Comparison of induction motor bearing diagnostic test results through vibration and stator current measurement

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The paper discusses results of tests performed by authors, related to the engine bearings diagnostic using vibration and stator current measurements.
Vibration methods for bearing diagnostics have one disadvantage - they require the availability of the machine for sensors installation. This is the reason for seeking new methods based on motor supply current analysis. It can be assumed that each bearing defect causes radial movement between the rotor and stator of the machine. These changes generate additional stator current harmonics. The paper contains the description of an automatic measurement system, developed for the measurement of those harmonics and processing that data to obtain bearing diagnostic information. System was tested on objects with intentionally made defects in bearings, results of this test was also shown in the paper.

1. Introduction

During normal operation of the induction motor, various failures in parts of the mechanical and electromagnetic system of the machine, may occur. Statistics shows that the most common defect in motors is damage of bearings (over 40% of all injuries). Therefore, diagnostic of this element of the machine is so important for driving system failure-free work.

The paper discusses results of tests performed by authors, related to the engine bearings diagnostic using vibration and stator current measurements.

Bearing diagnostic methods that uses vibration signal have been well developed both in terms of equipment and diagnostic algorithms. Unfortunately vibration method has one disadvantage - it require the availability of the machine for sensors installation. This is the reason for searching new methods based on motor supply current analysis. We assume that each bearing defect causes radial movement between the rotor and stator. It causes a change in the air gap in a way that can be described by a combination of rotational irregularities in two directions, with and against the direction of rotor rotation. These changes generate additional harmonics in stator current [4], [5]. Current (and power) components contains information about all the most common motor injuries - bearings, stator and rotor windings.

The method, that uses instantaneous voltage and current waveform has similar features. In mentioned method, in spectrum of multiplication of measured instantaneous voltage and current waveform appear components with vibration frequency, that do not appear in current spectrum. It's additional diagnostic symptom, that is being tested and in the future can be potentially very useful to develop further tests.

Diagnostic problems, with methods using electrical quantities measurement, that may occur, are strictly related to low diagnostic signal level comparing to other components. In bearings diagnostics this problem is quite significant. In this particular case it is necessary to use low-noise components especially at the measuring system entry.

Based on previous studies [2, 7] it was calculated that the level of noise should not exceed -90 dB comparing to the greatest component in the spectrum of current.

For purpose of this thesis special low-noise measurement system was designed and developed. Comparing to prototype this system has been significantly improved and gives precise results.

The paper describes a new computerized measuring system that can show current harmonics. In cooperation with signal processing method it obtains diagnostic information. Paper also presents selected results of tests made on objects with intentionally defected bearings. For the purposes of this study a wide range of bearings with specific defects were strictly selected.

Due to the possibility of appearing secondary damages during tests, in this study vibration diagnostic was also used, to check bearing condition. This paper presents comparison of results two different methods: vibration and current method. Conclusions drown are based on present and updated tests results. Report refers to usefulness of electrical signals measurement method in motors bearings diagnostics.

2. The measurement system

To measure motor supply current, input measuring system is proposed. Simplified diagram of this system is presented in Figure 1. The heart of the system is transformer wound on a high class ferrite core and operational amplifier. For purpose of this test special amplifier was used. Among the items available on the market is has the lowest noise characteristics. Transformer works with forced current – current flows through its primary winding, supplying motor winding.

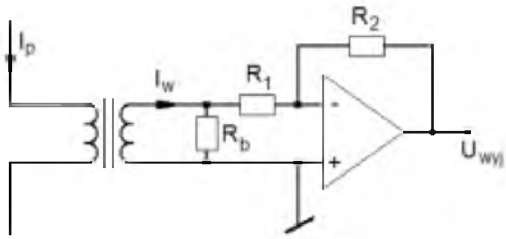

Fig. 1. Simplified diagram of current measuring system

The transmitter has been tested in special laboratory environment with measuring system created for this purpose. Signal received as outcome is converted in 24-bit A/D, installed in PXI rack. The measuring system was powered by batteries to avoid distorting impact of power grid. For this experiment system was prevented from external magnetic field, by using special shielding cover. To receive results and figures, special software was developed in LabVIEW. Example of the noise spectrum is shown in Figure 2.

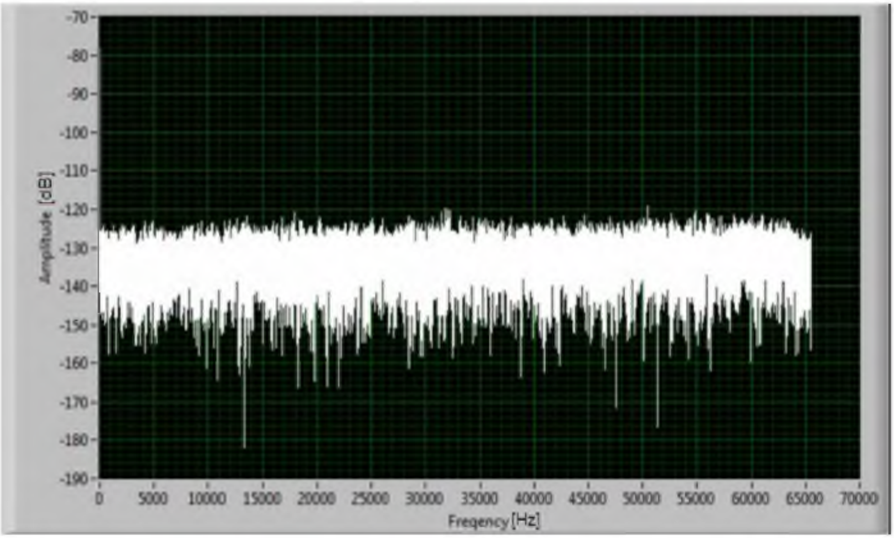

Fig. 2. Noise frequency characteristic of A/D converter including data acquisition card

Diagram shows that all requirements concerning measuring system self noise level are fulfilled. The results of the system tests are described more detailed in subject literature [6].

3. Test results

The test procedure was based on the simultaneous measurement of current supplying the motor and bearings vibrations. Vibration diagnostics comes down to finding in the vibration spectrum components with characteristic frequencies and their multiplications as well as valuation of those results. The relations defining characteristic frequencies for specific damages are shown in equations [1]: (1), (2), (3) and (4).

$$f_{out} = \frac{1}{2}\frac{n}{60}\left(1 - \frac{B_d}{P_d}\cos\alpha\right)N_b \tag{1}$$

$$f_{in} = \frac{1}{2}\frac{n}{60}\left(1 + \frac{B_d}{P_d}\cos\alpha\right)N_b \qquad (2)$$

$$f_c = \frac{1}{2}\frac{n}{60}\left(1 - \frac{B_d}{P_d}\cos\alpha\right) \qquad (3)$$

$$f_{rol} = \frac{1}{2}\frac{n}{60}\frac{P_d}{B_d}\left(1 - \frac{B_d^2}{P_d^2}\cos^2\alpha\right) \qquad (4)$$

where: f_{out} – frequency of rolling elements making contact with a certain point on the outer race, f_{in} – frequency of rolling elements making contact with a certain point on the inner race, f_c – frequency of cage spinning, f_{rol} – frequency of rolling elements spinning around their own axes, n – rotational speed [rev/min], N_b – number of rolling elements, B_d – the ball diameter [mm], P_d – the bearing pitch diameter [mm], α – the contact angle.

Vibrations were measured with a "DREAM" diagnostic system. Vibration test results are shown in Figures 3 and 4.

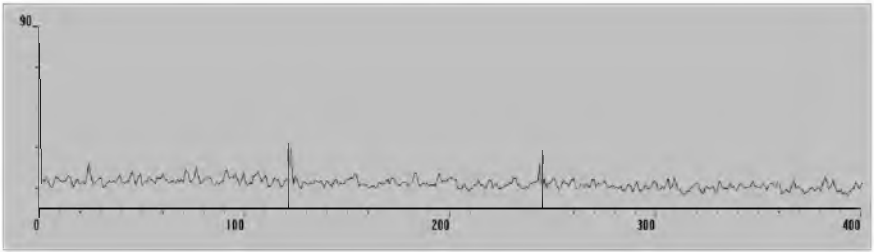

Fig. 3. Vibration diagnostic test result of healthy bearing

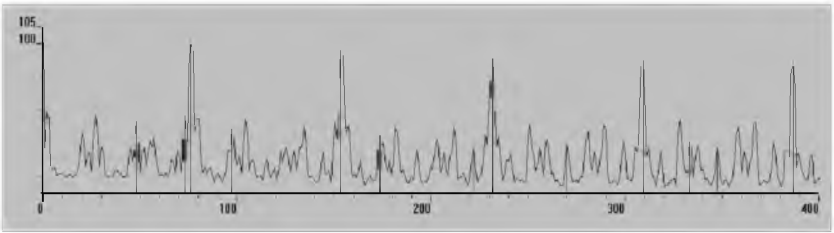

Fig. 4. Vibration diagnostic test result of bearing with outer race damaged

Vibrations are measured at the bearing installation point in motor. The vibration spectrum clearly shows outstanding results that are evidence of specific item damage. Due to physical properties of induction machine, the components with the characteristic frequencies do not occur in the spectrum of current.

In the monograph [7] the impact of vibration on the current spectrum and frequency of components in this spectrum, is described. Studies show different results for motor running during normal operation and also for motor running with damaged bearings. Results described in mentioned monograph also emerged current components during efficient motor running. This specific data was basis for further calculations. Presence of components with selected frequencies proves occurrence of specific damages of bearings. The results of these tests are shown in Figure 5.

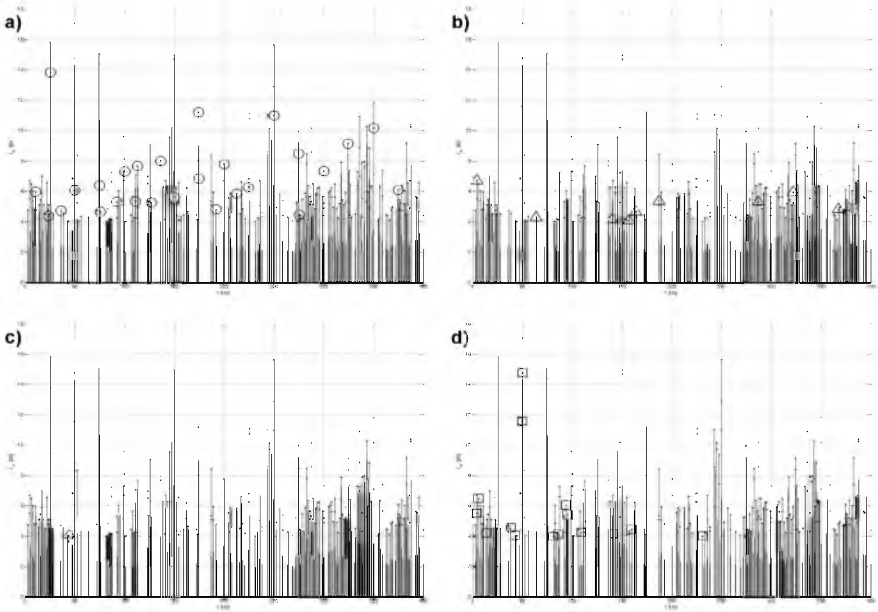

Fig. 5. Motor current amplitude spectrum of motor with damaged bearing

Figures 5 a) b) c) and d) shows the same amplitude spectrum of current. In each diagram different components are selected and highlighted. For those studies four different damages of bearings are defined and tested. Diagram 5 a) shows components with frequencies characteristic that may prove outer race damage (circles). Further graphs highlight components, with frequencies that may indicate following defects: 5 b) damage of the inner race (triangles), 5 c) damage of the rolling elements (diamonds), 5 d) damage of the cage (squares). To make the spectrum diagrams more visible, all components resulting with amplitudes below 4 dB compared to the average value of the noise were removed.

All presented graphs were compared taking under consideration quantities and values of marked components. In the first graph outstanding marks occur most frequently and show high values. On this basis, it can be deducted that there is a damage in the outer race of bearing. In the graphs b), c) and d) outstanding results are not clearly visible. It can prove the fact that bearing is not elsewhere damaged. Described conclusions were compared with vibration method results. Both methods correctly detected intentionally introduced damage.

4. Conclusions

The investigations were carried our using two different methods to give full perspective and show advantages and disadvantages of both. Using vibration method received diagnose is correct. It enable not only to see the type of damage but also precise damage degree. Studies proved that current method defines only type of damage. Comparing those two, report proves that bearings diagnostics method with vibration diagnostics is more effective than stator current method. For the future results current method requires further research and development. Only improved method can ensure reliable diagnose. It's deeply believed that described method can also determine the degree of damage but to prove that further research is required. Authors are determinate and theirs current studies focuses on looking for new diagnostic algorithms. New algorithms hopefully can increase the likelihood of accurate diagnose, obtained on the basis of current measurement. Work is in progress to implement new algorithms based on fuzzy logic and artificial intelligence methods.

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