High Speed Non-Destructive Rail Testing with Advanced Ultrasound and Eddy-Current Testing Techniques

Thomas HECKEL¹, Hans-Martin THOMAS¹, Marc KREUTZBRUCK¹ and Sven RÜHE²

¹ BAM VIII.4, Federal Institute for Materials Research and –testing, Unter den Eichen 87, 12200 Berlin, Germany
² PLR Prüftechnik Linke & Rühe, Altenhäuser Straße 6, 39126 Magdeburg, Germany

E-mail: thomas.heckel@bam.de, hans-martin.thomas@bam.de, marc.kreutzbruck@bam.de, ruehe@plr-magdeburg.de

Abstract

Today the rails face increased exposure to heavy loads, higher speeds and a very dense overall traffic. A continued development of testing methods for the rail inspection trains became necessary to match the modern needs for a fast detection and detailed classification of defects.

To guarantee the safe operation of rail traffic non-destructive inspection techniques with combined ultrasound and eddy current testing methods are used to detect damages on rails. One of the main actual challenges of automated rail testing is the high inspection speed which is very close to the physical limits. To overcome these limits digital signal processing algorithms have to be used which maintain resolution and detection quality independent of operation speed. This paper presents a recently developed state of the art rail inspection system which uses advanced ultrasonic and eddy current testing techniques. Testing results are shown in a newly developed so called Glassy-Rail-Diagram which is capable to present data with a fixed resolution independent of inspection speed.

Keywords: Non-destructive testing (NDT), rail inspection, ultrasound, eddy current, signal processing

1. Introduction

To guarantee the safe operation of rail traffic non-destructive inspection techniques are used to detect damages on rails. Nowadays rails are exposed to a constant increasing very dense overall traffic with heavy loads and high speed trains. Damages on rails increasingly originate from the surface as a result of rolling contact fatigue (RCF). Such damages became exceptionally dangerous for the operation of rail traffic.

During the last years a continued development of testing methods for the rail inspection trains was carried out. This includes for example the use of additional ultrasonic probes for the detection of SQUATs and the application of eddy current methods for the detection of damages caused by rolling contact fatigue. By combination of the ultrasonic inspection results with these from the simultaneously performed eddy current inspection synergetic effects arise. These can be excellently used to overcome problematic defect classification based on the results of only one testing method.

The large amount of incoming measurement data poses a challenge for the evaluation and the reviewing of the collected data. To keep this evaluation of data simple to the operator automated classification algorithms have to be developed and adapted. Testing results are shown in a newly developed high resolution Glassy-Rail-Diagram, which allows a very fast evaluation of data and sizing of defects. The detected findings are registered and fixed in position by GPS markers.

The system presented in this paper was implemented into the rail inspection train SPZ1 by PLR, Magdeburg, Germany, in 2008. Meanwhile the train is operated by Deutsche Bahn AG.

2. System setup

2.1 Sensor Frontend

For the rail testing we use ten ultrasonic probes and four eddy current probes per rail. The probe configuration is displayed in Fig. 1. There are two 2 MHz 70° angle beam probes, two 4 MHz 70° angle beam probes and one 4 MHz 0° normal probe used for the rail head, two 2 MHz 55° and two 2 MHz 35° angle beam probes used for the rail web and rail foot as well. One 4 MHz 0° normal probe is also used for the coupling check. The ultrasonic angle beam probes are operated in pulse-echo mode except the 4 MHz 0° normal probe used for the rail head which works in transmitter-receiver mode. All probes are GE type in standard housing with fix mounted wiring. Four HC-10 type eddy current sensors are situated in the region where rolling contact occurs. They are aligned according to the shape of the rail head. The sensors access a surface range of approximately 25 mm in the gauge corner of the rail.

The probes are mounted on five custom designed probe holders optimized for the individual probe arrangement. There have been four main challenges for the performance optimization of the probe holders during development: design of a robust and tough holding system with quick probe change option, enhance the probe life, keep the overall system length as short as possible and minimize the couplant consumption for ultrasonic inspection.
For ultrasonic inspection four slide-type holders strengthened with carbide shoes are used which house two or three ultrasonic probes. Each probe is fixed in position by springs with calibrated tension. The probes are adjusted with a special calibration device to a gap of 0.2 mm between the rail head and the probe shoe to keep abrasion minimal and coupling optimal. The holders are equipped with direction dependent and speed controlled couplant supply. For each probe a small water reservoir and a bleeder is provided. For easy access when charging the holders with probes they feature a lockable tilting mechanism.

The four eddy current sensors are positioned over each rail with a trolley-type holder. The four probes are mounted on a modular mechanism, which permits individual positioning on the measurement tracks. The sensors are mounted on a guidance device carried by a measuring trolley. With a special calibration device the sensors are fixed at a distance of 1 mm from the surface of a new profile UIC 60 rail. For worn rails the distance of the sensors can be varied according to the surface. The resulting change of sensor sensitivity can be compensated by the software by the analysis of the measuring data in a range of -1 mm to +2 mm.

2.2 System Hardware

Due to the high inspection speed the large amount of incoming measurement data poses the main challenges for the evaluation and the reviewing of the collected data. Additionally all data have to be processed in real time for online monitoring. Therefore a powerful signal processing system is necessary.

In this system all measurement data are delivered digital via network connection. The synchronisation of all devices is controlled by more than 80 hardware signals. The overall system consists of four modular multichannel ultrasound devices, two multichannel eddy current devices, eight dual-core personal computers for real time signal processing and system control, two 32 channel real time controllers, one GPS positioning system and two FPGA based custom designed signal processing hardware boards. The measurement system rack is displayed in Fig. 2.

For ultrasound data acquisition the recently developed modular inspection system MODUS03 is applied. For each rail two MODUS03 equipped with five high resolution ultrasound boards each connect the ten probes. 14-Bit A-Scan data, four fixed hardware gates and four interactive controlled gates are recorded continuously for each channel at a repetition frequency of 4650 Hz independent of operation speed. Measurement data are merged with the GPS information, time stamps, kilometre markers and additional event markers in real time.

For eddy current data acquisition two 4 channel PL300 series eddy current measuring devices are applied. The lateral resolution for eddy current data is 1 mm independent of operation speed. Measurement data are also merged with GPS information, time stamps, kilometre markers and additional event markers in real time.

2.3 Ultrasound at high speed

Speeds of more than 60 km/h are very close to the physical limits for ultrasonic testing methods. The maximum pulse repetition rate is limited by the sound velocity in the rail. This mainly affects the lateral resolution of ultrasonic measurements. The detectability of defects decreases with the increase of speed. This is shown in Fig. 3, depicting the number of detections of typical rail defects as a function of train speed with the ultrasound device running at a repetition rate of 5 kHz. These investigations were carried out at BAM for each probe on seven specimen with more than 80 reference flaws.
To overcome these limits caused by the repetition rate it is necessary to use digital signal processing algorithms which maintain resolution and detection quality independent of operation speed. Therefore real time algorithms and the Glassy-Rail-Diagram have been developed and tested at BAM.

The maximum testing speed is at least limited by the surface quality of the rail. On the other hand it seems to be no good idea to operate inspection trains up to more than 90 km/h due to reduced mechanical wear span of probe holders and probe maintenance costs.

3. The Glassy-Rail-Diagram

To keep evaluation of data simple to the operator a user friendly interface with a well-arranged visualisation is necessary. Therefore the Glassy-Rail-Diagram was developed at BAM. Like conventional B-Scans the Glassy-Rail-Diagram gives a side view from the rail. It contains the position of probe, angle of probe and sound path corrected overlaid scan data of all ultrasonic probes channels. The pixel size of $3 \times 3$ mm determines the diagram resolution. The colour represents the highest achieved amplitude in the pixel. An example is shown in Fig. 4. All data processing is done in real time.

Scan length can reach up to 300 km per day. For fast access to the recorded data the scan is separated in sections of 1000 m. For normal operation a viewing range of 1000 m gives a good overview of the collected data shown in Figure 5a. A viewing range of 10 m shown in Figure 5b is normally used for inspection by the operator. Here we can see some drill holes in a rail from a switch. Figure 5c shows a subsection of 64 by 64 pixels which is the standard viewing range for analyse mode.

Because of the fixed reconstructed data grid sizing of indications and measuring distances becomes very easy. Measurements in length, height, width and depth can be carried out with an overall accuracy of at least 3 mm. An example is shown in Fig. 6. The backwall echo from the rail foot can be used as an excellent consecutive coupling control.

The information which probes soundfield has hit the pixel respectively the reflector is recorded additional and separately. Therefore the hardware and interactive software gate functions are used. These data give detailed information about the position, orientation and the reflectivity of a flaw. For example if the indication is more laminar respectively a crack type reflector or volumetric respectively a drilling type reflector.

For a combined display of both the amplitude and the gate information the amplitude is converted from colour to grey-scale and the gates for each probe are displayed in a different colour. An example with an indication from a drilling is shown in Fig. 7. On the left the colour code for the probes is displayed.

Figure 7 shows the user interface for the operator. The main screen contains the two diagrams for the left and the right rail. The right side of the screen presents for each rail the rail height and the amplitude of the couplant control indication. The cursor position is shown in two different
An online software detection for drill holes and thermite welds is provided in the measurement software that allows the operator to present live pictures from these types of indications while measuring. With these pictures the performance of each sensor can be monitored. This information and the use of real time controller boards allows the operator online optimization of testing parameters during measurement. The parameter changes made by the operator are recorded. The offsets from the actual parameter set to these from the calibration are known for all measured positions.

4.2 Automated data analysis

When testing the rails with ultrasound and eddy current up to 250 Mbyte of data will be collected for one kilometre. For the operator it is not suitable to view these data by hand. To support evaluation of data by the operator automated classification algorithms have been developed and adapted which allow preselection of data displayed. The implemented data post processing uses algorithms based on neuronal networks and fuzzy logic. Optimizing these algorithms is an currently ongoing interactive and time consuming process based on expert knowledge.

The implemented algorithms mainly focus on the suppression of indication caused by acoustic and electric noise as well as the identification of non-generic indication patterns and indication patterns caused by drill holes and welds. Rail type can be evaluated by measuring rail height.

The offline data processing starts automatically when a section of 1000 m is finished. Each of the recorded clusters with a size of 64 by 64 pixels gives a feature list which is analyzed by a neuronal network. Recognized patterns are weighted with fuzzy logic to extract and mark the results. Uncertain indications are marked also. The analysis flow chart is depicted in Fig. 8.

The data processing results in a classified indication list with position markers. The markers are read into the evaluation software indicating an icon underneath the Glassy-Rail-Diagram (see Fig. 7). When viewing the data the operator can jump from marker to marker by display mode selection.

4. Data Processing

4.1 Online sensitivity control

The system can be calibrated by the use of a test block. When testing the rail the overall sensitivity of the testing system depends on the quality of the rails surface quality. To compare the measured indications with these from the test block drill holes and welds can be used.
5. Conclusion

A state of the art ultrasound and eddy current inspection system was implemented into the SPZ1 inspection train of Deutsche Bahn AG and brought into service. It uses ten ultrasonic probes and four eddy current sensors on each rail to be tested. A lot of detailed solutions have been developed and challenges have been overcome to allow a precise testing of the rail up to very high inspection speeds above 80 km/h. The testing results are shown in a unique Glassy-Rail-Diagram which allows the presentation of measured data with a fixed resolution independent of inspection speed. All data are digitally processed in real time.

The system uses GPS information and time-stamps for positioning. Additional Kilometre points can be set so that a full set of results per unit distance is provided and used to locate the affected sections of rail. The status of probes, measurement devices and scan parameters are logged and indicated continuously as well as the direction and speed of train movement.

Online Monitoring using the Glassy-Rail-Diagram allows real time sensitivity control. Automated data analysis tools based on trained neuronal networks and fuzzy logic give support to the operator when evaluating measured data with the Glassy-Rail-Diagram.

Due to the large amount of different rail types and profiles, the adaptation and optimization of algorithms is still in progress. Additional data analysis for advanced combined eddy current and ultrasonic methods for the detection of damages have to be applied as soon as new information from the track is available. Therefore special selected track sections have to be evaluated in detail.

References