# Research on tire uniformity testing equipment and its calibration technology

Luo Ping, Huang Wenjun, Lou Hong

(Hangzhou Chaoyang Rubber Co. LTD., Hangzhou 310018, Zhejiang, China)

**Abstract:** This article introduces the composition and working principle of tire uniformity testing equipment, systematically elaborates on the calibration process and methods for its mechanical, sensor, and control systems, and analyzes the importance of calibration in ensuring tire manufacturing quality and enhancing product performance.

**Key words:** tire uniformity; testing equipment; calibration

**Classification number:** TQ330.46 **Article number:** 1009-797X(2026)06-0022-05

**Document code:** B **DOI:**10.13520/j.cnki.rpte.2026.06.007

## 0 Introduction

The tire uniformity testing equipment is a crucial quality control and process optimization device in the tire manufacturing process. It not only sorts out unqualified tires but also enhances the tire yield by refining the grinding process, reducing scrap, and ultimately generating significant economic benefits for the enterprise.

Regular and standardized calibration of tire uniformity testing equipment is the only way to ensure accurate, reliable, and repeatable testing data. It serves as the cornerstone for maintaining product quality consistency. Its significance lies in: ① ensuring measurement accuracy: ensuring that the output parameters of the equipment are consistent with the true values. ② maintaining result repeatability: ensuring consistent test results for the same tire across different times or on different equipment. ③achieving process traceability: providing reliable data support for the adjustment and optimization of production processes.

## 1 Equipment introduction

The tire uniformity testing equipment is a comprehensive evaluation system that integrates automatic testing, analysis, correction, marking, and sorting. Its main components include a lubrication station, a testing station, a marking station, a measurement system, etc. Figure 1 shows the mechanical composition of the equipment.

### 1.1 Mechanical structure

#### 1.1.1 Lubrication station

The lubrication station, as a crucial front-end link in tire testing equipment, serves as an important hub connecting the production line and the testing process. Its operational status directly affects the efficiency and accuracy of subsequent testing stages. The automated conveyor mechanism equipped at this station, driven by a servo motor and paired with a precise positioning sensor, can smoothly receive tires from the production line for inspection, ensuring a hitch-free transmission and preventing appearance damage to the tires caused by collisions during transportation.

The precision guiding device for centering and positioning is equipped with multiple sets of adjustable guiding rollers and a laser positioning system. By real-time identification of the tire's outer diameter and center position, it automatically calibrates the tire's posture, ensuring precise alignment of the tire center with the subsequent clamping axis, providing a stable benchmark for subsequent lubrication and clamping. Its core lubrication system is divided into two modes: high-pressure spraying and roll coating, which can be automatically switched according to the tire bead material.

**Biography:** Luo Ping (1988-), an engineer, primarily engages in equipment technology and management.

The high-pressure spraying mode atomizes water-based lubricant into a uniform oil film through a fine-pore nozzle, covering the inside of the bead. The roll coating mode ensures no omissions in the application of lubricant through flexible contact between an elastic applicator roller and the bead surface. The refined lubrication process not only fundamentally eliminates mechanical resistance during the assembly of the tire and test rim, but also avoids problems such as wrinkles and cracks caused by excessive local friction during high-pressure inflation of the tire bead. At the same time, it solves the common issue of test air leakage caused by insufficient air tightness in traditional dry assembly.

Furthermore, the automated lubrication process precisely controls the amount of lubricant and the timing of application through a PLC program, ensuring a highly consistent lubrication state for each tire. This eliminates clamping deviations caused by operational differences during manual lubrication, providing a uniform initial condition for subsequent test stations to collect data such as radial force and runout. Simultaneously, the closed-loop controlled lubrication system avoids quality issues caused by excessive or insufficient lubricant, comprehensively ensuring the stability and reliability of the entire testing system.

### 1.1.2 Testing station

The testing station, as the core station of the tire uniformity inspection equipment, is a crucial component ensuring the accuracy of tire quality inspection. Its stable operation directly determines the reliability and validity of the inspection data, playing a vital role in subsequent tire performance evaluation and quality control. This station is composed of two core parts: the spindle-chuck system and the load wheel system, which work closely together to comprehensively inspect tire uniformity.

Among them, the chuck, with its high-precision clamping structure and flexible adjustment capability, can precisely clamp rims of different specifications and sizes. Whether it is the common household car tire rims or large truck tire rims, it can achieve stable and precise fixation, laying a solid foundation for subsequent inspection. The spindle, as the core of power output, driven by the drive system, can smoothly and uniformly rotate the tire, ensuring that the tire maintains a stable speed during the inspection process, simulating the rotating state of the tire in actual driving.

The load wheel system plays a crucial role in simulating real road conditions during testing. Through an advanced servo system, it can precisely apply a set load according to testing requirements. This load application process is precise and controllable, effectively simulating the pressure that tires endure under different road conditions, making the testing environment more realistic. At the same time, the load wheel system is equipped with high-precision sensors that can accurately and real-time collect various uniformity parameters of the tire during rotation, including radial force, lateral force, and dimensional runout. The collected data is transmitted to the control system in real time, providing accurate and comprehensive data support for subsequent data analysis and tire quality judgment. This helps staff to promptly identify potential quality issues in the tire production process, ensuring the performance and safety of the outgoing tires.

### 1.1.3 Marking station

The marking station, as the terminal key link in the tire testing process, serves as the core hub for converting test data into visual identifications. The accuracy and durability of its markings are directly related to the reliability of subsequent tire sorting, warehousing, and usage processes. This station can receive final test data from the testing station in real time, automatically extract core information such as product grade and high/low point locations, and adopt mechanical impact or thermal transfer marking methods according to tire type and customer requirements.

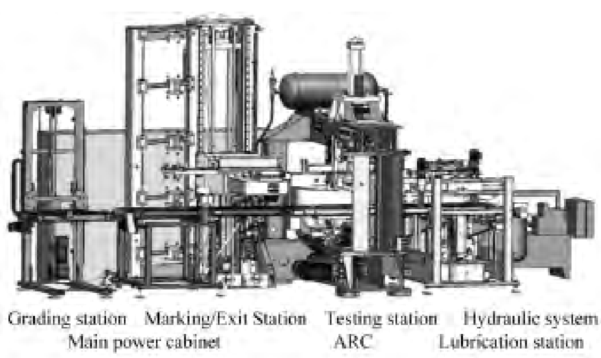


**Figure 1 Schematic diagram of tire uniformity testing equipment**

### 1.2 Measurement system

The core sensor of the measurement system consists of three major modules: force sensor, geometric probe, and position sensor.

The force sensing system employs a high-precision strain gauge sensor to monitor in real-time the radial force (Fz), lateral force (Fy), and their dynamic fluctuations (RFV/LFV) generated by the interaction between the tire and the simulated road surface. This provides core force data for uniformity analysis, as illustrated in Figure 2.


**Figure 2 Schematic diagram of force sensor**

The geometric probe includes lateral and radial runout probes, which simultaneously measure the radial runout (RRO) and lateral runout (LRO) of the tire, accurately evaluating the roundness and geometric accuracy of the tire, as shown in Figure 3.

**Figure 3 Schematic diagram of geometric probe**

The position sensing system, consisting of encoders and displacement sensors, is distributed across various motion axes. It provides real-time feedback on the spatial positions of the chuck, probe, and grinding device, ensuring precise execution of the testing, positioning, and grinding processes. This guarantees the repeatability and process consistency of the equipment.

## 2 Equipment calibration

Calibration is a crucial process to ensure the measurement accuracy of tire uniformity testing equipment, encompassing steps such as mechanical transmission, measurement system, and electrical control, providing reliable technical support for tire quality control.

### 2.1 Loadwheel calibration

Loadwheel calibration is divided into radius calibration, radial force calibration, and lateral force calibration. The schematic diagram of loadwheel calibration is shown in Figure 4, and the calibration process is as follows:

#### 2.1.1 Radius calibration

Using a high-precision standard radius gauge, the relative position between the rotation center of the load wheel and the spindle axis is precisely calibrated. This serves as the benchmark for determining the tire load radius and is directly related to the accuracy of subsequent force measurements.

#### 2.1.2 Radial force calibration

Through a loading system consisting of a lever and standard weights, a series of known and precise force values are applied to the load wheel. Simultaneously, the output voltage signal of the force sensor is recorded in the device software. A linear conversion relationship (i.e., a proportional factor) from voltage to force value is established and calibrated to ensure the accuracy of the entire measurement chain.

#### 2.1.3 Lateral force calibration

Its principle is the same as radial force calibration, but a dedicated lateral loading device is required to independently calibrate the lateral force sensor, in order to accurately measure the lateral force and fluctuations during tire rolling.

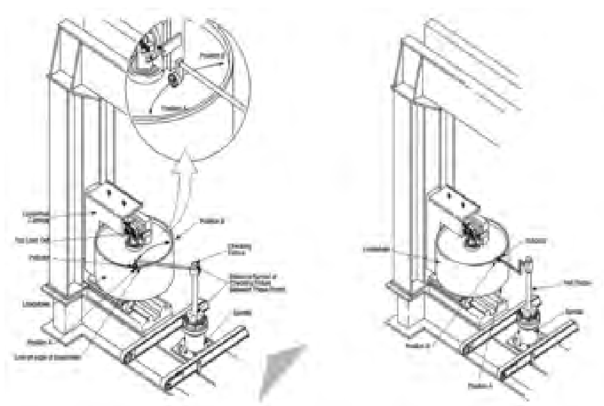

**Figure 4 Schematic diagram of load wheel calibration**

To ensure the effectiveness of calibration, the following precautions must be strictly adhered to: Before calibration, the equipment must be fully preheated to a thermally stable state, and the testing environment must be ensured to be stable. The process of applying and removing standard loads must be smooth and gradual, avoiding any impact that could affect the sensor or introduce dynamic errors. Finally, multiple measurements must be taken at each calibration point, and the average value taken as the final result, in order to minimize random errors and ensure the reliability of the calibration data.

## 2.2 Calibration of chuck and spindle

Calibration of the chuck and spindle system is a core aspect in ensuring the accuracy of measurement equipment. The calibration schematic is shown in Figure 5, and the calibration process is as follows:

First, perform AAWC (Automatic Area Width Calibration). By utilizing a standard block in conjunction with a displacement measurement system, accurately calibrate the linear correspondence between the chuck opening width and the position sensor signal. This ensures that the system can automatically adjust and precisely grip rims of different sizes according to tire specifications, with the gripping accuracy controlled within ±0.1 mm.

Next, proceed with the spindle runout calibration. Utilize a high-precision micrometer to measure the radial runout and end face runout of the spindle at its rated operating speed. These values must be strictly controlled within the engineering standard range to eliminate periodic interference on test results caused by unstable spindle rotation.

Finally, external reference pulse calibration is performed. By adjusting the zero pulse phase of the spindle encoder, an accurate angular reference is established to ensure that the data acquisition timing of the force sensor and geometric probe is fully synchronized with the specific rotation angle of the tire.

Special attention should be paid during the calibration process: the calibration of spindle runout must be carried out after the equipment has been continuously operated until it reaches thermal equilibrium, in order to eliminate the impact of temperature rise on mechanical accuracy. At the same time, only qualified standard rims that have been tested should be used. If the rim's own runout exceeds 0.015 mm, it will directly introduce measurement errors, resulting in invalid calibration results. Each calibration point should be measured multiple times and the average value should be taken to ensure the stability and reliability of the data.

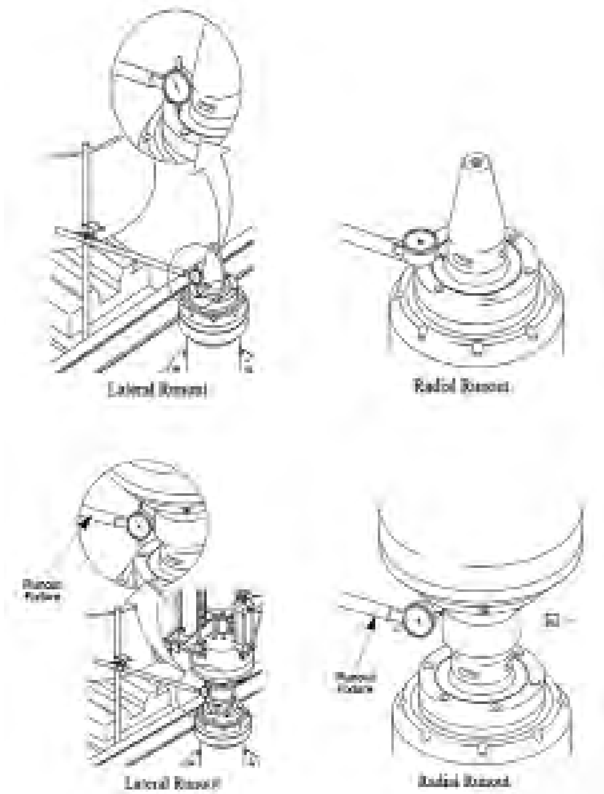


**Figure 5 Schematic diagram of chuck and spindle alignment**

## 2.3 Calibration of inflation system

Calibration of the inflation system is a crucial step in ensuring the standardization of tire testing conditions. Its accuracy directly impacts the precision of load radius calculations and test results. The calibration process requires the use of a high-precision standard pressure gauge (typically requiring a level of 0.1 or higher) with a precision level superior to that of the built-in sensors of the equipment as a benchmark. By applying step pressures to the bead seat inflation circuit and the test inflation circuit through a precise pressure source, the readings of two independent pressure sensors are systematically compared and calibrated, establishing an accurate correspondence between the displayed values of the equipment and the actual pressure values across the full range.

During the calibration process, special attention should be paid to the impact of sensor hysteresis characteristics. Multiple bidirectional measurements of pressurization and depressurization can be conducted near each calibration point, and the hysteresis error of the sensor can be identified and compensated through data comparison between the forward and reverse strokes. The entire calibration should be performed under stable ambient temperature conditions, and the pressure application process should be smooth and gradual to ensure synchronous data collection from the standard gauge and the device. After calibration, the system will generate a new pressure-voltage characteristic curve, providing a reliable basis for precise pressure control during different testing stages.

### 2.4 Probe calibration

The quality of probe calibration directly determines the detection and correction capabilities of the equipment. The schematic diagram of probe calibration is shown in Figure 6.

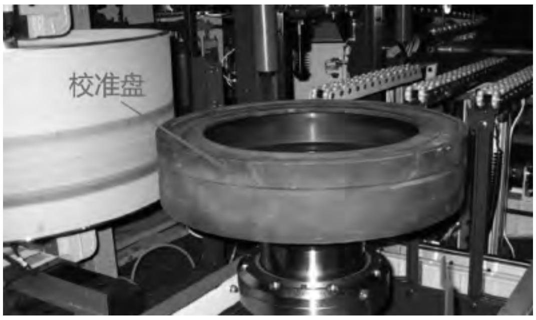


**Figure 6 Schematic diagram of probe calibration**

The probe calibration process begins with probe position calibration, utilizing specialized calibration fixtures or standard blocks to precisely calibrate the spatial orientation of both lateral runout probes and radial runout probes. By establishing their reference "zero positions" in the vertical, horizontal, and oblique directions, it ensures that all probes are precisely and uniformly positioned within the measurement coordinate system, providing a reliable measurement reference for accurately capturing tire radial runout (RRO) and lateral runout (LRO).

## 3 Calibration results and analysis

According to the technical specifications, the uniformity testing equipment of a tire manufacturing factory was calibrated. The calibration data is shown in Table 1, where the test object is a set of 215/60R16 reference tires (8 pieces), and the test conditions are an inflation pressure of 35 psi, a load of 500 kg, and 10 consecutive test cycles.

The results presented in Table 1 indicate that the standard deviations of all tested parameters are superior to the acceptance criteria:

Radial force $\sigma$ (0.062 daN) ≤ 0.170 daN

Lateral force $\sigma$ (0.041 daN) ≤ 0.133 daN

Radial runout $\sigma$ (0.012 mm) ≤ 0.02 mm

**Table 1 Test data**

| Key parameter test data (daN) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Radial force peak-to-peak (RFPP): | | | | | | | | | | |
| Test Sequence | 12.35 | 12.18 | 12.41 | 12.29 | 12.32 | 12.25 | 12.38 | 12.31 | 12.27 | 12.33 |
| Average | 12.31 | | | | | | | | | |
| Standard Deviation | 0.062 | | | | | | | | | |
| Lateral Force First Harmonic (Lfh1): | | | | | | | | | | |
| Test Sequence | 8.42 | 8.35 | 8.38 | 8.45 | 8.32 | 8.41 | 8.36 | 8.39 | 8.44 | 8.37 |
| Average | 8.39 | | | | | | | | | |
| Standard Deviation | 0.041 | | | | | | | | | |
| Geometric Parameter Test Data (Unit: Mm) | | | | | | | | | | |
| Radial Run-Out (Rro): | | | | | | | | | | |
| Test Sequence | 0.35 | 0.32 | 0.34 | 0.33 | 0.36 | 0.34 | 0.33 | 0.35 | 0.34 | 0.33 |
| Average | 0.34 | | | | | | | | | |
| Standard Deviation | 0.012 | | | | | | | | | |

## 4 Conclusion

The high precision of tire uniformity testing equipment necessitates the establishment of a comprehensive system calibration process. Regular standardized calibration of key components such as load wheels, chucks, inflation systems, and probes not only ensures the equipment's own performance but also enhances the core competitiveness of tire manufacturing enterprises, enabling high-quality sustainable development.