Abstract

As a means of transport, the railway is gaining in importance, and this has inspired a large number of innovations. International rail traffic, for example, and logistics solutions need to be improved, but technical safety must also be guaranteed, especially for high-speed trains. Reliability and availability of high-speed trains depends significantly on the quality of wheels, wheel sets and wheel set axles. There are, indeed, already a large number of national and international rules and regulations, for example on the inspection of wheels, wheel sets and tracks, which take this into account. European and – not least – Fraunhofer research together with industrial partners have assumed a leading role in this process, resulting in international demand for inspection systems developed in Europe. Having said that, the systems do need to be adapted to suit national specifications.

Keywords: High-speed train, ultrasonic, eddy-current, wheel-, wheel set-, axle testing

1. New Systems for Testing of Wheel Sets (UFPE, AURA)

The underfloor testing system (UFPE) inspects ICE high-speed train wheels using ultrasound technology (UT) without the need to remove the wheel sets from their motor coaches or multiple units. For testing, the wheel set is lifted from the rail head and rotated by an appropriate mechanical device. The ultrasonic transducers, attached to an appropriate fixture, are placed on the surfaces of the wheels to be tested. The wheels are inspected during one revolution.
The AURA testing system is used to inspect wheel sets that have been removed from the train set and refurbished as required by the maintenance plan. This stationary system is currently being used primarily to inspect non-driven wheel sets by ultrasound and eddy-current.

The IZFP Instruments and Systems Engineering Department is developing new concepts for testing of both rotating and stationary wheel sets based on progress in the development of miniaturized multi-channel ultrasonic and eddy-current testing systems. The goal is to position all system electronics and data acquisition/analysis modules as close to the transducer assembly as possible, in order to achieve a truly compact, portable, maintainable and reliable inspection equipment. The new AURA and UFPE systems are therefore equipped with new front-end electronics.[1]

The first generation of UFPE resulted from a cooperative effort between DB AG (Deutsche Bahn) Systemtechnik, BAM (German Federal Institute for Materials Research and Testing), Fraunhofer Institute for Non-destructive Testing IZFP, and Fraunhofer Technology Development Group TEG, and is currently in use at several DB maintenance workshops. With the further goals of reducing testing time, minimizing handling time and improving reliability and maintainability, a new concept for underfloor testing was developed by IZFP and TEG. The results include new compact transducer assemblies that simplify mounting and coupling to the wheel sets on train and the placement of the front-end electronics in close proximity to the transducer assembly as shown in Fig. 1 and 2.

The new and very compact testing system (Fig. 2 and 3) incorporates the above mentioned improvements as for reliability, maintainability, and reduced inspection time and is compatible with the economic demands of the ICE operation. The use of the miniaturized UT front-end electronics eliminates problems associated with long noise- and failure-prone cable connections in current systems, and also enables wireless data transmission to the operating unit which is placed besides the train. To be able to detect defect signals which are closely neighboured to geometrical indications which is the case for the inspection of the wheel disk, the new UT electronics features recording of high-resolution A-scans.

**Fig. 1:** Transducer assembly for testing of driven wheel sets: comparison between old (left) and new technology (right)

**Fig. 2:** UFPE system components with transducer assembly at rest position
The new AURA testing system mainly designed for the inspection of disassembled drive wheel sets (Fig. 4) also includes the advances resulting from the miniaturization of the transducer assemblies and of the new UT front-end electronics modules which are mounted at the probe system assembly (Fig. 5).

Different transducer assemblies are customized to meet the requirements for the inspection of various types of drive wheels. Depending on the wheel set type, the required transducer assembly, in combination with the necessary front-end electronics, is taken from a swap-module storage (Fig. 6) by means of a tool changer and automatically positioned on the wheel set. The supply for the water used as couplant, power supply, and transfer of digital data are achieved via the tool changer. The changing of the transducer assembly is likewise easily accomplished without the need of manual disassembly. Ultrasonic testing of wheel rims and discs also benefits from proven software technologies developed by IZFP for data acquisition, analysis, display and documentation.

Statistical analysis of test results, data storage and archiving use the IRMS software based on a data bank, which was developed by arXes.
Fig. 5: Transducer assembly including swap module with integrated front-end UT electronics.

Fig. 6: Swap transducer modules for different drive wheel types in magazine.

Fig. 7 depicts a combined testing station for wheels and solid axles of freight car wheel sets. The equipment operates at the Süddeutsche Rail Service GmbH, Kaiserslautern (SRS) which performs refurbishment, reconditioning, repair and maintenance on a variety of rail equipment components of freight cars. Ultrasonic techniques are used to inspect the wheel rims for cracking and volumetric flaws. The running surface is tested for surface cracking by eddy-current techniques. Both for ultrasonic and eddy-current testing IZFP’s front-end technology is applied.
The axles of freight cars are usually solid and are ultrasonically inspected for transverse cracking in the wheel seats, journal, dust-guard seat, and all areas with cross-sectional variations. In order to cover all these areas, a large number of different incidence angles are required. To reduce the overall time for axle inspection, a phased array system provided by GE Inspection Technologies is used. The incidence angles are electronically varied from 25° to 75°.

Fig. 7: AURA testing station at SRS Kaiserslautern for wheels and solid axle testing

2. **Ultrasonic wheel inspection system (RWI)**

The wheels of high performance rail-vehicles must be certified as safe and reliable. The Nizhny Tagil Metallurgical Combine (NTMK) in Russia has formerly been using a four-channel EMAT system for detecting flaws during the wheel production process.

As part of NTMK’s reorganization and restructuring, a modernized automated UT test facility for wheel inspections has been constructed.[2]

The specifications for the ultrasonic wheel inspection system require:
- automatic testing sequence using two immersion tanks (Fig. 8)
- one-minute test cycle per wheel (without disc inspection)
- disc inspection of every tenth wheel
- no mechanical rearrangement for various wheel diameters
- detection sensitivity corresponding to DSR 1 mm (disk shaped reflector of 1 mm diameter)
- 13 UT transducers per inspection tank, 16-channel UT electronics
- 10 mm minimal dead zone (below the test surface)
- inspection areas: wheel flange, wheel rim, disc, hub and stamp recognition
- automatic data analysis
- complete documentation and data storage of all inspection results
- data analysis using HF data acquisition
- online monitoring of A-scans for four probes
- remote diagnosis and maintenance for ultrasonic and PLC functions via internet.
Because of the high production rate (one wheel per minute) high testing speeds were required resulting in a circumferential speed of approx. 750 mm/sec. This could be achieved using a new 16-channel ultrasonic electronics consisting of single-channel UT pulser/receiver boards (PCUS 11 F) working in parallel. To attain a total inspection cycle time of one wheel per minute, two ultrasonic systems working in immersion technique had to operate in parallel. The wheel handling is performed by a dual crane system which is able to accept a wheel from a wheel conveyor and to load each of the immersion tanks using a timely optimized control process. Fig. 9 shows a schematic of an immersion tank including probe handling system; a view of the inside of the immersion tank is given in Fig. 10. The complete testing station during the test phase in Germany is depicted in Fig. 11.

The project headed by the IZFP Saarbrücken was executed in cooperation with the TEG, Stuttgart, Spezialkrane Frömberg, and arXes, Berlin, with support by various Russian engineers and technical personnel.

Technical challenges for the successful completion of this project included a high detection sensitivity equivalent to a disc shaped reflector of 1 mm diameter (DSR 1) for unfinished wheels and continuous operation for a period of 22 hours per day, seven days per week.
The complete rail wheel inspection system (RWI) had to be designed, manufactured and delivered in accordance with the following standards:

- RD 32.144-2000
- EN 13262
- UIC 812-3V
- AAR M 107-84
- ISO 5948
- DB-TL 918 272
- AFNOR 09-340
- AFNOR ND-FOIL-142
The RWI system is configured for ultrasonic straight-beam testing of solid wheels. It utilizes 13 ultrasonic transducers operating in immersion technique and 16 PCUS 11 F pulser/ receiver boards, three of them serving as spare boards.

Facility installation was completed in late 2003 and certification testing and handover to NTMK took place during 2004. Certification testing included demonstration of flaw detection in reference wheels containing artificial defects following the requirements in the standards RD 32.144, AAR and UIC. The same wheel testing systems are in use in Germany since 2002 at “Bochumer Verein Verkehrstechnik GmbH” and since 2004 at “Radsatzfabrik Ilsenburg.”

3. Hollow axle testing

The wheel sets of high-speed trains feature hollow axles which have to be inspected periodically by ultrasound to detect possible defects at an early stage. For example for the German high-speed train ICE the inspection is performed every 240,000 km. The axles are tested from the bore hole for internal defects and cracks in the outer surface. Areas of interest are especially axle journal, dust guard seat, wheel seat, brake disk seat, and all transitions of diameter.[3],[4]

To save time and cost during the maintenance process, the ultrasonic inspection has to be performed on train. Therefore there is a need for compact and mobile hollow axle testing systems which are versatile and easy to handle. Such a system has been developed by the working group consisting of arXes Information Design Berlin GmbH, BIP-Industrietechnik GmbH, Fraunhofer IZFP, and Q Net Engineering GmbH. The hollow axle testing equipment (HAT) is shown in operation in Figure 12.

![Hollow axle testing system](image)

Fig. 12: Hollow axle testing system in use at a CRH 2 train set

The heart of the system is the feed unit with an extendible probe system module and the integrated ultrasonic front-end electronics. Probe system modules are specifically designed for bore hole diameters ranging from 30 mm to 110 mm. Figure 13 depicts such a module usable for bore hole diameters from 60 mm to 65 mm which includes seven UT probes.
Fig. 13: Probe system module suitable for bore hole diameters 60 to 65 mm

Beam angles of 45° and 70° are applied to search for transversal defects in the outer surface with the beam skew angle oriented in positive and negative axial direction. A normal beam probe with separate transmitter and receiver is intended to detect internal defects. To find longitudinal defects in the outer surface, 70° probes with beam direction in positive and negative circumferential direction are used. All angle beam probes generate shear waves; the probe frequency is 4 MHz for every probe. The number and type of probes used in a probe system module depends on the requirements for the inspection of a specific axle model. The couplant used for the probes is oil. The oil pump and filter system are integrated into the feed unit.

For the inspection of an axle the feed unit is docked to the face of the axle by an adapter. The probe system module is introduced into the bore hole automatically. During the inspection, the probe system module is advanced at a constant rate of feed through the hollow axle while the probes rotate at a constant velocity.

Dependent on the bore hole diameter rotation speeds of up to 200 rpm can be reached. During scanning the ultrasonic signals are stored together with exact information on the axial and circumferential position of the probe. Rotating speed, feeding speed and pulse repetition frequency are selected in such a way as to ensure that the complete axle is inspected with the required sensitivity. Dependent on the demands on sensitivity, scanning time is between 2 and 10 minutes.

The ultrasonic data are digitally transferred from the UT electronics integrated into the feed unit to the host computer installed into a roll-front cabinet. After completion of the scanning procedure, the display of testing results is available immediately. C- or B-scan images which are calculated from the recorded A-Scans can be displayed in various combinations; an example depicting a combined B- and C-scan image is given in Figure 14. For analysis of ultrasonic indications it is possible to repeat the data acquisition in a selectable part of the axle with higher resolution. To assist himself in making decisions, the operator can switch the testing unit over from automatic to manual mode and stop the probe system module in a pre-determined position to watch and evaluate the A-scan signals of potential defects.

The high mobility and flexibility of the system allows to inspect any type of hollow axles on train using specifically designed probe system modules and axle adapters. The height of the wheel axle’s centre can vary between 350 mm and 1200 mm. Also axles of disassembled wheel sets can be inspected.
The HAT hollow axle testing systems are in daily operation for the periodic inspection of China Railway High-speed trains (CRH). Implementation of the systems and training of the operators has been done in cooperation with our partner Beijing Sheenline Technology. Also system maintenance and service occurs under this partnership.

References


