SDEMPED 2005 – Symposium on Diagnostics for Electric
Machines, Power Electronics and Drives
Vienna, Austria, 7-9 September 2005

Experimental Research on Rotor Fault Diagnosis Using External Coil Voltage Analysis and Shaft Voltage Signal Analysis

Alan Miletic
Faculty of Electrical Engineering and Computing
Department Electric Machines; Drives and Automation
Unska 3, 10000 Zagreb, HR
CROATIA
alan.miletic@fer.hr

Mirko Cettolo
Faculty of Electrical Engineering and Computing
Department Electric Machines; Drives and Automation
Unska 3, 10000 Zagreb, HR
CROATIA
mirko.cettolo@esa.fer.hr

Abstract: ***Induction motors are nowadays used more frequently than any other electric motor in various kinds of electric drives. Incipient fault diagnosis is very important because if the fault is undetected, small motor failure can lead to serious motor failure. Although several sophisticated fault detection methods can be found in literature and practice, the focus of this paper are two methods that could be used "on-line" in real-life situations, and can be performed in a short time. The experiments have been performed by analyzing the voltage in an external search coil, and the shaft voltage. In the case of the search coil voltage analysis, the tests were performed for six different search coil positions. The search coil voltage spectral analysis has also been performed. All tests were performed on 22 kW, 380 V, 1470 r/min induction motor, for the case of a healthy rotor and for the case of a rotor with different deliberately damaged rotor.***

EXTERNAL COIL VOLTAGE ANALYSIS TESTS

External coil voltage analysis can be used to detect various rotor faults. The goal of performed tests was to detect broken rotor bar in an early stage and in the case of a greater rotor fault to find out the amount of damage. The analysis can be performed in time as well in a frequency domain. The asymmetry caused by a rotor fault will induce voltage in a search coil with additional harmonics at frequencies given by [*Lit 1*]

$$f_{coil} = \frac{f_1}{p} \cdot (1 - s) \pm s \cdot f_1 \qquad (1)$$

Where f_1 - supply voltage frequency,
s – slip,
p – number of pole pairs.

The equation (1) gives the harmonics around the rotation frequency of the rotor displaced for $2sf_1$.
The tests have been performed on 22 kW, 380 V, 1470 r/min induction motor with 40 rotor bars for six different search coil positions (three in the middle of the outer joke, and the near the bearing) as can bee seen at Fig. 1. The 104 kW DC motor have been used to change the motor load.

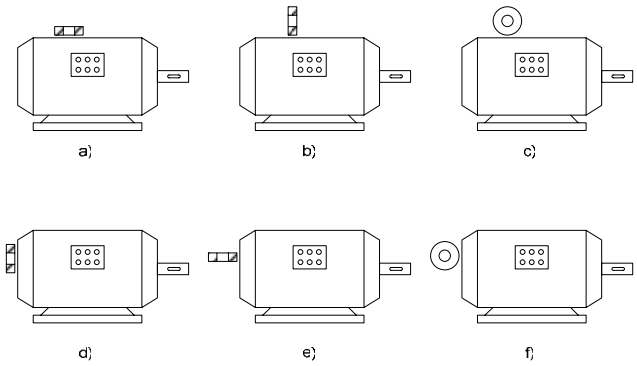

Fig. 1. Search coil positions

The most useful results have been taken at position a) (around the middle of a stator joke), and all of the following results have been taken at that position. The tests have been performed using PC equipped with 12bit A/D card (DAS 50, Keithley Metrabyte).

The motor has been tested in a healthy condition and with four different deliberately caused faults. In the first

case one of the bars was slightly cut, representing an early stage of the rotor fault. Later, the tests were performed with one broken bar and two broken bars. Finally three bars were taken out and the end ring was cut. This represented completely damaged rotor.

In this digest the voltage induced in the search coil is shown only for the case of a healthy rotor (Fig. 2) and rotor with three bars taken out and broken end ring (Fig. 3), at nominal load of approximately 42 A.

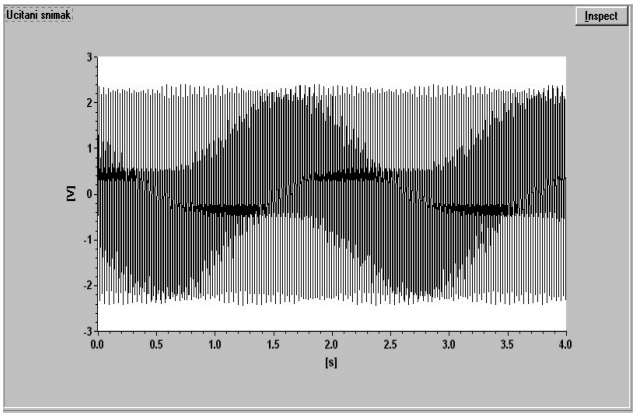

Fig. 2. Search coil voltage at healthy stage

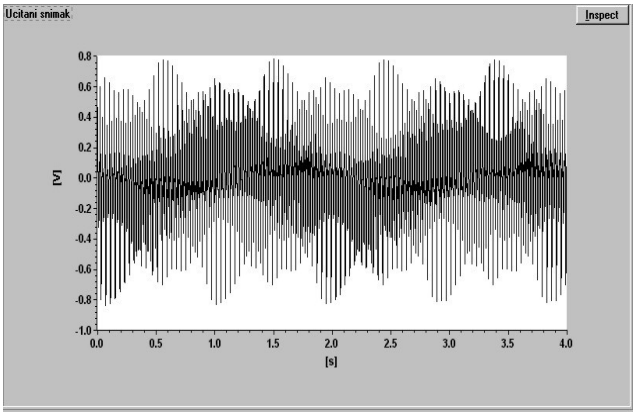

Fig. 3. Search coil voltage with completely damaged rotor

As can be seen in pictures, in the case of broken rotor bars the voltage induced in a search coil is more distorted than in the case of a healthy rotor (in the case of one broken bar the distortion is not so large). If the graph is zoomed the distortion of the voltage is even more obvious. The details of the voltage are shown in the Fig 4 and 5.

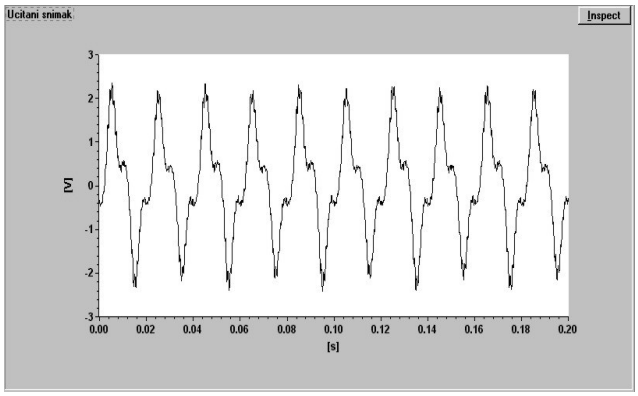

Fig. 4. Detail of the search coil voltage for the case of a healthy rotor

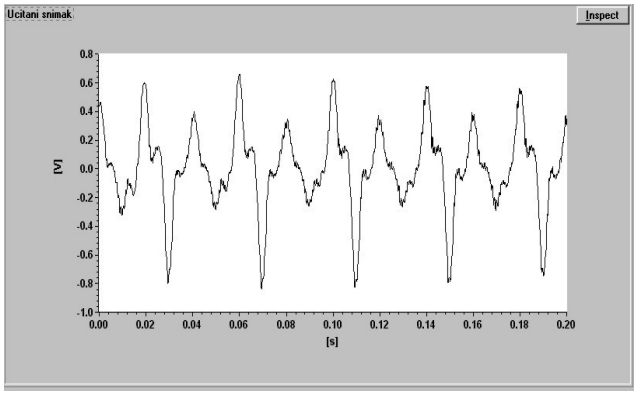

Fig. 5. Detail of the search coil voltage for the case of a damaged rotor

If the voltage is analyzed in the frequency domain, the additional harmonics near the main frequency are greater in the case of a broken than in the case of a healthy rotor as can be seen in Figures 6 and 7.

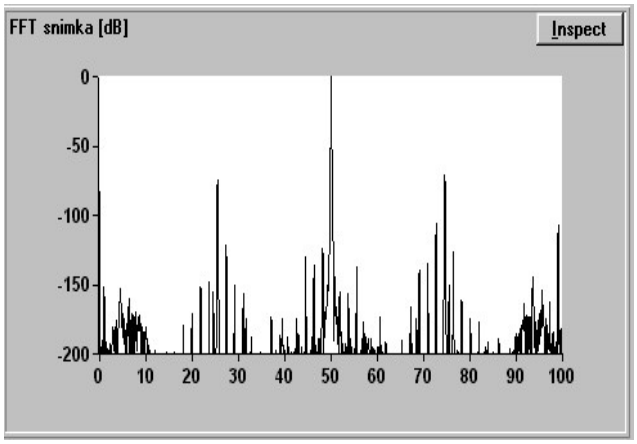

Fig. 6. Voltage spectrum with healthy rotor

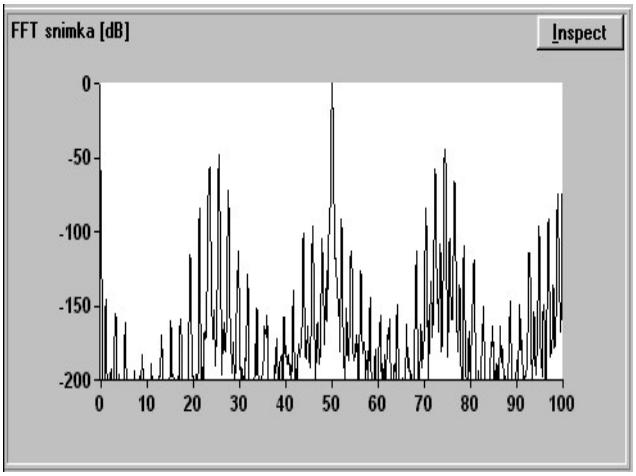

Fig. 7. Voltage spectrum with broken rotor

SHAFT VOLTAGE ANALYSIS

Shaft voltage analysis has been taken as an additional method for broken rotor bar detection. The tests have been taken using PC with an A/D converter. The shaft voltage signal have been taken using two sliding contact as shown in Fig:8.

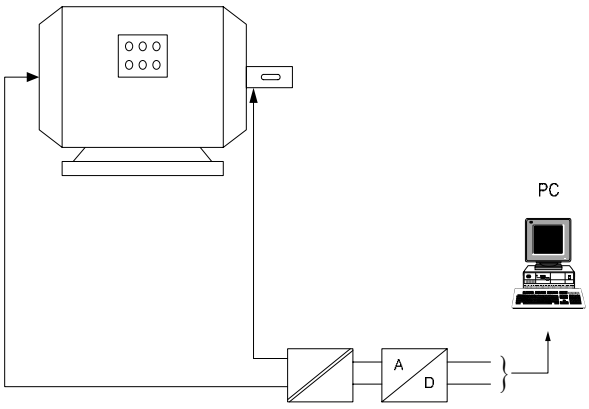

Fig. 8. Shaft voltage recording

The shaft voltage signal has been recorded for different rotor faults, and the motor load has been changed from no-load to 120% of the nominal load (50A).
The shaft voltage signals, taken at nominal load, are shown in Fig 9 to 11

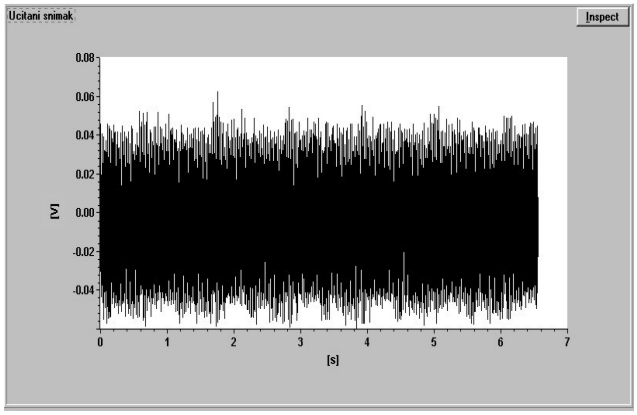

Fig. 9. Healthy rotor

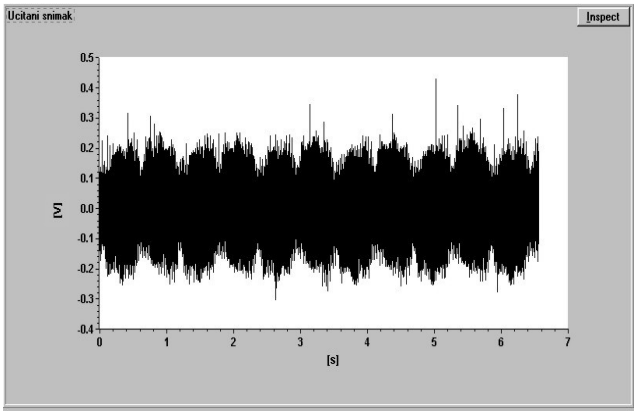

Fig. 10. One broken bar

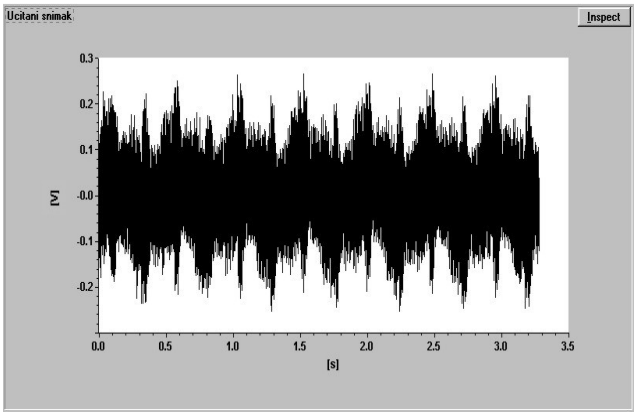

Fig. 11. Three bars taken out, end ring broken

As can bee seen in the pictures, the shaft voltage in the case of a broken rotor is enlarged and distorted. The voltage signal is modulated with an additional signal with frequency $2sf_1$. Those modulation can also bee found in speed and torque signal [*Lit 1*].

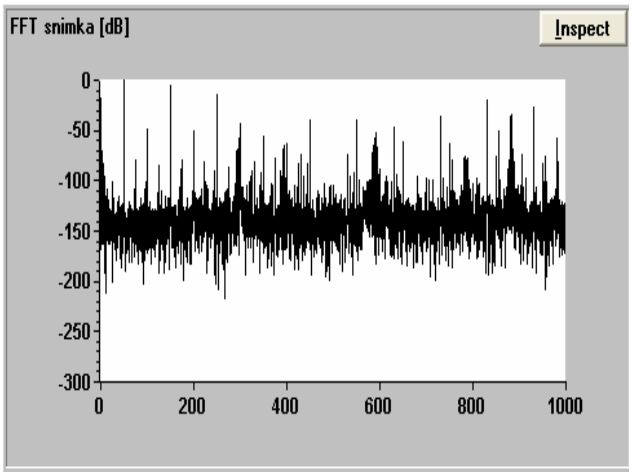

Fig. 12. Healthy rotor

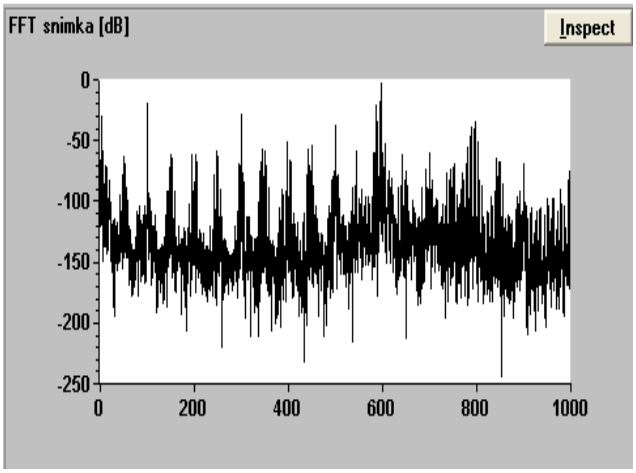

Fig. 13. Three bars taken out, end ring broken

The shaft voltage spectrum is shown in Fig. 11 and 12. The Fig 11 shows the spectrum for healthy rotor, and Fig 12 for rotor with three bars and end ring broken. As can be seen in the pictures the voltage spectrum for the case of a broken rotor has larger harmonics but in the case of a healthy rotor. However it is not easy to determine the number of broken bars.

The motor load had no significant influence oh the shaft voltage signal. However the frequency of modulation signal did change.

SUMMARY

The preformed tests have shown that those two methods can be used as additional methods in broken rotor bar detection. Although the motor current signature analysis is still more powerful method in broken bar detection, especially if one wants to know how great the fault is, those two methods could be used to incipient fault detection. Search coil voltage can also be used to detect stator winding or the bearing faults. The search coil voltage recording can easily be performed in real-life situations during the normal motor operation, in a very short time. The result could be very useful especially in situations when the signal of a healthy new motor is known. In those situations short comparison of that signal and signal taken after some period of usage could make easier to early detect motor faults.

However shaft voltage recording is not always so simple to perform. Sometime, the sliding contacts can not easily be put on the motor shaft or can not be used at all. Far more it is not so easy to detect an early stage of s fault, and the number of broken bars can not always be predicted. Therefore this method should be used in situations when shaft voltage is already measures for some other reasons (as for an example measuring bearing currents) in large machines.

LITERAMTURE

1. Elkasabgy N. M., Estham A. R., Dawson G. E., "*Detection of Broken Bars in the Cage Rotor on an Induction Machine*", IEEE Transactions on Industry Applications, Vol. 28, No. 1, Jan/Feb 1992.
2. A. Miletic; “Diagnostic Methods and Criteria for Assessment of Induction Motor Electromechanical Condition”, Masters Thesis, 2002. FER Zagreb, CROATIA
3. Thomson W. T., "*A Review of On-Line Condition Monitoring Techniques for Three-Phase Squirrel-Cage Motors – Past Present and Future*", IEEE SDEMPED '99, Spain, Sept. 1999., pp. 3-18.
4. Thomson W. T., Rankin D., "*Case Histories of On-Line Rotor Cage Fault Diagnosis*", 2nd International Conference Proc. Condition Monitoring, University College Swansea, 1887, pp. 798-819.