

A Study of the Impact of Squirrel-Cage Rotor Faults on the Stator Current Signature

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Abstract. *The present paper considers the impact of the degree of damage to a squirrel-cage rotor of an induction motor on the spectrum of the stator current. The study is based on the motor current signature analysis. Performed, for this purpose, were scientific experiments on eight samples of squirrel-cage rotors, seven of which with pre-inflicted faults using Dynamic Motor Analyser. The obtained results are herein presented in graphical and tabular form and are further compared with the ones acquired from an induction motor with an intact rotor winding. It can be clearly ascertained that the larger the number of damaged rotor bars, the more significant the increase in the current amplitude as correspondent to the side band amplitude.*

Keywords: motor current signature analysis, squirrel-cage rotor, induction motor, rotor fault, fast Fourier transformer

Introduction

Induction motors are some of the most used and widespread electric motors in electric drives in various industries, such as: nuclear power, electric power plants, oil and gas production, textile production, and all kinds of transport. This is due to the relatively low cost, simple construction, relatively high efficiency, and high reliability. This makes them one of the main consumers of electric power; today from 40% to 50% of the energy produced is used to supply various types of induction machines with electric power (Singh & Naikan, 2018), (Saad, Irfan & Ibrahim, 2019).

Each induction machine is designed to meet one of the 10 operating modes defined by the IEC 60034-1 standard; however, as a result of the high rate of development in the industry, additional operating conditions are created beyond those provided by the IEC operating modes (Agrawal, 2001), (Robinson, Whelan & Haggerty, 2004). This results in a number of faults causing emergency failures. Information is available (Singh & Naikan, 2018), (William & Culbert, 2017) on the percentage distribution of faults occurring in induction machines.

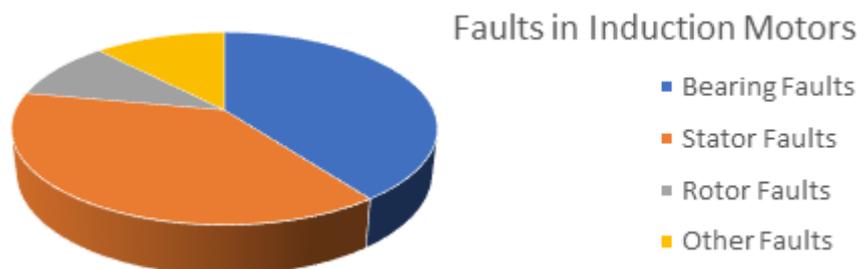


Fig. 1. Percentage distribution of faults in induction machines.

Of utmost importance, in modern industry, is the ability of drive systems to realize a long service life with minimal time for maintenance or repair . This, in turn, requires the development of methods and tools for monitoring and diagnostics of electrical machines (Karmakar, Chattopadhyay, Mitra & Sengupta, 2016), (Fiser & Ferkoj, 1998). The main diagnostic methods are sound analysis, acoustic analysis, thermal analysis, vibration analysis and others (Mehala & Dahiya, 2007), (Saad & Ibrahim, 2019).

One of the frequently used diagnostic techniques is the motor current signature analysis MCSA, whose application has undergone significant development over the last few years. This method is characterized by its universality and enables detection of faults in almost every element of the machine (Mohanty, 2015), (Bellini, Franceschini, Tassoni & Kliman, 2001 MCSA is monitoring stator current of the motor. The stator windings are used as transducer, picking the signals from the rotor. In the next step the received current data are processed using the fast Fourier transform (Karmakar, Chattopadhyay, Mitra, Sengupta 2016).

The purpose of this article is to investigate the impact of the faults occurring in the rotor winding on the spectrum of stator current in an induction motor with a squirrel-cage rotor.

Experiment

To perform the experiment, 1 stator and 8 structurally identical rotors of a three-phase induction motor type ELPROM Troyan 4AO-80V-2D were used. To reduce the speed of rotation and ensure mechanical stability in the experimental test, the stator of the motor was rewound from 2 to 4 poles.

Considered were 7 kinds of faults in the rotor winding. Seven of the eight rotors had pre-inflicted faults: one or more rotor bars were broken. Outlined in Table 1 is every single option of those within the main focus of the present research.

Table 1. Tested Rotors.

№	Sample	Fault
1	A	intact rotor
2	B	rotor with 1 broken aluminum bar
3	C	rotor with 2 broken aluminum bars next to each other
4	D	rotor with 3 broken aluminum bars next to each other
5	E	rotor with 4 broken aluminum bars next to each other
6	F	rotor with 2 broken aluminum bars at 180°
7	G	rotor with 2 broken aluminum bars at 90°
8	H	rotor with 4 broken aluminum bars at 90°

The testing of each of the samples was performed at two values of current load. The experiments were performed using Dynamic Motor Analyser which enables analysis of the current spectrum by the MCSA method – Figure 2. The measurements were performed in real time with pre-set time of analysis.

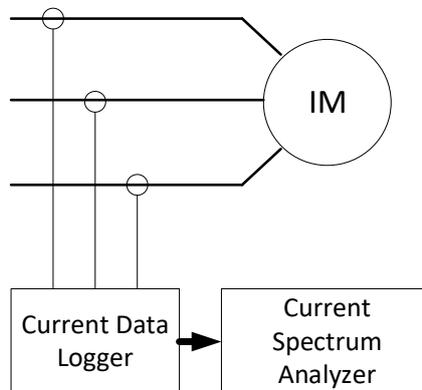


Fig. 2. Experiment scheme.

Results and discussion

Using the MCSA-based analysis equipment, the following results were obtained for the stator current spectrum and depicted on Figure 3÷18. There are pointed values for Sideband Frequency (SBF) and Sideband Amplitude (SBA).

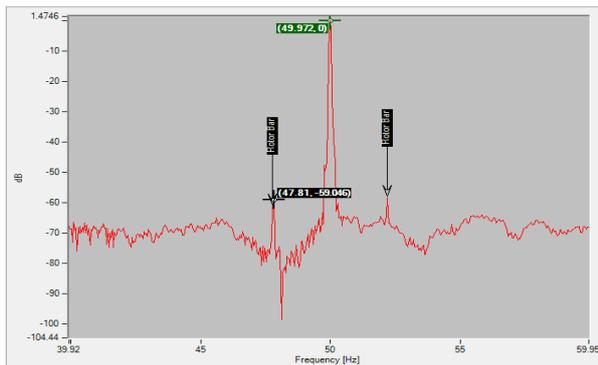


Fig. 3 – 45.0% Load SBF 47.81Hz SBA; -59.046dB – Rotor sample A

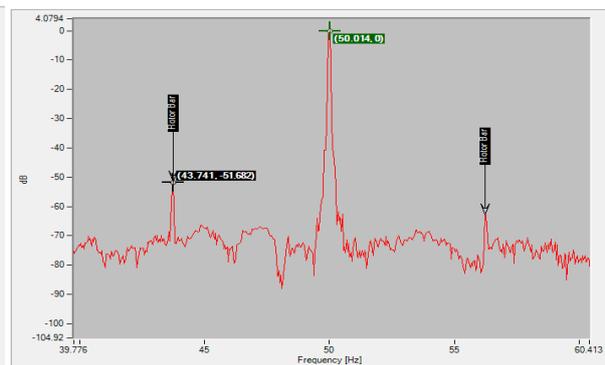


Fig. 5 – 95.0% Load SBF 43.741Hz SBA; -51.682dB – Rotor sample A

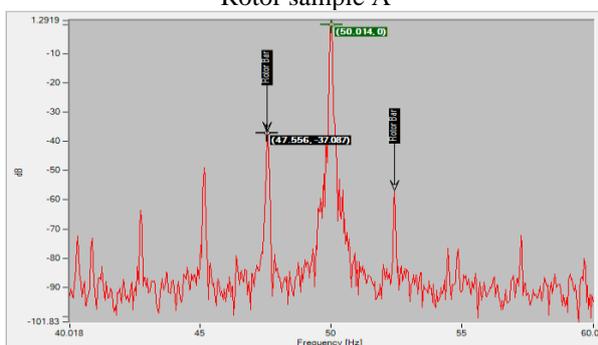


Fig. 5 - 50% Load SBF 47.556Hz SBA; -37.087dB – Rotor sample B

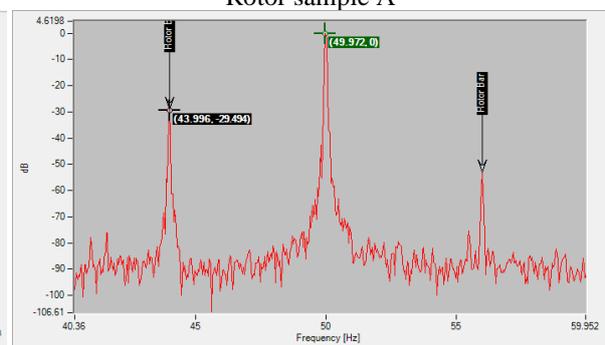


Fig. 6 - 96.6% Load SBF 43.996Hz SBA; -29.494dB – Rotor sample B

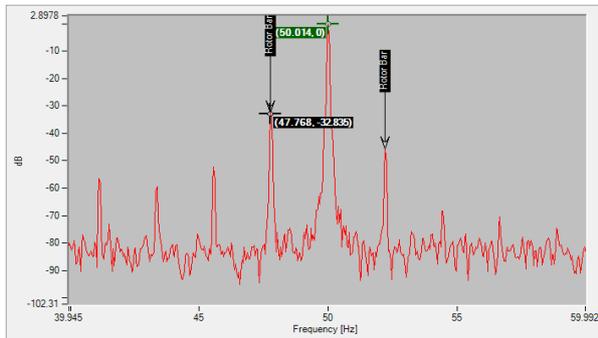


Fig. 7 - 42.9% Load SBF 47.768Hz SBA; -32.835dB – Rotor sample C

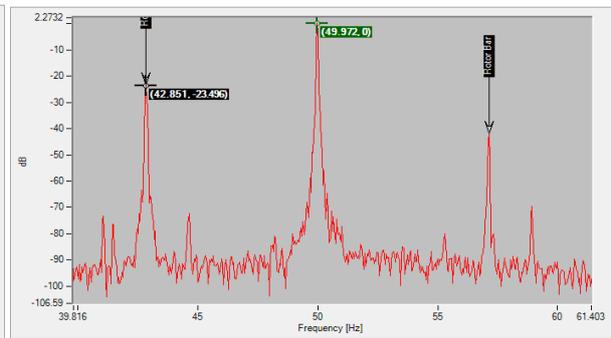


Fig. 8 - 96.2% Load SBF 42.851Hz SBA; -23.496dB – Rotor sample C

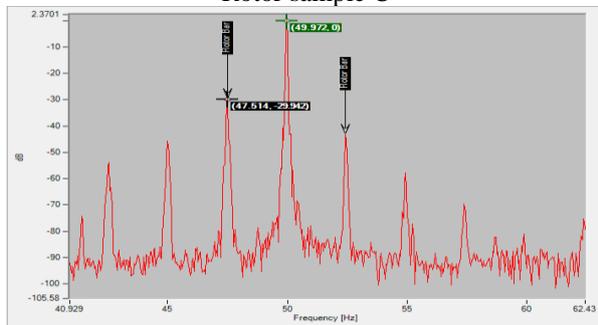


Fig. 9 - 43.3% Load SBF 47.514Hz SBA; -29.942dB – Rotor sample D

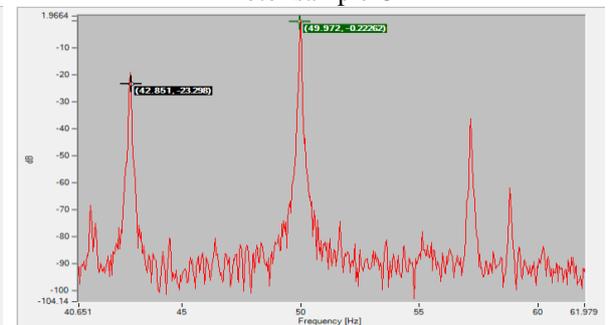


Fig. 10 - 90.0% Load SBF 42.851Hz SBA; -23.298dB – Rotor sample D

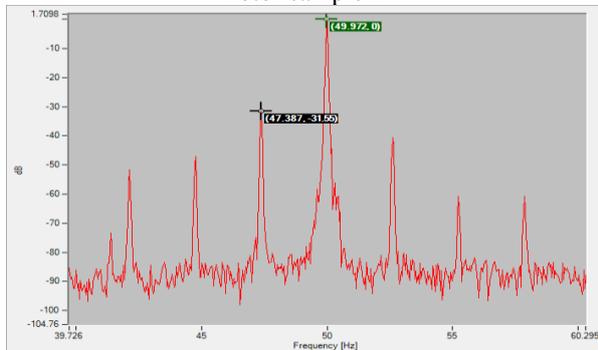


Fig. 11 - 45.5% Load SBF 47.387Hz SBA; -31.550dB – Rotor sample E

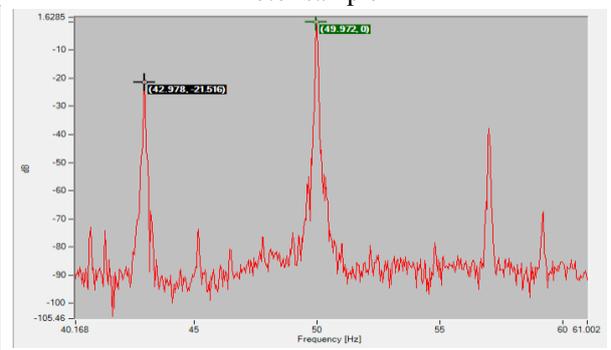


Fig. 12 - 87.5% Load SBF 42.978Hz SBA; -21.516dB – Rotor sample E

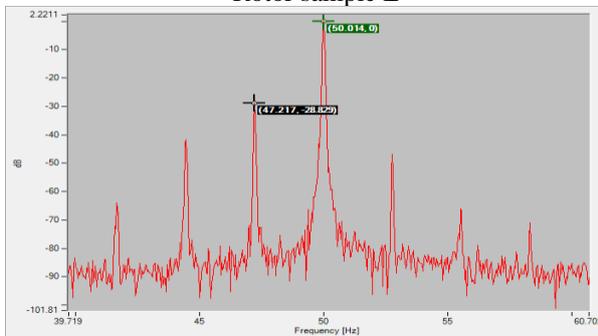


Fig. 13 - 56.1% Load SBF 47.217Hz SBA; -28.829dB – Rotor sample F

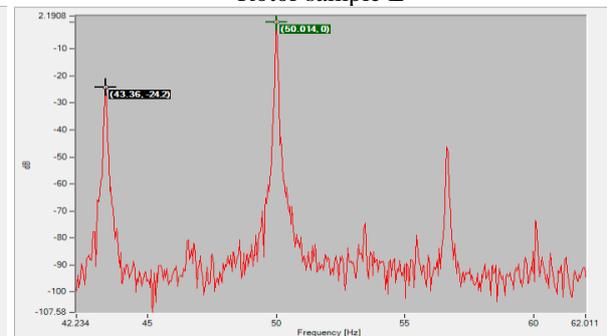


Fig. 14 - 102.5% Load SBF 43.360Hz SBA; -24.200dB – Rotor sample F

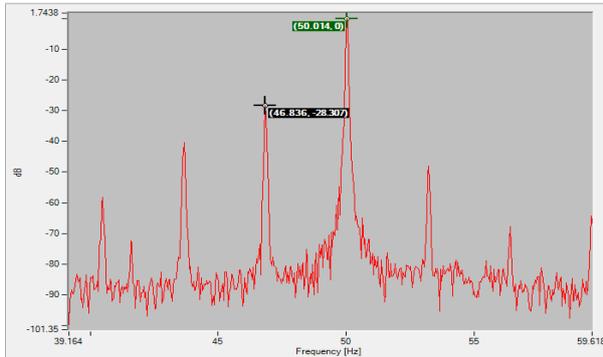


Fig. 15 - 57.7% Load SBF 46.836Hz SBA; -28.307dB – Rotor sample G

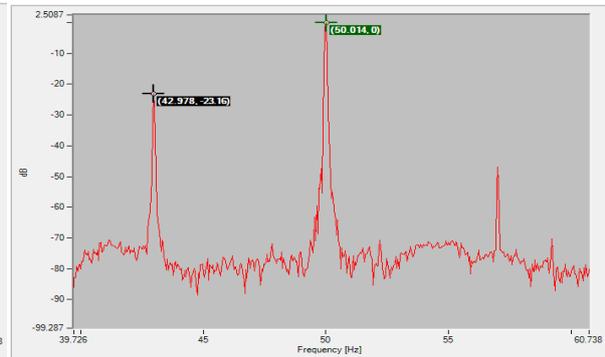


Fig. 16 - 98.3% Load SBF 42.978Hz SBA; -23.160dB – Rotor sample G

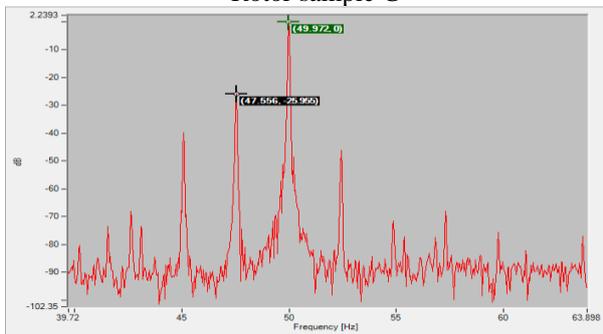


Fig. 17 - 44.2% Load SBF 47.556Hz SBA; -25.955dB – Rotor sample H

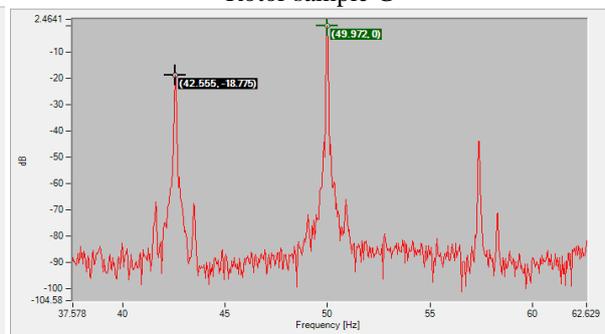


Fig. 18 - 95.6% Load SBF 42.555Hz SBA; -18.775dB – Rotor sample H

Based on the conducted experiments, a table is generated to express the values of the current spectrum corresponding to frequency $f_1(1-2s)$ at different faults and loads. The results are presented in Table 2.

Table 2. SBA values in dB corresponding to current spectrum at frequency $f_1(1-2s)$ with different number and configuration of broken rotor bars compare with an intact rotor.

Sample rotor	SBA, I=40-60% In	SBA, I=90-100% In
	<i>dB</i>	<i>dB</i>
A	-59	-52
B	-37	-29
C	-33	-23
D	-30	-23
E	-32	-22
F	-29	-24
G	-28	-23
H	-26	-19

The results from the respective faults have different values of current amplitude with a frequency corresponding to $f_1(1-2s)$, but there is a tendency towards its increase along with the increase in the number of defects in the rotor bars.

An analysis was also performed on samples with identical number of broken rotor bars (2 and 4 bars): samples with broken rotor bars located next to each other – sample C and E; with broken rotor bars distributed at 90° - sample G, and 180° geometric degrees – sample F and H. The corresponding results are briefly reported in Table 3 and Table 4.

Table 3. SBA values in dB corresponding to current spectrum at frequency $f_1(1-2s)$ with 2 broken rotor bar compare with an intact rotor.

Sample rotor	SBA, I=40-60%In	SBA, I=90-100%In
	<i>dB</i>	<i>dB</i>
A	-59	-52
C	-33	-23
F	-29	-24
G	-28	-23

Table 4. SBA values in dB corresponding to current spectrum at frequency $f_1(1-2s)$ with 4 broken rotor bar compare with an intact rotor.

Sample rotor	SBA, I=40-60%In	SBA, I=90-100%In
	<i>dB</i>	<i>dB</i>
A	-59	-52
E	-32	-22
H	-26	-19

No significant difference was observed in the results obtained for samples G and F, which means that when two rotor bars are broken, regardless of whether they are at 90° or 180°, the current spectrum which is below the primary frequency has a strong amplitude. Unlike these two variants, sample C shows a significant increase in the amplitude of the current at frequency $f_1(1-2s)$.

The SBA by a sample E is higher than a sample H, which means that when four rotor bars are broken next to each other the current spectrum increases in comparison to the rotor bars located on 90 degrees.

Conclusion

A case study of an approach for detecting rotor cage defects based on motor current signature analysis was presented in the current paper. Based on the results described above and the analysis performed, it can be clearly concluded that with an increase in the number of damaged rotor bars, a significant increase occurs in the current amplitude corresponding to the frequency $f_1(1-2s)$. The highest SBA values are obtained when the broken rotor bars are next to each other.

In order to obtain correctly achieved measurement results through the applied method, it is necessary to provide a static load during the experiment with a value of not less than 50% of the rated motor power and with the range of the current sensors being as close to the measured values as possible.

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References

- Agrawal, K.C. (2001). *Industrial Power Engineering and Applications Handbook*. Butterworth-Heinemann. <https://doi.org/10.1016/B978-075067351-8/50110-0>.
- Bellini, A., F. Filippetti, G. Franceschini, C. Tassoni, G. B. Kliman (2001, September-October). Quantitative Evaluation of Induction Motor Broken Bars by Means of Electrical Signature Analysis. *Journal of IEEE Transactions on Industry Applications*, 37, 5, 1248-1255. <https://doi.org/10.1109/28.952499>.
- IEC 60034-1. (2017, May). Rotating electrical machines – Part 1: Rating and performance. International Electrotechnical Commission (IEC)
- Mehala, N., R. Dahiya (2007). Motor Current Signature Analysis and its Applications in Induction Motor Fault Diagnosis. *International Journal of Systems Applications, Engineering & Development*, 2(1), 29-35. <https://www.naun.org/main/UPress/saed/saed-5.pdf>
- Mohanty, A. R. (2015). *Machinery condition monitoring: Principles and practices*. Taylor & Francis Group, LLC, CRC Press
- Fiser, R., S. Ferkolj. (1998). Magnetic field analysis of induction motor with rotor faults. *COMPEL – The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, 17(2), 206-211. <https://doi.org/10.1108/03321649810203143>
- Karmakar, S., S. Chattopadhyay, M. Mitra, S. Sengupta. (2016). *Induction Motor Fault Diagnosis Approach through Current Signature Analysis*. Springer Science+Business Media Singapore. <https://doi.org/10.1007/978-981-10-0624-1>.
- Robinson, J., C. D. Whelan, N. K. Haggerty. (2004). Trends in advanced motor protection & monitoring. *IEEE Transactions on Industry Applications*, 40(3), 853-860. <https://doi.org/10.1109/TIA.2004.827472>
- Saad, N., M. Irfan, R. Ibrahim. (2019). *Condition Monitoring and Faults Diagnosis of Induction Motors Electrical Signature Analysis*. CRC Press Taylor & Francis Group. <https://doi.org/10.1201/9781351172561>
- Singh, G., V.N.A. Naikan. (2018, September 15). Detection of half broken rotor bar fault in VFD driven induction motor drive using motor square current MUSIC analysis. *Journal of Mechanical Systems and Signal Processing*, 110, 333-348. <https://doi.org/10.1016/j.ymssp.2018.03.001>
- William, T., I. Culbert (2017). *Current signature analysis for condition monitoring of cage induction motors*, IEEE press, <https://doi.org/10.1002/9781119175476>