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APPLICATION OF FLAW DETECTION METHODS FOR DETECTION OF FATIGUE PROCESSES IN LOW-ALLOYED STEEL

Summary. The paper presents the investigations conducted in the Fraunhofer Institute (IZFP Saarbrücken) by use of a BEMI microscope (BEMI= Barkhausenrausch- und Wirbelstrom-Mikroskopie or Barkhausen Noise and Eddy Current Microscopy). The ability to detect cyclic and contact fatigue load influences has been investigated. The measurement amplitudes obtained with Barkhausen Noise and Eddy Current probes have been analysed. Correlation of measurement results and material's condition has been observed in case of the eddy current mode method for frequencies above 2 MHz (for contact-loaded material samples). Detection of material's fatigue process (at 80 % fatigue life) in the sample subjected to series of high-cyclic loads has been proven to be practically impossible. Application of flaw detection methods in material fatigue tests requires modification of test methods and use of investigation methods relevant to physical parameters of the investigated material. The magnetic leakage field method, which has been abandoned by many researchers, may be of significant use in the material fatigue assessment and may provide new research prospects.

ZASTOSOWANIE METODY MAGNETYCZNEGO POLA ROZPROSZENIA W DETEKCJI PROCESÓW ZMĘCZENIOWYCH W STALACH NISKOSTOPOWYCH

Streszczenie. W artykule przedstawiono wyniki badań przeprowadzonych w Instytucie Frauenhofera (IZFP Saarbrücken – Germany). Badania miały na celu przedstawienie trudności w wykrywaniu zmian zmęczeniowych materiału stosowanymi powszechnie metodami defektoskopowymi. Badania porównawcze dla dwóch metod defektoskopowych (wiroprądowej i szumu Barkhausena) przeprowadzono na wycinkach próbek klesydrycznych i pierścieniowych. Czułość detekcji tych metod jest niższa od wykrywalności zmian zmęczeniowych metodą pomiaru magnetycznego pola rozproszenia. Opisano przykład badania powierzchni tocznej zestawu kołowego metodą magnetycznego pola rozproszenia i wskazano na jej wysoką użyteczność.

1. INTRODUCTION

Constructional steel due to its excellent mechanical properties is still the basic material used in engineering. A constructional element built of iron alloy can be characterised by magnetic properties, hence it may be inspected by magnetic methods (apart from other known methods). The physical quantities related to the material's structure are magnetic permeability (initial and maximum), coercivity, hysteresis losses, eddy current losses, relaxation losses. The variation in material's permeability at a given steady temperature [1] may be caused by plastic deformationworking, heat treatment, specific cooling agent, relaxation of stress and ageing phenomena.

Magnetic methods are used to analyse microstructure and to determine iron alloys phases. They may also be used for the diagnosis of the fatigue process in machine elements.

This paper presents correlation of selected magnetic parameters with material fatigue process and detection tests of fatigue zones by eddy current, Barkhausen and magnetic leakage field methods. A rResearch strategy has been worked out in the Railway Engineering Department of Silesian University of Technology The test samples were made of the rim of railway wheel set rims steel. Fatigue calibration of the samples has been carried out in Institute of Fundamental Technological Research of Polish Academy of Sciences (IPPT PAN). The structural tests have been performed, carried out in the Railway Engineering Department of the Silesian University of Technology. The detection of fatigue changes has been carried out in Fraunhofer Institute in Saarbrücken (Germany), with the help of the BEMI device (**B**arkhausen Noise and **E**ddy Current **MI**croscope). The possibilities of generalising magnetic test methods have been determined and pointed out. A magnetic description of the material fatigue process has been proposed. The investigation of the rolling surface of railway wheel sets has been carried out to document the detection procedures for material fatigue by magnetic leakage field method.

2. TEST SAMPLES

P54T steel used in railway engineering for the rim of wheel -set rims has been used in tests [2, 3]. The following types of samples have been prepared: hourglass-type – for scalable application of cyclic fatigue load (at MTS universal testing machine), and ring-type – for contact loads at AMSLER stand (Table 1). The Preparation of the samples is shown in Table 2. The material microstructure compared with the cyclic mechanical loading data is documented in Table 3. The comparison of the material microstructure due to different load histories is shown in Table 4.

Table 1

Types of samples

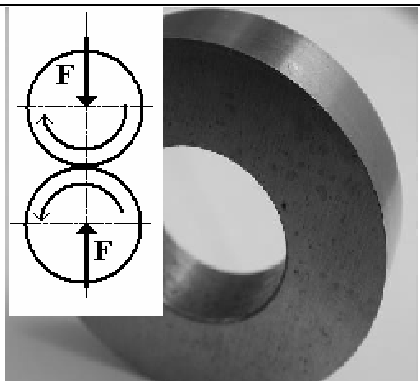
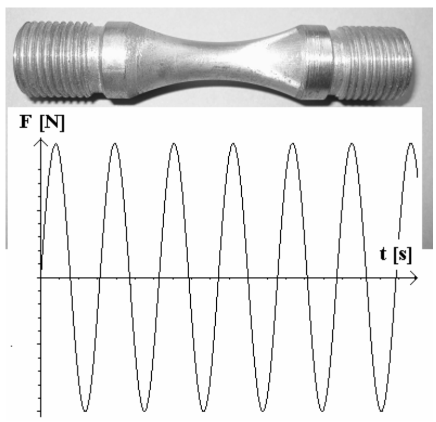
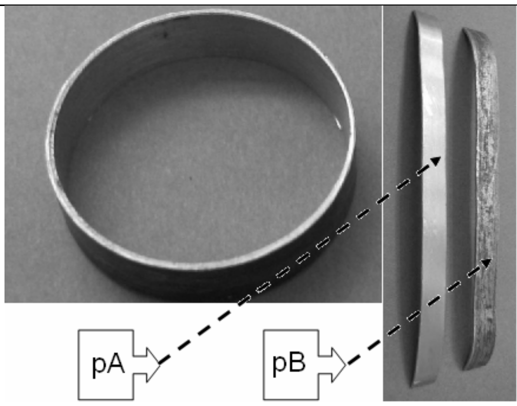
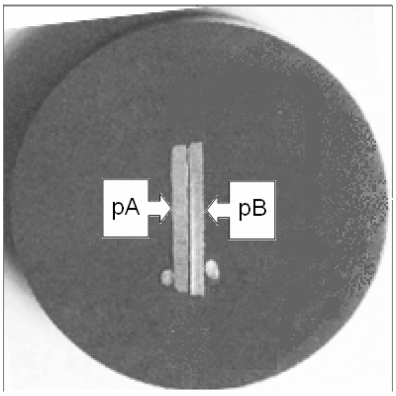
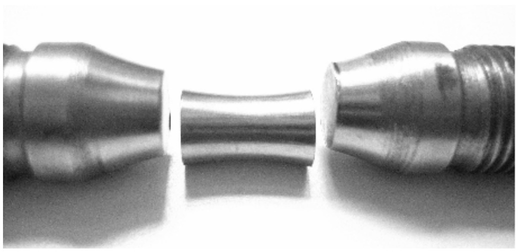
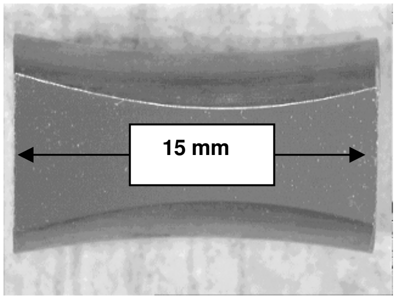
for contact loads at AMSLER stand	for cyclic fatigue load at MTS stand
	

Table 2

Sample preparation process

<table>
<tr><td colspan="2">Ring samples – sample preparation process</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Hourglass-type samples - sample preparation process</td></tr>
<tr><td></td><td>
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Effects due to fatigue are seen in the final stage of fatigue process. For hourglass-type samples the changes are located irregularly along the percentage reduction of area, in the middle (the narrowest part). The thickness of dark layers observed in the photos does not exceed several-hundredths to se veral-tenths of millimetre. Samples prepared for microscopic examination (hour-glass and ring types both) have been tested after by magnetic methods by the BEMI**.**

The change of material microstructure in the ring sample is due to contact load. The improper loading leads to laminations and flaking at bigger depths than those shown in the photos. Additionally phase changes takes place and this also determines the fatigue process. Deformation of the grains as well as displacements occur and this is one of the basic causes of fatigue cracks emergence.

3. SAMPLE EXAMINATION WITH *B E M I*

The fatigue results are obtained by investigating local changes of magnetisation. Other testing procedures are based on phenomena related to characteristic features of magnetisation process (Barkhausen effect) and changes in electrical conductivity and relative magnetic permeability in eddy-current methods. Figures 1 and 2 shows results of scanning the middle part of the surface of the hour-glass sample with the BEMI microscope. The BEMI microscope graphical user interface window is shown in Figure 1, documenting eddy-currents test results at 80000 and 120000 loading cycles, respectively. Figure 2 shows the Barkhausen noise analysis. Each graphical user interface window visualises results of tests of the sample surface and the transducer signal behaviour at a given coordinate indicated in the graphic by the cursor.

Table 3

Material microstructure vs. cyclic mechanical load cycles

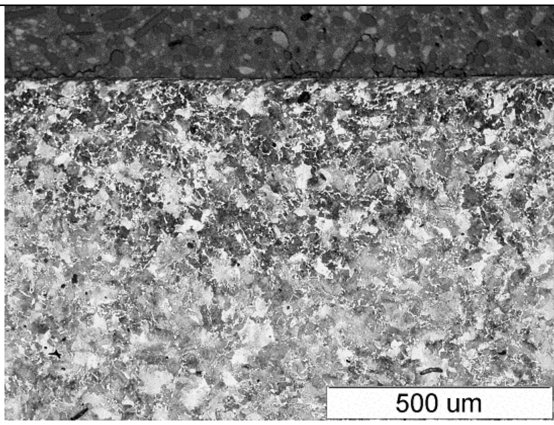
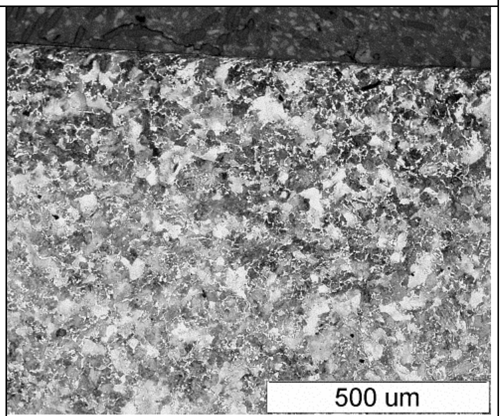
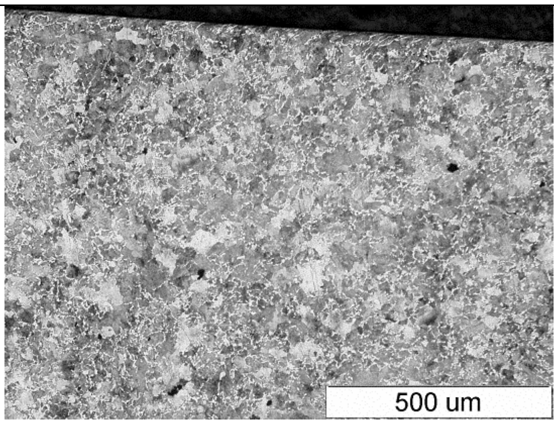
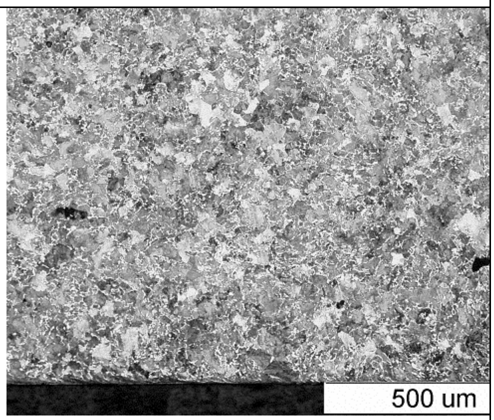
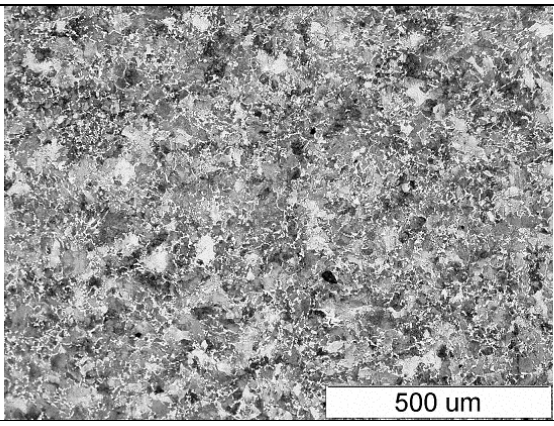
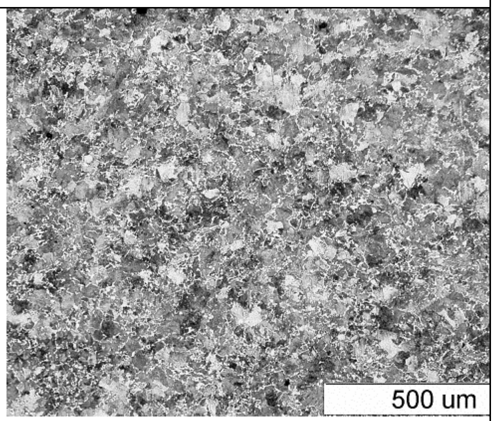
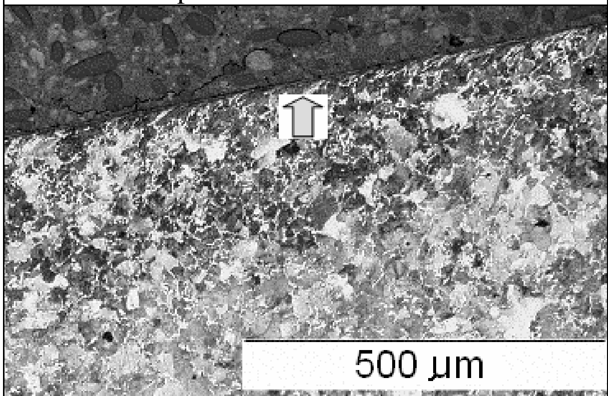
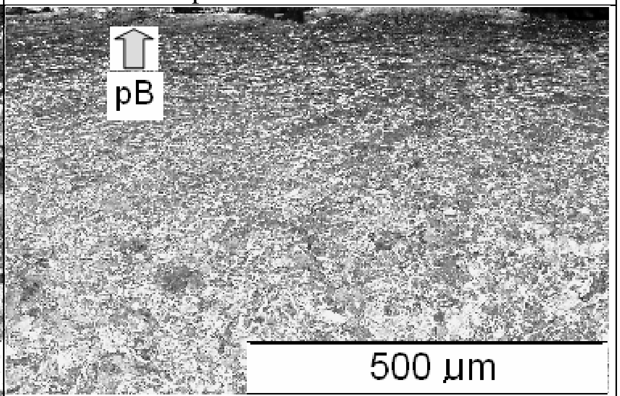
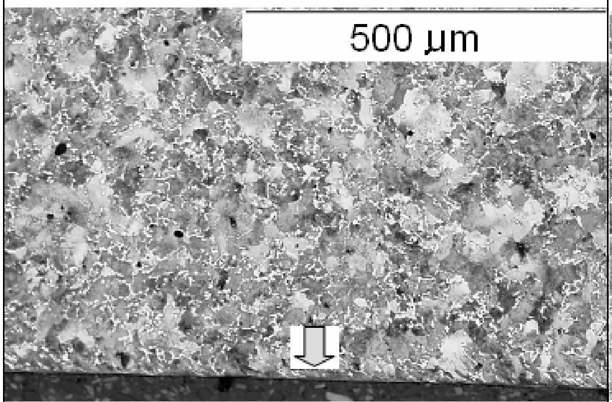
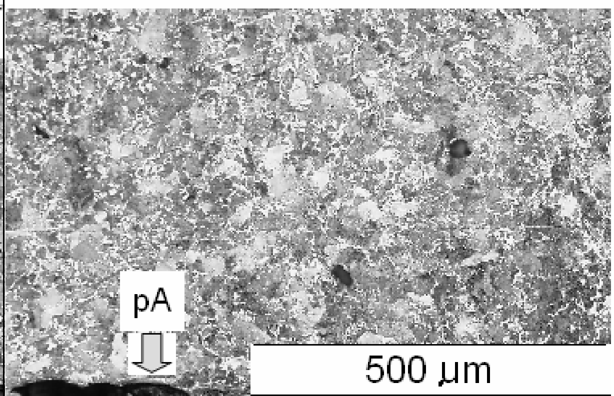
No. of cycles	Hourglass-type samples material structure	
120 000 cycles 78% fatigue life		
80 000 cycles 52% fatigue life		
60 000 cycles 39% fatigue life		

Table 4

Comparison of material microstructure degradation, material subjected to cyclic and contactmechanical loads

Contact loads Ring sample / AMSLER stand	Cyclic loads Hour-glass sample / MTS machine
 Material surface after loading	 Material surface after loading
 Material surface before loading	 Material surface before loading
100% sample surface fatigue (flaking)	78% sample surface fatigue

According to the change of the sample surface image with the fatigue process correlation has been undertaken for surface slices from disks subjected to tests at AMSLER stand. The samples have been examined before and after contact loading.

4. COMPARISON OF TEST RESULTS

Detection of the fatigue processes at the fore hourglass sample surfaces was effectively possible for eddy current frequencies greater than 2 MHz, as shown in Figure 5 t. The number of cycles investigated ranged from a set number n to maximum number n_{max} as a function of probe signal.

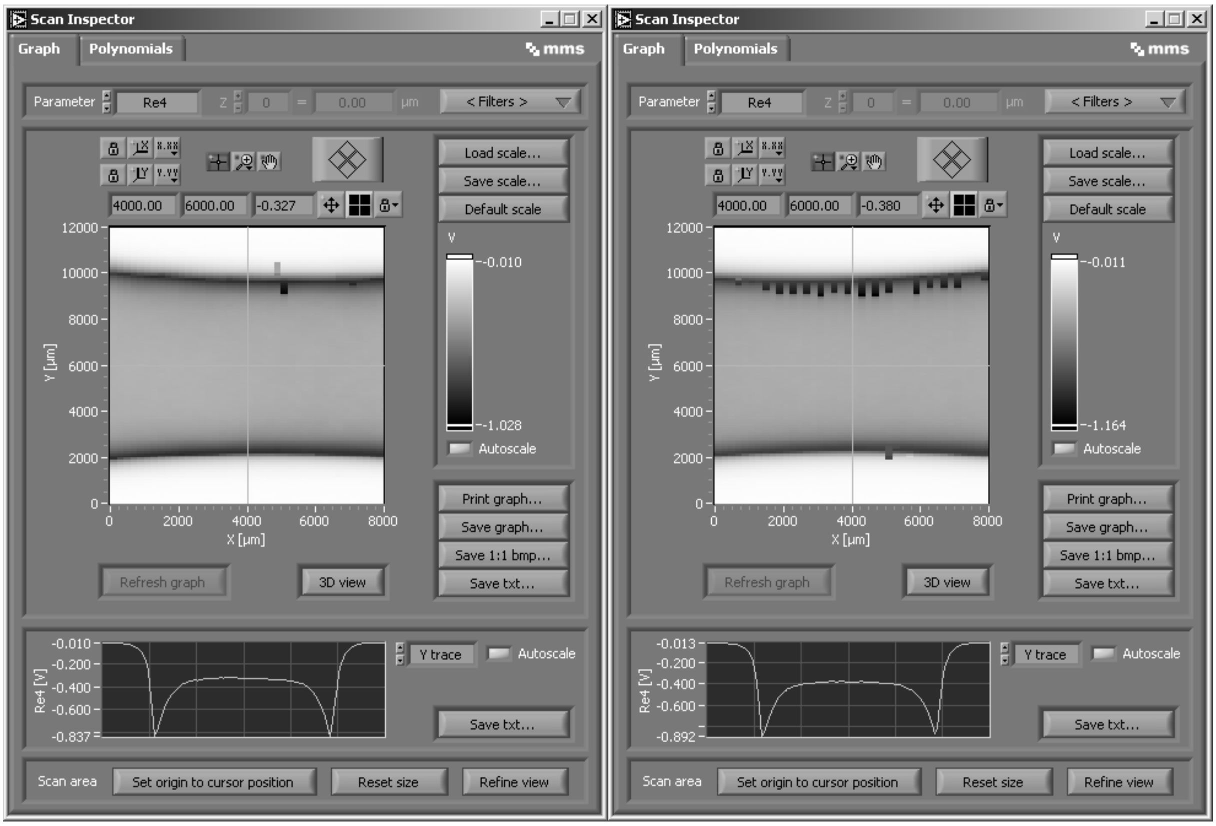


Fig. 1. Graphical user interface windows for (2 MHz) eddy-current - test results for samples with 80000 cycles (left), and 120000 loading cycles (right)

Rys. 1. Okna programu systemu pomiarowego dla badań wiroprądowych (2MHz) próbek obciążonych liczbą cykli: 80000 (z lewej) i 120000 (z prawej)

Figure 3 shows results of eddy-current scanning of surfaces pA and pB samples for 0,5MHz and 2 MHz.

Figure 4 shows results of (DH25 = full peak width at 25% of the maximum and M max = Barkhausen noise maximum) the Barkhausen noise scanning analysis of samples pA and pB.

Such a detection was not possible by comparing amplitudes of probe signals during Barkhausen noise testing (Figure 6).

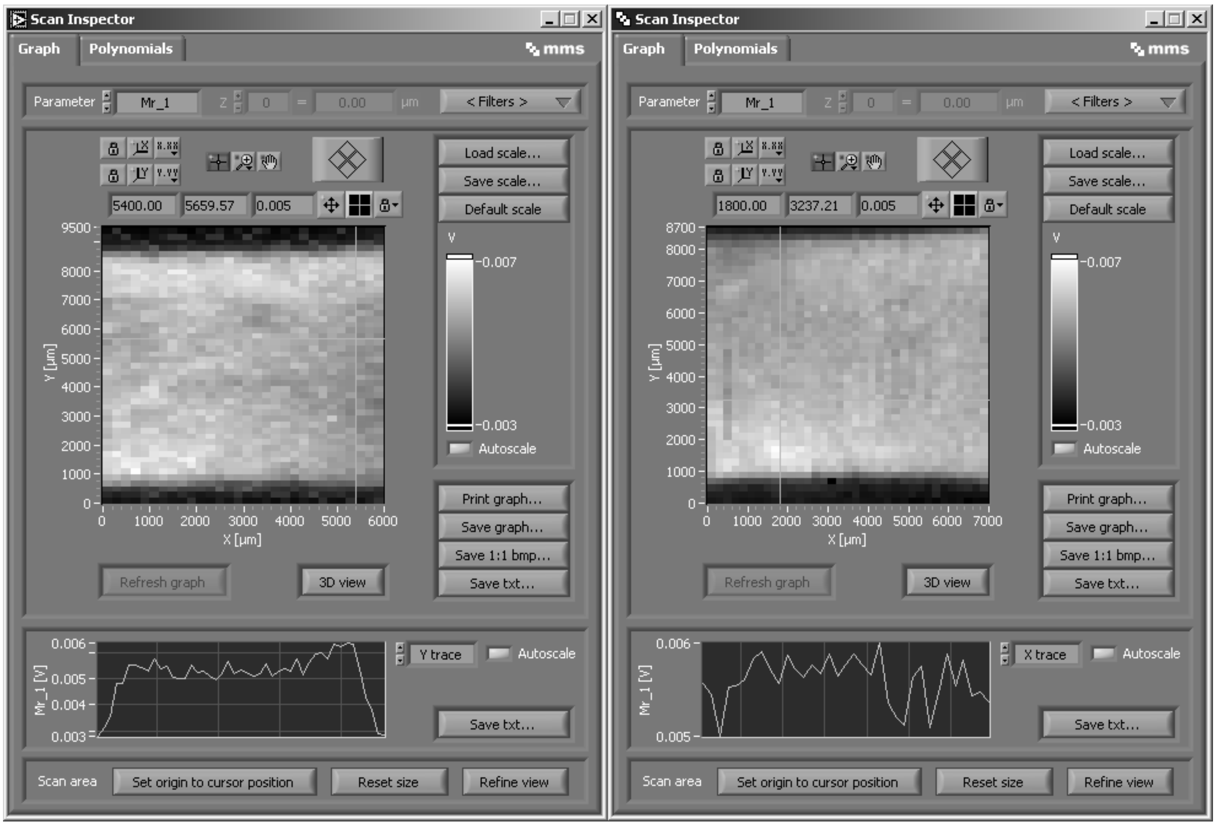


Fig. 2. Graphical user interface windows for the Barkhausen noise analysis – test results for samples with 80000 cycles (left), and 120000 loading cycles (right)

Rys. 2. Okna programu systemu pomiarowego dla badań szumu Barkhausena próbek obciążonych liczbą cykli: 80000 (z lewej) i 120000 (z prawej)

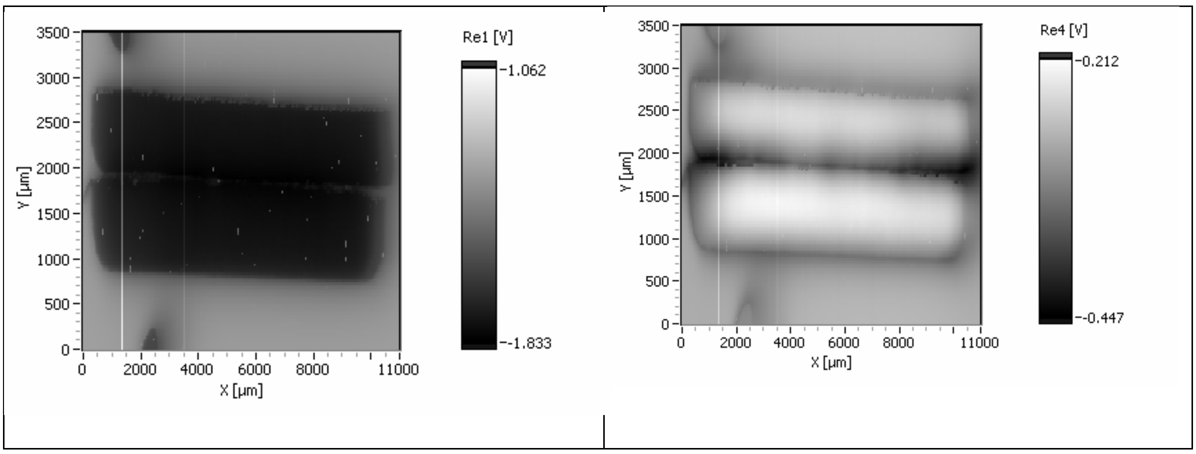


Fig. 3. Graphical user interface window information for eddy-current analysis

Rys. 3. Obraz skanowania próbek w metodzie wiroprądowej

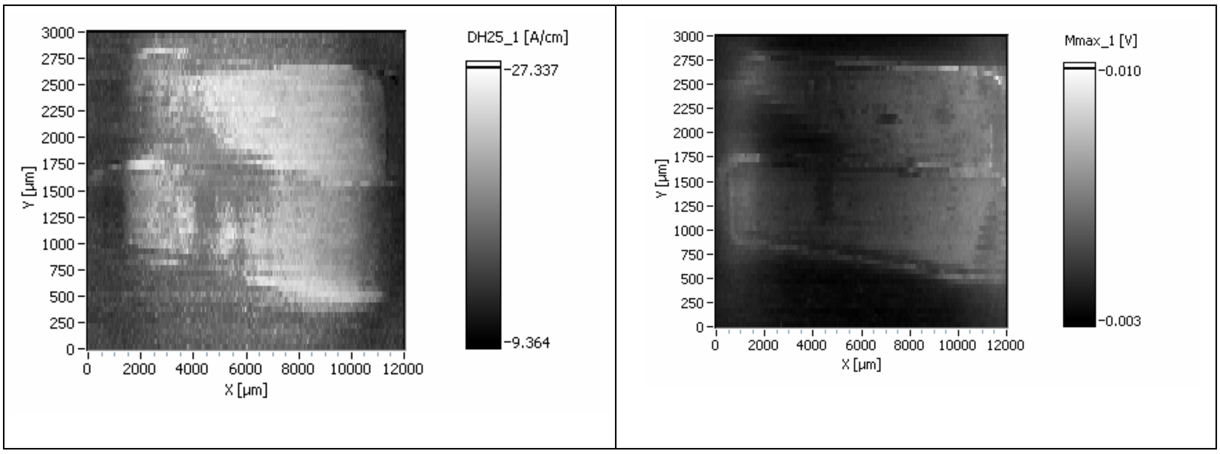


Fig. 4. Graphical user interface window information for the Barkhausen noise scanning analysis
Rys. 4. Obraz skanowania próbek w metodzie szumu Barkhausena

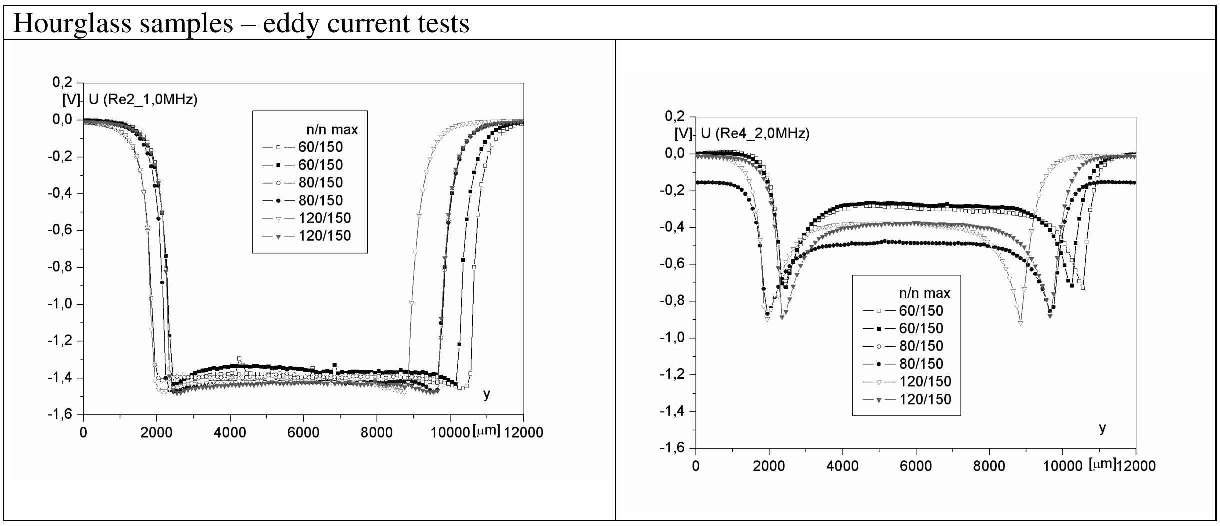


Fig. 5. Comparison of eddy current testing
Rys. 5. Porównanie wyników dla badań wiropradowych

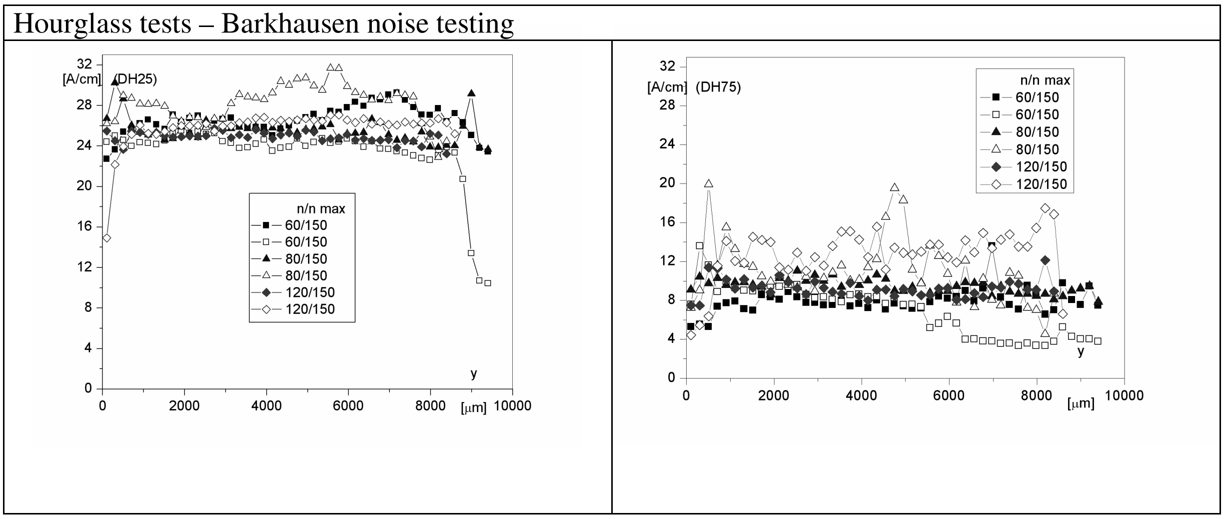


Fig. 6. Comparison of Barkhausen noise testing
Rys. 6. Porównanie wyników dla badań szumem Barkhausena

As opposed to these facts, in case of contact-loaded ring samples a separation between pa and pB samples was possible by eddy current tests for frequencies greater than 2 MHz. However, Barkhausen noise method made the characterization of the contact-loaded sample possible, as shown in Figure 7.

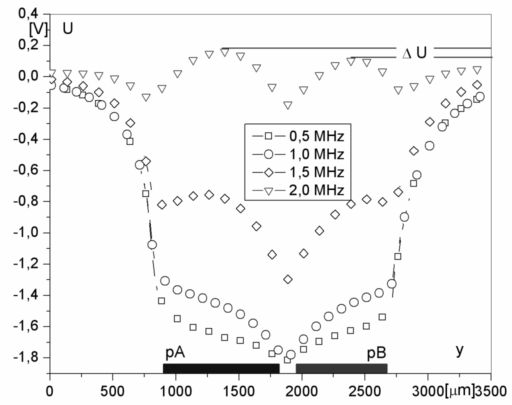
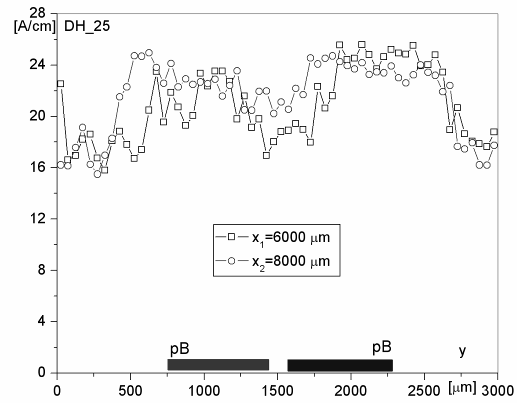
Ring samples – eddy current testing	Ring samples – Barkhausen noise testing
	

Fig. 7. Comparison of Barkhausen noise and eddy current testing
Rys. 7. Porównanie skuteczności metody szumu Barkhausena i metody wiroprądowej

The results prove that only contact-loaded samples may be tested by both eddy currents and Barkhausen noise methods.

5. CONCLUSIONS

The amplitudes of the eddy-current impedance measurement do not reflect the material's condition at 0,5 and 1 MHz frequencies. For frequencies greater than 2,0 MHz eddy-current signals show some differences in the material condition for contact-loaded samples pA and pB. In case of Barkhausen noise method the differentiation between material changes was possible for contact-loaded samples only. The change in material's magnetic parameters (up to 30 per cent) due to fatigue stresses was detected by the eddy current method – the signal increased at approximately the same rate (up to 30 per cent) for both magnetic permeability and coercivity. When the Barkhausen noise method was applied, the results were not so obvious. It must be noted that for the BEMI microscopic inspection the samples were specially prepared. In real life and when the railway wheel set rolling surface is investigated, the detection may be highly effective if the leakage magnetic field is measured [4] (Figure 8).

The eddy currents with 2 MHz or higher frequencies only penetrate element's surface near zones. More significant information for subsurface layers may be obtained by analyzing the magnetic leakage field, and in particular, by investigating the tangential component of this field. The BEMI microscope principle is useful in fundamental research; however, in practice (in railway transport service diagnostics) testing of tangential component of leakage magnetic field is a very effective research method, whereas the information often changes in the material's continuity obtained from eddy current or ultrasonic tests is supplementary.

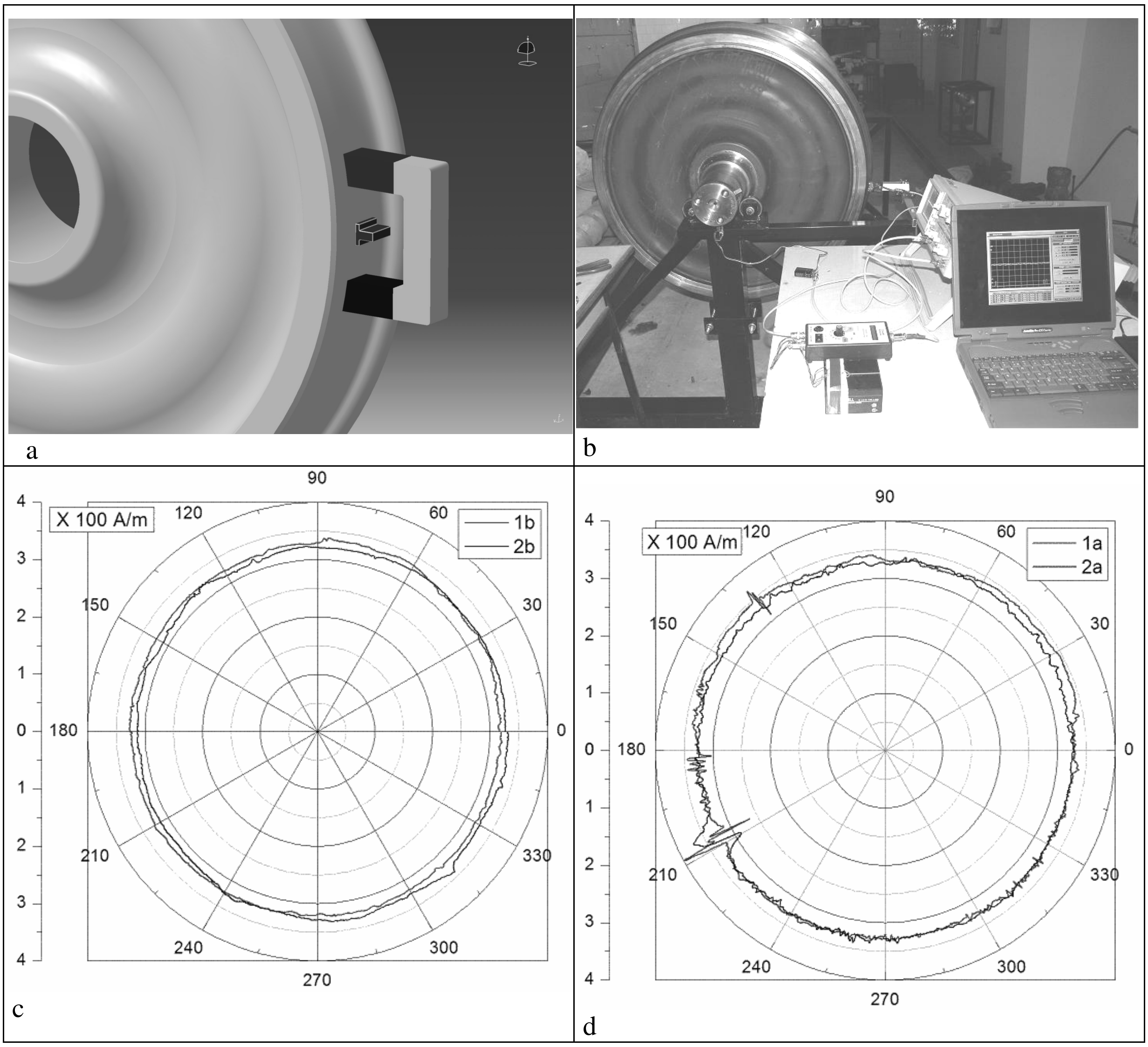


Fig. 8. Measurement principle – a, test rig – b, leakage magnetic field in a brand-new wheel – c, leakage magnetic field in a damaged wheel – d

Rys. 8. Zasada pomiaru – a, obręcz badania – b, magnetyczne pole rozproszenia koła nowego – c, koło uszkodzone – d

Literature

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