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Long Range Ultrasonic Technique for Rail Inspection

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***Abstract** - Application of guided waves for rail inspection in railroad industry is considered in the paper. They are particularly sensitive to vertical defects and they are used at relatively low frequency so they are not significantly attenuated by weld material. Dispersion curves and mode shapes for guided waves in rails were calculated using finite element technique. For the experiments a mode that only propagates in the web of the rail at frequency less than 100 kHz was chosen. Novel transducers were designed which produce in-plane displacements. For damping of the transducers a specially designed backing material composite was used in order to reduce the ringing effect of the piezo element at low frequencies. Experiments were conducted using a single transducer and array of four transducers. Different materials were evaluated for dry-coupling of the transducers to the rail surface. The experimental prototype system enables the screening of 20 meters of rail from a single array position.*

***Keywords:** Guided waves, long range ultrasonic testing, rail inspection, alumino-thermic welds.*

1. Introduction

Ultrasonic inspection systems that operate in the MHz range have been used for many years for the in-service testing of rails. Two specific areas that can present significant challenges for ultrasonic testing as currently deployed are the detection of smooth transverse/vertical defects and the volumetric examination of alumino-thermic welds. Guided wave inspection is very attractive in this application as it is particularly sensitive to transverse vertical defects since the waves travel along the length of a rail. Additionally at the frequency range used the material attenuation is low and hence alumino-thermic weld material can be readily penetrated and tested [1-4].

The complications of using guided waves in a system such as a rail, are connected with the many different modes of guided waves that can exist. These modes generally have different and frequency dependent velocities Without careful design of the transduction system and a full understanding of guided wave mode behaviour, the superposition of multiple modes all travelling at different velocities will result in data that is difficult to interpret. The key to an effective and practical test is the determination of the particular guided wave modes that are required for the test and the preferential generation and detection of these modes relative to the other unwanted modes [2-4].

2. Experimental specimen and guided mode selection

For the experiments were used specimens of rail section with length of 1 m. The rail is of type S49 (49E1 according to EN 13674-1) [5]. The cross section of the rail is given on figure 1.

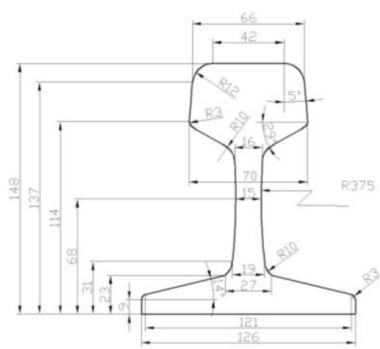

Figure 1 Cross section of rail S49

One specimen with alumino-thermic weld was made from two 0.5 meter long rail sections. Second specimen containing artificial reflector was also made. This reflector is 10 mm diameter cylindrical hole, drilled in the web of the rail and its position is presented on figure 2.

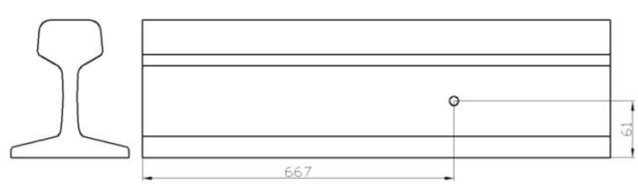

Figure 2. Drawing of rail section with cylindrical artificial defect

The dispersion curves for the rail are presented on figure 3. They were calculated using FEA software. There are two modes that can be generated in the web of the rail: mode T2 and mode T3.

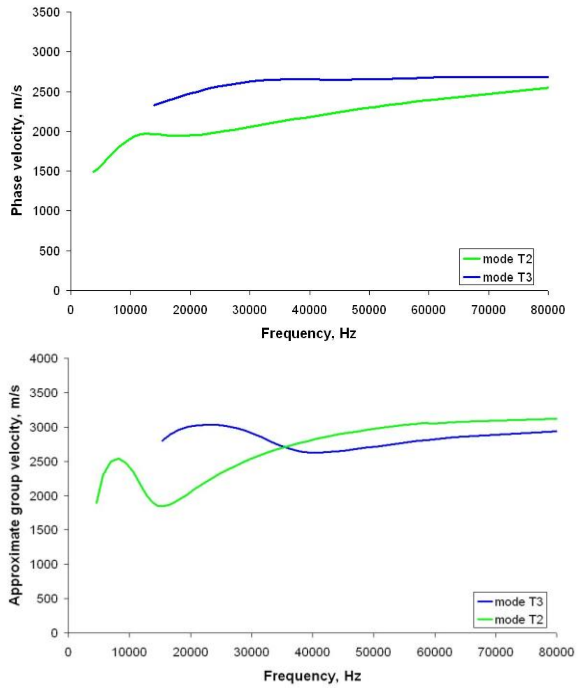

Figure 3 Dispersion curves for rail type S49

The shape of the displacements of mode T2 is calculated using FEA software and is presented on figure 4.

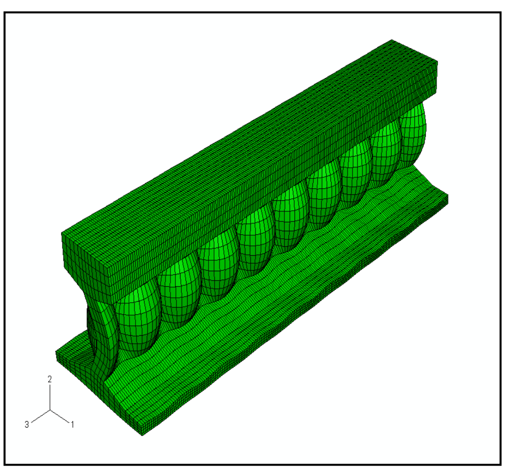

Figure 4 Displacement profile of mode T2

The acoustic energy of mode T2 is focused mainly in the web of the rail. The shape of the displacement profile corresponds to the fundamental axi-symmetric mode A0 in plates.

3. Equipment

Specially designed arbitrary signal generator was used for generation of low-frequency ultrasonic pulses. It is driven by software running on personal computer. It generates pulses with arbitrary form and duration. In order to drive the ultrasonic transducer at non-resonant frequency a high voltage sinusoidal signal with desired frequency is applied on the piezo-element. The frequency can vary from 1 kHz up to 300 kHz. The number of cycles can be adjusted between 1 and 30. The output signal of the generator can be modified with window function (Hanning, Hamming, Gaussian and others). The application of window function leads to reduction of output signal bandwidth. The amplitude of the signal varies from 0 V to 5 V. This signal is fed into high-power low frequency amplifier together with the synchronization signal. The amplitude of the signal is increased up to ±50 V (100 Vp-p). The bandwidth is 500 kHz. The output of the amplifier is directly connected to the electrodes of the piezo-element. The build-in preamplifier for the received signal has a variable gain of 80 dB and output amplitude 10V. The output of the pre-amplifier is fed into a digital oscilloscope. The sampling frequency is set to 1 MHz. The signal recording is done by standard software supplied with the oscilloscope. The interconnection scheme of the equipment is presented on figure 5.

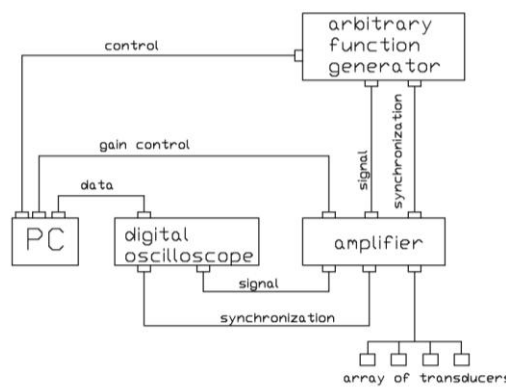

Figure 5. Equipment set-up

4. Transducers construction

Specially designed piezo-electric transducers were used. The piezo-element is rectangular with dimensions 18x9 mm and thickness 5 mm. The damping body is made from composite material with epoxy resin matrix and iron powder filler [6]. The filler content is around 50%wt. The acoustical impedance of the backing material is around 45 MRayl and is close to that of the piezo-element – 35 MRayl.

The piezo-element is mechanically protected by a thin layer of epoxy resin. The construction of the transducer is presented on figure 6. The experiments are conducted using piezo-element transducers having in-plane motion.

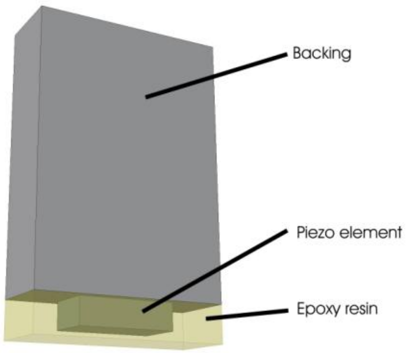

Figure 6 Schematic diagram of the constructed transducer

5. Transducers arrangement

During the experiments was used an array of several transducers. The exact positioning of array on the web of the rail is of critical importance for the generation of the selected mode. There are two possibilities for the positioning of the transducers in the array – one-sided and two-sided, which are presented on figure 7.

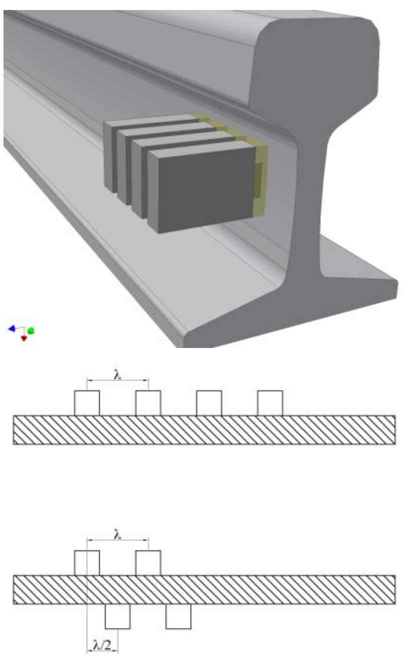

Figure 7. Transducers arrangement

The transducers are positioned at one wavelength distance between them. In the case of two-sided arrangement the transducers on one of the sides are shifted at half wavelength relative to the transducers on the other side. The wavelength for the selected mode is calculated according to: $C_{ph} = f.\lambda$ *, where:* C_{ph} – phase velocity [m/s]; f – frequency [Hz] and λ – wavelength [m].

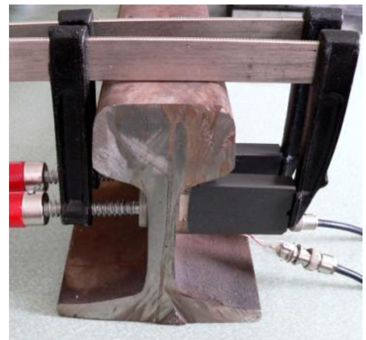

Figure 8. Clamping of the transducers

The transducers are fixed to the web of the rail using clamps (figure 8). The arrays were driven using a 7 cycles Hanning windowed tone-burst at 70 kHz. The applied peak-to-peak voltage is 100V. The applied pressure on each transducer is 0.7 MPa.

6. Experimental results

On figure 9 is presented the signal obtained using a single shear element transducer at 70 kHz. Hanning windowed 7 cycles tone-burst was used for excitation of the piezo-element. The acoustical contact was accomplished using grease. The dominant mode that is generated in this case is T2.

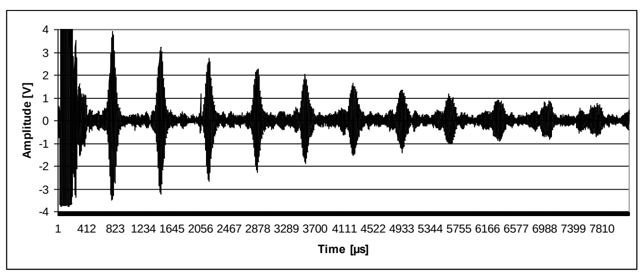

Figure 9 Mode T2 in the web of the rail using single transducer at 70 kHz

The change of back-wall echo amplitude vs. number of transducers is presented on figure 10.

Increase of the number of transducers leads to increase of the amplitude response of the array. The largest difference in response is between a single transducer and an array of two transducers. The slight difference between the responses of the two types of arrays is mainly because of the uneven acoustic contact.

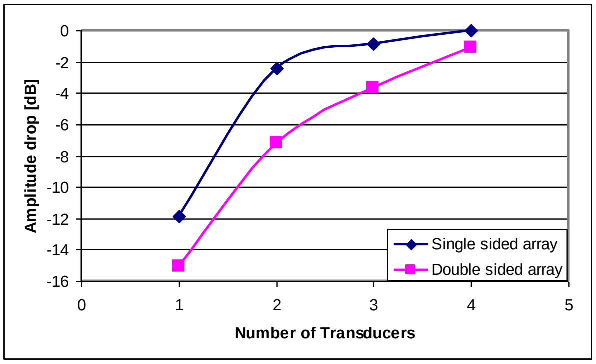

Figure 10 Amplitude of the back-wall echo for different transducer arrays

An A-Scan obtained with a single sided 4 transducers array is presented on figure 11. The coherent noise is at acceptable level and the spatial resolution of the mode is around 300 mm at 7 cycles tone burst using Hanning window.

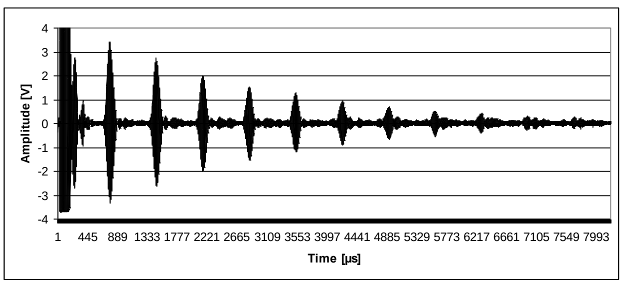

Figure 11 A-Scan obtained using single sided 4 transducers array

The improvement in SNR between a single transducers and a 4 transducers array is 14 dB.

In order to apply guided wave inspection on rails a dry contact between the transducer and the rail was used. Because the corroded surface of the rail in order to have a reproducible and reliable contact a transducer with deformable matching layer was used. The results obtained were comparable to the results using ultrasonic coupling gel.

6.1. Results from the specimen with artificial cylindrical defect

On figure 12 is presented an A-Scan received when mode T2 is generated in defect free specimen. On the next figure 13 is presented an A-Scan of sample containing a 10 mm diameter through hole in the web. These A-Scans are recorded using two transducers and single sided arrangement of the array. The acoustical contact is achieved using ultrasonic coupling gel.

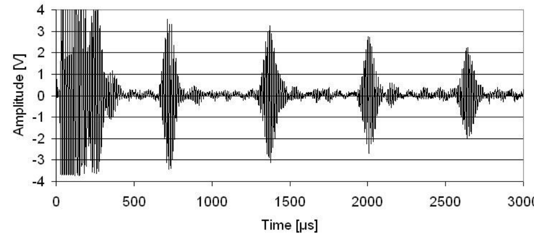

Figure 12. A-Scan from defect free specimen

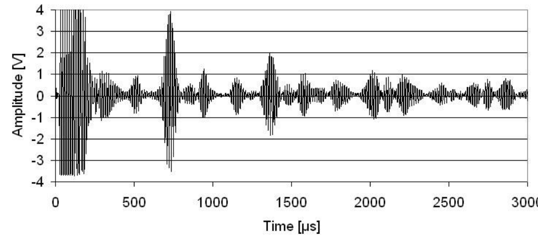

Figure 13. A-Scan from specimen containing defect

On figure 12 the multiple reflections from the side wall of the rail are visible. On figure 13 these multiple reflections are also visible but between them there are also other signals. These signals are multiple reflections from the through-hole defect in the web. The first reflection is positioned at time 550 µs on the A-Scan. The received echo from the defect is high enough for reliable registration. From the conducted experiment can be concluded that even smaller than 10 mm diameter defects can be registered.

6.2. Possible applications for the inspection of alumino-thermic welds.

The possibilities of the proposed technique for the inspection of alumino-thermic welds were evaluated. On figure 14 is presented an A-Scan of defect free specimen containing alumino-thermic weld in the middle. No indication form the welded zone can be seen. This indication is expected to be at time 500 µs. Based on this results we can conclude that the reflection from and scattering in the weld material is very low. Using this technique rails having alumino-thermic welds can be reliably inspected and their presence will not reduce the range of inspection.

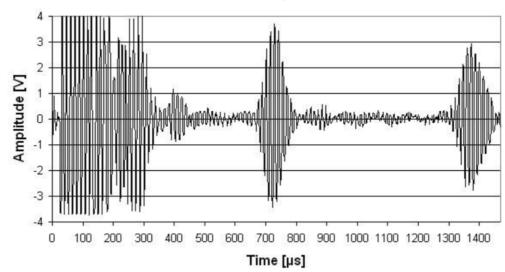

Figure 14. A-Scan of specimen containing alumino-thermic weld

7. Conclusions

The following conclusions can be drawn from the experimental results presented in this paper:

- The most appropriate mode for inspection of the web of the rail is T2;
- The application of backing material with large enough dimensions is very important to reduce the transducer ringing effect;
- The application of multiple transducers in an array led to reduction of the coherent noise and increases the inspection range;
- The optimum number of cycles is 7;
- Using this technique a 10 mm diameter side drilled hole in the web of the rail can be registered;
- At the frequency range used the guided waves pass through the alumino-thermic welds with very low reflection and scattering.

The further development of the technique is foreseen to be connected with the following:

- In order to increase the inspection range the resonant frequency of the transducers should be as close as possible to the frequency of the selected mode;
- Further investigations should be made on the applicability of the system for inspection of the head and the foot of the rail;

This paper presents developments currently being carried out under an EU funded Collective project: "Long Range Ultrasonic Condition Monitoring of Engineering Assets" (LRUCM)
LRUCM is a collaboration between the following organisations: TWI Ltd, Deutsche Gesellschatt fur Zerstorungsfreie Prufung EV, European Federation of Non Destructive Testing, Asociacion Espanola de Ensayos no Destructivos, Associacao Portuguesa de Manutencao Industrial, Associazone Italiana Prove Non Distruttive Monitoraggio Diagnostica, Balgarski Saiuz po Zavariavane, Ukrainian Society for Non Destructive Testing and Technical Diagnostics, Coaxial Power Systems Ltd, I & T Nardoni Institute Srl, Sonatest NDE Plc, Isotest Engineering S.r.l., RARI - Construcoes Metalicas Engenharia Projectos E Solucoes Industriais, Lda, A Casa Inteligente, Lda., Atlantis NDE Ingenieria de Inspeccion no Destructiva SL, NDT Consultants Ltd, Advanced Technology Group Sro, Instituto de Soldadura e Qualidade Associacao, Kingston Computer Consultancy Limited, Zenon Robotics and Informatics SA, Kauno Technologijos Universitetas, Nexus Engineering Ltd. The Project is co-ordinated and managed by TWI Ltd. and is partly funded by the EC under the Collective SME programme ref: Number Coll-CT-2005-516405.

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