

DIAGNOSTIC SENSITIVITY OF ULTRASONIC MOBILE FLAW DETECTION OF HEAD CHECKING TYPE FLAWS IN RAILWAY RAILS

Piotr LESIAK

Technical University in Radom, Faculty of Transport,
29 Malczewskiego St., 26-600 Radom, e-mail: plesiak@pr.radom.net

Summary

This paper presents analysis of diagnostic sensitivity of ultrasonic mobile testing of railway rails done with the help of measurement car. To verify the concept, most hazardous flaws of head checking type were used. These faults cause multiple rail cracks and fractures. The properties of these flaws and testing procedures have been described together with diagnostic sensitivity analysis on the basis of measurements run on a representative section of railway main line.

Keywords: diagnostic sensitivity, railway rails, ultrasonic tests, head checking flaws.

WRAŻLIWOŚĆ DIAGNOSTYCZNA ULTRADŹWIĘKOWYCH MOBILNYCH BADAŃ WAD TYPU HEAD CHECKING W SZYNACH KOLEJOWYCH

Streszczenie

W pracy przedstawiono analizę wrażliwości diagnostycznej, ultradźwiękowego mobilnego badania szyn kolejowych wagonem pomiarowym. Do weryfikacji wykorzystano niezwykle niebezpieczne wady typu head checking, które powodują liczne pęknięcia i złamania szyn. Omówiono właściwości tych wady, technologię badania oraz przeprowadzono analizę wrażliwości diagnostycznej na podstawie badań reprezentatywnego odcinka magistralnej linii kolejowej.

Słowa kluczowe: wrażliwość diagnostyczna, szyny kolejowe, badania ultradźwiękowe, wady head checking.

1. INTRODUCTION

Railway track is a technical structure exceptionally susceptible to defects, therefore it is subjected to routine diagnostics. We expect the track to be safe and the journey to be comfortable, this is especially important since train speed rise all the time.

When it comes to track quality measurements, ultrasonic mobile diagnostics of rails, conducted with the help of specialised vehicles such as light weight cars and measurement cars [4], is of utmost importance. It is aimed at flaw detection in rails and rail joints of standard, welded and thermite welded types. Rail measurement results should be reliable, since they constitute the basis for making diagnostic decisions during rail operation. In particular, assessment of nearly critical flaws is most important. If such a flaw is not detected or if it not assessed correctly, then it may lead to huge economic losses and put human safety at risk. That is why the author conducts research targeted at improving diagnostic susceptibility of ultrasonic rail diagnostics [6].

The key issue in ultrasonic rail diagnostics is to determine the set of diagnostic signals or signal properties. Analysis of diagnostic sensitivity might be the tool helping to solve this problem [7]. Application of this analysis, using expert knowledge and intuition will be helpful in creating more efficient and effective diagnostic system.

In order to verify these issues, most dangerous flaws of head checking type, which cause numerous rail cracks and fractures have been utilised in this paper [1, 3, 8].

2. PROPERTIES OF HEAD CHECKING FLAWS

Last ten years of 20th century have brought about a whole new class of rail flaws. These have been colloquially called contact stress flaws. The primary cause of these flaws is significant stress occurring in wheel-rail contact zone.

The head checking flaws may be referred to as the classic example of contact stress flaws, they are labelled as 2223 in flaw catalogue [3], Fig. 1. They are present mostly at the rail head inner surface in curves or in straight portions of the track. They arise in places with maximum dynamic action (centrifugal force). These are small cracks seen more or less regularly at 0.5 to 10 mm, at 10 to 15° angles depending on the prevailing rail-wheel contact geometry. When they develop, in some cases they may attain a depth of few mm.

These inconspicuous flaws are characterised by high concentration of stresses in the railhead. Given their cyclic occurrence, they may cause multiple rail fractures. This poses enormous threat to train operation [1].

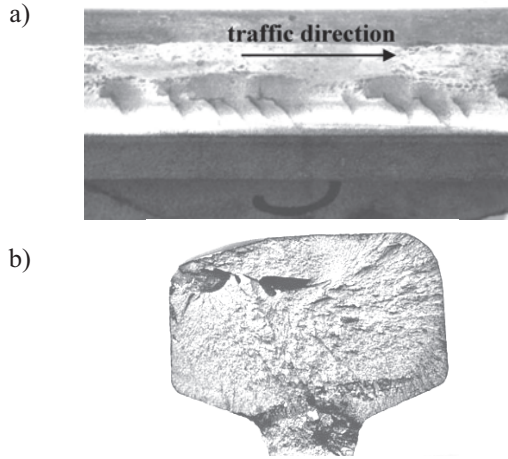


Fig. 1. Characteristic patterns of head checking flaws: a) with surface shining in the flaw zone, b) wear centre at the railhead lateral surface

3. MEASUREMENT BASICS

In PKP measurement car, TOFD method (Time-Of-Flight Diffraction -[2]), is used to detect head checking flaws. This method is based on diffraction of ultrasonic waves at the flaw edge - see Fig. 2 [5].

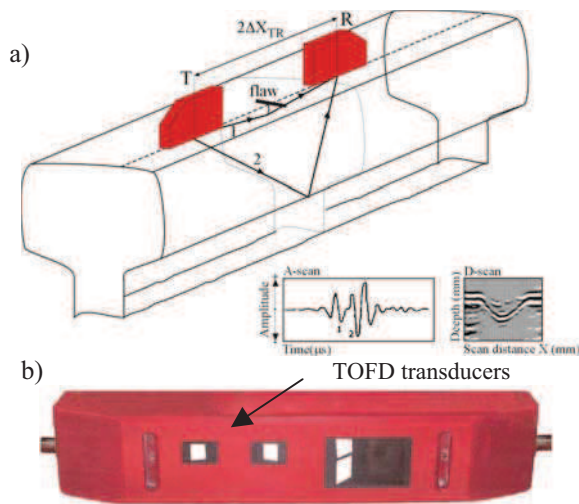


Fig. 2. Probe used for head checking flaws detection, with subsurface transducers, a) measurement principle, b) probe construction

Ultrasonic probe utilising longitudinal subsurface wave with very short impulses is used (so-called wideband probe). Additionally, piezoelectric transducers should be placed as near as possible to each other (small ΔX_{TR}) and shifted in relation to rail longitudinal symmetry axis towards the track centre (Fig. 2b). Electronic circuits must allow for impulse precise time measurements.

In this case, the depth of diffusing fault edge at the nth rail level is equal to:

$$Y_n = \frac{1}{2} \sqrt{(t_o C_L)^2 + 4t_o C_L \Delta X_{TR}} \quad (1)$$

where: t_o – delay time of diffractive impulse (1) – Fig. 2a, related to subsurface wave impulse (this

wave passes directly between sending transducer T and receiving transducer R), $2\Delta X_{TR}$ – distance between ultrasonic transducers centres, C_L – velocity of longitudinal ultrasonic wave in the rail.

Absolute error of flaw edge location, after differentiation, may be calculated from:

$$\Delta Y_n = \left(\frac{C_L}{2Y_n} \right) \Delta t_o \sqrt{Y_n^2 + \Delta X_{TR}^2} \quad (2)$$

where: Δt_o – absolute error of time measurement of diffraction impulse location.

Measurement accuracy decreases for faults located close to the surface, where Y_n is small (in rail track measurement practice, the measurements are achieved for depths greater than 5 mm). This limit is due to the measurement principle and is the most serious drawback of the method.

Example of head checking flaw recording on railway track is shown in Fig. 3. This fault has been recorded by probe #9 (as in Fig. 2), for 194 mm length, it was 5-6 mm deep down into the rail and echo of rail head bottom was equal to 33 mm at the average. In one case there was a reflector present in the head at 11 mm depth.

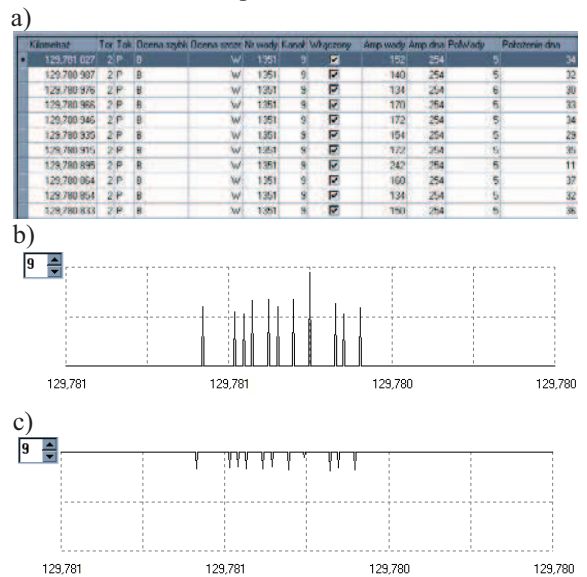


Fig. 3. Recording of head checking flaw with measurement car: a) flaw record window b) flaw amplitude signal, c) flaw depth

4. SENSITIVITY ANALYSIS

The task of diagnostic sensitivity analysis of railway rails is the selection of specified subset from the available set of diagnostic parameters characteristics. These characteristics are measurable indicators of rail technical condition.

Sensitivity ϖ of parameter characteristic Ω to technical condition λ_i of R rail is defined as the relative change of this characteristic's value due to this condition, or [7]:

$$\varpi(\Omega(R)|\lambda_i) = \frac{V(\Omega(R)|\lambda_i)}{V(\Omega(R)|A)}, A = \{\lambda_1, \lambda_2, \dots, \lambda_I\} \quad (3)$$

where: R – investigated rail, A – set of rail technical conditions, λ_i – examined technical condition, $\Omega(R)$ – value changes of the parameter characteristic under investigation, $V(\Omega(R)|A)$ – maximum value of measure of variability V of parameter characteristic Ω , taking into consideration whole set of conditions, $V(\Omega(R)|\lambda_i)$ – value of measure of variability V of parameter characteristic Ω , determined for investigated technical condition λ_i .

Only two signal characteristics are measured in ultrasonic diagnostics: ultrasonic wave amplitude determined with 8-bit resolution and time of wave flight in the rail (when velocity of the given ultrasonic wave and probe transducer angle are calculated, the fault depth or rail height is obtained – for a standard probe). Imaging precision of geometrical diagnostic parameters is influenced by the distance between successive wave generations by ultrasonic transducer, that is sampling step (in practice it is 2, 5 and 10 mm), and this defines horizontal resolution of fault geometry. Under operational conditions, decreasing sampling step along the rail would cause decrease of testing speed at the track and would affect train traffic, hence biggest sampling step is routinely adopted.

Signal characteristics such as e.g. time vs. ultrasonic wave velocity may be influenced by local changes in rail steel structure, rail temperature or stress; amplitude may be affected by condition of railhead surface, geometrical dimensions of the track and its dynamic properties (quality of acoustic coupling between the probe and the railhead may vary).

In order to assess the sensitivity of *head checking* flaws, the results of tests carried out with PKP measurement car have been analysed. The measurements were run in 2007 at four tracks with total length of *c.* 200 km, at the mainline with allowable speed limit of 160 km/h - Fig. 4. This line is continuously subjected to modernisation, hence different rails, with different operation time may be found here. Therefore it may be assumed to be representative for analysis purposes.

Classifier automated algorithm has been the basis for assessment of rail technical condition. To increase assessment reliability, the algorithm has been additionally subjected to expert analysis (done by the author of this paper).

In many cases classification was changed. Different worthiness classes have been assigned to the rails: λ_B – no fault, partial worthiness λ_O – fault to be monitored, unworthiness λ_W – hazardous fault.

Total amplitude of ultrasonic wave

$\sum_{m \in R} S_m$ received by the probe in different samples (m longitudinal cross-sections of R rail section) has been adopted as single fault parameter characteristic Ω .

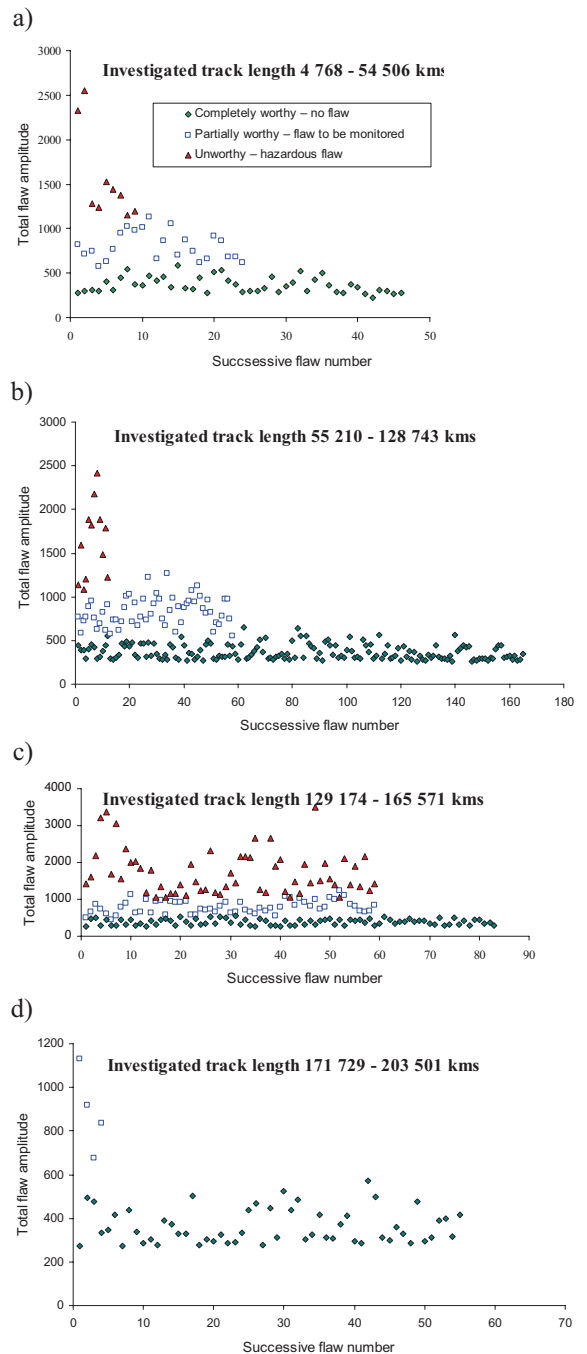


Fig. 4. Results of railway rails mobile tests; rails with head checking flaws

Next, average value of these amplitudes for all detected ν flaws at a given rail section R and classified into every λ_i technical condition under consideration has been determined, i.e. $\frac{1}{\nu} \sum_{\nu} \sum_{m \in R} S_m$.

Finally, the results for ρ track sections have been summed up (for instance, there were 4 sections in Fig. 4 example).

As a result, starting with formula (3), average sensitivity $\bar{\omega}$ of flaw signal amplitude S to technical condition λ_i of R rail has been obtained:

$$\bar{\omega}(S|\lambda_i) = \frac{\sum_{\rho} \left[\frac{1}{\nu} \sum_{\nu} \sum_{m \in R} S_m |\lambda_i| \right]}{\sum_{\rho} \left[\frac{1}{\nu} \sum_{\nu} \sum_{m \in R} S_m |A| \right]}, A = \{\lambda_B, \lambda_O, \lambda_W\} \quad (4)$$

In particular, complete unworthiness of the R rail is important. Therefore changes in signal amplitude arising from several flaw classes have been determined for the summed results of tests seen in Fig. 4. Average sensitivities $\bar{\omega}(S|\lambda_W) = 0.504$, $\bar{\omega}(S|\lambda_O) = 0.34$ i $\bar{\omega}(S|\lambda_B) = 0.153$ have been calculated from Table 1.

Even though the hazardous flaws are characterised by highest possible diagnostic sensitivity, it does not mean that the ultrasonic method is perfect. Alternative diagnostic methods of head checking type flaws are continuously researched [5].

Table 1

track kms	Flaws amplitudes						
	λ_B		λ_O		λ_W		
	no flaw		flaw to be monitored		hazardous flaw		
	1	2	1	2	1	2	3
4.768 - 54.506	16913	368	19310	805	14114	1568	2741
55.210-128.743	60878	367	49102	832	20666	1590	2789
129.174-165.571	31942	384	47055	797	101494	1720	2901
171.729-203.501	19960	362	3560	890	0	0	1252
Σ		1481		3324		4878	9683

1- sum of amplitudes of all flaws, 2- average amplitude value per flaw, 3- sum of average flaw amplitudes for all rail conditions

5. CONCLUSION

Analysis of diagnostic sensitivity of ultrasonic rail tests is original concept suggested by the author. It is also a proposal for PKP appropriate services to adopt this indicator in order to improve diagnostic system.

During further analyses the length of analysed track should be increased, different line categories should be tested and other than head checking popular flaws should also be analysed.

Other signal characteristics might also be adopted for sensitivity analysis, e.g. value of rail load Q in Tg [8]. These data are given in manual tests results (if available), for hazardous flaws in

particular. Hence assessment of rail technical condition might be practically limited to λ_W .

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Dr inż. **Piotr LESIAK** works as Assistant Professor at the Faculty of Transport in Technical University in Radom. He researches measurement and diagnostic tools for rail transport. His scientific achievements include many technical solutions implemented by railway operators. He has won three awards of Minister of Higher Education and Science for his designs.