

NON-DESTRUCTIVE TESTING OF WHEEL-SETS AS A CONTRIBUTION TO SAFETY OF RAIL TRAFFIC

Ensayos no destructivos del conjunto eje-rueda como contribución a la seguridad en el tráfico ferroviario

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Los conjuntos eje-rueda de los vagones de ferrocarril son elementos relevantes para la seguridad, ya que cualquier falla en los mismos puede producir accidentes serios, con daños a las personas y al medio ambiente. Por esta razón, los conjuntos eje-rueda de los trenes de pasajeros y de carga son sometidos a controles permanentes.

El Instituto Fraunhofer de Ensayos no Destructivos (IZFP) ha desarrollado en estrecha cooperación con la Compañía Alemana de Ferrocarriles (Deutsche Bahn AG) métodos y equipamiento especializados para la inspección en servicio de los conjuntos eje-rueda, en estaciones de mantenimiento. En este trabajo, se describe el potencial de un puesto de ensayos para la inspección ultrasónica automatizada del borde y el plato de las ruedas en los conjuntos desmontados. Se presenta además un sistema para la inspección en movimiento de la superficie rodante de las ruedas de los trenes de alta velocidad, que utiliza ondas de Rayleigh excitadas electromagnéticamente. Se explica un procedimiento que se usa durante la reparación de la superficie rodante, para optimizar la profundidad del corte. Este procedimiento permite medir la profundidad de las regiones dañadas, mediante el uso de ondas transversales linealmente polarizadas.

En último término, se presentará una técnica ultrasónica ampliamente probada para la evaluación de estados de tensión generados en las ruedas de los trenes de carga debido al sistema de frenado. En efecto, en algunos trenes de carga, se utiliza un sistema de freno basado en la presión ejercida por zapatas sobre la superficie rodante; las tensiones generadas por esa presión en el borde de las ruedas pueden llegar a causar la rotura del elemento.

Wheel-sets of rail vehicles are safety relevant components. A failure may cause serious accidents with personal injury and impairment of environment. Therefore the wheel-sets of passenger and freight trains are subject to a permanent control.

IZFP developed in close co-operation with the German Railway Company (Deutsche Bahn AG) methods and equipment for in-service inspection of wheel-sets in maintenance stations. The paper outlines the potential of a testing station for automated ultrasonic inspection of rim and disk of wheels at dismantled wheel-sets. In addition a system for the in-motion inspection of the rolling surface of wheels of high-speed trains using electromagnetically excited Rayleigh waves is presented. To optimise the depth of cut during refurbishing of the rolling surface, a procedure is explained which is used to measure the depth of damaged regions in the rolling surface using linearly polarized shear waves.

Finally an ultrasonic technique is outlined which is well proved for the evaluation of stress states in the rim of wheels of freight trains which are braked pressing brake-shoes onto the rolling surface, such producing tensile stresses which may cause failure of the wheel.

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I. WHEEL-SET TESTING STATION

Wheel-sets of railroad cars and engines, especially of high-speed trains, like the German ICE, are subject to high dynamic loads. In order to detect possible defects at an early stage, the wheel-sets are inspected at regular intervals, e.g. every 240.000 km in the case of the ICE. The inspections are performed at the dismantled wheel-sets at the maintenance facilities using ultrasound. In the past mainly manual testing was applied.

Over the last years, safety requirements have continuously been increased. As a consequence the scope of inspections to be performed at wheel-sets was extended to a 100% inspection of the rim and of the disk. Time required for manual testing of one wheel-set now took about two hours. To manage this volume of work there was a need for automated ultrasonic wheel-set testing stations.

Based on technical requirements defined by the Research and Technology Center of the Deutsche Bahn AG (FTZ Kirchmöser), Fraunhofer IzFP developed together with the Fraunhofer Technology Development Group (TEG) such a testing station for the Nürnberg maintenance facilities, which is responsible for the reconditioning of high-speed trains⁽¹⁾. The testing station, named AURA, which is integrated into the production line, is depicted in Fig.1. It is in full operation since April 1999. Since that time two more testing stations have been set up at maintenance facilities in München and Neumünster, near to Hamburg.



Figure 1. AURA testing station.

The testing station is capable to accept wheel-sets with diameters ranging from 780 mm to 1300 mm, and a maximum weight of 2000 kg. The inspection of the wheel-set takes approximately 8 minutes if no ultrasonic indications are detected. Considering additional time for the analysis of findings, the output

per shift is between 20 and 30 wheel-sets. The machine is operated by only one examiner.

The AURA testing station consists of a steel frame with a vertical (z-)axis, a probe system carrier which is mounted to the z-axis, a wheel-set barring gear, the necessary mechanism to feed and to eject the wheel-sets to be tested, and finally the operator's cabinet including the ultrasonic inspection and evaluation equipment.

Twenty-six conventional normal beam and angle beam ultrasonic transducers (testing frequencies 2 and 4 MHz) and two EMAT transducers are used for the inspection of a wheel-set (EMAT: ElectroMagnetic Acoustic Transducer). The areas inspected by this transducer arrangement in the wheel rim and disk are outlined in Fig. 2.

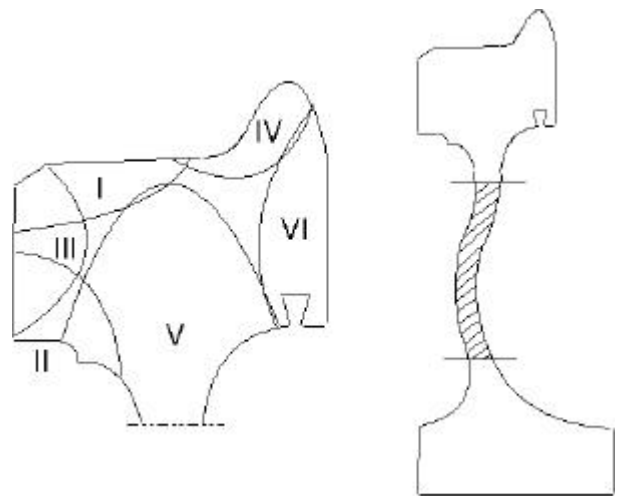


Figure 2. Inspected areas in wheel rim and disk.

A special feature of the AURA testing station is the ability to inspect the wheel disk from the rolling surface. This is done using conventional shear wave transducers for defects oriented in radial direction and EMAT transducers for defects oriented in circumferential direction. The applied EMAT transducers generate linearly polarized shear waves with normal incidence as shown in Fig. 3.

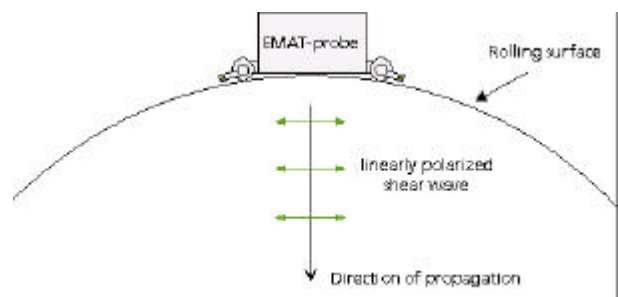


Figure 3. Application of linearly polarized shear waves for the inspection of the wheel disk.

This wave type can even be used for the inspection of curved wheel disks. For each wheel design the optimal testing frequency (between 1 and 2.5 MHz)

and axial transducer position have to be evaluated carefully by experiments at test wheels.

Since the inspection is performed from the rolling surface, the time-consuming and costly disassembly and re-assembly of sound absorbers and subsequent magnetic particle inspection of the wheel disk are not necessary. Furthermore, the removal of corrosion-protective coating on the disk is not required.

The applied ultrasonic testing equipment comprises a modular 40-channel UT device PCUS40 and the necessary electronic components to operate the EMAT transducers. The PCUS40 allows to select various data acquisition modes corresponding to the individual inspection task requirements: gating technique, ALOK, pixelized A-scan, and RF-data recording⁽²⁾. For the inspection of wheel-sets the gating technique is used, providing amplitude and corresponding metal path length for a maximum of four gates. The ultrasonic components are integrated into a 19" rack-mount system. Operation and control of the AURA testing station is performed through a menu-driven user interface running under Windows NT 4.0.

Inspection of a wheel-set is started setting a reference mark for the circumferential position and feeding the wheel-set from the wheel-set storage to the testing station. The probe system carrier is moved down to the wheel-set and the ultrasonic transducers are coupled to the rolling surface and to the inside surface of the rim (see Fig. 4). Exact positioning of the system components is monitored using inductive and optical sensors.



Figure 4. Transducer system carrier being positioned to the wheel.

Data acquisition is started after one revolution of the wheel-set, which is used to wet the surfaces to guarantee optimal coupling conditions for the piezoelectric transducers. During data acquisition the A-scans of four selectable ultrasonic transducers are displayed simultaneously on the TFT flat panel display to support

on-line control of the inspection. Additionally the progress of inspection is shown by a horizontal bar on the bottom part of the screen (Fig. 5).

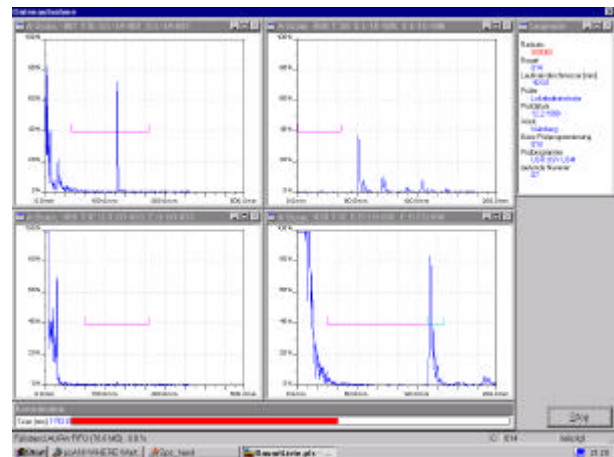


Figure 5. A-scan display during data acquisition.

Immediately after data acquisition the inspection result is displayed as a bar diagramme separately for both wheels. For each transducer ultrasonic indications are displayed in a horizontal bar, ranging from 0° to 360° in circumferential position. Registrations can be done for signals exceeding the registration level or for those falling below this level, e.g. in the case of gates programmed for monitoring of backwall echoes. Fig. 6 depicts a bar diagramme for the reference wheel, which has to pass through the testing station at the beginning and at the end of each shift to control proper operation and sensitivity settings of AURA.

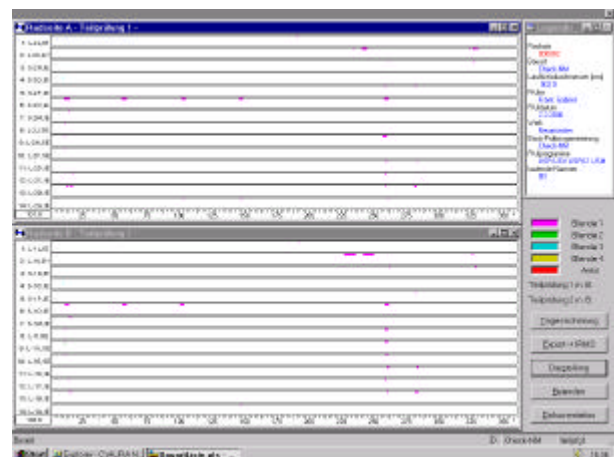


Figure 6. Result display.

In case of findings further analysis can be performed, e.g. by looking to the amplitude-dynamic curves of selected regions containing indications, as shown in Fig. 7. Selection of transducer and range in the bar diagramme is done using the computer mouse.

A helpful function to evaluate the origin of findings is a side-view (Fig. 8) which can be selected for each wheel to measure the exact depth position of a reflector.

Using the A-scan mode the operator can turn the wheel-set backwards and forwards to the position showing the A-scan of an indication to be evaluated, simply using mouse functions.

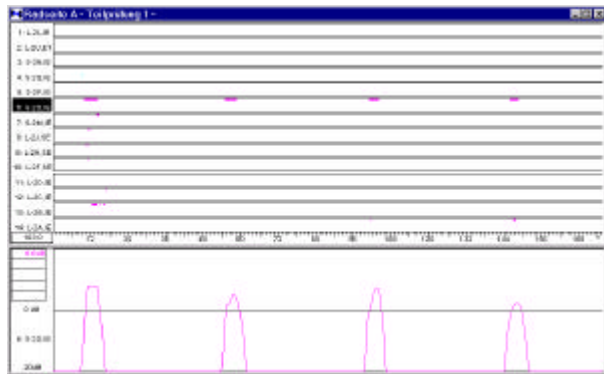


Figure 7. Display of amplitude-dynamic curves.

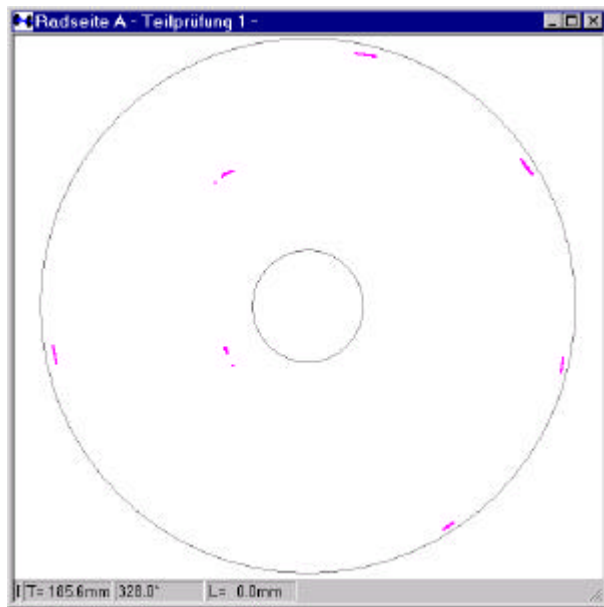


Figure 8. Side view of ultrasonic indications.

After confirmation of the inspection results by the operator, the second part of the inspection is performed with the transducer carrier rotated by 180° around the z-axis. In this way full coverage of the volume to be inspected is achieved and inspection reliability is increased since angle beam probes are now operated with opposing scan direction. Result display and post-processing is as shown for the first part of the inspection.

When the inspection is completed the computer automatically generates a list of indications. Result data, images, and inspection parameters are stored to a server via a network link. A data base module, installed at this server allows comprehensive monitoring of the condition of all wheel-sets of the rolling stock, including generation of logbooks of individual wheel-sets.

In order to minimize periods of disuse AURA provides a variety of tools for diagnosis in the case of malfunction. All functions of the testing station can be remote controlled via telecommunication links. Even upgrade of the operating software can be performed in this way.

Further developments aim to reduce the inspection time to about four minutes for one wheel-set and to include eddy-current testing for detection of cracks in the rolling surface.

II. IN-MOTION INSPECTION OF THE ROLLING SURFACE OF THE WHEELS OF HIGH-SPEED TRAINS

In modern rail traffic the rolling surface of wheels is exposed to high dynamic loads due to an increase of speed as well as a higher rate of service time. The development of cracks is monitored by periodic non-destructive testing. Apart from visual testing, objectively operating automated testing methods are necessary to be used directly at the vehicle without special manipulations.

For the monitoring of the rolling surface of the wheels of the German ICE high-speed train, an ultrasonic system was developed by Fraunhofer IzfP, executing recurrent inspections at the railroad cars without dismounting the wheel-sets. The system detects critical defects whilst the vehicle passes over ultrasonic transducers embedded in the rail heads. Four couplant-free operating EMAT transducers are applied for the inspection, two each per rail. As soon as the wheel gets into contact with a transducer, a Rayleigh surface wave is transmitted (Fig. 9). The wheel is circulated several times by the ultrasonic pulse and, consequently, a series of repetition echoes (round-trip signals) is detected by the receiver if the rolling surface is undamaged.

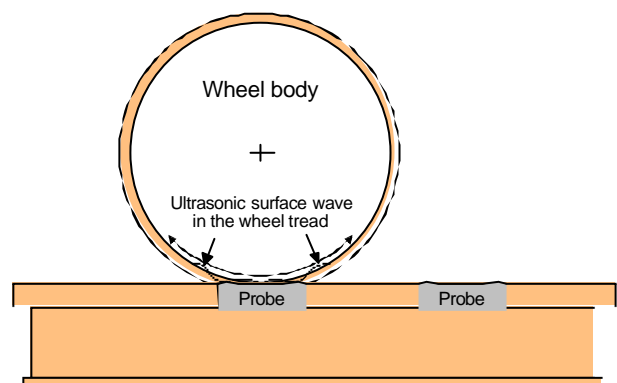


Figure 9. Testing principle.

Fig. 10 depicts the construction of the transducer. The transducer coil is passed by an alternating-current pulse inducing eddy-currents in the rolling surface. The coil is positioned near to the transducer contact area. By means of an electromagnet a steady magnetic field is generated which penetrates the rolling surface perpendicularly, superimposing the eddy-currents.

Through Lorentz forces a deflection of the metal lattice takes place, thus generating an elastic wave. The ultrasonic testing frequency is equal to the frequency of the applied alternating-current pulse. Fig. 11 shows a wheel-set moving over the transducer set embedded in the rail heads.

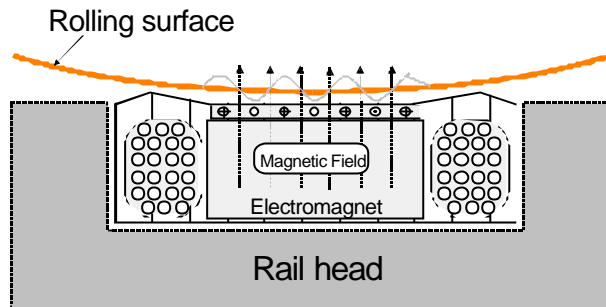


Figure 10. Construction of the EMAT transducer.



Figure 11. Wheel-set being tested.

If the rolling surface is undamaged, only the round-trip signals (RT) will be received by the EMAT transducer. In case damages exist such as cracks or material shelling or spalling, apart from the round-trip signals (RT), echoes (E) of these defects will be registered (Fig. 12).

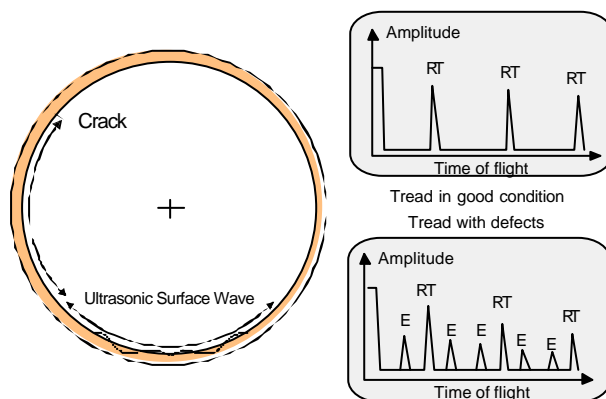


Figure 12. Schematic A-scan for undamaged and damaged tread of wheel.

The evaluation of the recorded ultrasonic signals is performed by computer programs according to criteria considering amplitude values of the echoes and signal form. For each wheel a status class is determined and transferred to the central computer system at the ICE maintenance facilities. Fig. 13 shows the inspection result for a test wheel-set with a calibration reflector inside a cold deformed tread. Probes 1 and 3 have been applied to the inspection of the wheel with the damaged surface, probes 2 and 4 were used for testing the flawless wheel of the wheel-set.

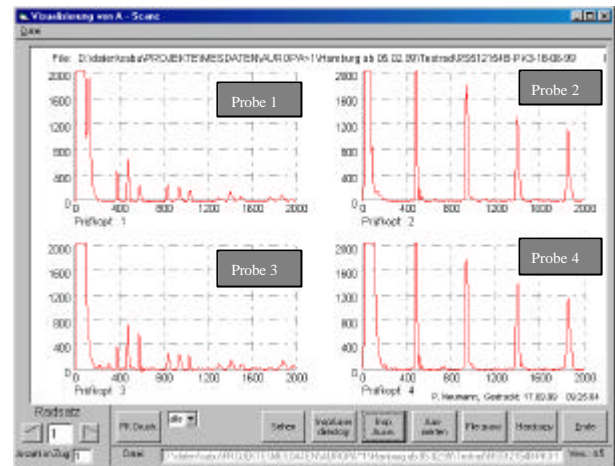


Figure 13. Inspection result for a test wheel-set.

Licence has been given to the Hegenscheidt company, Germany, for industrial production and sales of the inspection equipment. Presently, three systems are in operation.

III. DETECTION AND SIZING OF CRACK-LIKE DEFECTS IN THE TREAD OF RAILWAY WHEELS

The high loads acting to railroad wheels can result in surface breaking cracks in the tread of the wheel.

By routine non-destructive inspection the development of cracks is controlled. A technique for the fast detection and localization of crack-like defects using ultrasonic surface waves propagating in the near surface zone of the wheel, which is in field operation since some years for the In-service Inspection (ISI) of the wheels of the German High-speed Train ICE was described in the previous section. Once a crack in the tread has been detected its depth is of most interest first due to safety considerations and second due to economical aspects. With the exact knowledge of the crack depth, e.g. the depth of cut during re-shaping of the tread can be minimized saving manpower and material costs.

To localize a crack-like defect and to determine its depth an ultrasonic technique has been developed which is based on the mode conversion of linearly polarized shear waves^(3,4). The transducer is positioned at the inside surface of the rim as shown in Fig. 14.

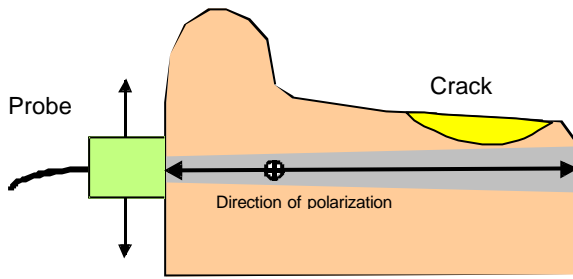


Figure 14. Principle of the testing method.

The beam direction is normal to the surface, the polarization of the shear wave is in circumferential direction. By the use of couplant free electromagnetic acoustic transducers (EMAT's) a simple way to generate the shear motion inside the wheel is assured.

In case there is a crack-like defect with transversal orientation (with respect to the circumferential direction of the wheel) within the sound field of the transducer, a part of the shear wave is mode-converted into a surface wave travelling along the flanks of the crack and reducing the amplitude of the reflected backwall echo (BWE).

This effect has a very steep local gradient and can easily be differentiated from any other effects also reducing the echo-amplitude. Besides the change in amplitude there is also a phase shift of the BWE which is a further reliable indicator for the presence of a crack-like defect.

Fig. 15 depicts the amplitude locus curve (ALC) of the first backwall echo recorded at a test specimen with a geometry similar to that of a wheel tyre. Cracks were simulated by saw cuts of depths 15, 12, 8, and 5 mm. The EMAT probe was moved along a scanning line (x) as shown in the figure.

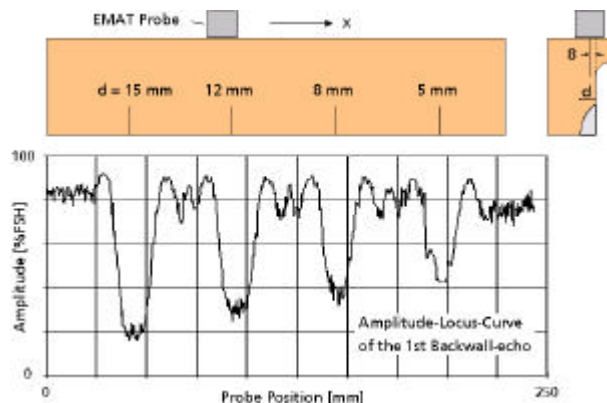


Figure 15. Amplitude-locus-curve of the 1st backwall echo of saw cuts of various depths.

When the probe is approaching a defect, the amplitude of the BWE first increases slightly and drops down when the probe index is at the position of the crack. The amount of this amplitude drop depends on that part of the sound-field interacting with the defect, which means it depends on the depth of the defect and on the beam spreading of the probe. In the example of

Fig. 15 the probe center is 8 mm below the rolling surface, hence the amplitude drop reduces with decreasing defect depth. Moving the probe away from the defect position, the amplitude of the BWE increases again till a local maximum before reaching its 'normal' level at positions without defects.

The depth of a defect is determined by moving the transducer in radial direction towards the center of the wheel and finding out that position of the transducer at which the BWE has the same level like at defect free positions.

The construction of the EMAT probes, which are used to generate the linearly polarized shear waves, is sketched in Fig. 16. By two permanent-magnets with opposite magnetic polarity and a soft iron yoke a magnetic field is generated which penetrates the RF-coils of transmitter and receiver perpendicularly. These are flat rectangular coils and generate together with the magnetic field the transversal displacement-field. The effective aperture of the probe is 20 x 20 mm².

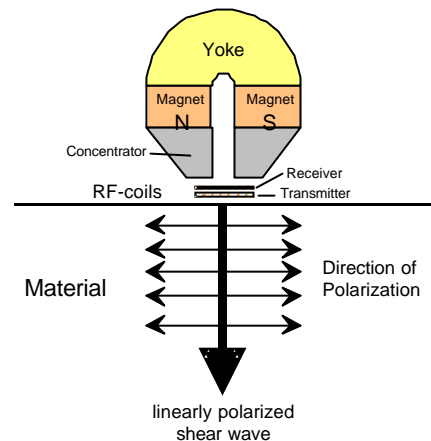


Figure 16. Construction principle of the EMAT probe.

First results of manual inspections performed at test specimen with artificial defects (saw cuts), at samples of wheel tyres with real defects as well as at complete wheel-sets showed that the evaluation of the amplitude of the first BWE is not reliable enough for the detection and localization of cracks. The amplitude is also influenced by other parameters, e.g. surface conditions, which can lead to amplitude drops of the BWE similar to those caused by a defect. However the ALC of the BWE (see e.g. Fig. 15) recorded by scanning the probe along the circumference of the wheel shows a characteristic pattern with strong gradients caused by a crack-like defect, i.e. increase of the amplitude before and behind the main amplitude drop. This structure is also present in the ALC of the 2nd BWE, however with a slightly larger width due to the divergence of the sound-field. This is demonstrated in Fig. 17 by a typical ALC of the 1st and 2nd BWE recorded at a wheel with a real crack in the tread. Both the typical structure of the ALC and the very sharp decrease of the amplitudes of 1st and 2nd BWE at the position of the crack become obvious. It can also be

seen that the amplitudes of both BWE's are varying more or less along the whole scanning path but with much smaller local gradients than in the case of a crack.

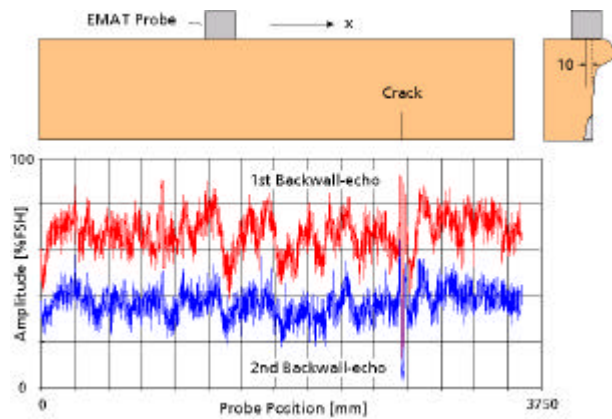


Figure 17. Amplitude-locus-curves of the 1st and 2nd backwall echo recorded at a wheel-set with a single crack.

To eliminate the mentioned disturbing effects also causing amplitude changes of a BWE, the normalized difference of the logarithms of the amplitudes of the 1st and 2nd BWE is calculated. Applying this mathematical operation to the ALC-data of Fig. 17 shows that this difference exceeds the ground level only at the position of the crack (Fig. 18).

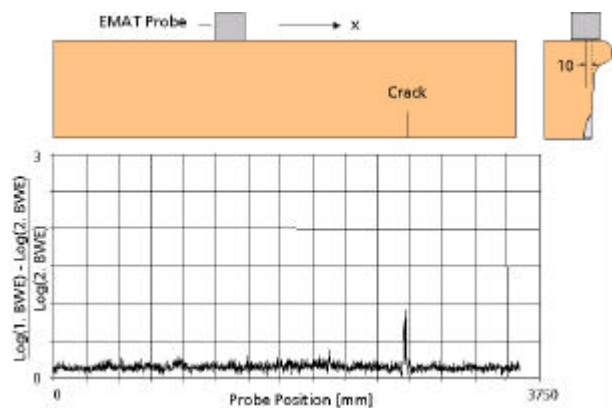


Figure 18. Normalized difference of the amplitude-locus-curves of the 1st and 2nd backwall echo of Fig. 17.

Similar results were obtained for a test wheel set with several transversal cracks in the rolling surface, as depicted in Fig. 19.

Some of the eight detected cracks were broken up in order to determine their depth and to compare real depth and result of the described NDT technique. In all cases the correlation was excellent. Exemplarily the surface of fracture of crack No. 5 is shown in Fig. 20.

To measure the depth of cracks at wheels whose treads have to be re-profiled, EMUS RITIM was developed, a semiautomatic equipment which is designed for application under the environmental conditions of maintenance facilities. The EMAT probe is attached to the inside surface of the wheel rim as

shown in Fig. 21. Data acquisition is performed while the wheel-set is rotated by the underfloor turning lathe. By the computer-controlled manipulator the radial position of the probe center relative to the rolling surface can be varied. The RITIM device (see Fig. 22) automatically records both probe position and maximum amplitudes of the 1st and 2nd BWE and computes the normalized difference.

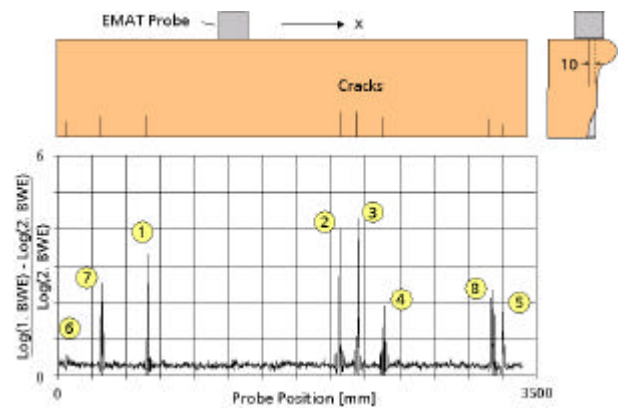


Figure 19. Normalized difference of the amplitude-locus-curves of the 1st and 2nd backwall echo for a wheel-set with several cracks.



Figure 20. Result of destructive testing for crack No. 5.

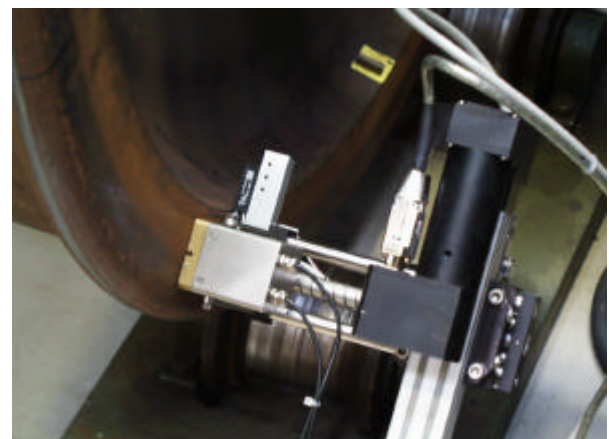


Figure 21. Manipulator for moving the EMAT probe in radial direction.



Figure 22. RITIM device.

Fields of application of the RITIM equipment are the determination of the depth of cracks already detected by other UT-techniques or by visual inspection and as previously shown the minimization of the depth of cut during re-profiling of the wheel tread.

IV. ULTRASONIC EVALUATION OF STRESSES IN THE RIM OF WHEELS

The stress states in the wheels of railroad freight cars are strongly influenced by the heating and cooling process during and after brakings using break shoes. Harmless micro-cracks in the rolling surface can grow rapidly under the influence of tensile stresses and may even cause the failure of a wheel.

A typical distribution of the tangential (circumferential) stresses in the cross section of rims of used monoblock wheels is depicted in Fig. 23. The highest tensile stresses have been found in the edge area of the rolling surface and the outer side of the rim.

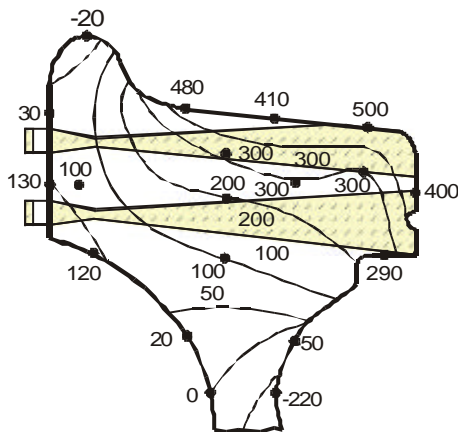


Figure 23. Circumferential stress [MPa] and stress profiles in a heavily braked railroad wheel.

The stresses were evaluated using a totally destructive cutting and sectioning technique. The points

give the positions and the results of the strain gauge measurements; the lines are numerically evaluated.

The result can be regarded as representative with respect to stress distribution; the absolute values are of course strongly dependent on the braking conditions. Considering fracture mechanical evaluation of cracks, the knowledge of the stress states in the layers near the rolling surface and near the outer face of the rim is most desirable. However, there is no suited technique available.

Ultrasonic techniques enable a fast and non-destructive evaluation of stress states in the rim of railroad wheels. The applied approach is based on the fact that changes of the stresses in the surface near areas yield also changes of the stress state in the bulk of the rim. Hence, the velocities of ultrasonic waves propagating the bulk of the rim are influenced by the stress state and its change. The application of a shear wave passing through the width of the rim with radial and then with circumferential polarization provides information about stresses in the rim by evaluation of the following equation:

$$\sigma_{\tan} - \sigma_{\text{rad}} = K (t_{\text{rad}} - t_{\text{tan}}) / t_{\text{tan}}$$

σ_{\tan} and σ_{rad} are the principal stresses along the circumferential and radial direction; t is the time-of-flight of the shear wave vibrating along the direction indicated as index. K is a material dependent constant, evaluated in the laboratory using representative material samples. This technique is described in more detail by Schneider et al.⁽⁵⁾

As to be seen in Fig. 23, the sound propagates the whole width of the rim. The result of the measurements is the mean value of the principal stress differences along the ultrasonic path. Depending on the material, the maximum value of acceptable stress difference has been defined for different wheel types in order to assure the safety of the wheels during their service life between the periodical inspections. Besides the material dependent quantities and the results of fracture mechanical investigations, the characteristics of the detected cracks (number, length, orientation) is taken into account.

Different set-ups are available to evaluate the stress states in rims of railroad wheels using the same approach. Compared to set-ups provided by competing companies, IzfP's UER device works fully automatic and evaluates the principal stress differences continuously along the height of the rim on a radial scan line⁽⁶⁾. The uppermost and deepest position of the ultrasonic probe is illustrated in Fig. 23.

A further unique feature of the UER device is the application of electromagnetic ultrasonic transducers (EMAT's) providing the advantage that no coupling medium is needed. This is an indispensable pre-requisite for automatic scanning; moreover any loss of coupling is avoided.

Two versions of UER set-ups are available: One is designed for the daily use in workshop environments, the other type is portable and hence to be used for the inspection of endangered wheels on the track. Both types of the UER system are identical with respect to

measuring technique, data evaluation, and documentation. Figures 24 and 25 show the portable UER-T system, which may be run from rechargeable batteries, during the inspection of a wheel. About 30 UER systems are presently in use at maintenance facilities of railroad companies or wheel manufacturing plants in European and non-European countries.



Figure 24. Base unit of the portable UER-T set-up for the automated evaluation of stress states of wheels.



Figure 25. Manipulator mounted at the wheel rim.

Since the UER system is able to evaluate the principal stress differences $\sigma_{\tan} - \sigma_{\text{rad}}$ along the height of the rim, it allows the localization of the extreme stress values in terms of the distance from the rolling surface. It is obvious that the stress profile depends on the braking conditions as well as on the load history of the wheel. Fig.26 depicts in its upper part the stress profile of a wheel which was heavily braked just recently before stress analysis. The stress maximum is

right in the near surface zone. The lower part of Fig. 26 shows the stress profile of a heavily braked wheel which was in service for some time after the braking. The load and the influence of lower braking temperatures caused a decrease of the surface near tensile stress.

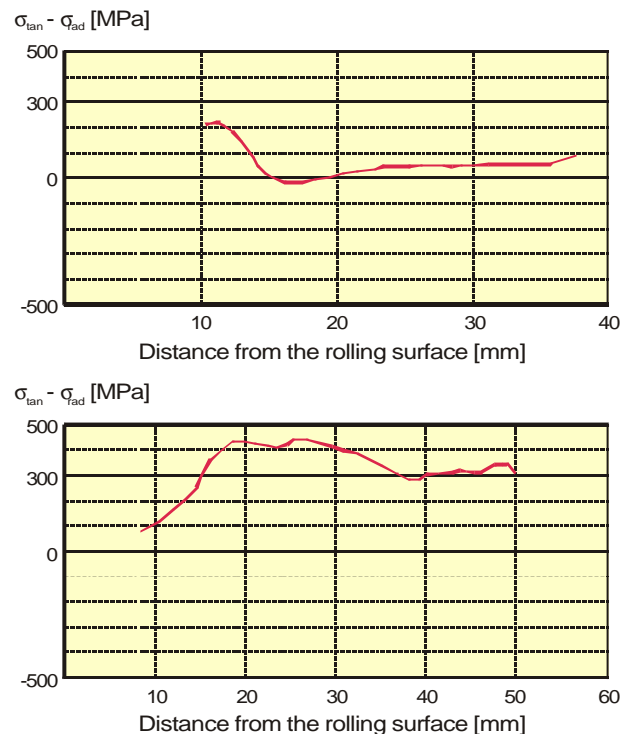


Figure 26. Change of stress state with the distance from the rolling surface of a wheel heavily braked immediately before stress analysis (upper part) and of a wheel heavily braked long before stress analysis (lower part).

The major part of the inspected monoblock wheels is forged and heat treated. This procedure has, among others, the advantage that there is no significant texture. Investigations showed that there is a slight texture in some of these wheels, but the texture caused error in the result of the stress analysis is less than about ± 15 MPa.

Sometimes wheels have to be inspected that have coarse grains, large segregations or other microstructural anomalies causing a very high ultrasonic attenuation. Some other wheels are found to have a strong texture which changes in strength at different positions of the same wheel. Others have a texture which is homogeneously developed around the circumference.

The UER measuring routines and the evaluation software are able to measure at least some of the wheels with microstructural anomalies or with texture.

UER measures the ultrasonic signals amplitude as a function of the distance from the rolling surface. In case the amplitude profile is found to be like the solid line in Fig. 27, the next step of the measuring program, i.e. evaluation of the stress state, is executed. If the amplitudes are smaller (dashed line), the stress analysis

is only made in the depth area in which the amplitudes are well above a given threshold.

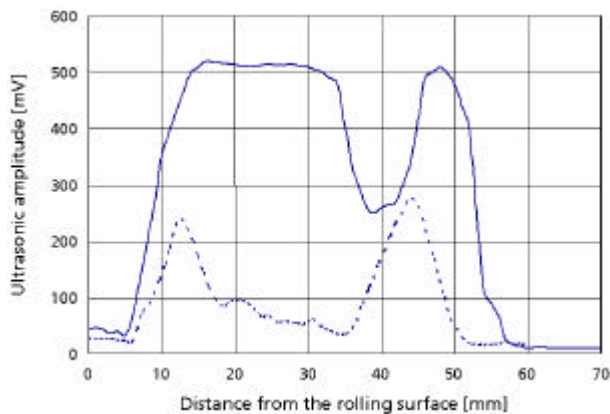


Figure 27. Change of the ultrasonic signals amplitude with the distance from the rolling surface measured using a wheel of a new type (solid line) and of an older type (dashed line).

In order to recognize textured wheels, amplitude and time-of-flight of the shear wave are measured during the automated change of the shear wave polarization direction from the radial (0°) into the circumferential (90°) direction. In Figures 28 and 29 the variations of the ultrasonic signal amplitude with the change of the shear wave polarization direction are displayed.

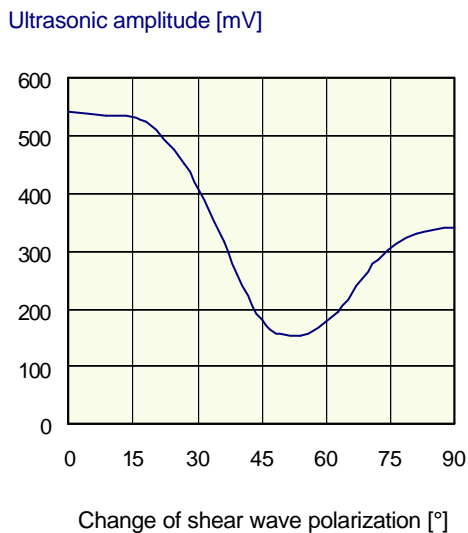


Figure 28. Ultrasonic amplitude versus change of shear wave polarization from the radial (0°) into the circumferential (90°) direction as measured using a wheel with a strongly developed texture.

The significant change as shown in Fig.28 is found using wheels with strongly developed texture. The result as displayed in Fig.29 is a typical result for wheels without or with a slightly developed texture.

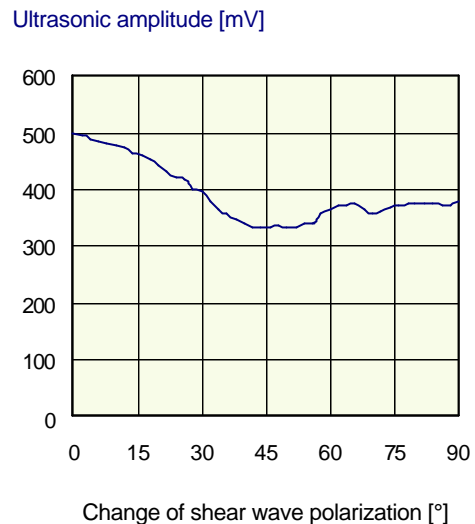


Figure 29. Ultrasonic amplitude versus change of shear wave polarization as measured using a wheel with no or a slightly developed texture.

Stress analysis on wheels with a strongly developed texture is only possible if the texture is homogeneous along the circumference of each wheel and if the texture influence on the measuring quantities is within only small variations for wheels of the same type or for wheels of the same manufacturing period.

The additional measurements of the ultrasonic amplitude and the time-of-flight as a function of the shear wave polarization direction is automatically started by the UER system if the usual evaluation procedure results in stress values which are not within certain predetermined limits. The additional measurements prolong the inspection time for one wheel from about 1.5 to about 2.25 minutes.

V. CONCLUSION

Practical experience with the described methods and equipment for wheel-set testing confirm their importance to improve safety of rail traffic. Presently more and more maintenance facilities of the Deutsche Bahn AG will be equipped with such automated instruments, including equipment for the inspection of wheel axles.

By network links between the installed testing stations and evaluation of the testing results using data bases, the condition of the complete rolling stock of the railroad company can be monitored and maintenance activities be optimized.

Further developments of testing equipment for wheel-sets aim to further reduction of the inspection intervals. This can be achieved by equipment which is able to inspect a wheel-set without dismounting it from the train, similar to the in-motion inspection system for the wheel tread, however, with extended testing functions to cover the complete rim and disk of wheel.

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