Study of a train axle inspection system for automatically detecting defects in hollow axles

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Abstract. Train axles are safety critical components and they undergo a great number of charge/discharge cycles. Although existing studies regarding the control cracking show that fatigue failures are usually rare, when they occur unexpectedly they carry not only a high cost of replacement and repair, but also catastrophic consequences.

Therefore, it is important to determine any type of failure at an early stage to predict a safe life. Currently, as part of preventive maintenance activities, manual ultrasonic testing is used, which requires time and exceptional understanding of the ultrasonic signals with the consequent costs associated.

In this paper an ultrasonic hollow train axle inspection NDT system is presented, which is able to test the complete axle from just one side of the train with almost 100% of the axle being inspected in one pass with an inspection time of less than 25 minutes. This is carried out by utilizing different angular and zero degree ultrasonic probes to maximize the probability of detection.

The system set-up negates the need to prepare complicated calibration setups before each inspection. As well as being easy-to-use, it is versatile, allowing the testing of different types of axles within a range.

One of the main aspects considered has been the development of software, which allows real time visual representation, giving a summary of the most important indicators, as well as the state of the system, the position of the probe, the results of the inspection in real time and the ‘A’ Scan of each probe.

1. Introduction

Today's rail networks are getting busier with trains travelling at higher speeds and carrying more passengers and heavier axle loads than ever before. Rolling stock, is designed to last for thirty years, but is often used for much longer. The combination of these factors, leads to rise demands in the inspection and maintenance of rail assets.

Fatigue failures in axles are usually rare. However, although statistically very safe, a number of rail accidents have been directly related to the failure of axles, which means an increase for the inspection and maintenance of such components in order to detect any growing fatigue cracks.

High safety standards that apply in a railway management call for periodic inspections of rolling stock, one of the most critical components, to assert its ongoing capability to perform within the required safety margins. In the case of axles, a main objective of maintenance operations is the detection by NDT of cracks, that might lead to an in-service breakdown with potentially catastrophic consequences [1] [2].
Visual inspection and Magnetic Particle Inspection are the current standard practices used for manual non-destructive testing of axles. However, these processes require removal of the wheel-set from the wagon/locomotive bogie and full disassembly in order to facilitate access. Inspection is also carried out by some wagon providers using ultrasonic testing (UT) but its application is also limited to disassembled wheel-sets.

To be cost effective and to cause minimal disruption to train services, the NDT inspection should not require the disassembly of the wheel-sets and supporting bogies from the vehicles. In addition, there is also evidence that full disassembly can be counterproductive and lead to future maintenance problems.

Thus, in recent years, Tecnitest has been working to develop a system based on the use of ultrasound to inspect hollow axles in service, in order to replace manual procedures and get a system of automated quality control.

The use of ultrasound, allows to analyze the structural condition of the axle with the greatest reliability, avoiding therefore possible service failures and their consequences. So the system is able to:

- Reduce human error
- Register data and generate detailed reports that allow a guaranteed traceability of the inspection.
- Perform a complete inspection from one side without removing the train axle.
- Increase the reliability of the test.

2. System Definition

2.1 Features of the axes

The axes are structural elements in the train and have a complex geometry. It’s possible to define two types of axes; motor shaft (Figure 1) and trailer shaft (Figure 2).

![Fig. 1. Axle for inspection. Motor shaft](image1)

![Fig. 2. Axle for inspection. Trailer shaft](image2)

These axes meet the following technical data:

Motor shaft:
- Maximum static load per axle 17T
- Strength on the wheel (curved movement) 136 kN
- Lateral strength (curved movement) 58 kN
- Maximum traveling velocity 350 km/h
- Ambient temperature from -30º C to +50º C
- Weight without added elements 1.306 kg approximately
- Weight with added elements (with reducer) 1.626 kg approximately

Trailer shaft:
- Maximum static load per axle 17T
- Strength on the wheel (curved movement) 131 kN
- Lateral strength (curved movement) 50 kN
- Maximum traveling velocity 350 km/h
- Ambient temperature from -30º C to +50º C
- Weight 927 kg approximately
- Weight with brake discs on the axle 1,343 kg approximately

Both types of shafts are exposed to possible damage such as impacts, loads, material fatigue, stresses in areas of fillet radii, manifesting as shown in Figure 3.

![Fig. 3. Appearance of damage in axes](image)

### 2.2 Ultrasonic Inspection

Ultrasonic testing will be used as a method of nondestructive inspection. There are a wide range of waves that can be applied depending on the defects. In this case, have been used longitudinal waves and shear waves.

**Longitudinal waves:** The particles oscillate in the same direction as the direction of wave propagation. The fluctuation of the particles with respect to its equilibrium position, causes compression and depression zones moving through the material at a constant velocity, and unique for each medium (C). Each material has a propagation velocity fixed and known, varying from each other.

**Shear waves:** In this type of wave, the vibration of the particles is perpendicular to the direction of propagation, this vibration occurs when applying a shearing and periodic force on the edge of a solid material. This shear force is transmitted to the particles adjacent planes, resulting in delayed transverse oscillations, by their distance to excitation level.

The relationship between the velocity of longitudinal and shear wave, for the same material is:

\[ C_t = C_l \sqrt{\frac{1 - 2\mu}{2(1 - \mu)}} \]

Poisson's ratio (\(\mu\)) has a value between 0 and 0.5 for all solid materials, so the velocity of shear wave is less than the longitudinal for the same material.

Acoustic velocity is a generally constant feature for each material, regardless of the frequency/wavelength used (although could be affected by pressure and temperature, mainly in liquids and gases).

The velocity increases with the strength needed to return to equilibrium (elastic property of the medium) and decreases with density \(\rho\) (proportional to the inertia of the medium).

The shear waves have shorter wavelengths than longitudinal ones to the same frequency, and therefore have greater sensitivity to small reflectors.
3. System components

The final objective of the work was the development of a portable system for inspection from one side of hollow shafts using the ultrasound technique that complies with DB 907 01 01 and allows:

1.- Use of several probes with a different inclination for inspection of shaft from inside.
2.- Inspection method of rotation and advance. There is no continuous movement, spiral type, to sweep all the axis.

For this, the system was defined and developed, including several modules on it:

- **Ogive.** It contains the probes used in the inspection and it is installed on the telescopic arm.
- **Telescopic arm.** It allows the inspection of the entire length, from one side of the machine.
- **Actuator of acquisition.** It is responsible for positioning the ogive into the shaft.
- **Actuator of elevation.** It allows to raise the entire tray, so that the inspection level varies between 280mm and 1800mm.
- **Twirl to transport.** The entire system must rotate to allow the transport of equipment compactly.
- **Transport trolley.** On its upper part, the structure will have holes to allow the transport with either electric or manual commercial pallet truck.
- **Oil bomb.** Used to supply couplant to the ogive. Equipped with flow regulator and pressure gauge to ensure that this one does not exceed the allowable limits.
- **Control cabinet.** It contains all the electronics of motion control for acquisition, including computer and screens.
- **Ultrasonic equipment.** It’s formed by a double card that can operate with 16 channels. It’s possible to use multiple frequencies and independent DAC curves.
- **Computer and software composed of three applications.**
  - Positioning control, programming. It allows generate sweep files in which will be indicated the areas of inspection for each probe and the gain used; as well as the length of the gates.
  - Acquisition. Responsible for data capture and generation of acquisition files. It will present the captured signals indicating that the probe has detected that signal.
  - Evaluation. It presents graphically the signals, showing what signal is obtained by each probe. All these files must be stored on the computer together with axis data, serial number, operator... The program must comply with the inspection procedure DB907 01 01.

3.1 Ultrasound system.

Oil is used as a coupling medium (less dense than water, but more viscous). The inspection for the axis is performed in a single pass, with 10 probes (4 MHz) grouped in an ogive.

Eight of the ten are angular probes, of 45°, 70°, 38° and 39.4° (four are oriented in each direction). Its objective is to detect defects in the outer surface of the shaft (transverse and longitudinal defects). The probes generate transverse or shear waves in the medium about 3280 m/s (they are not propagated in liquids or gases as they offer no resistance to shear).

The other two probes are 0° transducers, that detect defects in the shaft volume and control the correct coupling (oil layer between the ogive and shaft) along the inspection. They generate longitudinal or compression waves with a velocity about 5920 m/s (easy to generate and to detect in any medium and with a high speed).
3.2 Software Development

One of the main aspects considered has been the development of software, which allows real
time visual representation, giving a summary of the most important indicators, as well as
visibility of the details of all the control points.

A system has been developed that allows the definition of the geometry of the axle to
be inspected. Each different axle is defined by introducing sections of different diameter,
providing each section a starting point and length. Furthermore, the definition of sections list
has an additional column with the value (in dB) that applies to that section, when a variable
gain inspection mode is being used.

During the process of evaluation/inspection, it is possible to see three windows
simultaneously. The top window shows the geometry of the selected axle and a scale
representation of the ogive (transducer holder) and its location in the axle at a given time.

The middle window displays the C-Scan with the information found during the
inspection, colour-coded according to the channel that has detected it.

The bottom window shows the A-scan of each channel. Moving the mouse cursor
over the window of the C-Scan, will automatically update the A-Scan channel corresponding
to that point. Figure 4.
When the inspection is finished, the program processes all indications found and groups them according to the distance between them, this helps the operator to identify potential defects. The total number of defects found is then displayed.

It is also possible to filter the fillet radii (geometric indications) and automatic numbering of the defects found. Figure 5.

All the raw data of each inspection are automatically stored in the database system, assuring traceability. Ease of access and reporting of stored inspections. Figure 6.
3. Demonstration

In addition to ease of use and analysis with A, B and C-Scan representations it is possible to:

- Inspection of nearly 100% of the axis from one side (Figure 7), the system can cover 2.5m from one side.
- Variable height of the system to suit individual inspection areas. The height of the inspection arm can be moved to meet the height of the train axle. No need for specifically built inspection areas.
- The inspection arm can be rotated for storage and safety during movement.

Fig. 7 Inspection.

- Easy replacement of the ogive. Quick release connectors facilitate easy removal.
- Robust, easy-to-use and transport. A Battery operated fork lift truck is incorporated in the system for transport along the line of the inspection.
- Inspection time less than 25 minutes, with a normal index of the Ogive.
- Different axle diameters. Adaptable to different types of shafts.
- Post-processing of the signals. As the raw data of each inspection are saved, off-line analysis can be carried out.
- Coupling guaranteed by oil. The Ogive is filled with oil which is constantly kept at a positive pressure. Although oil loss is at a minimum due to the design of the Ogive.
- Multiple types of transducers. The angles of the transducers necessary for detecting transverse, and longitudinal cracks as well as checking the volume are included.
- Inspection volume below 20 mm of the surface according to the Deutsche Bahn AG (BN 918 275).
- Individual inspection reports or for complete unit, with a summary of the results of all axes of each unit.
- Full traceability of stored inspections. Assignment Unit, axis number and serial number thereof.
- Unified screen with positioning information of the probe in the axle, C-Scan amplitudes with the positioning of defects and A-Scan in real time from all probes.
- Coupling control throughout the inspection. Using a probe 0° for verification of continuous coupling.
- Volume control throughout the inspection. Using a second probe 0° for verification.
- Determining the length of the defects 6dB drop method.
4. Conclusion

In this paper an ultrasonic hollow train axle inspection NDT system has been presented, which is able to test the complete axle from just one side of the train with almost 100% of the axle being inspected in one pass with an inspection time of less than 25 minutes. This is carried out by utilizing different angular and zero degree ultrasonic probes.

The different tests made using the developed system has shown that it meets the criteria regarding test velocity, robust design, ease of use, versatility, accuracy, and traceability, maximizing the probability of detection.

It is also in accordance with the DB Systemtechnik GmbH and test axles TW 258 (trailer axle) and TW 259 (motor axle).

References


[3] DB 907 01 01


