Near-service ultrasonic testing of solid axles on vehicles with corrosive load and its technical implementation

An abstract of precommissioning inspection at DB Schenker Rail

Stefan BETHKE 1, Jochen KURZ 1

1 DB Systemtechnik GmbH Department of Nondestructive Testing, Brandenburg, Germany

phone: +49 3381 812 312, e-mail: stefan.bethke@deutschebahn.com

Abstract. Solid axles of rolling stock tend in certain conditions to crack and also axle shaft fractures are known in several cases. NDT for rolling stock in the field of maintenance in dismantled position is for many years state of the art. With new calculated NDT intervals after fracture mechanics determine of axles BR403/406 and 411/415, the remaining mileage revised by the Federal Railway Authority, even for existing vehicles with solid axles the NDT intervals had been shortened dramatically. These receivables are concerned for axles of double-deck carriages, passenger carriages and freight wagons. To avoid dismantling of wheelsets after a two-year-interval, there was an urgent need to develop a method in near-service conditions to test the solid axles when they are installed! An economically feasible implementation of logical and precautionary measures is only successful and realizable by means of innovative testing technologies and -philosophies. This is where the initiative for the development of a prototype "solid axles test based on Phased Array Ultrasonic Technology" from DB Systemtechnik GmbH centred. Many Projects of innovation with co-partners had to be done before DB Systemtechnik GmbH realized the phased array technology on coatings with defined beam angle to start building a prototype. The test involves axles up to three braking disks. The ultrasonic testing of solid axles, when they are installed underneath the vehicle, needs following technical solutions:

• Application with different beam angles (Phased-Array-Technology)
• Coupling on cleaned and coated axles
• Consideration of several surface conditions to ensure high quality measurements
• Digitized evaluation of test results and display in 3D view
• Requirements of test sensitivity and scope of testing of railway guidelines
• Potential solution to exped up to axles with up to three braking disks

DB Schenker`s maintenance plant for corrosive freight wagons, located in Rostock-Germany, took over the prototype for a terminable testing phase. While the mechanised test rig was installed, inspectors tested more than 200 wheelsets in various conditions (fixed or corroded surfaces at the coupling region) underneath the vehicle. For this connection and period of test the coating qualities and axle surface were tested and documented.
1. Introduction

A test system which is used to detect cracks of solid axles when installed in a vehicle will be presented in this article and called "VPS-Mobile". The solid axle test in the installed state contributes to the safety of rail transport in Europe. The first steps to combine the design of a maintenance plant with the rig, were to move the probes to the shaft surface and define positions for coupling. The innovation using new probes and the simultaneous use of different probes as well as the application of a new testing technology produces over the existing maintenance drain a monetary reduction in maintenance expenses. For the period of laboratory tests, a probe carrier was designed, manufactured and feasibility studies were carried out. This study was related to the detection of reference defects by longitudinal or transverse UT waves with different test frequencies, attachment wedges and numbers of piezo elements.

The basic conditions of the probe dimensions and the necessary adaptation of the probe sole for optimizing the testing of solid axles is described for axles with up to three installed breaking discs. To allow the examination of solid axles, the technology of the proven test technology in dismounted condition could not be adapted since a special portal stand would be necessary. Thus, the concept for a rig, fitted into the pit had to be adapted and the media delivery and turning device for the axles underneath the vehicles had to be positioned into the pit to avoid difficult handling.

2. VPS-Mobil

2.1. Concept and implementation

The crack endangered areas of a solid axle increase under certain operating conditions the risk of a possible real crack. Reasons are load changes, mechanical damage or the influence of corrosive cargo. These areas include, in particular, the cross-sectional transitions, the bearing seats, axle stub (oil seal seat), wheel seats and the shaft with all adjacent three-centre curves. The evaluation of the test results of a defective wheelset revealed the need to expand the test area to investigate NDT at shafts of solid axles.[1] In order to guarantee the 100% inspection of an axle surface underneath the vehicle, it is necessary to rotate the wheelset during testing. The first concepts included the lifting and turning of the wheelset by using heavy devices during the examination process. With an one-side infeed (Figures.1 and 2) for the probes and a manual adjustment spindle for axial and horizontal displacement, it was possible to test the axle up to the stub and wheelset bearing. This solution allows an exact and wear-free positioning of the probes to test the acoustic properties, the optimally coupling position for different axle contours and provides a constructive function carrier for the device.

While developing of the infeed, the probes for the minimal variance underneath the vehicle were technologically advanced in collaboration with manufacturing companies and adapted to the test programs for pre-defined coupling positions. In cooperation with DB Schenker Rail AG first tests were carried out in the field of corrosive cargo wagons. More than twenty individual tests of wheelsets provide an overview of existing surfaces and coating states of the built-in axles. The experiences and redesigns from this experience were integrated into the production of a prototype. The extension of the test rig with mechanized adjustment leads to a complete examination of the lateral surface of the solid axle when installed. Each axle is tested out of four coupling positions in repeated movement and the ultrasound is transmitted into the axle shaft by two phased array probes in axial direction.
With a mechanical and sensor-controlled positioning of the guide arms, the probes are coupled to the shaft and approach the different positions in a fast and a slow movement. The hand wheels, which started the displacement in the prototype, have been replaced by electric motors and a user-friendly control gives the examiner the possibility of precise control and activation of the guide arm position. Limits for the axial and horizontal direction, combined with an encoder at the motor allows the positioning of the probe arms and provides a reproducibly and safe approach and a prevention of mechanical defects. Figures 3 and 4 illustrate the test at the „internal“ inspection position underneath the vehicle and Figure 4 shows the water-coupling on a pre-cleaned axle shaft.

Due to insufficient corrosion protection painting, filth adhesion and damage at the coat of painting, the cleaning of the axle is inevitable for a better coupling at the surface and is carried out by a motor brush combination. Having appropriated bristle hardness, adhering dirt from the coating will be dissolved and will be removed by hand during the following steps. The anticorrosive coating is not damaged by this work. Paints, flaking and repairs lead to ads at the shaft area which have to differ from cracks or damage from external influences and demand a high concentration of the inspector. Overall, an examination of a solid axle in the installed state can be stated and is carried out within 20 minutes. This time includes the set-up for the rig, the wheelset lifting and turning and the preliminary cleaning work and will be reduced by future changes in the field of displacement of the rig and process optimizations.
2.2. Test and evaluation of the axle

The ultrasonic phased array technique is state of the art in the field of mechanized testing at the railway industry. Wheel testing rigs as well as test stands for axles with longitudinal boreholes are equipped with this technique with increasing accuracy, reproducibility of the test results and a higher probability of detection (POD). By using phased array probes, all areas of the surface are covered by delay and angle variable acoustic beams out of four coupling positions and are instantly changed in the angle ranges between 28° and 72°. DB Systemtechnik did not replace the existing testing technology for the period of prototype stage, rather the new and optimized probes were adapted to the existing technology and the test procedure prolonged the examination of an axle.

The four ultrasonic probes, each equipped with 32 individual elements, have curved transducers and a predefined focus range. Due to the constructive specified width of the cylindrical coupling surface for axles with three breaking discs between the three-centre curves of wheel and brake disc seat, the structural limitations of the probe were communicated with the manufacturer and during the test phases optimized in frequency and angle range. The first experiments with a probe frequency of 4.2 MHz, lead to good S/N ratio of ≥12dB, reproducible results and defect recording in the angular range of up to 60°. For longer sound paths than 500mm in the angular range over 60° the gain curve rises sharply, so that the S / N ratio falls below 6dB. With repeated optimized probes in a frequency range of 3.5 MHz for longer sound paths and angle ranges within the stub area and bearing set, the resolution was significantly increased in 400 to 600 mm long sound paths.

The technical and low-wear implementation of the testing on the axle surface is feasible with a purified and paint drip free surface. Furthermore, the experiments are designed to distinguish between testable and non-testable surfaces. The material properties of the axle as well as the surface of the coating are the two main factors which are particularly recorded during testing. The sound properties of an axle in comparison to an axle with initiated cracks and acoustic permeability is a criterion for exclusion and coating damage or coupling losses an can lead to misinterpretations and an avoidable dissembling of axles. By comparison of test results and image documentation any detection can be defined within a catalogue. Figure 5 illustrates a sporadically occurred problem at the coupling trail and leads to a lifting of the probes and a bad coupling behave.

Fig. 5: uneven coating at the coupling area
3. Display of results

First, a wheelset with integrated predefined reference flaws was created. The method, to optimize the results by using saw cuts as reproducible references is state of the art. The influence of the coating on the test result was determined by one-sided grinding of the coating on the shaft. Figure 6 illustrates this effect between the coated side A (left) and uncoated B-side (right) of the wheelset.

![Image](image1.png)

**Fig. 6:** Test results with coating (A-side / left) and without coating (B-side / right)

The circumferential coupling trail is a statement for the quality of the coupling and the insertion of ultrasound into the shaft. If there are coupling problems the shaft surface is possibly damaged or the water delay path could not bridge the gap between probe and shaft. If the coupling trail interrupt rise above predefines tolerable settlement with $\geq 10^\circ$, the test must be repeated. As far as possible the experiments shows a number of good surfaces of installed solid axles and also a good gimbal balancing of the probe holder with domed or roughened coatings. Each axle is tested with two test cycles and moved to the second scan to cover the whole axle surface. A complete examination of the shaft is occurred when both test cycles do not show an indication. With the integrated V-transmission, the gain adjustments were made for determining the sound permeability of the axle.

![Image](image2.png)

**Fig. 7:** evaluation of the reference standard

**Fig. 8:** aperture settings at the outer irradiation position
4. Outlook

The satisfactory tests under operational conditions led to checklists and specification requirements for future projects. In addition to the technical test results the extensive and portly mechanic of the lifting and turning device felt into consideration. The next development step does not need a lifting and turning device and it is able to carry an exposed shaft at the lateral surface with an ultrasonic testing device. Through a new approach consisting of a rotating examination system “VPS-Ring”, where the probes move around the built-in and stationary wheelset, the interim ultrasonic inspection could be reduced by this factor of time and increases the efficiency of maintenance. By using entangle the probes in the radial direction, a force-fit and form-fit connection around the axle is produced and covers the diameters which are used for corrosive freight trains. The schematic drawing, shown in Figure 9, illustrates the examination of the solid axle in the installed state with a movable apparatus. A capacitive inclination sensor determines the exact circumferential position of the probes and ultrasonic indications at succeed diagnostics are approached with reproducible quality. This ring combination can be coupled once for a singular test or added by equal racks on the shaft as often as possible up to four times.

![VPS-Ring](image)

**Fig. 9:** VPS-Ring (solid axle rotating test with motor feed motion)

**Fig. 10:** VPS-Ring (schematic drawing and labelling of components)

Based on a number of two probe combinations, data of the axle material is recorded and an adjustment of the gain values, as a result of the acoustic properties, is performed out of these results from opposing pairs of probes. Magnetic distance rollers are connected to the wheel hub and serve to prevent the axial displacement of the unit on the shaft surface. The cross struts between both probe holders define a constant distance and lead to a reproducible sound transmission. A spring-adjustable ring carrier is shown in its basic position in Figure 9 and will be unfolded to fit around the shaft.
The motor drive has its own spring-loaded clamping force to avoid slipping by the frictional force of the probes. The ring rack contains the probe holder for the ultrasonic probes, motors, inclination sensors and spacers. Defined pressure on the shaft is applied through a quick-locking mechanism, so that the probes and the drive rollers of the motors can be pressed and move free of slippage. The rack moves circumferential on the wheelset shaft surface and repeats the movement in the reverse direction. The procedure of testing starts with the wetting of the surface in the forward movement while the backward movement is for testing the axle for operational defects. The cable and hose package coils up. After wrapping the probe holder drive unit around the shaft, the moving components turns the direction of the motion in relation to the considered rig. This variant provides a cost reduction since a lifting and turning device is not required any work. The wheelset testing with the existing equipment and the current principle will continue until 2017 and the new construction will be further developed in parallel. This device is independent of infrastructural requirements and the motion and adjustment is by means of workshop trolley self-sufficient with regard to the choice of location and can, regardless of the infrastructural conditions, be used in all plants with a pit.

5. Conclusion

The new testing technology and mechanized functional carrier for solid axles of freight, double-deck and passenger coaches can be test in the installed state. A two-year inspection interval within the maintenance of wheelsets of corrosive freight wagons would be introduced and makes a disassembly no longer necessary. The dissembling of wheelsets with corrosive load is similar to noncorrosive freight transport and underlies a six-year interval and the VPS-Mobil inspection is interposed. In the early days of the experiment and test trials, the remaining operating wheelsets for safety were expanded for a further period of one year continued operation and are supplied afterwards to the maintenance for reproducible testing. Both results of the mechanics and the ultrasonic equipment are basics for further developments of the solid axle test in the installed state. The working conditions and the difficulties of the influences of the environment (for example, the influence of surface pollution and the infrastructural conditions) were important experience factors. During further activities of the examination, pollution survey of used axles will be reported and also recommendations for recoating axles will be given too. The requirements for the inventory components refer to the sound characteristics and the coating, which are major conclusion of these results. Using the lifting and turning device by manual displacement on the rail underneath the vehicle, the handling is not easy and would be mechanized during possible variance of the following steps. Fixing screws on the rail, the elevated railway and rail bridges indicates to a rail guided displacement into the pit of the whole rig and an adaption of infrastructural leads to a cost- and time-consuming implementation of the rig. By redesigning the mechanics and reversing the concept of movement, the handling could be simplified. This eliminates the demanding lifting and turning of the wheelsets which could be replaced by an adaptation of the “VPS-Ring” with a self-sufficient testing system.

References