ISSN 1232-3829

tts 10/2013

Technika Transportu Szynowego koleje ▪ tramwaje ▪ metro

LESIAK Piotr, AMBROZIŃSKI Łukasz, TCHÓRZ Adam

ULTRASONIC IMMERSION METHOD FOR TESTING WELDING JOINTS IN RAILWAY RAILS

Abstract

Authors proposed the new ultrasonic technology being based on an immersion method for testing welding joints in railway rails. The method was verified on samples of welding joints directly extracted from the track. Obtained image of C type allowed for the precise assessment of the shape and transversal area of the flaw occurring in cross-section of the rail. Flaw assessment criteria`s were constructed on the basis of threshold and proximity functions.

INTRODUCTION

Welded joints of rails are the hot spots important for railway traffic safety. According to the statistics of the rail operators, about 20% of the overall rail failures origin from the joints' cracks [1,2]. These defects often cause train derailments.

Therefore, improvement of rails' welding techniques is of great research concern for many companies and universities [5, 14, 15, 16, 21, 22, 23]. Still, scheduled inspections are required for safe railways exploitation, hence, there is a need for qualified and certified personnel training and new, advanced methods for welded joints non-destructive testing (NDT) [3, 8, 13, 17, 18, 19].

Centrum Diagnostyki PKP PLK S.A., is a department of PKP company that conducts rails inspections using ultrasonic testing (UT) technique. Manual inspections are normally performed from the rail head surface, side walls and the rail's foot. Longitudinal wave transducers and shear wave wedge probes are used. To date, conventional tests based on a typical A-scan representation are used. The amplitude of the damage-reflected impulse and its envelope are used as a damage symptom and measure. These tests require calibration of the probe-flaw detector system [8].

Many years of experience prove, that not always it is possible to assess the real damage size. The inspections are time-consuming and the result strongly depends on human factor. The main drawback of automated tests using railroad testing vehicles, that are often used in high velocity lines, is their one-side access [10].

Therefore, simulation analyses [6, 7, 16] and intelligent algorithms [11] are used to improve the UT methods for rails' welded joints inspections.

In this paper an immersion technique for investigation of rails sections with welded joints is proposed. Since the test is performed in a plane parallel to the weld interface, it is possible to investigate the whole cross-section of the joint. Two approaches: based on a threshold value and similarity measure were used for automatic assessment of the defects area.

Although, the technique is not suitable for operational tests, it can be successfully used for an extended imaging of defects in laboratory investigations of welded joints, and welding technique. Moreover, the technique can be used as a validation method for tests performed in training process. Further investigation of similarities between the results of the classical UT tests and the proposed technique can lead to improvement of damages quantification in the welded joints.

The next step to find the solution of these problems is application of radiography testing (RT) and computed tomography (CT), which is the further work of the authors.

1. EXPERIMENTAL SETUP

The tests were performer on a random sample of a termite welded joint, presented in fig. 1, taken from a bad maintained railway. The missing part of the joint implies that a significant crack could exist in the joint. The sample was insered in an immersion tank, with an automatic scanner system, presented in fig. 2a. The sample was investigated from the plane parallel to the cross section of the weld with resolution in XY plane of 2x2 mm.

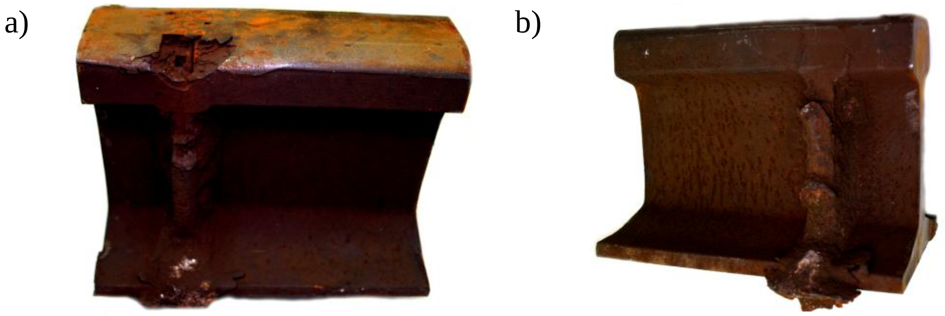


Fig.1. Test sample used for experiments a) crack at the head of the rail, b) other view of the sample.

The tests were conducted using a plug & play PCI card USPC7100LC, provided by Socomate, France. The signals were captured at 200 MS/s at 10 bits resolution [20].

For the investigation, an immersion, non-focused probe for longitudinal waves, provided by CTS Valpey was used [4]. The frequency of the probe was 10 MHz.

The system was used to capture A-scan in the successive points. These signals were then used for the further offline processing to obtain C-scan images.

Measuring Data are recorded into the PCI Card Memory at constant rate and then each Packet is Transferred toward the RAM with the use of interruption.

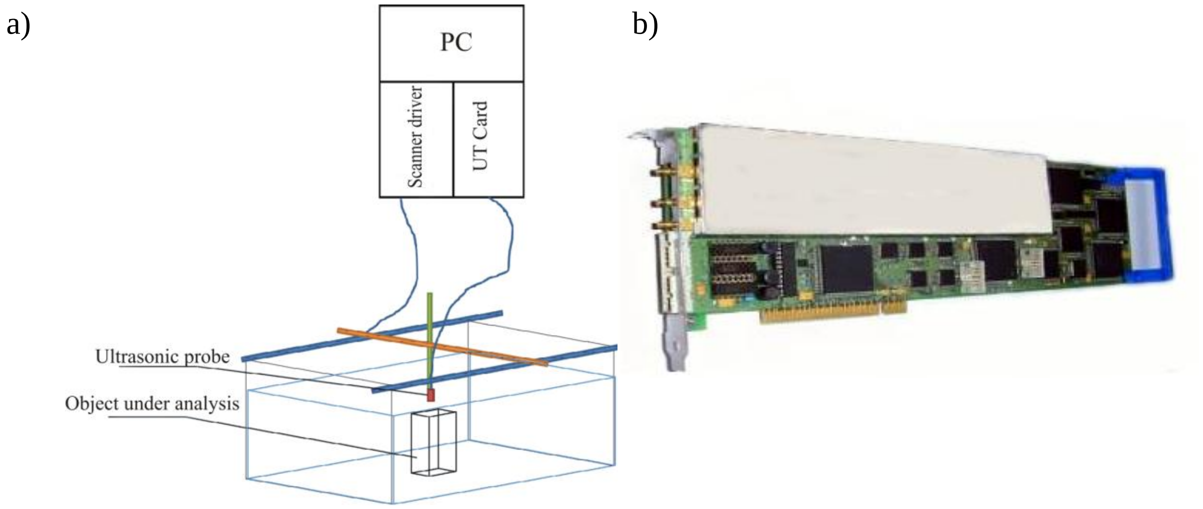


Fig.2. Experimental setup: a) tank and UT scanner, b) UT PCI card Socomate USPC7100LC

2. ALGORITHM FOR A-SKANS PROCESSING

A-scan is a time-response of ultrasonic wave captured in a given point over the investigated test-sample. Examples of typical A-scans obtained during the investigation of the welded joint were presented in figs. 3, 4, and 5. The horizontal axes of these plots were calculated from time of flight (TOF) to the propagation distance of the wave. This operation was performed assuming velocity of the longitudinal wave in the steel.

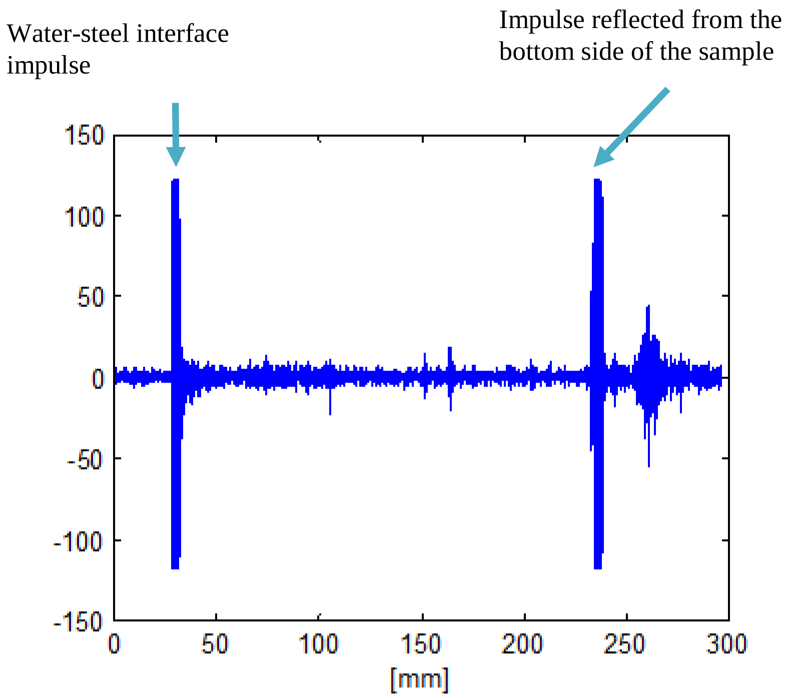


Fig. 3. Example of A-scan obtained in a spot without any damage

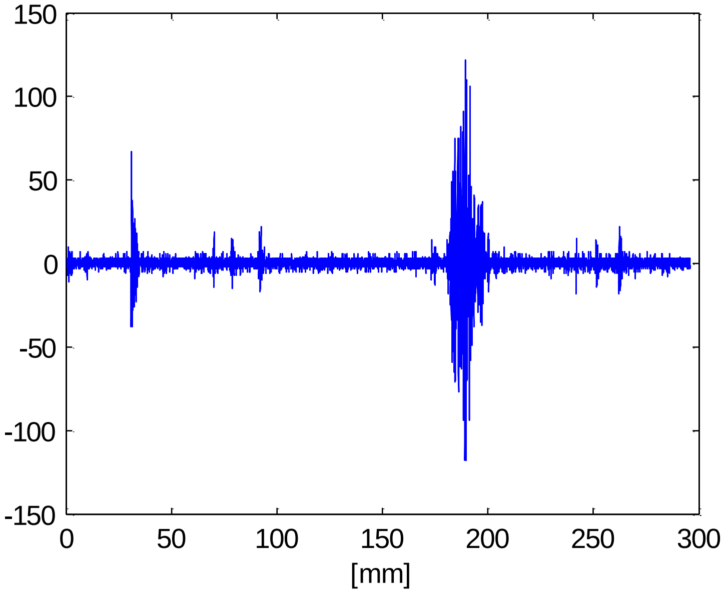


Fig. 4. A-scan representing reflection from the convex bead

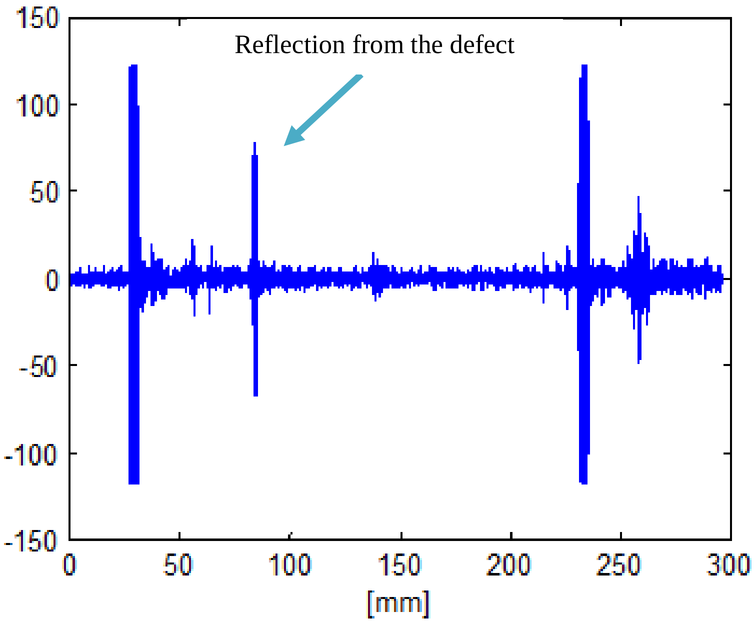


Fig. 5. A-scan obtained for a damaged case

In order to investigate the damages in the welded joint, the A-scans were processed to C-scan images. In the first step of the algorithm the water-steel interface (IF) impulse is sought. If the probe is above the test sample, as in the case presented in figs. 3 and 5, the echo is the first impulse in the signal. In the next step, another impulse of amplitude higher than 30 is searched. It can be a damage or bottom surface-reflected wave. To find the depth of the flaw *d*, the TOF difference between the interface and the second impulse is calculated. Next, the distance of propagation is calculated, assuming the velocity of longitudinal wave in steel, (V=5920 m/s). For each reflection, XY coordinates are assigned and the depth of flaw *d* is converted into a color or grayscale. An example of a C-scan image was presented in fig. 6.

The algorithm for C-scan calculation can be summarized in the following steps:

1. Place probe in a point XY and capture A-scan.
2. Find TOF of the water-steel interface reflection.
3. Find the first impulse that exceeds the assumed amplitude level of 30.
4. Find TOF difference between impulses found in pts. 2 and 3.
5. Calculate the TOF to distance, according to d = TOF*5920 / 2 (where 5920 m/s is longitudinal wave velocity in steel).
6. On the image at the point of coordinates of XY set value of d.

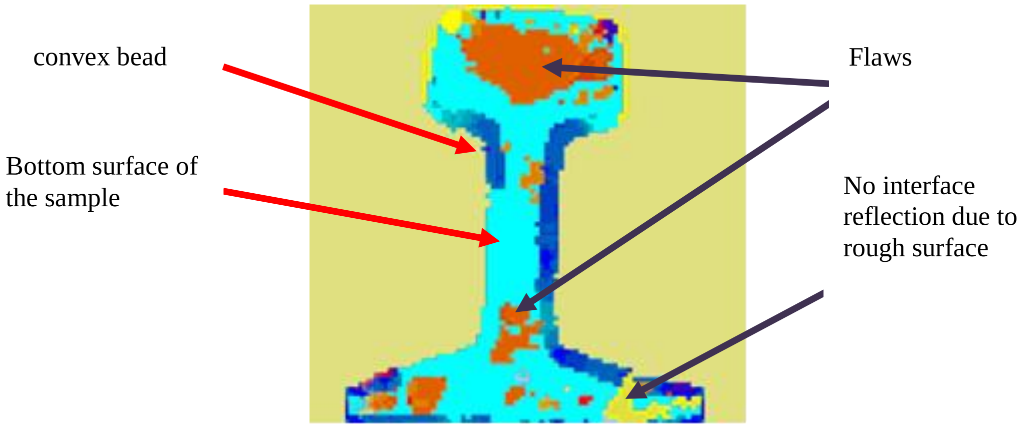


Fig. 6. C-scan of the welded joint, in which color (or grayscale) indicates the flaws depth

3. FLAWS ASSESMENT

Two different approaches for damages assessment were assumed: threshold value and distance function. Using the first approach, damaged areas, presented in fig. 7a, were extracted using a simple, arbitrary selected threshold value of 50 In the next step the ratio of damaged area to the area of the rail's cross-section, shown in fig. 7b, was calculated. The result was 0.3, therefore the damage is significant and dangerous for the joint.

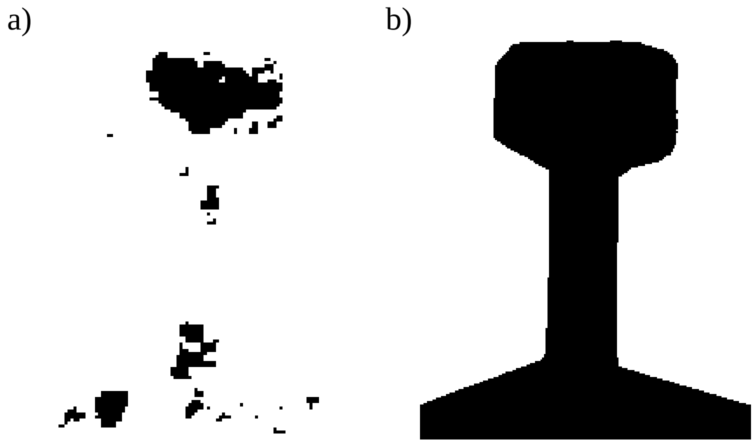


Fig. 7. Example of thresholding: a) the flaw in the joint after thresholding with the value of 50, b) the image of rail after thresholding with the value of 180

When this ratio exceeds critical value then the welded joint is replaced with the patch. However such approach has a substantial drawback. It does not allow distinguishing flaws on the basis of their shapes and intensity-pixel distributions. Hence, authors proposed other flaws assessment relying on similarity measures – proximity and distance functions. In this method images are presented as intensity-pixel matrices.

Let images of flaws of welding joints $w(m,n)$ and its references $\tilde{w}(m,n)$, for $m = 1, 2, \ldots M$ and $n=1,2,\ldots N$ be presented as $R = M \cdot N$-elements vectors of the form $\mathbf{w}=[w_1, w_2, \ldots, w_R]^T$ and $\tilde{\mathbf{w}}=[\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_R]^T$ where T represents transpose of a vector. Similarity function can be presented either in the form of distance function $D(\mathbf{w},\tilde{\mathbf{w}})$ or proximity function $B(\mathbf{w},\tilde{\mathbf{w}})$. There is the following relationship between them, $D(\mathbf{w},\tilde{\mathbf{w}})=1/B(\mathbf{w},\tilde{\mathbf{w}})$ for $B(\mathbf{w},\tilde{\mathbf{w}})\neq 0$. The distance between the flaw and its corresponding reference are usually calculated with the use of an Euclidean distance:

$$D^{Eu}(\mathbf{w}, \tilde{\mathbf{w}}) = \sqrt{\sum_{r=1}^{R} (w_r - \tilde{w}_r)^2} \tag{1}$$

Its main advantage is insensitivity of the distance between two images of flaws to addition of new outlying data. Its main drawback is a large impact of differences among ranges of elements on calculations. In order to eliminate this negative effect data normalization was performed. Normalized Euclidean distance can be expressed as:

$$D^{Eu\_normal}(\mathbf{w}, \tilde{\mathbf{w}}) = \frac{1}{\sqrt{\sum_{r=1}^{R} \tilde{w}_r^{\,2}}} \sqrt{\sum_{r=1}^{R} (w_r - \tilde{w}_r)^2} \tag{2}$$

Proximity measure can also be calculated with the help of the correlation function:

$$B^{C}(\mathbf{w}, \tilde{\mathbf{w}}) = \frac{\mathbf{w}^T \tilde{\mathbf{w}}}{\|\mathbf{w}\| \, \|\tilde{\mathbf{w}}\|} \tag{3}$$

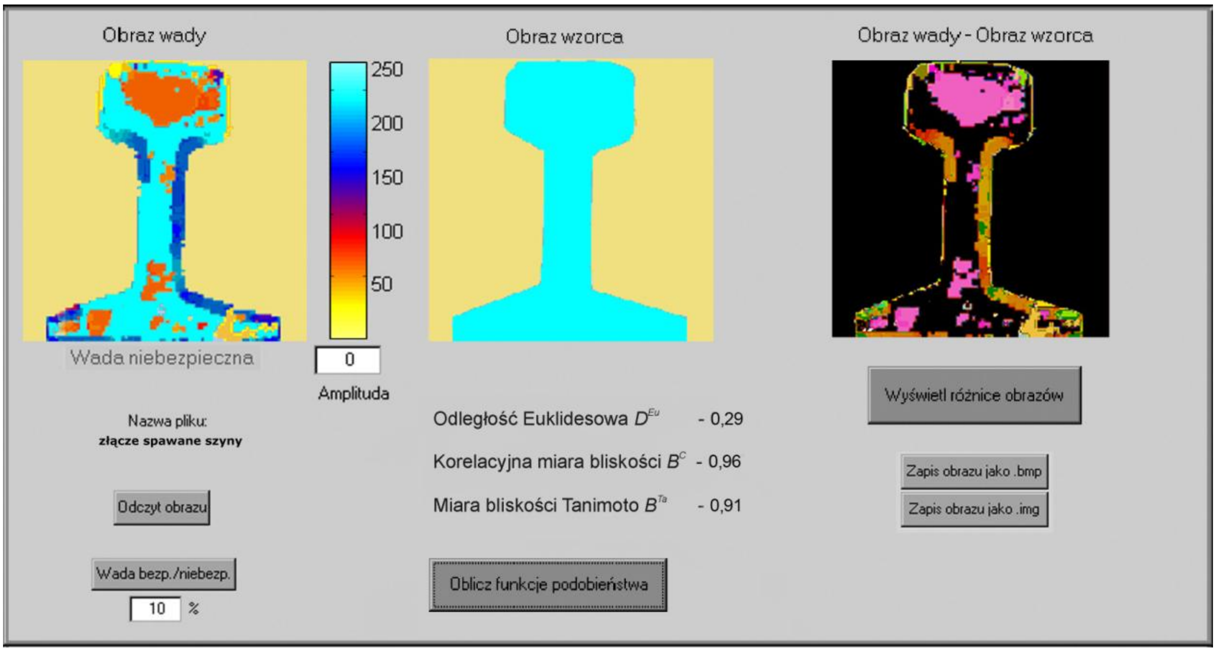
where: $\|\mathbf{w}\|$ represents modulus of a vector $\mathbf{w}$ (image),

or Tanimoto function:

$$B^{Ta}(\mathbf{w}, \tilde{\mathbf{w}}) = \frac{\mathbf{w}^T \tilde{\mathbf{w}}}{\tilde{\mathbf{w}}^T \mathbf{w} + \tilde{\mathbf{w}}^T \tilde{\mathbf{w}} - \mathbf{w}^T \tilde{\mathbf{w}}} \tag{4}$$

In simplified case, when images are in the binary form, similarity measures are logic functions. Hence Hamming distance, χ^2 statistics and Jaccard coefficient can be used [9].

Print-screen of program calculating similarity functions for images of welded joint (actual and ideal) in rail was shown in Fig.8.



0

Nazwa pliku:
złącze spawane szyny

Odległość Euklidesowa D^{Eu} - 0,29

Korelacyjna miara bliskości B^{C} - 0,96

Miara bliskości Tanimoto B^{Ta} - 0,91

10 %

Fig. 8. Print-screen of program calculating similarity functions for images of welding joint

CONCLUSIONS

Conducted investigations of welding joints in railway rail in cross-section plane allowed gaining more information than in case of a classic method using for testing railway rails. It turns out that this method is not employed by diagnostic headquarter of PKP. It can be used as a additional tool during training the staff or used for random checking samples being collected on the track.

It seems that a better visualization of flaws in joints can be achieved by an application of radiography methods and computed tomography. It allows for 3D visualization and an improvement in accuracy of measurements.

REFERENCES

1. Bałuch H., Bałuch J.: *Prognozowanie pęknięć szyn*. Problemy Kolejnictwa – Zeszyt 151, str. 116-135, Instytut Kolejnictwa, Warszawa 2010.
2. Bałuch H., Bałuch J.: *Pękanie szyn w spoinach termitowych w świetle statystyk*. Materiały II Konferencji Spawalnictwa Nawierzchni Szynowych, Pszczyna 2011.
3. Colombier T.: *Development of an ultrasonic technique, sensors and systems for the volumetric examination of aluminothermic welds.* Copyright © TWI Ltd. IoRW IoRW Seminar - 11 st December 2010.
4. CTS Valpey Corporation. Internet http://www.ctsvalpey.com.
5. Davis D., Kalay S., Sun J., Steele R.: *Wide-Gap Welding Techniques*. Transportation Technology Center, Inc. (TTCI), Association of American Railroads (AAR), Transit Cooperative Research Program (TCRP Project D-7), 2000.
6. Jasiūnienė E., Žukauskas E.: *The ultrasonic wave interaction with porosity defects in welded rail head* . Ultragarsas (Ultrasound), Vol. 65, No. 1, pp. 12 -18, 2010.
7. Jasiūnienė E.: *Testing of the middle zone of the rail weld.* Ultragarsas (Ultrasound), Vol. 65, No. 3, pp. 35-40, 2010.
8. Id-17. *Wytyczne ultradźwiękowych badań złącz szynowych zgrzewanych i spawanych*, PKP PLK SA, 2005.
9. Krzyśko M., Wołyński W., Górecki T., Skorzybut M.: *Systemy uczące się*. WNT, Warszawa 2008.
10. Lesiak P.: *Mobilna diagnostyka szyn w torze kolejowym.* Wyd. Politechniki Radomskiej, seria monografie, nr 116, Radom 2008.
11. Lesiak P., Bojarczak P.: *Inteligentne algorytmy analizy ultradźwiękowych obrazów w badaniach bezstykowych złączy szyn metodą TOFD*. Logitrans 2012, Logistyka 3/2012 (płyta CD).
12. Lesiak P., Bojarczak P.: *Przetwarzanie i analiza obrazów w wybranych badaniach defektoskopowych.* Monograficzna seria wydawnicza Biblioteka Problemów Eksploatacji, ITE Radom 2012.
13. Lu Ch., Deng D., Li L.: *Ultrasonic Phased Array Inspection for Gas Pressure Welds Joint of High Speed Railway.* Przegląd Elektrotechniczny R.88, Nr 1b, pp. 173-176, 2012.
14. Mistry K.C.: *Rail welding: Back to Basic.* Transnet Freight Rail is a division of Transnet SOC Ltd. South Africa, 2012.
15. Raude A.: *RAILECT Project.* 15th Technical meeting of the IRW. Copyright © TWI Ltd 30th April 2009.
16. Raude A., Colombier T., Rudlin J., Jasiuniene E., Kotsikos G.: *The Solution for Volumetric Assessment of Aluminothermic Rail Welds*. Copyright © RAILECT Consortium 2012. 18th World Conference of Non-destructive Testing, Durban, South Africa, 16-20 April 2012.

17. Reilect. *Detection of weld defects in rails using phased array ultrasonic analysis software.* Internet http://www.railect.com
18. Saarna M., Laansoo A.: *Rail and Rail Weld Testing.* 4th International DAAAM Conference "INDUSTRIAL ENGINEERING – INNOVATION AS COMPETITIVE EDGE FOR SME" 29 - 30th April, pp.217 – 219, Tallinn, Estonia 2004.
19. Shitara H., Therashita Y., Tatsumi M.: *Nondestructive Testing and Evaluation Methods for Rail Welds in Japan*. QR of RTRI, Vol. 44, No 2, pp. 55 – 58, May 2003.
20. Socomate International. Internet http://www.socomate.com.
21. Stencel G.: *Spawalnictwo elementów nawierzchni w aspekcie utrzymania dróg szynowych i bezpieczeństwa ruchu*. Infrastruktura Transportu, nr 4, str. 78 – 83, 2011.
22. Thermit Welding (GB) Ltd. Internet http://www.thermit-welding.com
23. Wielgosz R.: *Łączenie bezstykowych szyn kolejowych.* Mechanika Czasopismo Techniczne, Wyd. Politechnika Krakowska 2-M, zeszyt 6, rok 106, str. 7 -19, 2009.

ULTRADŹWIĘKOWE BADANIA IMMERSYJNE ZŁĄCZY SPAWANYCH SZYN KOLEJOWYCH

Streszczenie

Autorzy zaproponowali innowacyjną technologię ultradźwiękowych badań złączy spawanych (termitowych) szyn kolejowych metodą immersyjną. Wykonano badania przykładowej próbki wyjętej z toru. Uzyskane zobrazowanie typu C pozwoliło na dokładną ocenę kształtu i pola poprzecznego wady w przekroju szyny. Porównano kryteria oceny wady w oparciu o funkcje progowe i bliskości.

Autorzy:

Dr hab. inż. **Piotr Lesiak,** prof. nadzw. - Uniwersytet - Technologiczno - Humanistyczny w Radomiu, Wydział Transportu i Elektrotechniki,

mgr inż. **Łukasz Ambroziński** – AGH w Krakowie, doktorant Katedry Robotyki i Mechatroniki,

mgr inż. **Adam Tchórz** - Instytut Odlewnictwa w Krakowie, Zespół Laboratoriów Badawczych.