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COMPARISON OF THE RESULTS OF TESTS ON AXISYMMETRIC ELEMENTS CONDUCTED ON AN INDUSTRIAL AND LABORATORY TEST STAND AND EMPLOYING AN EDDY CURRENT METHOD

Key words

Eeddy current, defect detection, bearing ring.

Abstract

The aim of the study was to compare the test results obtained at the stand intended for the industrial inspection of the quality of bearing rings with the results of tests performed on the laboratory stand. The tests concerned four inner bearing rings. In three of them, artificial defects were made, while the fourth ring played the role of a model ring. Both the inner and outer surface of the ring was scanned at the time of the test.

The tests on both the industrial and laboratory stand revealed a lower level of signal for an inner defect that resulted from the distance between the measurement head and the tested surface.

The results of tests formed the basis for the determination of the border values of the measurement signal categorising the ring as faulty. Due to the different level of the signal for the outer and inner surface, the authors proposed that the border values should be determined separately for each surface. The obtained results enabled the development of the calibration method for the system of automatic inspection of the quality of the bearing rings.

Introduction

The production of the bearing ring is a multistage process including forging, turning, quenching, and grinding. Inaccurate execution of the process can lead to material defects in the end product, i.e. the bearing ring. The discontinuities in the form of blisters, cracks, or non-metallic inclusions can result in a stress concentration that in turn can damage the ring and lead to industrial or transport accidents.

There are a number of non-destructive test methods that enable the inspection of bearing rings, e.g. optical inspection, magnetic-powder method, ultrasound, X-ray (tomography), and the eddy current method. The problems with the application of optical inspection lie in the difficulty to detect subsurface defects of the bearing ring. Selected literature [1] shows that the presence of grinding smudges on the surface of the ring indicates the presence of a subsurface defect. This issue has not been fully recognised yet, and it needs to be further studied. The methods that enable the detection of subsurface material discontinuities are the magnetic-powder method and ultrasound defectoscopy. However, these two methods cause fouling the tested surface. The method that helps one to properly define the location of the defect and its dimensions is the X-ray method. Unfortunately, the use of this method needs to be governed by very strict health and safety regulations. Moreover, X-rays and computed tomography (CT) are time-consuming methods, and the synchronisation of the devices employing them with the cycle of the production line would require simultaneous operation of many stands. Therefore, the method of eddy currents seemed to be the most appropriate as far as the inspection of bearing rings was concerned [2]. This was due to the fact that it can detect both surface and subsurface defects [3], does not call for the use of the coupling agent or other operating fluids, and does not need the measurement head to be in the direct contact with the object tested. Additionally, this is a quick test method.

1. Application of the eddy current method in quality inspection of goods

The eddy current method is widely used in devices intended for the inspection of the quality of final products. The main challenge is the proper interpretation of the signal generated by the defectoscope. Paper [4] describes an algorithm of the interpretation of the scanning signal of a pipe constituting an element of a nuclear reactor. The objective of the study was to develop the algorithm enabling the determination of the kind of defect in an axisymmetric element. In this case, the tests need to be conducted for many frequencies of a transducer. Paper [5] describes a device intended for semi-automatic, cyclical inspection of the wheels of airliners. The scanning is automatic at a manual installation of the wheel in the testing machine. The time of the test was shortened to 4 minutes per wheel, and the results were compared with the results obtained when the ultrasound method was used. At the time of the verification of the system, a faulty wheel was found, whose defect was also observed during the tests complying with the current regulations.

Paper [6] presents an idea on how to use the eddy current method for automatic control of carbon fibre reinforced composites (CFRP) obtained through the automatic fibre placement (AFP). The authors indicated that the eddy current method has a great potential in the automatic detection of changes in the structure of carbon fibres in the composite.

2. Test objectives and research instrumentation

The objective of the study was to verify the possibility to detect material discontinuities by the system intended for automatic inspection of the quality of bearing rings. For that purpose, the readings of the eddy current defectoscope were compared in industrial and laboratory environments. The tests conducted in the industrial environment were performed using a stand for industrial inspection of the quality of bearing rings developed at the Institute for Sustainable Technologies – National Research Institute. The system is intended for the automatic inspection of rings of tapered roller bearings [7, 8].

During previous tests performed on the laboratory stand, the authors decided that the measuring head should be placed in a grip guaranteeing constant contact with the tested ring [9] and that the scanning should be conducted at the transducer frequency of 0.06 kHz [10]. A drop in the frequency means that the depth of the eddy current penetration into the tested material is greater, which enables the detection of subsurface material defects [11]. Paper [12] shows that the eddy current method helps one to detect 45μm deep corrosion losses. The detection of small surface defects needs the frequency of the transducer to be in the range of 5–25 kHz, which prevent detection of subsurface defects.

A kinematic draft of the measurement system for inner bearing ring tests is presented in Fig. 1. The laboratory tests were performed on the stand shown in Fig. 2. The ring was placed in a three-jaw chuck powered by the servomotor.

The tests were conducted for the rotational speed of the ring of 60 rpm. The previous work indicated that the increase in the rotational speed facilitates the detection of both surface and subsurface defects [10]. The determination of the rotational speed is necessary for the detection of a defect, the reduction of vibrations of the industrial test stand, and the required efficiency of the inspection process.

At the time of laboratory and industrial tests, an SSEC III PC eddy current defectoscope was used. The device is equipped with a digital output and two analogue outputs determining the real and imaginary part of the readings of the measuring head. The analogue signal is generated in a voltage form in the range of 1000–1000 mV, and it is used for the communication with the external devices. The digital signal is intended for the communication between the defectoscope and the PC, and through it, the user sets up the operation of the measuring device.

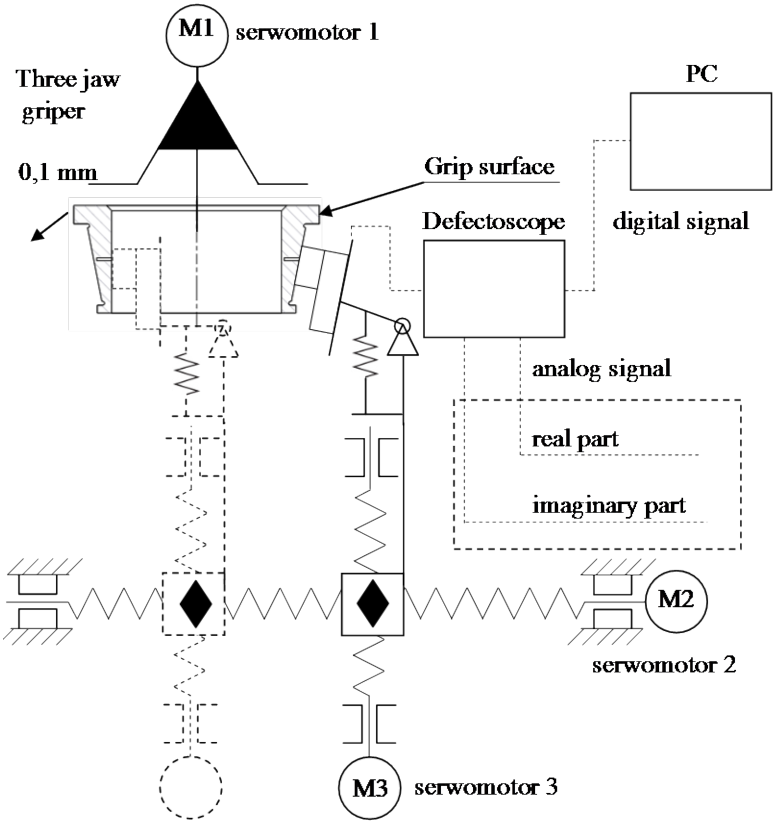

Fig. 1. Schematic of the measurement stand in the industrial stand

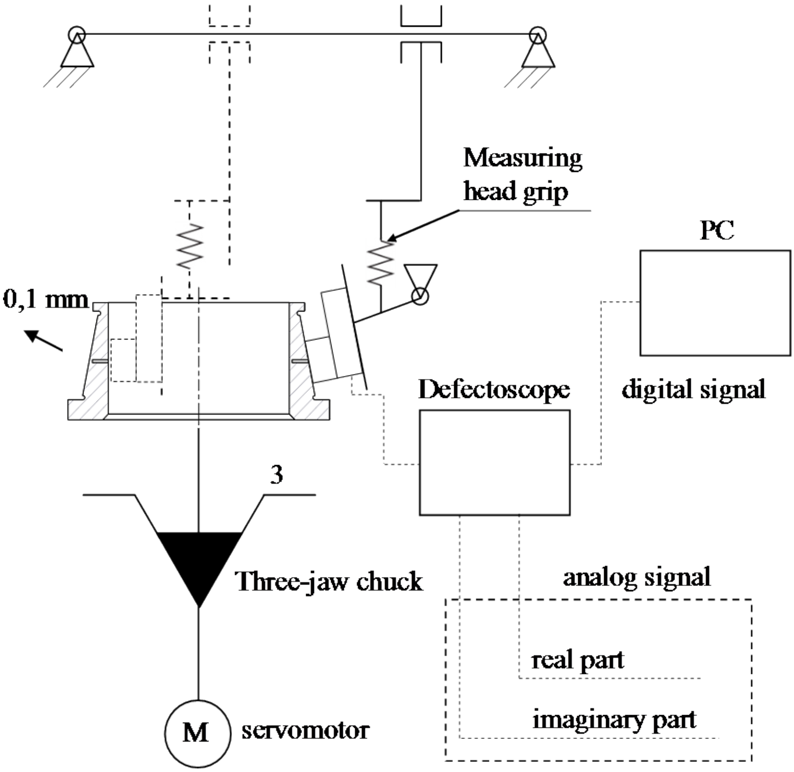

Fig. 2. Schematic of the laboratory stand

3. Test object

The tests were conducted for four inner rings of the tapered roller bearing. In three of them, artificial test defects were made, while the fourth was used as a model ring. The test defects in the form of blind holes were made to reconstruct real defects created during the technological process. The studied rings are presented in Figures 3–6.

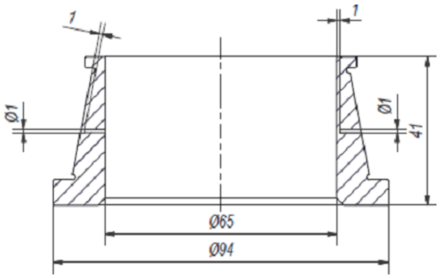

Fig. 3. Ring 1

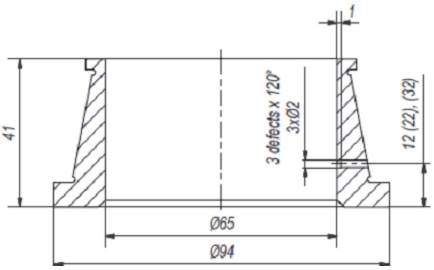

Fig. 4. Ring 2

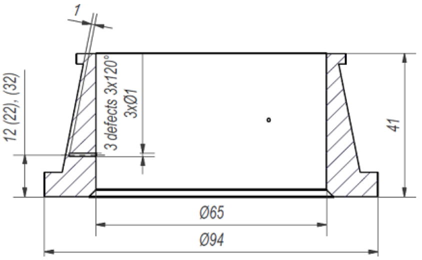

Fig. 5. Ring 3

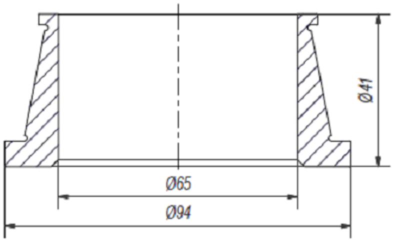

Fig. 6. Ring MR

4. Tests on a laboratory stand

The tests were performed for the inner and the outer surface of the ring. There were five measurements conducted for each ring. The examples of the results are presented in Figures 7–14. The values that were measured included the size of the defect for the real and the imaginary component, which was defined as the peak-to-peak value of the signal. In order to improve the transparency of the graphs, the value of the imaginary component was reduced by the constant value of 400 mV.

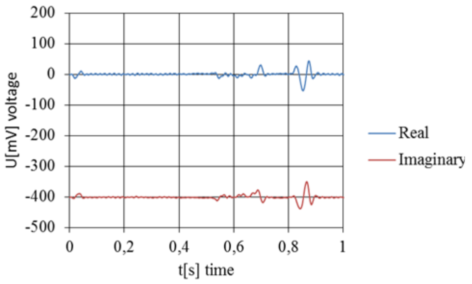

Fig. 7. Ring 1 test from the inside

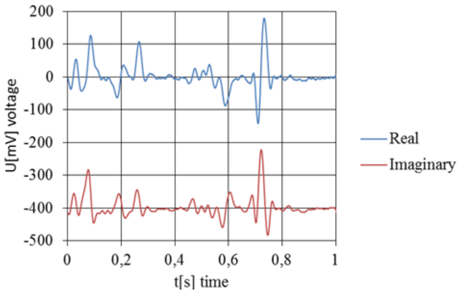

Fig. 8. Ring 1 test from the outside

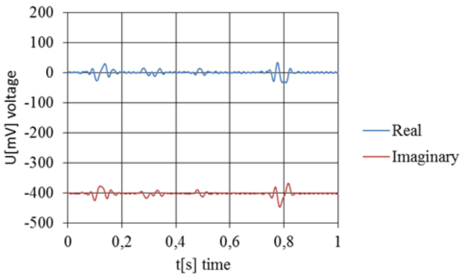

Fig. 9. Ring 2 test from the inside

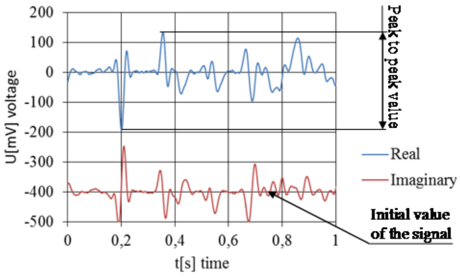

Fig. 10. Ring 2 test from the outside

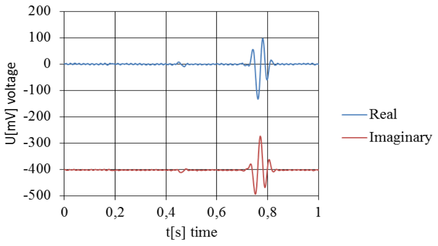

Fig. 11. Ring 3 test from the inside

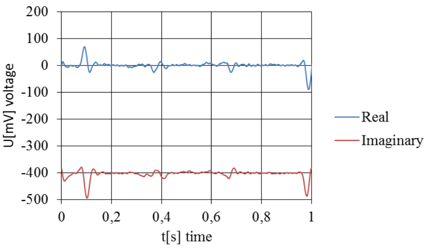

Fig. 12. Ring 3 test from the outside

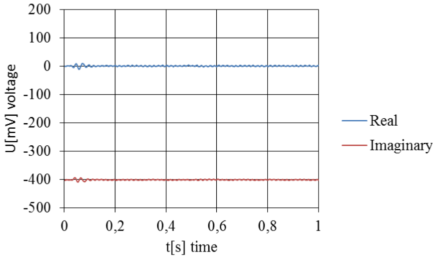

Fig. 13. Model ring test from the inside

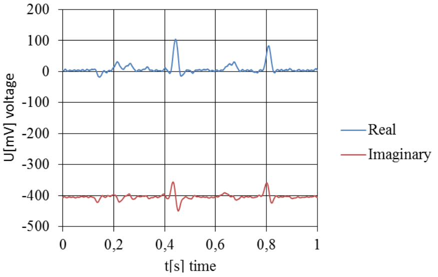

Fig. 14. Model ring test from the outside

The authors observed that for Ring 1 and the model ring (MR) the peak-to-peak value of the signal was lower in the case of the inner surface. The cause for the differences is the distance of the middle point of the measuring head from the tested surface [10], which in the case described was 0.6 mm (the width of the measuring head = 13 mm, the diameter of the ring = 65 mm). The collective results of the tests on the laboratory stand are presented in Table 1.

Table 1. Collective results of tests on the laboratory stand

		Peak-to-peak value [mV]			
		Scanning of the outer surface		Scanning of the inner surface	
Value	Ring	Real	Imaginary	Real	Imaginary
Arithmetic mean	1	305.8	280.2	89	93.2
	2	316.2	259.4	78.4	73.6
	3	155.4	136	223.8	217.4
	MR	108.6	105.4	19.4	17.2
Standard deviation	1	19.7	17.8	5.1	4.8
	2	13.4	9.1	8.2	4.6
	3	3.6	18	3.3	3
	MR	10.1	7.1	1.1	1.5
Minimum value	1	284	261	84	88
	2	295	247	67	68
	3	150	115	220	214
	MR	98	94	18	15
Maximum value	1	331	304	97	97
	2	327	271	87	79
	3	159	156	229	221
	MR	122	113	21	19

5. Tests on the industrial stand

Each ring was tested five times. One measurement concerned the full ring test (scanning of the inner and outer surface). The examples of the measurements are presented in Figures 15–18.

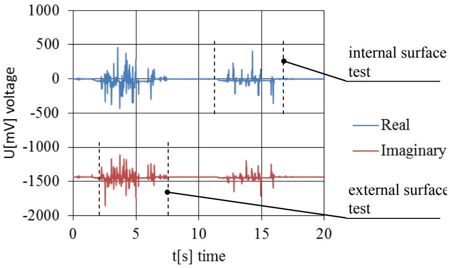

Fig. 15. Test of Ring 1

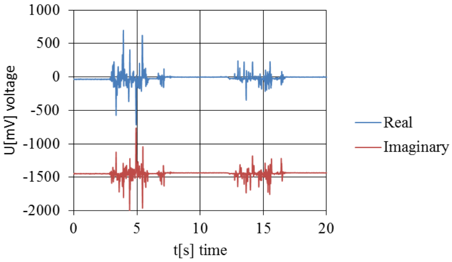

Fig. 16. Test of Ring 2

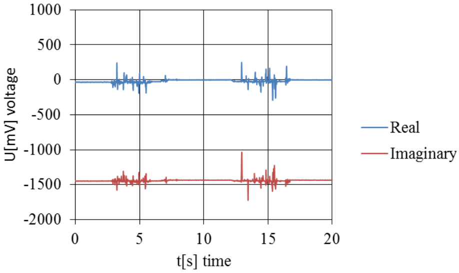

Fig. 17. Test of Ring 3

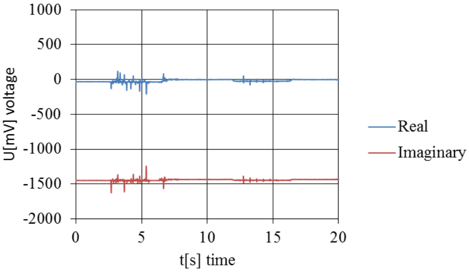

Fig. 18. Test of Model Ring

For each measurement the following statistical values were defined: the highest, arithmetic mean, and the standard deviation. The cumulative results of the test are presented in Table 2.

Table 2. Cumulative results of tests on the industrial stand

		Peak-to-peak value [mV]			
		Scanning of the outer surface		Scanning of the inner surface	
Value	Ring	Real	Imaginary	Real	Imaginary
Arithmetic mean	1	818.8	795.2	689.2	404.6
	2	1253.6	1417.8	643.6	606.6
	3	334.6	343.4	627.2	738.8
	MR	319.8	321	104.8	103.2
Standard deviation	1	50.5	54.8	59.9	73.1
	2	143.3	111.7	104.1	82.8
	3	100.7	79.2	166.6	142.2
	MR	20.6	24	16.3	13

		Peak-to-peak value [mV]			
		Scanning of the outer surface		Scanning of the inner surface	
Value	Ring	Real	Imaginary	Real	Imaginary
Minimum value	1	744	742	620	317
	2	1065	1320	532	496
	3	217	246	477	532
	MR	303	299	88	88
Maximum value	1	885	875	761	520
	2	1408	1603	801	721
	3	443	417	836	876
	MR	354	357	121	114

The threshold defining the ring as faulty was the maximum value of the signal generated for the model ring. The authors observed that, in the case of the scanning of the external surface of Ring 3, both components of the signal exceeded the border value only in Test 4 (Table 3). The results that were not higher than the border value are presented in bold.

Table 3. Peak-to-peak value of the signal for Ring 3

	Scanning of the outer surface		Scanning of the inner surface	
Test no	Real [mV]	Imaginary [mV]	Real [mV]	Imaginary [mV]
1	**312**	398	505	729
2	434	**270**	541	689
3	**217**	417	477	876
4	267	386	836	868
5	443	**246**	777	532

6. Comparison of results

The results of the tests performed on the industrial stand are different from the tests on the laboratory stand. The values of the signal generated by the industrial measurement system are several times higher than are those generated by the laboratory stand. Table 4 shows the quotient of the average values of the results obtained on the laboratory and industrial stand (Equation 1). The problem during the tests on the industrial stand concerned the noise with the value of about 100 mV, which for the test on the laboratory stand is only about 10 mV.

$$K = \frac{U_I}{U_L} \tag{1}$$

Where:

K – Signal comparison coefficient,
U_I – Average value of the signal on the industrial stand,
U_L – Average value of the signal on the laboratory stand.

Table 4. Comparison of results obtained on the laboratory and industrial stands

K coef.	Scanning of the outer surface		Scanning of the inner surface	
Ring	Real [mV]	Imaginary [mV]	Real [mV]	Imaginary [mV]
1	2.68	2.84	7.74	4.34
2	3.96	5.47	8.21	8.24
3	2.15	2.53	2.8	3.4
MR	2.94	3.05	5.4	6

Conclusions

Despite significant differences in the results of measurements, all rings in which artificial test defects were made were qualified as faulty, both in the case of laboratory and in the case of industrial tests. The factor hampering the execution of tests on the industrial stand were the vibrations of the measurement system at the time of the operation of the device, which increased the measurement noise. At the time of the development of the automatic testing machine, it is necessary to increase the stiffness of the structural elements.

The increase value of the signal observed at the time of tests on the industrial stand stems from the complex movement of the measuring head. At the time of the test on the laboratory stand, the measuring head is immobilised, while on the industrial stand it moves along the surface of the cone (when the track is tested), or the cylindrical surface (at the time of the test of the surface of the bearing seated in the shaft).

Because the values of the signal generated at the time of the test of the model ring are different for the scanning of the inner and outer surface, it is justified to define separate border values categorising the ring as faulty. The tests also indicated that it is necessary to analyse the real and the imaginary components. The results of the tests were used in the configuration of the system for the industrial inspection of the quality of bearing rings.

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Porównanie wyników badania obiektów osiowosymetrycznych z wykorzystaniem metody prądów wirowych na stanowisku przemysłowym i laboratoryjnym

Słowa kluczowe

Prąd wirowy, wykrywanie wad, pierścień łożyskowy.

Streszczenie

Celem badań było porównanie wyników uzyskanych na stanowisku przeznaczonym do przemysłowej kontroli jakości pierścieni łożyskowych z rezultatami badań przeprowadzonych na stanowisku laboratoryjnym. Badaniu poddano cztery wewnętrzne pierścienie łożyskowe. W trzech pierścieniach wykonano sztuczne wady testowe odwzorowujące defekty, które mogą wystąpić podczas procesu produkcyjnego. Czwarty pierścień pełnił funkcję wzorcową. Skanowano powierzchnię wewnętrzną oraz zewnętrzną. W zależności od orientacji głowicy pomiarowej wady testowe odwzorowywały defekty powierzchniowe lub podpowierzchniowe.

Zaobserwowano, że podczas badań na stanowisku przemysłowym i laboratoryjnym poziom sygnału jest niższy dla badania powierzchni wewnętrznej, co jest skutkiem oddalenia punktu środkowego głowicy pomiarowej od badanej powierzchni.

Wyniki badań były podstawą do określenia wartości granicznych sygnału pomiarowego określających badany pierścień jako wadliwy. Ze względu na różny poziom sygnału dla badania powierzchni zewnętrznej i wewnętrznej zaproponowano określenie osobnych progów dla powierzchni wewnętrznej i zewnętrznej. Uzyskane wyniki badań umożliwiły opracowanie metody kalibracji systemu do automatycznej kontroli jakości pierścieni łożyskowych.