



A REVIEW OF WHEEL INSPECTION DEVICES AND CONDITION MONITORING SYSTEMS FOR RAILWAY VEHICLES

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Abstract – Railway wheel wear changes the wheel profile and affects wheel–rail interaction, making reliable inspection essential for maintenance planning. This paper reviews wheel inspection devices and condition monitoring systems, focusing on wheel profile geometry, flange height, flange thickness, the qR dimension, and wear assessment. Portable measuring devices are compared with stationary systems that inspect wheels during train passage. The review considers measurement principles, operating conditions, data handling, and the contribution of each approach to maintenance decisions. Particular attention is given to the transition from individual measurements to historical wear monitoring and maintenance prediction. Portable devices provide flexibility for workshop inspections, whereas automatic wayside systems enable frequent measurements across a fleet. However, increased measurement frequency alone does not establish predictive capability. Reliable predictions also require consistent wheel identification, comparable measurements, and records of operating conditions and reprofiling. The review highlights the importance of measurement quality and data continuity when selecting inspection systems and integrating their outputs into condition-based maintenance.

Keywords – railway wheels, wheel profile measurement, qR dimension, wear monitoring, predictive maintenance.

1. INTRODUCTION

Railway wheels undergo wear and damage during service, progressively changing their geometry and contact conditions. Wheel inspection therefore supports both operational safety and decisions concerning reprofiling and replacement. Recent reviews distinguish workshop inspection, wayside monitoring, and on-board monitoring, which differ in sensor placement, measurement frequency, and the condition indicators they provide [1,2].

For wheel profile assessment, portable instruments and automatic wayside systems are particularly relevant. Portable devices allow targeted measurements on stationary vehicles, while wayside systems inspect passing vehicles at designated locations. Both approaches can produce geometric information, but their contribution to maintenance depends on how measurements are identified, stored, and evaluated over time.

This paper presents a focused review of wheel

profile inspection and its connection to wear monitoring and maintenance prediction. Representative commercial devices are examined alongside recent scientific literature. The comparison covers measurement outputs, deployment conditions, and data management. Manufacturer documentation is used to identify declared product capabilities, while scientific publications provide the basis for discussing measurement methods and predictive maintenance. The review does not constitute an independent performance ranking.

2. WHEEL PROFILE PARAMETERS AND WEAR ASSESSMENT

Wheel profile inspection provides information on the geometry of the flange and tread. Common outputs include flange height (Sh), flange thickness (Sd), the qR dimension, and the measured profile curve. Depending on the instrument and its configuration, additional outputs include wheel diameter, hollow tread, rim thickness, and equivalent

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conicity [2].

These quantities describe different aspects of wheel condition. Flange height and thickness characterize the flange geometry, while qR describes a geometric feature associated with flange steepness. Full profile acquisition provides additional information by enabling comparison with a reference contour or previous measurements of the same wheel. Laser measurement and machine vision can also be combined to assess geometry and visible surface damage [3].

Profile comparison requires consistent alignment and reference definitions. Otherwise, changes in sensor positioning or profile registration may be interpreted as wear. Similarly, a percentage-based wear indicator is meaningful only when its calculation, evaluated region, and reference profile are explicitly defined.

Geometrical wear assessment should also be distinguished from damage detection. Measuring a transverse profile does not, by itself, establish the absence of cracks or localized defects around the wheel circumference. Broader wheel inspection may require complementary techniques [1,2]. Within the present review, the primary concern is the measurement and evolution of profile geometry.

3. WHEEL INSPECTION DEVICES AND SYSTEMS

Figure 1 outlines the two inspection approaches considered here and their common use in maintenance planning. Both provide profile data; monitoring additionally requires wheel identification and measurement history, while prediction requires a validated model.

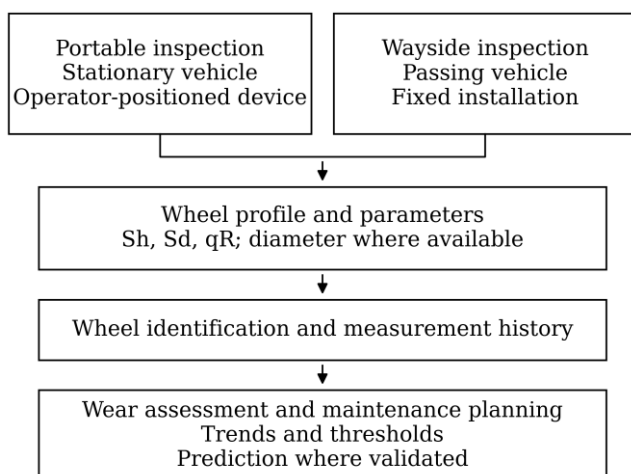


Fig. 1. Inspection approaches and use of wheel profile data in maintenance planning.

3.1. Portable measuring devices

Portable devices are suitable for workshop inspections and measurements at selected locations.

Their use allows individual wheels to be examined without a permanent measuring installation. Digital instruments can reduce manual transcription and retain profile data for subsequent analysis.

The CALIPRI C42 measures the wheel profile cross-section and evaluates parameters including flange height, flange thickness, qR , and hollow tread [4]. Goldschmidt's Wheelgauge Profile supports measurements directly on railway and tramway vehicles without removing the wheelsets [5]. ELAG's OPTIMESS WP uses contact-free laser scanning, automatically calculates profile parameters, and provides profile comparison and data export functions [6]. Figure 2(a) shows the OPTIMESS WP positioned on a wheel, illustrating the local access required for portable inspection.

Other examples include the Paragon LPM-5 and Althen FDKP. The LPM-5 reports flange dimensions, qR , and wear-related parameters; its published specification identifies supported Indian Railway profiles [7]. The FDKP combines laser profile acquisition with magnetic positioning, reference comparison, and database storage [8].

These devices illustrate different implementations of digital profile inspection. However, automatic acquisition after positioning should not be confused with unattended inspection of a moving train. Portable measurements still involve operator access, instrument placement, and association of the result with the correct wheel.

3.2. Automatic wayside measuring systems

Wayside systems inspect wheels as vehicles pass through a fixed installation. Their principal advantage is the opportunity to collect repeated fleet measurements without stopping each vehicle for a dedicated manual inspection. Nevertheless, permissible measuring speeds vary substantially between systems.

CALIPRI X is a permanently installed automatic wheel profile measurement system that can be integrated with CALIPRI Predictor [9]. KLD Labs' WheelScan uses lasers and imaging to determine profile parameters, including flange height, flange thickness, qR , and wheel diameter. Measurements are linked to vehicle identification and can be transferred to a fleet database [10]. Figure 2(b) shows CALIPRI X installed beside the rails to inspect passing wheels.

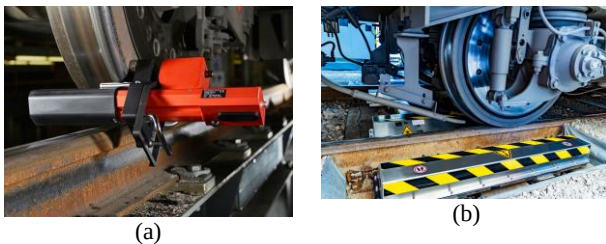


Fig. 2. Measurement arrangements: (a) portable OPTIMESS WP (source: ELAG [6]); (b) automatic wayside CALIPRI X (source: Hexagon [9]).

MERMEC's Profile and Diameter system provides full profile reconstruction and several wheel dimensions, with a declared measuring speed of up to 250 km/h [11]. HEGENSCHIEDT's ARGUS 2 is intended for lower-speed passage, with a specified measuring range of 3–15 km/h [12]. ARGUS S addresses higher-speed applications; its technical table specifies 0–80 km/h, with a design capability up to 160 km/h [13].

Table 1 summarizes representative solutions. The listed capabilities are based on supplier documentation and should be interpreted for the stated system configuration.

Tab. 1. Representative wheel profile inspection devices and systems.

Device / system	Deployment and capabilities
CALIPRI C42 [4]	Portable; full profile, flange dimensions, qR, hollow tread
Wheelgauge Profile [5]	Portable; profile inspection directly on the vehicle
OPTIMESS WP [6]	Portable; laser profile and diameter; comparison and data export
LPM-5 [7]	Portable; flange dimensions, qR and wear parameters
FDKP [8]	Portable; profile, Sh, Sd, qR; comparison and database
CALIPRI X [9]	Wayside; profile measurement and wear analysis integration
WheelScan [10]	Wayside; profile and dimensions; identification and fleet data
MERMEC [11]	Wayside; profile and diameter; up to 250 km/h
ARGUS 2 / S [12,13]	Wayside; profile and diameter; historical data and maintenance integration

3.3. Criteria for comparison

A useful comparison must consider the complete measurement process. Sensor resolution, measurement accuracy, repeatability, and uncertainty represent different characteristics and should not be treated as interchangeable. For example, the distance precision specified for a laser sensor does not necessarily describe the uncertainty of a calculated qR value.

Operating conditions also matter. Accessibility and

positioning influence portable inspection, while vehicle motion, environmental exposure, and measurement availability affect wayside applications. The proportion of successfully measured wheels should therefore be considered alongside the quality of individual measurements.

Portable and wayside devices can serve complementary roles. A wayside installation may identify wheels requiring attention, followed by a targeted workshop measurement. Such a workflow requires compatible parameter definitions and an understanding of differences between instruments.

4. WEAR MONITORING AND MAINTENANCE PREDICTION

An individual measurement describes wheel condition at a particular time. Repeated measurements can reveal the evolution of profile parameters, provided they are associated with the same wheel and obtained using comparable procedures. For this purpose, a measurement record should include wheel identification, date, measured profile, calculated parameters, and, where available, accumulated mileage. As indicated in Fig. 1, data acquisition is therefore only the first stage of the maintenance workflow.

Reprofiling records are particularly important because machining changes wheel geometry and interrupts the preceding wear trend. Analysing measurements across a reprofiling event without identifying that intervention could produce a misleading estimate of wear progression.

Commercial software illustrates how inspection data can support this process. CALIPRI Predictor provides historical storage, tolerance monitoring, profile comparison, and wear trend analysis [14]. WheelScan can operate with TrainBase and related applications for fleet evaluation, trending, and maintenance reporting [10]. Such functions support condition assessment, although their presence does not independently demonstrate prediction accuracy for a particular fleet.

Recent research addresses maintenance prediction through both data analysis and physical modelling. Lourenço et al. [15] discuss the formulation and evaluation of data-driven approaches for wheel and track monitoring, including difficulties in transferring research methods into operational use. Zeng et al. [16] examine wheel wear modelling and reprofiling strategy optimization using maintenance data. Miao et al. [17] investigate wheel wear prediction while considering wheel–rail elastic deformation and measurements collected during a reprofiling cycle.

For practical implementation, the predicted quantity should be clearly defined. Examples include the expected evolution of flange thickness or the mileage remaining before a specified maintenance

threshold is reached. Predictions should be evaluated against subsequent measurements and should account for uncertainty. A trend estimated for one operating regime may require updating when routes, loads, or maintenance practices change.

Accordingly, the transition to predictive maintenance requires more than additional sensors. It depends on reliable measurements, continuous records, an appropriate prediction method, and a defined connection between the predicted condition and the maintenance action.

5. CONCLUSION

Wheel profile inspection devices provide a basis for assessing wear and planning maintenance. Portable instruments offer flexibility for targeted inspections, while automatic wayside systems enable repeated measurements during vehicle passage. Their suitability depends on operating conditions, required parameters, measurement quality, and the integration of results into maintenance records.

The review indicates that full profile data and consistent wheel identification are particularly valuable for tracking changes over time. Automatic data acquisition can improve the availability of condition information, but predictive maintenance additionally requires validated methods and accurate records of interventions. A practical inspection strategy should therefore combine appropriate measuring equipment with reliable data management and clearly defined maintenance criteria.

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