THE PPOSSIBILITIES OF USING ULTRASONIC TESTING IN CONTROL QUALITY OF RAILS

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Abstract: The rails are an important and critical part of a railway system and are exposed, during service, to high stresses of different types, frequency and orientation and also to different environmental. Different NDT methods exist for testing rails in service, enabling the detection of external and internal flaws, suck as, for example, eddy current methods, although ultrasonic testing is also very often used.

NDT methods; ultrasonic testing; control quality; rail.

1. Problems generals

The rails are an important and critical part of a railway system and are exposed, during service, to high stresses of different types, frequency and orientation and also to different environmental. In Europe, rail quality and the acceptance criteria are regulated by international standard UIC 860 V, with which all national standards are in accordance. The high external stresses are superimposed with the internal stresses, representing a serious load on rails with the potential to extend existing flaws resulting from deviation in the technology of steel production and processing, as well as the final stages of finishing, and considered in this work. The most frequent flaws occurring during the operation, classified per type and positions, are considered. The possibilities of using ultrasonic testing in control quality of manufactured rails and rails in service in order to detect flaws and determine their positions and nature are also described. It has been found that by ultrasonic testing of rails, using different probes and frequencies, internal flaws such as flakes, cracks, non-metallic inclusion can be successfully detected [4].

2. Acceptance investigations

Inspections checks for manufacture rails include determination of the following characteristics:

- Chemical composition
- Resistance to impact
- Tensile strength and elongation
- Macro-structure
- Hardness
- Shape, dimension and weight
- Appearance.

Defects originate either from original facets (hydrogen cracks or non-metallic inclusion), or from operating effects. The majority of significant defects occur in the head of the rail.The most common ones are as follows:

Tache ovale (defect originating internally in the head from an original defect)

The rest are from operating wear:

Head checking or *Gauge corner cracking*; surface-breaking multiple cracks.
Tongue lipping
Squats; often caused by local impact from something picked up on the wheel.
False flange damage; caused by uneven wheel wear.
Wheelburns [6]

Rolling contact fatigue.

3. Ultrasonic instrumentation for rail inspection

In the past – and probably in the future – automated ultrasonic methods have been use to inspect the rail *in situ*. However, the existing automatic methods involving dedicated rail cars (limited to 20 mph) can use logistical problems, as the entire length of track being inspected is not available for normal use. Currently, the preferred method for the inspection of railtrack is semi-manual pulse echo ultrasonics, although tandem ultrasonic techniques and radiography are used for weld inspection.

Semi-manual ultrasonic inspection involves an ultrasonic operator (supported by a team of `look-outs´ to warm of approaching trains!) pushing a mechanical device known as a rail trolley or `walking stick´ along the track.

The trolley incorporates the ultrasonic flaw detector, irrigation reservoir and ultrasonic probe block. The probe block includes forward and backward facing 70 degree angle probes and a 0 degree compression probe. The design of the probe ensures that, as the trolley is pushed over the rail, all of the commonly occurring discontinuities are detected [2, 4, 6, 7].

The semi-manual ultrasonic inspection of rail *in situ* involves most of the human challenges encountered in the majority of manual testing situations. This include:

- exposure to weather conditions
- exposure to distractions – such as line traffic
- varying noise levels
- varying lighting conditions
- high volume of testing
- relatively low incidence of defects
- requirement to record, estimate and positions defects located
- requirement to record high volume thickness measurements
- signals from artifacts – such as bolt holes
- a number of different defect types giving different responses
- uncomfortable conditions – walking on track.

The latest instruments offer the following:

- Digital technology which gives robustness (no fragile tube), lightweight, small size.
- Pre-recorded set-up which only requires on-site verification of calibration using standard procedures. This takes less time and offers more consistency in calibration.
- Transreflective LCD display which is much more visible in sunlight or in high light levels.
- *Freeze on defect* - this optional feature enables the display to *freeze* when the alarm is violated, drawing the attention of the operator who has to take action before testing can continue.
- Digital read-out of signal positions.
- Recording of high volume (5000 readings or more) thickness measurements, particularly valuable for high corrosion environments suck as tunnels.
- Recording of parameters for a testing period – operator, track location, length of track to be tested etc.
- Recording of A-scan defect signals with manually selected defect coding and positioning.
- Up-load the previous test results for a particular stretch of line followed by comparison of current with previous test – the ability to display the A-scan from the

previous test of a particular defect, add the current test A-scan and record the combination.
- Electronically download the results of a testing period to a computer which produced a report in the format currently used in the industry.

4. Investigation of rails in operation

Rails are periodically tested during their service life, in order to determinate any previously undetected flaws and to detect new flaws caused by the large operational stresses in the rails. Different NDT methods exist for testing rails in service, enabling the detection of external and internal flaws, suck as, for example, eddy current methods, although ultrasonic testing is also very often used.
During service, different types of flaw can appear and cause, under the influence of increased stress, breakage of the rail. Rail breaks are carefully investigated to determine the type and origin of the breaks. Service flaws on rails can be divided according to their location (head, web or foot of the rail) or type of flaw (vertical or cross-selectional cracks, fibrous cracks etc), [4].
Figure 1 gives a review of commonly detected flaws and failures, as related to location and type.
Flaws developing in service can be divided into the following main groups:
- Group I Delamination and damage the driving surface of the rail.
- Group II Cross-selectional cracks in the rail head.
- Group III Vertical cracks in the rail head.
- Group IV Roughness of the rail head.
- Group V Flaws in the rail web.
- Group VI Flaws in the rail base.
- Group VII Breaks covering the cross-section.

5. Ultrasonic characterization of defects in rails

Knowledge of the echo dynamics of both zero-degree longitudinal and refracted shear waves interacting with rail defects (both vertical and transverse) is important in optimising ultrasonic rail inspection. Studied [2] the echo response for 70° refracted shear waves in two rail specimens having Electrical Discharge Machined (EDM) notches to model transverse defects with different sizes and orientation to the transverse plan. In addition, we examined echoes of longitudinal and reflected shear waves in five specimens with Vertical Split Heads (VSHs).
The results show that the detection of the EDM notches depended on the profile of the worm rail head, the lateral position of the transducers, and the size and orientation of the EDM notches. The results from the five VSH specimens show that these specimens had jagged surfaces that were non-coplanar in the vertical plane and nonlinear along the length of the rails. The results from the VSH specimens further demonstrated the need for electronic scanning across the width of the rail and continuous beam steering along the rail in order to inspect irregular surfaces in the vertical (X-Z) plane. Alternatives to the electrical scanning and continuous beam steering are to use either phased array technology or laser ultrasonics.
The percentage distribution of various rail defects data taken over one year is in table 1 [2].

Table 1. The percentage distribution of various rail defects. Data taken over one year.

Detected Defects	Notified Rail Failures

Defected Weld	22%	Transverse Defects	33%
Bolt Hole Defects	19%	Defected Weld	30%
Transverse Defects	18%	Bolt Hole Defects	9%
Vertical Split Heads	9%	Vertical Split Heads	8%
Head and Web Separation	7%	Detail fracture	4%
Detail fracture	6%		
Engine Burn Fractures	6%		

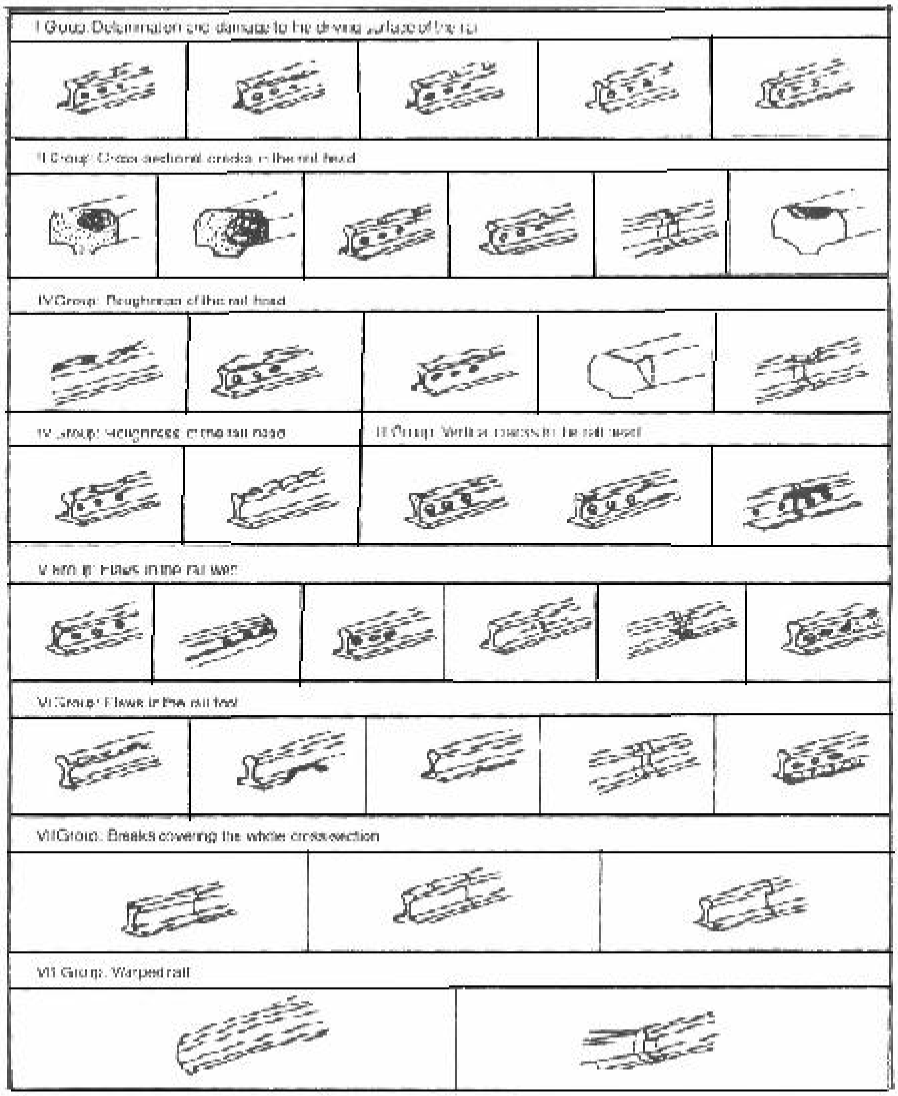

Figure 1 Review of flaws and failures in rails [6]

The variation of the amplitude (as a percentage of full screen height) of reflected signals for the 70° refracted shear waves from EDM notches oriented at different angles for a given gain setting is plotted in Figure 2A. the variation of amplitude (%FSH) of the reflected shear waves depends on the angle of incidence, which, in turn, depends on the orientation of the EDM notches. Experiments demonstrated that the amplitude of the reflected signals increased from 5° to 20°; thereafter, the signal decreased linearly as the notch angle increased from 20° to 35° (Figure 2A). The relationship between the latter orientation angles of the EDM notches an the amplitude of the reflected shear waves was similar to the first half of the curve except the slope of the second half of the curve was negative.

The refracted wave striking an EDM notch at a right angle is reflected with a maximum amplitude when all other conditions remain the same, including the topography of the reflecting surface. As was expected, the maximum amplitude was from the EDM.

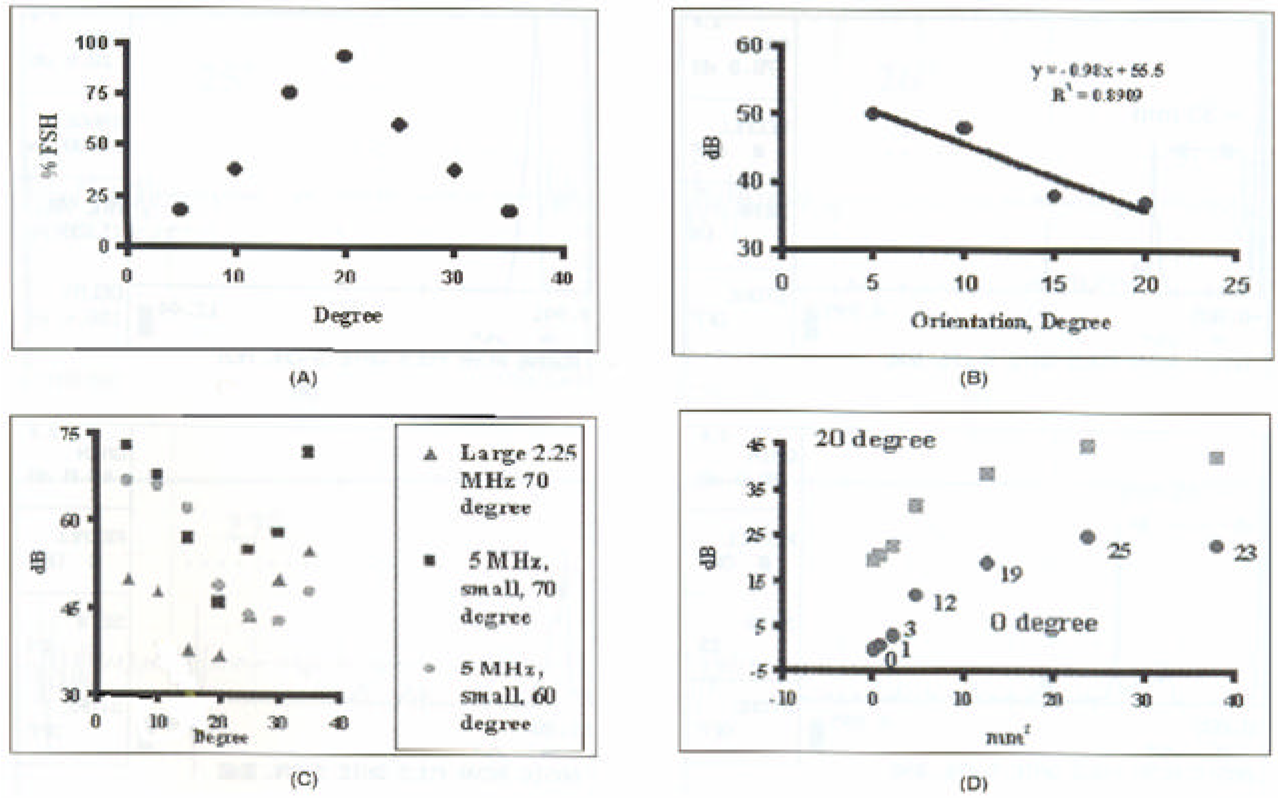

Figure 2. (A)Variation of amplitude (%full screen height , FSH) for 70° refracted shear wave versus the orientation of EDM notches, (B) variation of dB needed for 80 % FSH for the amplitude of shear waves refracted at 70°versus the orientation of EDM notches, (C) variation of dB needed for 80 % FSH for shear waves refracted at 60° a 70°having a different crystal size versus the orientation of EDM notch, and (D) variation of dB needed for 80 % FSH for a 70°refracted shear wave versus the size of the EDM notches.

Notch oriented at 20° and lying perpendicular to the incident 70° refracted shear wave (Figure 2A).

In order to have a quantitative understanding of the relation between the signal amplitude of the reflected waves and notch orientation, the gain (dB) needed for the amplitude of the reflected waves for a signal at 80% full screen height (FSH) was plotted against the EDM notch orientations (Figure 2B). These results showed that the relationship was linear, and each degree change in orientation decreased the amplitude in the reflected waves by approximately 1 dB. The correlation coefficient was R = 0.99 and the equation of the regression line shows that the negative slope for the curve was 0.98, i.e., approximately 1 (Figutre2 B). A similar trend is expected for the amplitude and EDM notch orientation (20° to 35 °), except the curve has a positive slope.

The results further show that the large crystal size (19.1 x 25.4 mm^2) had a higher amplitude that the small crystal size (12.7 x 12.7 mm^2), thereby indicating the dependence of sensitivity on the effective cross-section of the transducers (Figure 2C). The Y-axis shows the dB needed to display a signal with an amplitude equivalent to 80% FSH; a high dB values means the transducer had a low sensitivity. Frequency is the other variable that may have contributed to the difference in the dB.

The relationship between the amplitude of the ultrasonic signals and the size of the notches was not linear for the large EDM notches, due to the comparable size of ultrasonic beam and the EDM notches. However there was a linear relationship between the

amplitude and transducers size where the area was smaller that 13.97 mm^2 (Figure 2D). In addition, the amplitude of the echo signal from a given range of EDM notches depends on the orientation of each notch with respect to the transverse plane.
The echo amplitude reflected from the notch oriented at 20° had a signal that was approximately 20 dB higher that the signal from the notch lying at 0° (Figure 2D). This finding can be used to extrapolate the amplitude of a reflected wave from an EDM notch oriented at an angle while using the known amplitude at a given orientation.

6. Conclusions

The railroad industry continues to present the NDT professional with a serious challenge. Through a target R&D effort based on a sound understanding of the basic issues of concern, better technology will be brought to the world's rail roads [1÷7].

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