Design and Development of an Embedded - Based Control System for Torsion Bar Testing Special Purpose Machine (SPM)

K. S. Subhashini[1], Gayathri.A[2], Dhivya.N[3]
[1]Assistant Professor,ECE, Sri Venkateswara College of Engineering
[2,3]B.E ECE Student, Sri Venkateswara College of Engineering

***Abstract*—The Heavy Vehicles Factory (HVF), Avadi, utilizes a torsion bar testing machine-WOLPERT for qualifying suspension bars in tank production. Due to its obsolete hardware, a cost-effective indigenous retrofit system was developed using a Raspberry Pi 5 as the main processor. The system integrates an incremental rotary encoder with signal conditioning circuits for accurate angular measurement and employs a load cell interfaced via serial communication for torque acquisition. Motor control is handled through a drive system, while a Python-based GUI enables automated testing, data logging, and report generation. The retrofit system was implemented at under ₹5 lakhs, significantly reducing cost compared to imported alternatives and supporting the "AATMANIRBHAR BHARAT" initiative for self-reliance in defense manufacturing.**

***Index Terms*—embedded system, Raspberry Pi 5 Torsion bar, WOLPERT.**

I. INTRODUCTION

Torsion bars are suspension elements in main battle tanks such as the T-72 and T-90. They act as torsional springs, absorbing shocks through controlled angular deformation. Each torsion bar must undergo testing to verify torque capacity, elasticity, and residual deformation before installation. A typical tank (T-72/T-90) has 12 wheels, 6 on each side, connected by 12 torsion bars. These are equally divided into 6 Left-Hand (LH) and 6 Right-Hand (RH) bars based on their orientation. By retrofitting although the main advantage was a huge cost reduction of less than 1% of a new machine's cost added features such as personalization of the system design adding pause and resume option during test, an analog and Digital angle monitoring dials, Automatic torsion Bar type assigning and many more cutting-edge features which are not possible in an imported machine of a very high cost.

II. NEED FOR RETROFITTING

The need for retrofitting arises due to:

- Obsolete and unsupported control hardware.
- Unavailability of spare parts.
- Frequent machine breakdowns causing production delays.
- High cost (6 crores) and long lead time for new machines.
- Requirement for indigenous technological development.
- Scope for improved accuracy, reliability, and automation.

The retrofitted system provides a cost-effective and reliable solution comparable to modern systems.

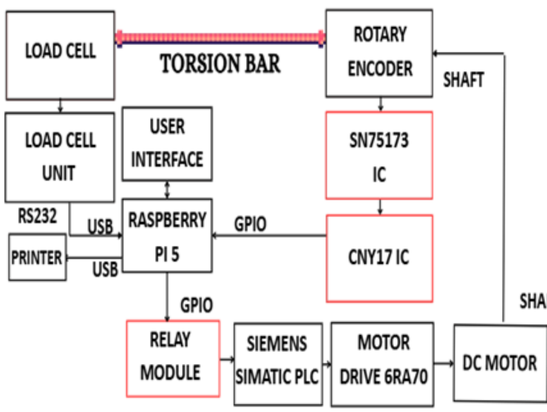
III. LITERATURE SURVEY

Thiyagarajan *et al.* developed a Raspberry Pi Model B retrofit for the WOLPERT machine at HVF Avadi, but their single-channel encoder counting was susceptible to directional errors and electrical noise. Kumar and Singh presented strain gauge torque measurement using Wheatstone bridges similar to the WOLPERT load cell, though their RS-232 interface lacked real-time parsing and suffered high serial latency.

The angular twist torque meter study established incremental encoder standards but lacked modern FSM quadrature decoding suitable only for unidirectional testing. Sharma *et al.* examined digital torque conditioning but their USB conversion latency exceeded 2ms making it inadequate for 1°/s torsion testing. Patel and Desai demonstrated FSM quadrature decoding for encoders but omitted differential receivers like SN75173 and optocoupler isolation making it noise-prone for industrial use. None of these works integrated Raspberry Pi 5, Heidenhain ROD 420, SN75173/CNY17 conditioning, and SIMATIC PLC control specifically for WOLPERT machine retrofitting.

IV. SYSTEM ARCHITECTURE

Block Diagram:
The proposed system consists of five main subsystems controlled by a Raspberry Pi 5:



Block Diagram of WOLPERT

- Torque Measurement: Load cell → signal conditioning → RS-232/USB → Raspberry Pi
- Angle Measurement: Encoder → SN75173 → CNY17 → GPIO
- Motor Control: Raspberry Pi → relay → PLC → DC drive → motor
- Mechanical System: Motor → gearbox → torsion bar
- User Interface: GUI display and report generation

V. HARDWARE IMPLEMENTATION

A. Machine Mechanism
The torsion bar is fixed at one end and rotated at the other using a DC motor through a reduction gearbox. Torque is developed during twisting, and the residual angle after release is measured as the key quality parameter.

B. Torque Measurement
A high-capacity load cell (Model: INTERFACE 1220AF) measures torque using strain gauge principles. The generated low-level analog signal is passed through a signal conditioning unit, where it is amplified, filtered, and converted into a digital form. This ensures accurate and noise-free measurement. The conditioned signal is then transmitted via RS-232 to the Raspberry Pi for real-time processing.

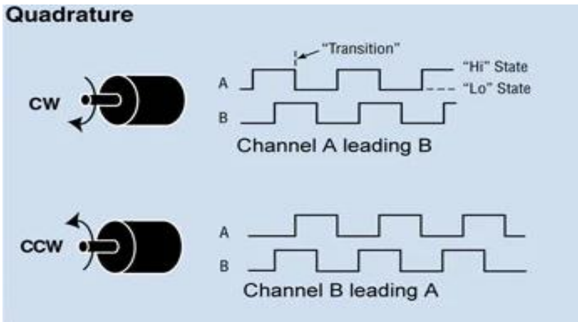
Load Cell Interface 1220AF-50K

Load Cell Conditioning Unit

C. Angle Measurement
Angular position is measured using a Heidenhain ROD 420 incremental rotary encoder. The encoder provides quadrature output signals (A, B) which are phase-shifted by 90°, enabling direction detection and precise position measurement.

Incremental Rotary Encoder
Heidenhain ROD 420

- Resolution: 1024 pulses per revolution (~0.35° per pulse)
- Output: Differential signals (A, /A, B, /B)
- Supply: 5 V DC



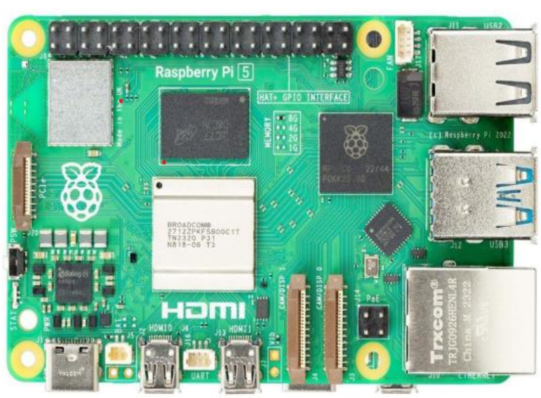
Encoder A, B Pulse

The encoder signals are processed through:

- SN75173 IC removes noise from differential signals
- CNY17 IC provides electrical isolation
- GPIO reads quadrature signals for direction and angle calculation

D. Central Processing Unit (Raspberry Pi 5)

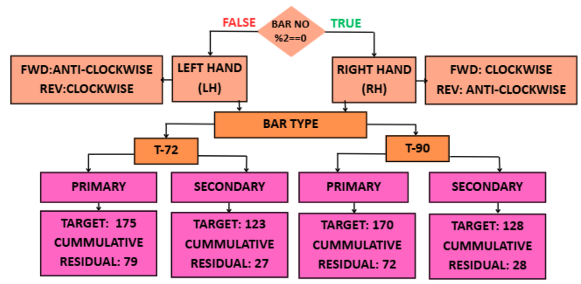
The Raspberry Pi 5 acts as the central controller, performing real-time data acquisition, processing, and control. It interfaces with the encoder via GPIO for angle measurement and communicates with the load cell unit for torque data. It also controls the motor through relays and runs the Python-based GUI for monitoring and automation.



Raspberry Pi 5

E. Motor Drive System

A DC motor is controlled through a PLC and drive unit. The Raspberry Pi 5 sends control signals (run, direction, brake) via relays, ensuring precise and safe operation.



Classification of Torsion Bars and Corresponding Target and Residual Limits

The flowchart illustrates the classification of torsion bars based on type (T-72/T-90) and orientation (LH/RH), along with their respective target angles and permissible cumulative residual limits used during testing.

VI. SOFTWARE AND CONTROL

A. FSM Quadrature Decoding

A Finite State Machine (FSM) is used to determine rotation direction using encoder signals:

- Clockwise → increment count
- Anticlockwise → decrement count
- Invalid transitions → ignored

Angle calculation:

$$\text{Angle} = \text{Pulse Count} \times 0.35°$$

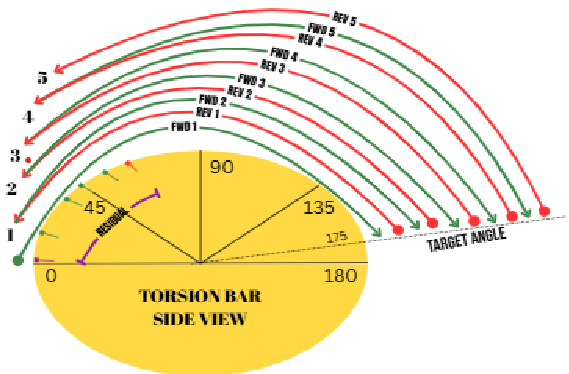
B. Five-Cycle Test Protocol

Each torsion bar undergoes five test cycles:

- Forward twist to target angle
- Hold (dwell time)
- Reverse to zero torque
- Measure residual angle

Cycle	Dwell Time
1	30
2	1
3	1
4	60
5	1

Forward angle is adjusted based on previous residual values to ensure accuracy. The rotation direction varies with the torsion bar type. For Right-Hand (RH) bars, forward rotation is clockwise and reverse is anticlockwise, whereas for Left-Hand (LH) bars, the directions are reversed.

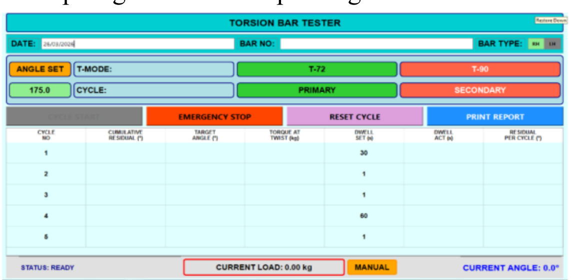


Torsion Bar Angular Deformation During Multi-Cycle Testing

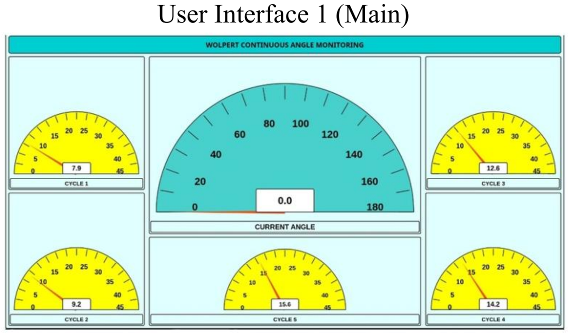
C. GUI Features

The Python-based GUI provides:

- Automatic bar-type detection (RH/LH)
- Predefined angle settings
- Real-time torque and angle display
- Automated test execution
- Report generation and printing



User Interface 1 (Main)



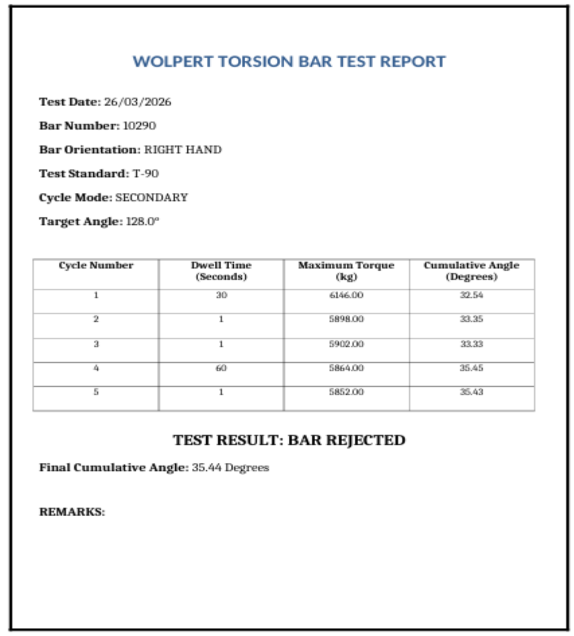
User Interface 2

VII. RESULTS

A. Test Results

A sample test showed:

- Gradual reduction in torque across cycles
- Residual angle reduced significantly after each cycle
- Final cumulative residual within permissible limits



WOLPERT TORSION BAR TEST REPORT

Test Date: 26/03/2026

Bar Number: 10290

Bar Orientation: RIGHT HAND

Test Standard: T-90

Cycle Mode: SECONDARY

Target Angle: 128.0°

Cycle Number	Dwell Time (Seconds)	Maximum Torque (kg)	Cumulative Angle (Degrees)
1	30	6146.00	32.54
2	1	5898.00	33.35
3	1	5902.00	33.33
4	60	5864.00	35.45
5	1	5852.00	35.43

TEST RESULT: BAR REJECTED

Final Cumulative Angle: 35.44 Degrees

REMARKS:

Sample Report

B. Key Observations

- Stable and accurate torque measurement
- Reliable angle tracking using FSM decoding
- Minimal error in dwell time control
- Fully automated pass/fail decision

C. System Comparison

The proposed system offers:

- Improved reliability and automation
- Better noise immunity
- Modern software interface
- Significant cost reduction

D. Cost Analysis

The retrofit cost is approximately ₹5 lakhs, compared to 6 crores for a new system, achieving major cost savings with comparable performance.

VIII. CONCLUSION

An indigenous Raspberry Pi 5–based control system for torsion bar testing was successfully developed and implemented. The system integrates accurate torque and angle measurement with automated testing and reporting. It achieves reliable performance for tank suspension testing at a significantly lower cost, supporting self-reliance in defense manufacturing.

Old Electric Panel

New Electric Panel

Future improvements include direct load cell interfacing and enhanced user interface integration.

IX. FUTURE IMPLEMENTATION

- The HX711 Load cell amplifier module can be used to replace the conditioning unit.
- The touch screen can be used with Raspberry PI.
- Open PLC software can be used in a separate raspberry pi replacing SIMATIC module.

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REFERENCES

[1] "Analysis and Development of the Angular Twist Type Torque Meter," Measurement, vol. 47, issues 1–4, Dec. 1999.

[2] S. Kumar and R. Singh, "Design and Development of Strain Gauge Based Torque Measurement System," IEEE Sensors Journal, vol. 15, no. 6, pp. 3452–3459, 2015.

[3] A. Sharma et al., "Digital Torque Measurement Using Signal Conditioning Techniques," International Journal of Engineering Research & Technology (IJERT), vol. 4, no. 3, pp. 112–116, 2016.

[4] M. Patel and K. Desai, "Angular Displacement Measurement Using Optical Rotary Encoder," in Proc. IEEE International Conference on Instrumentation and Control, 2017, pp. 210–214.

[5] P. Verma and S. Gupta, "Microcontroller Based Automated Torsion Testing Machine," in Proc. IEEE International Conference on Advances in Mechanical Engineering, 2018, pp. 98–102.

[6] R. Karthik et al., "Real-Time Data Acquisition System Using Raspberry Pi for Industrial Applications," IEEE Access, vol. 7, pp. 12345–12353, 2019.

[7] J. Lee and H. Kim, "Fatigue Analysis of Torsion Bars Under Cyclic Loading," International

Journal of Mechanical Sciences, vol. 120, pp. 45–52, 2017.
[8] R. Brown and T. Wilson, "Automated Material Testing Systems for Mechanical Characterization," Journal of Materials Engineering and Performance, vol. 28, no. 9, pp. 5120–5128, 2019.
[9] H. Cao et al., "Development of Torque Measurement Systems Using Strain Gauge Technology," Sensors and Actuators A: Physical, vol. 134, no. 2, pp. 600–607, 2007.
[10] Y. Zhang and L. Wang, "High-Precision Torque Measurement for Rotating Shafts," Measurement Science and Technology, vol. 23, no. 8, pp. 1–8, 2012.
[11] A. Kumar and P. Singh, "Design of Load Cell Based Force Measurement System," International Journal of Scientific Research Engineering & Technology, vol. 5, no. 6, pp. 234–238, 2016.
[12] Texas Instruments, "HX711 24-Bit Analog-to-Digital Converter for Weigh Scales," Datasheet, 2018.
[13] Raspberry Pi Foundation, "Raspberry Pi 5 Documentation," 2023.