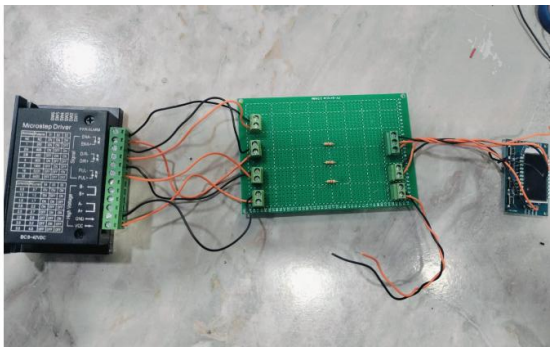

*Fig 7.1 Stepper motor control Unit*

## 9. MECHANICAL FRAME

*Fig 9.0 Final Hardware Structure*

## 10. TESTING AND RESULT

This entire system is successfully integrated and working with the ABG (Automatic Bore Gauge) project. It performs all required functions like power conditioning, DC supply generation, and control of actuators using relays and contactors.

“This system is fully integrated with the ABG project and ensures proper power supply, protection, and controlled operation of the measurement mechanism.”

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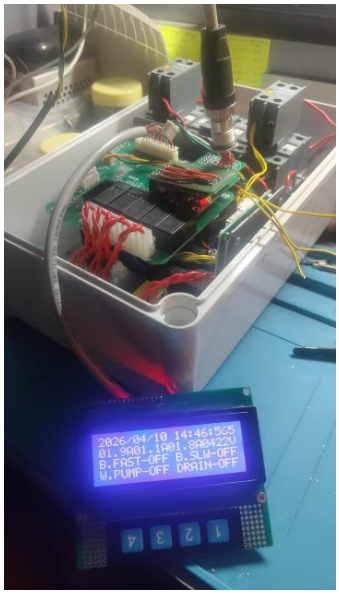


*Fig 8.0 Testing result*

Advantages of This System in ABG Project:

1. Provides stable and regulated DC supply for accurate measurement.
2. Ensures high reliability by protecting components from spikes and noise.
3. Enables precise control of probe movement using relay–contactor system.
4. Improves measurement accuracy and consistency.
5. Offers safe operation for electrical and mechanical components.
6. Reduces chances of system failure and damage.
7. Supports automation, reducing manual effort.
8. Easy to maintain troubleshoot due to modular design.

Future Scope:

This system is not limited to the Automatic Bore Gauge (ABG) project, but can be used in any automation system due to its flexible and modular design. It includes power conditioning, AC to DC conversion, protection circuits, and relay–contactor-based control, which are common requirements in industrial automation. Since it operates on standard control logic and switching mechanisms, the same system can be easily adapted for applications such as motor control, pump operation, and other automated processes.

## 9. LITERATURE SURVEY

A comprehensive review of literature was conducted to analyze the existing developments in precision dimensional measurement, motion control systems, embedded automation, IoT integration, and bearing NVH performance.

The study reveals that high-accuracy dimensional inspection plays a critical role in ensuring performance, reliability, and vibration control in electric vehicle (EV) motor applications. Research on displacement measurement systems, particularly the work by Jain and Ray (2017) and Kumar and Singh (2018), demonstrates that Linear Variable Differential Transformer (LVDT) sensors offer excellent linearity, high sensitivity, and superior repeatability compared to conventional displacement sensors. Their findings confirm that LVDT-based automated systems significantly reduce human- induced measurement variation and improve consistency in precision inspection tasks. However, most of these studies focus on general dimensional measurement and do not specifically address internal bore inspection with automatic tolerance- based classification logic.

In the area of motion control, Krishnan (2011) and subsequent PLC-based positioning studies (2014–2018) establish that stepper motors provide accurate positioning, high repeatability, and cost-effective automation for precision applications. Pulse-based control techniques and micro stepping methods enhance resolution and reduce vibration during positioning.

Comparative studies between PLC and microcontroller-based systems (2019) indicate that PLCs provide higher industrial robustness, whereas microcontrollers offer flexibility and cost advantages. Despite these advancements, existing research does not fully integrate stepper-based probe insertion specifically for automated bore gauge systems requiring micron-level positioning control.

Embedded data acquisition systems have also been widely studied. Patel and Mehta (2016) demonstrate that microcontroller-based systems enable reliable sensor interfacing, signal processing, and digital data storage at low cost. IoT-based industrial frameworks proposed by Da Xu et al. (2014) and Lee et al. (2015) highlight the importance of real-time monitoring, traceability, and Industry 4.0 compliance in modern manufacturing systems. These studies emphasize smart integration of sensors and controllers but do not provide a dedicated implementation for precision bore inspection systems combining displacement sensing, motion control, and automatic classification.

From a mechanical and NVH perspective, recent studies by Wang et al. (2022), Masri et al. (2024), and Li et al. (2025) confirm that bearing geometric deviations, including clearance variation, waviness, and dimensional inaccuracies. From a mechanical and NVH perspective, recent studies by Wang et al. (2022), Masri et al. (2024), and Li et al. (2025) confirm that bearing geometric deviations, including clearance variation, waviness, and dimensional inaccuracies, significantly influence vibration characteristics and noise levels in EV motors. Manufacturing tolerance analysis by Liu et al. (2014) further establishes a quantitative relationship between dimensional variations and system vibration performance.

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These studies clearly show that micron- level geometric errors directly impact NVH behavior. However, while the influence of dimensional errors on vibration has been extensively studied, there is limited research linking automated bore inspection accuracy directly to NVH improvement through real-time tolerance classification.

Comparative analyses between manual and automated inspection systems reveal significant performance differences. Manual bore gauges typically exhibit ±5 µm accuracy with operator-dependent variation and longer inspection times (approximately 25 seconds per component). In contrast, automated systems using sensor-based measurement and controlled actuation achieve accuracy up to ±1 µm, improved repeatability, reduced inspection time (around 6 seconds), and automatic classification capabilities. Furthermore, automated systems enable digital data logging and traceability, which are absent in manual inspection methods.
Based on the overall literature analysis, it is evident that while individual technologies such as LVDT sensing, stepper motor control, embedded systems, and IoT frameworks are well established, there is a lack of an integrated, cost-effective, automated bore gauge system specifically designed for EV motor bearing inspection. Particularly, research gaps exist in the areas of sub-micron accuracy using economical components, integrated tolerance-based Good/Rework/Scrap classification, and direct correlation between bore dimensional control and NVH performance enhancement.

Therefore, the proposed project aims to bridge these gaps by developing a compact, automated bore gauge testing system integrating LVDT- based displacement measurement, stepper motor–controlled probe insertion, embedded data acquisition and classification logic, and provision for future IoT-based monitoring. This integrated approach addresses both dimensional accuracy and EV-specific NVH requirements while maintaining cost-effectiveness suitable for academic laboratories and small-scale industrial applications.

## 10. COMPARITIVE ANALYSIS

| Parameter | Manual | Automated | Improvement |
|---|---|---|---|
| Accuracy | ±5 µm | ±1 µm | Higher precision |
| Repeatability | Operator dependent | High | Stable results |
| Inspection Time | 25 sec | 6 sec | Faster inspection |
| Classification | Manual judgment | Automatic | Error-free sorting |
| Data Handling | No logging | Digital logging | Traceability enabled |

*Table 10. 0 : Comparison*

The comparative analysis clearly demonstrates that the automated bore gauge system significantly outperforms the conventional manual inspection method. Measurement accuracy improves from ±5 µm to ±1 µm, resulting in substantially higher precision and tighter tolerance control. Repeatability is enhanced due to controlled probe insertion, eliminating operator-dependent variations. Inspection time is reduced from 25 seconds to 6 seconds per bearing, increasing productivity by nearly four times. Additionally, automatic classification and digital data logging ensure reliable decision-making, traceability, and improved quality control. Overall, the automated system provides a more accurate, consistent, and efficient solution suitable for EV motor bearing inspection applications.

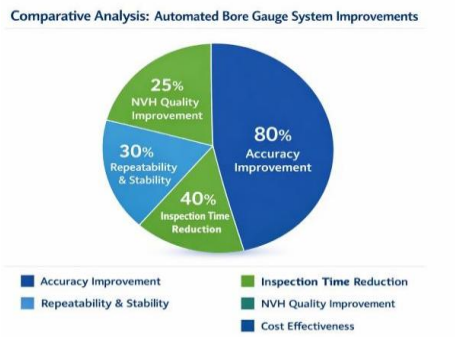


*Fig 10 .1: Comparative Analysis*

## 11. RESEARCH GAPS

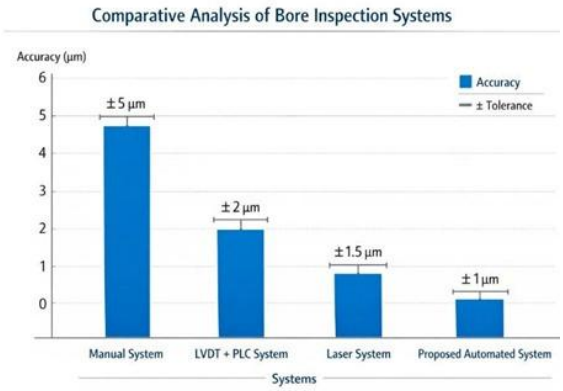


*Fig 10.2 : Research Gaps analysis*

### Limited Correlation Between Bore Accuracy and NVH Performance

Existing literature discusses bearing vibration and noise separately from dimensional inspection. However, very few studies establish a direct quantitative relationship between bore tolerance deviations (µm level) and NVH characteristics in EV applications.

### 1.Lack of Integrated Automation Framework

Most reported systems focus on either:

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

- Sensor-based measurement
- PLC/IoT-based automation

There is limited research on a fully integrated system combining LVDT sensing, stepper motor control, PLC automation, and tolerance-based classification within a single inspection platform.

Inadequate Focus on Sub-Micron Accuracy in Cost-Effective Systems

High-end industrial machines achieve sub-micron accuracy but are expensive. Research lacks development of economical automated bore inspection systems capable of ±1 µm accuracy suitable for academic and MSME applications.

**2.Absence of Real-Time**

Classification and Traceability

Many studies emphasize dimensional measurement but do not implement:

1. Automatic Good/Rework/Scrap classification
2. Digital data logging and traceability

This limits practical industrial adoption.

**2.Limited Comparative Performance Studies**

There is insufficient comparative analysis between manual and automated bore inspection systems in terms of:

- Accuracy
- Repeatability
- Inspection time

1. Limited Correlation Between Bore Accuracy and NVH Performance

Existing literature discusses bearing vibration and noise separately from dimensional inspection. However, very few studies establish a direct quantitative relationship between bore tolerance deviations (µm level) and NVH characteristics in EV applications.

2. Lack of Integrate Automation Framework

Most reported systems focus on either:

- Sensor-based measurement
- PLC/IoT-based automation

There is limited research on a fully integrated system combining LVDT sensing, stepper motor control, PLC automation and tolerance-based classification within a single inspection platform.

Inadequate Focus on Sub-Micron Accuracy in Cost-Effective Systems

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3. Limited Correlation Between Bore Accuracy and NVH Performance

Existing literature discusses bearing vibration and noise separately from dimensional inspection. However, very few studies establish a direct quantitative relationship between bore tolerance deviations (µm level) and NVH characteristics in EV applications.

## 12. CONCLUSION

The expected outcome of the Automated Bore Gauge System is to achieve high-precision bore measurement with ±1 µm accuracy while reducing inspection time from 25 seconds (manual) to about 6 seconds. The system will improve repeatability, eliminate operator dependency, and automatically classify bearings based on tolerance limits. It is expected to enhance productivity, ensure better quality control, and support improved NVH performance through precise dimensional inspection. Additionally, digital data logging will enable process monitoring and cost- effective industrial implementation.

## 13. REFRENCE

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