AUTOMATED ULTRASONIC TESTING SYSTEM FOR RAILWAY AXLES

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1 Overview

Automated Ultrasonic Testing system for solid shaft axles in production flow
according to different national standards
Online test report and result transfer to host computer
Short cycle times: 3 - 7 min

2 The Test Task and the Purpose of the Test

2.1 Introductions and Testing Problem

Automated ultrasonic testing of railway axles during the manufacturing process has become an ever-increasing part of the testing needs in the railway segment, which is a growing portion within the worldwide field of transportation. .

Due to the high safety requirements railway axles are inspected thoroughly and comprehensive already during the manufacturing process for defects and irregularities. During the past mostly the axles have been inspected manually. The present requirements however ask for inspection already in the production line. This inspection especially deals with irregularities caused by and during the manufacturing process in the axle material.
During later train operation the wheel sets are subject to alternating bending stresses, which, over a period of time, could cause rise to fatigue cracks. Unnoticed they cause axle fractures, which in turn, can cause serious accidents.

This testing machine is predominantly designed to inspect full, solid axles.
Axles with a center bore are partly also testable from the outer cylindrical section.
The tests from inside the center bore require additional equipment.

Besides the ultrasonic inspection also other tests are common during the manufacturing process. These are magnetic particle inspections as well as optical geometry measurements.

2.2 The Requirements of the Project

The main pre-requirement of the inspection is to make the material flow through the testing machine in the production cycle.
According to the requirements set by the standards the testing machine must be able to carry out different scanning programs. During the individual scans between the probes actually required are automatically selected. For this purpose various testing parameter sets are stored for the relevant type of axle.

Immediately after the test the result should be transmitted to a central control system. The axle handling system has to sort out such axles, which show unacceptable indications. Mostly they are forwarded to a separate review station.

With this technical aim a testing system has been developed for cycling times in the range of 3 to 7 minutes. The cycle time mainly depends from the selected test standard.

3 Ultrasonic Test Methods for Railway Axles

3.1 The Testing Method - in General

The ultrasonic test uses the pulse-transit time method with normal beam probes.
For this application best results are achieved with probes in composite technique -
having a large bandwidth The sound is transmitted into the face side of the axle by direct contact via a small water gap.

All sound transmissions, which are entered from the outer surface into the axle, are using a larger water delay path. This is beneficial for the axle testing as it allows a fast adaptation to different types and geometries of axles.
During the test the axle is turned on a roller block. The feed for the probes can be freely selected through the scan program.

For each probe a DAC (Distance Amplitude Correction) has been provided, which compensates the individual probe characteristics related to the material depth.

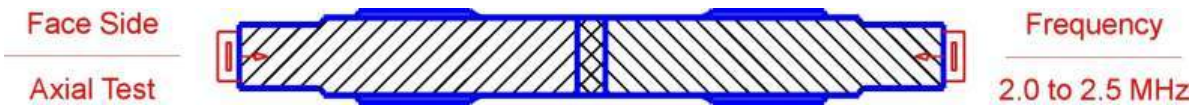
Following the test arrangements are described which are basically feasible, however, without referring to specific standards applicable in different countries. To some extend the technology described exceeds the relevant volumes of standards.

3.2 Axial Body Test from the Axle Face Side

The inspection of axles from the face side is carried out preferably at an early stage of the production. In this situation either no boreholes or only the punch bores for the alignment of the shaft during the manufacturing are machined in. Each probe has two tasks:

- → Detection of internal reflectors up to the center of the shaft
- → Monitoring of the back wall echo (opposite face side) for checking the sound absorption.

The measuring of the sound absorption is carried out using fix positioned probes.
The scanning for internal defects is carried out with a vertical test feed from the center of the shaft to the top.



Picture 1: Face side test

Typical sizes of test defects are: Axial Bores
Up to a depth of 380 mm: ø 3.0 mm FBH (flat bottom hole)
Up to a depth of 700 mm: ø 5.0 mm FBH
Up to the center of the shaft: ø 9.0 mm FBH

3.3 Radial Body Test from the Cylindrical Surface Area

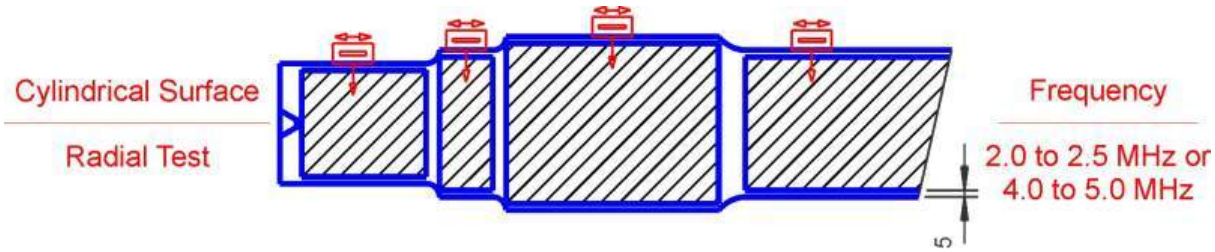
The transmission of the sound happens in radial direction on the lateral area of the shaft. This applies for all test segments of the shaft, which are:

- → The Journal
- → The Dust Guard Seat
- → The Wheel Seat
- → The Axle Shaft

The inspection is always activated in the cylindrical section. The feed of the probes is controlled by servomotors, thus resulting in a homogeneous test line helix in longitudinal direction of the shaft. In order to achieve a higher testing throughput, several wide-beam-probes in offset arrangement are in use. Thus the effective testing trace having a width of 60 to 80 mm per turn is generated.

Also cone shaped axle shafts can be inspected with the testing machine. To do this

- → The probes are slightly swiveled dynamically during the test; the widths of the monitoring gates are automatically tracked before the back wall echo.



Picture 2: Radial body test on the cylindrical part

Typical sizes of test defects are: Radial Bores

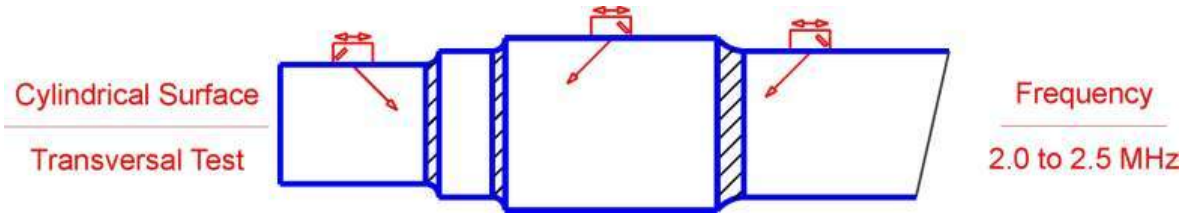
In all test segments: ø 3.0 mm, resp. ø 5.0 mm FBH

3.4 Transversal Test of the Transient Areas of the Different Axle Sections

The test is carried out using angular beaming with probes, which are arranged above the axle in the 12 o'clock position Here especially all transition areas of the axle are tested, these are:

- → Journal to Dust Guard Seat
- → Dust Guard Seat to Wheel Seat
- → Wheel Seat to Axle Shaft

The inspection for transversal oriented irregularities is carried out using two immersion probes, which are arranged that way that each of them is beaming in the right and left direction. This inspection is done in a second test run.
Because of the smaller width of the test trace in this inspection, a smaller feed is applied.



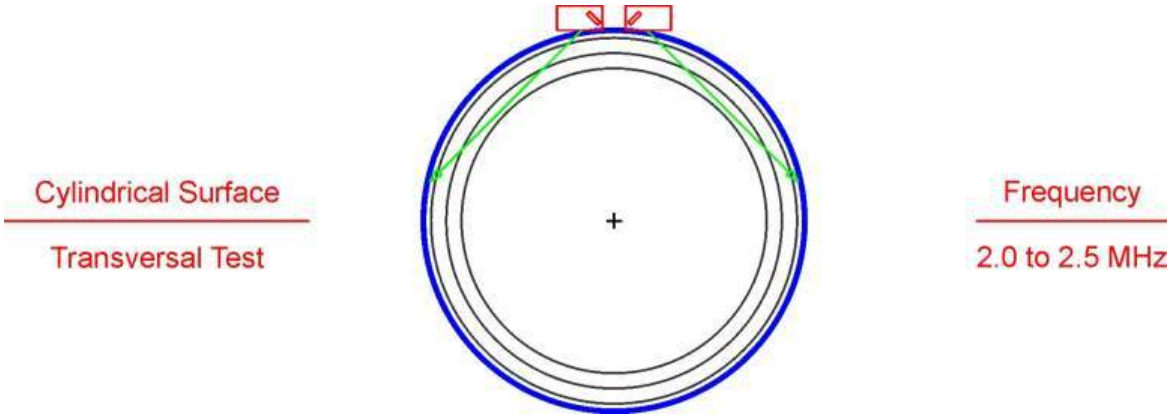
Picture 3: Transversal test of the transition areas

Typical sizes of the test defects are:
Bores arranged inclined under 40 degrees in all transition sections: ø 3.0 mm FBH

3.5 Transversal Test of the wheel seat area

The test is done by angle beaming with immersion probes, which are beaming clockwise and counter clockwise into the wheel seat area.
Here especially longitudinal orientated surface cracks shall be detected.
The angle of incidence is approx.: 45 degrees.

The test is carried out in both directions of sound propagation on the circumference of the shaft, in order to detect natural defects, which can also be an inclined oriented cracking.
Also this inspection is done in the second testing scan, together with the aforementioned transversal test, under 2.4.



Picture 4: Transversal test of the wheel seats

Typical sizes of the test defects are:
Longitudinal notches, 10 mm long, 1.5 mm deep

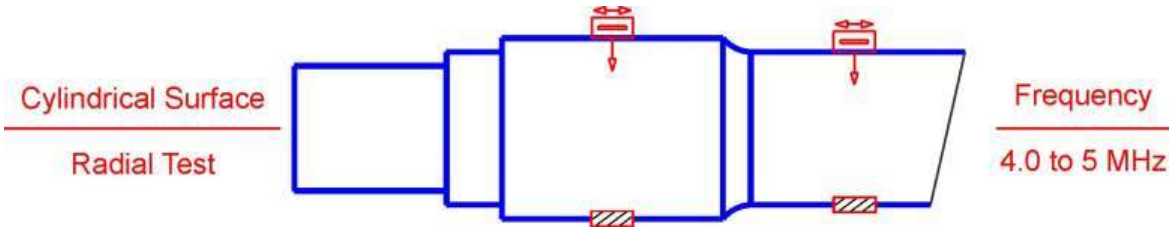
3.6 Radial Body Test for Sound Attenuation

The permeability check will be performed in cylindrical axle segments.
In this case probes with a narrow bandwidth achieve the best test results.
An axle with typical grain size generates a back wall echo for Full Screen Height.

The evaluation is performed by two methods:

- → Fixed Threshold:
  A back wall echo drop down of more than 6 dB generates a “Reject”

- → Evaluation of Relative Amplitude Variation:
  In case of high back wall echo response, also the back wall echo amplitude is monitored. When the back wall echo differences of a comparable zone group are more than 6 dB (value selectable) the axle also will be considered as “Reject”



Picture 5: Radial body test for sound attenuation

4 World Wide Test Standards

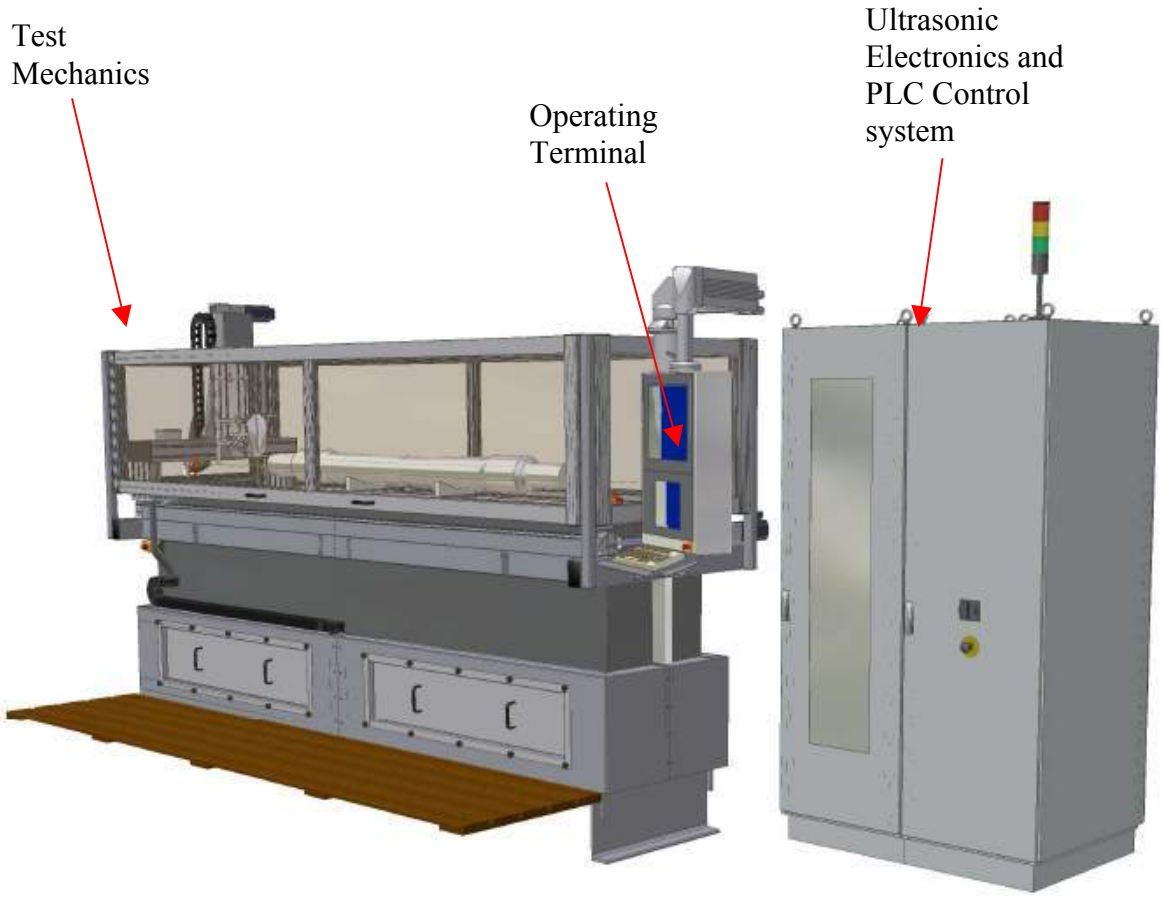
4.1 Survey of well established Test Standards

ISO 5948 - International Standard
EN 13261 - European Standard
RD 32.144 - Russian Standard
AAR M101 - American Standard

In addition also technical delivery specifications of national Railway Companies may apply: e.g. TL 918275 of the German Railways.

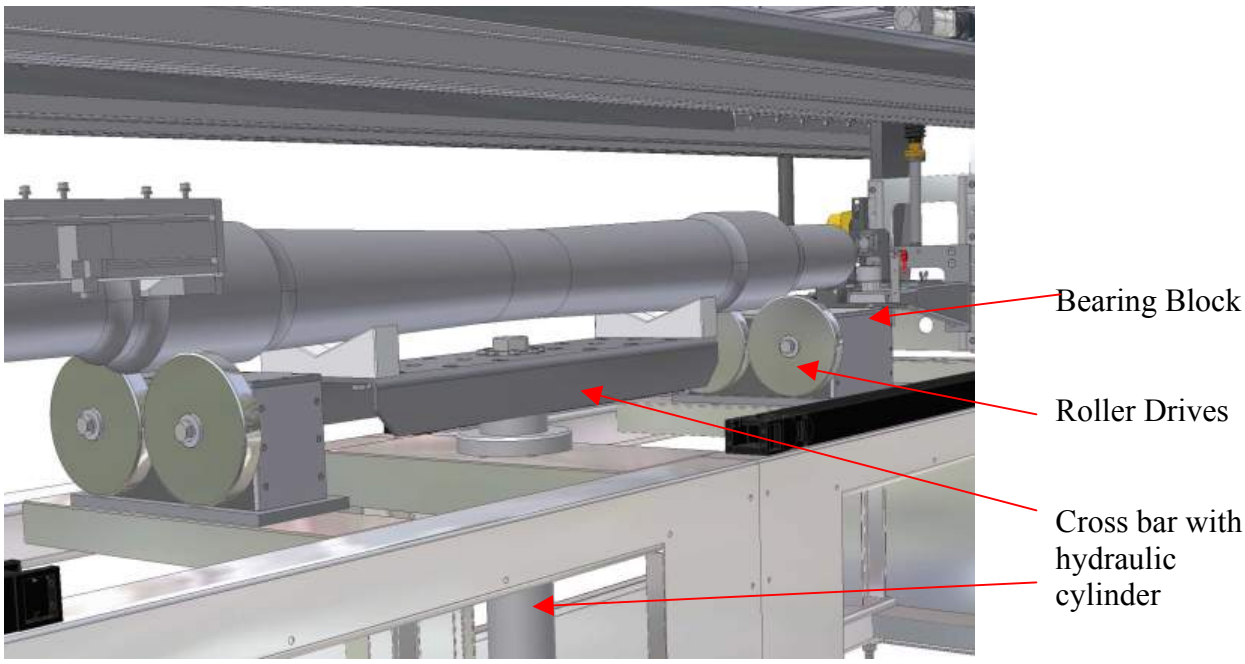
5 The Design of the Testing Installation

5.1 Testing Mechanism



Picture 6: Ultrasonic Axle Test System

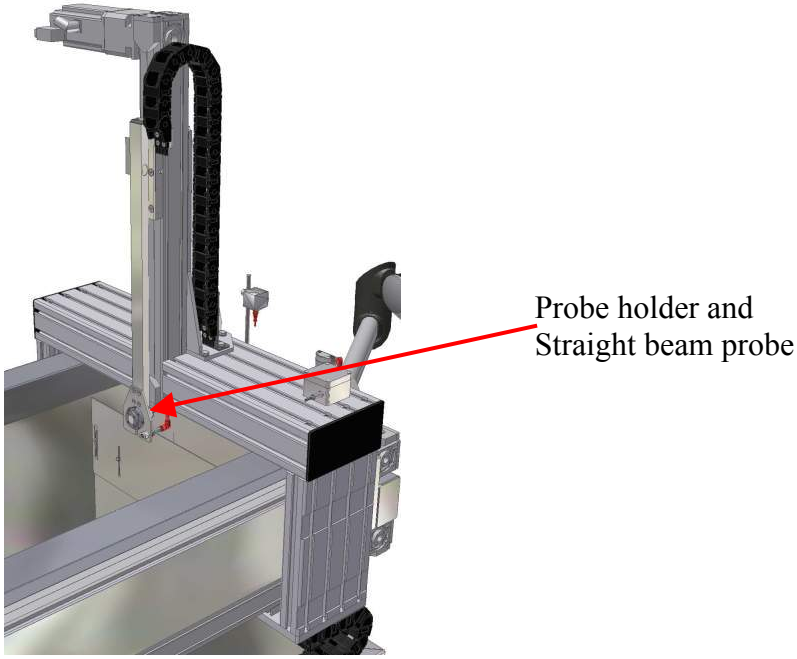
The test system consists of an immersion tank with drives for 4 axes to inspect the complete railroad car axle and a double cabinet for the ultrasonic electronic and PLC. A moveable operating panel mounted at the emersion tank allows an easy setup of the system close to the probe holder assembly and test piece. The axles will be loaded from the top of the tank onto a support cross bar for lowering and lifting the axle into and out of the ultrasonic immersion test basin.
When an axle has been discarded on the support a hydraulic cylinder lowers it onto a bearing block with roller drives for rotating the axle during the inspection. (refer to Picture 7: Bearing Block with Roller Drives)



Picture 7: Bearing Block with Roller Drives

The probe holder assembly is located at a feeding construction that allows moving the probes by electrically controlled drives in two directions.
The drive for the axis Z moves the probes up and down, thus the distance to the axle can be adjusted individually.
The drive for the axis X moves the probes along the axle during the test or set up.

For the axial test 2 straight beam probes will be positioned to each axle front end (right and left). Each probe is fixed in separate probe holders moving the probe to the right (left) front face of the axle.
(refer to Picture 8: Probe holder axial test from the side of the axle)



Picture 8: Probe holder axial test from the side of the axle

This design allows the inspection of solid railroad car axles, which can vary, in diameter and length in a wide range.
The coupling medium is pure water that will be circulated in a closed circuit for heating (cooling) and cleaning. This improves the water quality in regard to freshness, prevention of algae and reduces problems with bacteria.

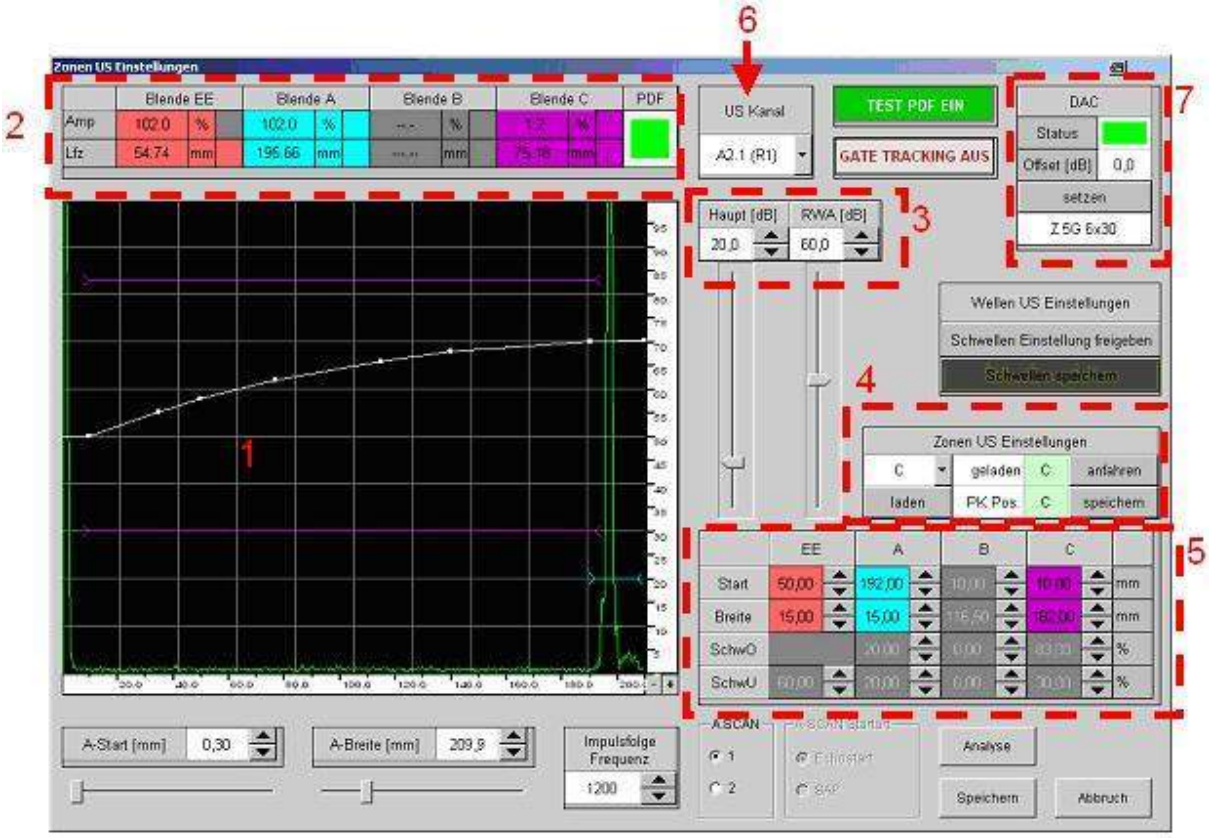
5.2 Ultrasonic electronics VIS

5.2.1 General

The ultrasonic electronics VIS is a modular system, which can be used as a parallel or multiplexed device. The electronic boards are located in a 19-inch modular rack for installation in standard electronic cabinets. In one rack is room for 12 parallel or 48 multiplexed channels. The electronics is completely operated via a PC with the operating system Windows XP.
Features like DAC (Distance Amplitude Correction), gate tracking, 2 independent amplifiers for flaw and back wall echo, signal sequence counting for noise suppression, PRF up to 20 kHz, 3 flaw gates, 1 back wall gate etc. are standard items.

5.2.2 Application program

Specially designed application software for railroad axle testing allows an easy and user-friendly setup of the system. A direct communication between ultrasonic application software and the PLC control unit enables the control of the probe positioning and loading of the ultrasonic parameters for the actual position of the probes.
(refer to Picture 9: Operating window for the ultrasonic axle zone parameters)



Picture 9: Operating window for the ultrasonic axle zone parameters

1. Ultrasonic display in real time

2. Status line of gates with amplitude reading and time of flight
3. Independent gain settings for flaw and back wall echo
4. Axle zone control, for positioning of the probe to a certain area (zone) of the axle and loading of the corresponding ultrasonic parameters for this section
5. Parameters for 4 evaluation gates
6. Channel selection
7. Information about the used DAC (Distance Amplitude Correction)

The axle will be divided into different sections (zones) according to the geometry of the different parts of the axle. Thus each section requires a different setting of the ultrasonic parameters. During the automatic inspection of the axle the system loads for each axle section the corresponding ultrasonic parameters so that for each section the correct and equal evaluation is provided.

5.3 Test result presentation

5.3.1 Evaluation

The 4 evaluation gates carry out the evaluation of the ultrasonic signals. Three gates are equipped with 2 thresholds that can be used for flaw evaluation or back wall echo monitoring. One gate with 1 threshold will be used as interface echo gate.
Each threshold has independently working signal sequence counters used for interference suppression.

When during the inspection the system identifies a flaw or coupling error the system indicates this by a flashing light near the test equipment on the top of the electronic cabinet. When the axle test has been finished the axle will be classified.
Three sorting classes can be applied: Accept / Reject / Untested

5.3.2 Reporting

During the inspection an online graphic (refer to Picture 10: Event graphic with all active probes and test methods) will be generated nearly simultaneously to the progress of the actual test position of the probes.
The Online Graphic is a chart that displays the evaluation results of a test piece (axle) along its horizontal axis. Each line of this record can be individually arranged according to customer requirements. In this diagram the X–axis represents the length of the axle, so that defects are displayed true to the axial location.
Typically for each probe one line shows the results of flaw detection and coupling loss in different colors.

Green inspected section of the axle where no flaw has been detected

Brown lower threshold

Red upper threshold

Blue coupling failure

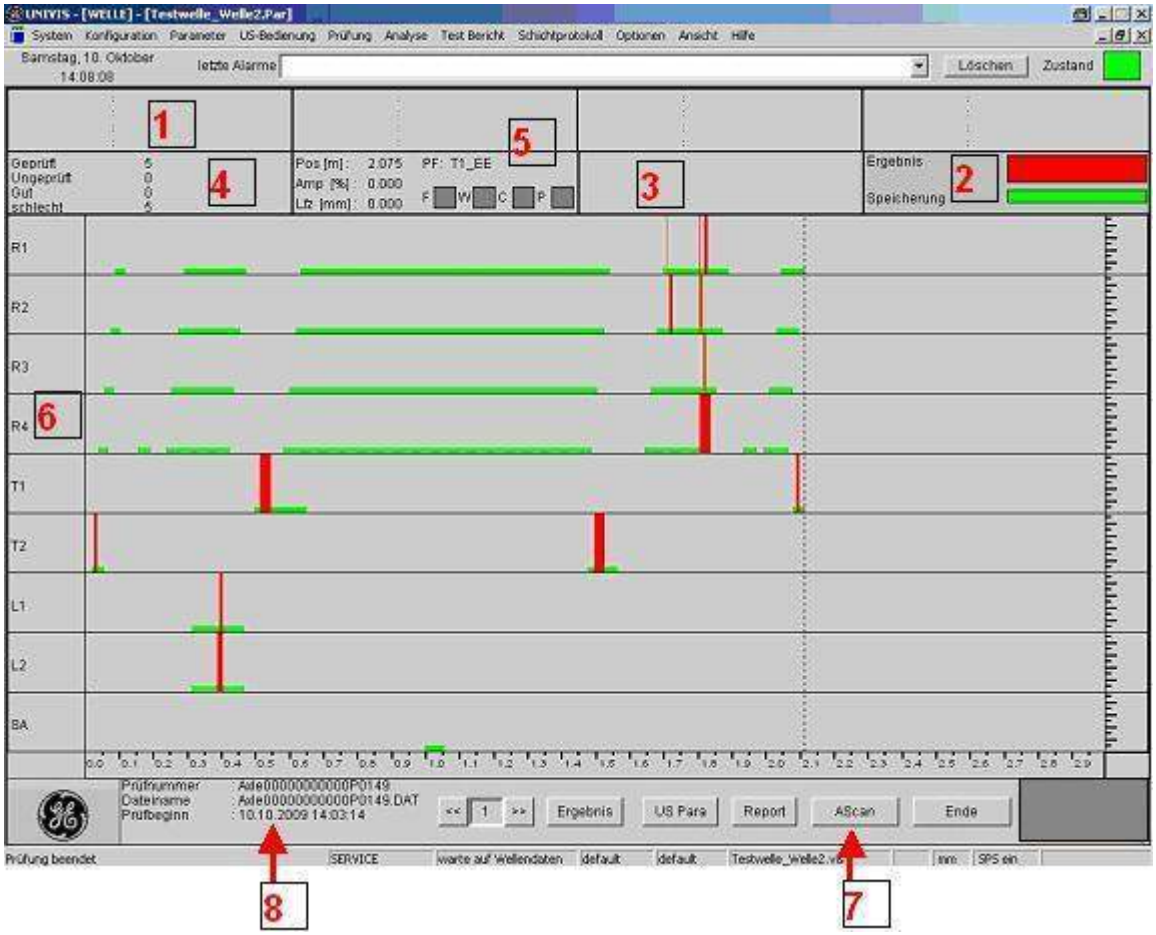
Gray untested zone

The acquisition of the test results is effected in the "real-time mode", that means that any signal exceeding a threshold is always recorded with pulse resolution true-to-location in the X - axis. The test piece will be divided into sections of 5 mm length. For each section the system determines the values for maximum (flaw gate) or minimum (back wall echo gate) signal amplitude with the appropriate time of flight and section classification. After the test is finished the amplitude and time

of flight for each inspected 5 mm section can be displayed for analysis.

The online graphic can be arranged with several pages (maximum 16), and each page can be arranged with different charts. The first page always shows the event display with one line for each probe and all related gates of the probe.

The following 2 online graphics present the results of an axle test with artificial defects in the form of flat bottom holes having a diameter of 3 mm.



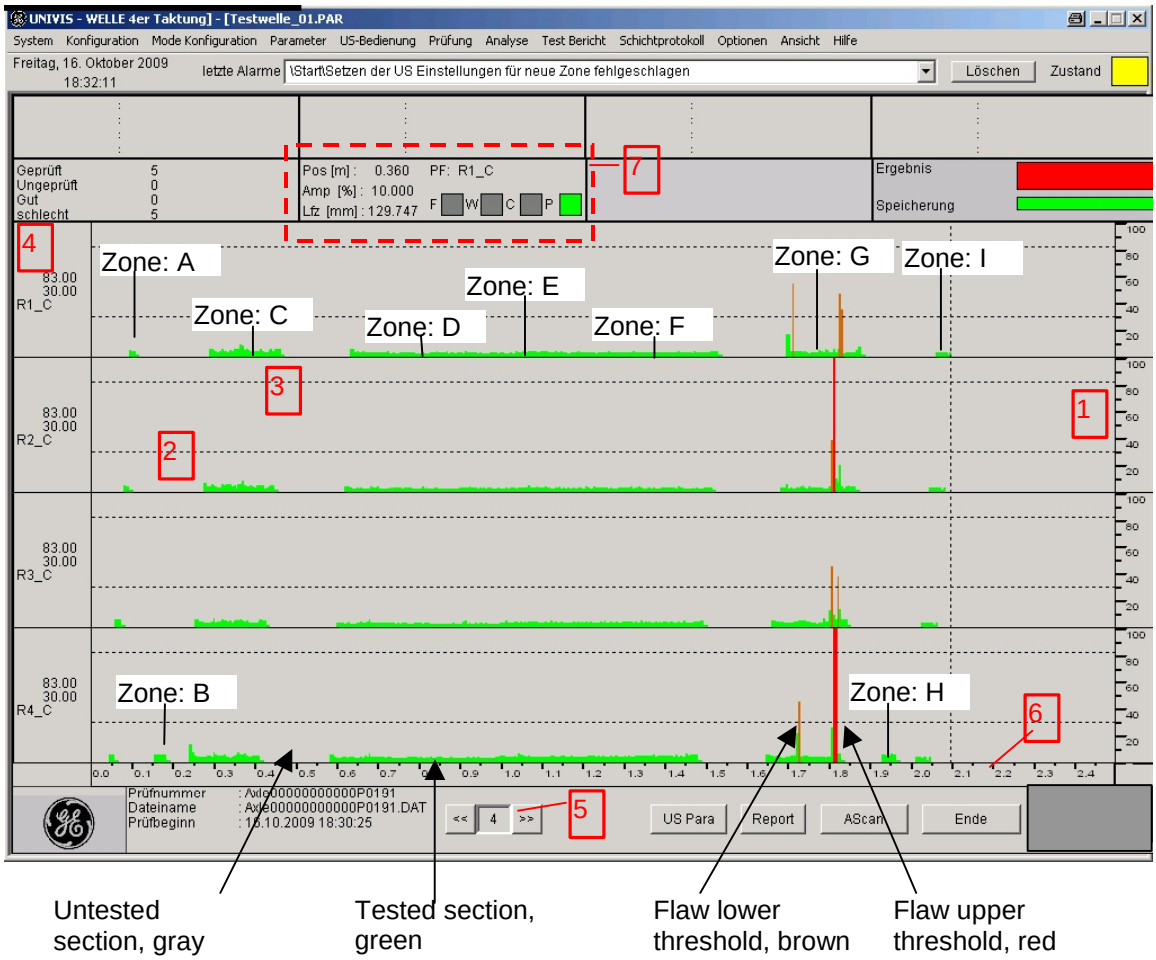
Picture 10: Event graphic with all active probes and test methods

Legend referring to Event and Analogue online graphics:

1. Header data
2. Display of results
3. Test Data Release (TDR)
4. Statistics
5. Instantaneous display of test results
6. Online display of test results
7. A-Scan display
8. Data management

Each line represents a probe:

R1 to R4: Radial probes (internal defects)
T1, T2: Transversal probes (transversal defect)
L1, L2: Transversal probes (longitudinal defect)
SA: Permeability probe



Picture 11: Analog graphic for the radial probes R1 to R4

Legend:

1. Scale for screen height
2. Position of the lower threshold
3. Position of the upper threshold
4. Designation of probe and values for the lower and upper threshold
5. Page selection
6. Scale in meter for axle length
7. By clicking in a 5 mm section of one line (probe) detailed testing information will be shown in this field.

All test results will be stored on the hard drive of the system PC, and on request on a customer network directory.

The result data consist of:
Online graphics
Test report
Ultrasonic parameter setting for this test

5.4 Testing sequence in production flow

5.4.1 Control system

The following describes the sequence of three different tests of the GOST standard.

After loading the required test parameters for the corresponding axle type and specification as well as all mechanic adjustments have been finished, the automatic inspection can start.

When all conditions for the automatic test are met the UT system signalizes to the customer “operational readiness”. The hydraulic plunger is powered up. The loader thereupon deposits the axle on the prism of the hydraulic cylinder.

The position of the axle on the hydraulic cylinder is then checked, and only if the axle is within the permitted range, the test cycle is continued.

Once the axle is correctly positioned on the prism, the UT system starts lowering the axle. As soon as the hydraulic cylinder has reached the final lower position, the stopper-roll moves to the start position at the axles left face side.

The customer PLC sends the information what type of axle are going to be inspected and its identification number. When the correct parameters have been loaded, the UT electronics is ready for the automatic test and the UT system continues with the test cycle.

When the stopper roll has reached the start position, the axle begins to rotate, in order to be driven against the stopper. An initiator recognizes when the axle reaches the limit stop.

Depending on the parameters adjusted, the inspection of the first horizontal zone begins. After setting the signal “Test Data Release ON” the UT electronics records the inspection data on the “Online Graphics”. All broad beam probes for the “A2”- test (radial inspection) can be slightly inclined, which will be used especially for the tapered shaft area. According to the loaded test zone program all other zones of this axle will be tested until the last zone has been finished.

Two carriage runs will perform the whole test.

1. Run: A2 (radial inspection) and T2-test (permeability test)
2. Run: A3 (transversal test of the transition areas)

After all horizontal zones have been inspected, the probe holder will move into its park position. At the same time all other motors are moving into their parking positions, and the axle stops rotating.

After all motors have reached their parking positions, the hydraulic cylinder will lift the axle so that the loader can pick it up again. At the same time the results of the inspection data are transmitted to the customer’s Host computer for data storage and further evaluation as well as to the PLC transport control for sorting the axle.

The classification signals are: “Accept” / “Reject” / “Untested”

As soon as the axle has been picked up the next axle can be placed in, and the inspection process starts again.

5.4.2 Ultrasonic inspection

The ultrasonic test is divided into 2 test applications:

I. RUN
- Radial inspection with 4 x 5 MHz probes for internal flaws (broad beam probes)
- Sound attenuation with 1 x 5 MHz probe (material permeability test)

II. RUN
- Transversal inspection with 2 x 2,5 MHz probes (for angle beaming, 50 degrees in the tested material)

All probes are working in three parallel systems and within each system in a multiplexed operation. The whole test is carried out in 2 test runs, so that the probe holder assembly with all probes runs along the X-Axis of the rotating axle.

6 Economic Benefits

The testing machine described here is able to achieve the following cycle times:

→ AAR – Test : ≤ 3 min (Test only from the faces)
→ GOST – Test : 5 – 7 min. (Test only from the lateral area)

The manual inspection would require – for a comparable testing volume 30 – 40 minutes.
With actual modern production lines a throughput up to 120.000 axles per year is given.
The use of such an automatic testing machine guarantees a high degree of efficiency.

There are however, still many side aspects which justify the use of such a machine, such as:

→ the automatic evaluation:
the aspect of the human error has been excluded to a large extend

→ storage of the detailed testing results:
the results are available for later follow up inspections

→ the transfer of all testing results to a master computer at the customer:
there the collection of results of NDT- inspections resulting from ultrasonic-, magnetic particle- and geometry measuring takes place.

7 Summary

Railway axles belong to the safety components in the field of vehicle manufacturing, to protect human lives. The ultrasonic inspection, carried out already in the manufacturing plant, belongs to the fundamental quality elements in the production process.
The concept of the testing system allows the parameterization of the inspection technology according to different international standards.

The following tests thus are realized:

→ Volume of the axle body – by Longitudinal Test

→ Volume of the cylindrical axle areas – by Radial Test

→ Volume of the Axle Transition areas – by Transversal Test

→ Longitudinal surface cracks in the wheel seats – by Transversal Test

→ Permeability Check – by Longitudinal Test

The testing system was adapted especially to the requirements of fully automatic manufacturing lines. The testing machine introduced here, presents a new development, which connects modern ultrasonic testing technology with a high efficiency in production.