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The Effect of Dynamic Eccentricity on Induction Machine Stator Currents (Part A)

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***Abstract*—**Current spectrums of a high power induction machine was calculated for the cases of full symmetry, static and dynamic eccentricity.

The calculations involve integration of 93 electrical plus four mechanical ordinary differential equations. Electrical equations account for variable inductances affected by slotting and eccentricities. The calculations were followed by Fourier analysis of the stator currents in steady state operation.

The paper presents the stator current spectrums in full symmetry, static and dynamic eccentricity cases, and demonstrates the harmonics present in each case.

The effect of dynamic eccentricity is demonstrating via comparing the current spectrums related to dynamic eccentricity cases with the full symmetry one.

The paper includes one case study, refers to dynamic eccentricity, to present the spectrum of the measured current and demonstrate the existence of the harmonics related to dynamic eccentricity.

The zooms of current spectrums around the main slot harmonic zone are included to simplify the comparison and prove the existence of the dynamic eccentricity harmonics in both calculated and measured current spectrums.

Keywords—Current spectrum, diagnostics, harmonics, Induction machine

I. INTRODUCTION

ROTATING electrical machines play a very important rule in the world's industrial life. Among them, the three-phase induction motor is frequently used because of its relatively simple, robust construction and its low price.

Design and analysis of new induction machines remain an important topic in electrical engineering [1]. Besides, there is also a strong industrial demand for reliable and safe operation of rotating machines.

Faults and failures of critical electromechanical parts can indeed lead to excessive downtimes and generate high costs in reduced output, emergency maintenance and lost revenues.
Hence, diagnosing such machines is a very important issue.

Mature procedures have been elaborated by many researchers [2], [3], [4] dealing with diagnosing cage asymmetries. Development of these procedures can be supported by induction machine models recognizing only the fundamental harmonic. In contrast to this, the models admitting static or/and dynamic eccentricities have to be based on poly-harmonic models.

The calculations presented in this paper as well as in [5], [6] are based on the poly-harmonic model accounting for static and dynamic eccentricity, stator and rotor slotting, parallel branches as well as cage asymmetry. In addition, in [7] the effect of the polluted supply voltage on the current spectrum was accounted for as well.

This paper will present the spectrums of the induction machine stator currents for the cases of full symmetry, static and dynamic eccentricity and demonstrate the effect of each ailment via comparing the harmonics contained in stator current spectrums in each case.

The spectrums presented in this paper rely on calculations performed with special software (AS2) [8].

The spectral analysis was performed by program Sp1 that calculates Fast Fourier Transform (FFT) as well as least squares approximation of the fundamental component of the currents.

The calculations performed refer to a 3.15 MW squirrel-cage induction machine, possessing one pole pair (p=1), N_S/N_R = 48/40 of stator/rotor slots and two parallel branches in each phase.

All current spectrums refer to the steady state operation, by full loading torque TL = 10000 Nm.

II. FULL SYMMETRY

In order to provide reference basis the calculation of the stator current spectrum has been performed for the case of fully symmetrical machine (no eccentricity, no clutch wobbling).

The spectrum of the stator current is shown in Fig. 1. It does not contain any extraordinary harmonics, neither around the 50 Hz fundamental harmonic nor in the main slot harmonic zone. It only contains the 50 Hz fundamental harmonic as well as the main slot harmonic Slh, of the frequency of about 2042 Hz and amplitude of about -40 dB.

The spectrum contains also the second slot harmonic of the frequency of about 3934 Hz.

The frequency of the main slot harmonic can be predicted by the following formula [9]:

$$\left| \; f_1 + h \cdot N_R (1 - s)\, n_s \; \right| \qquad (1)$$

where: the supply frequency f_1 = 50 Hz, the parameter h = 1 [10], the no. of rotor slots N_R = 40, the slip s = 0.00394, and the synchronous speed $n_s = f_1/p$ = 50 revolutions per second.

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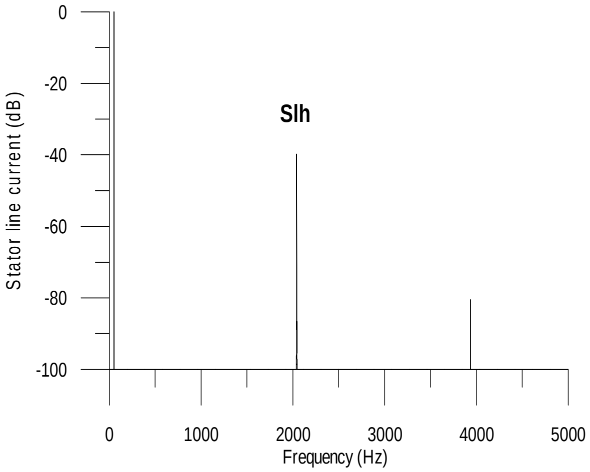

Fig. 1 Spectrum of the calculated stator current (Full symmetry)

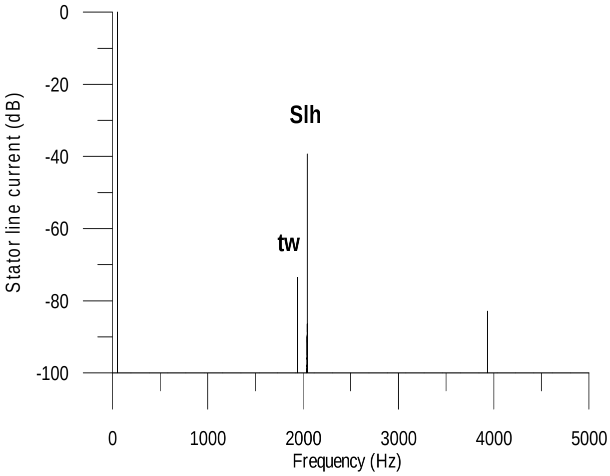

Fig. 2 (a) Spectrum of the calculated stator current (50% static eccentricity)

III. Static Eccentricity

In this case the spectrum of the stator line current i_A will be demonstrated, considering that the rotor axis is shifted by a certain value of the geometrical air gap thickness toward the first coil group of the stator phase A [11], [12].

Fig. 2 (a) refers to the case of 50% static eccentricity. The spectrum of the stator line current contains a pair of harmonics in the main slot zone; as compared to just the main slot harmonic Slh in the case of full symmetry. This new twin harmonic tw is spaced by about 100 Hz to the left of the main slot harmonic, as shown in fig. 2 (b). Its frequency is about 1942 Hz and its amplitude about -74 dB.

The frequency of the twin harmonic to the left of the main slot harmonic can be predicted by the following formula [9]:

$$\left| \ f_1 - h \cdot N_R (1-s)\, n_s \ \right| \tag{2}$$

where: the supply frequency f_1 = 50 Hz, the parameter h = 1 [10], the no. of rotor slots N_R = 40, the slip s = 0.00394, and the synchronous speed $n_s = f_1/p$ = 50 revolutions per second.

In order to demonstrate the sensitivity of the twin harmonic amplitude to the degree of static eccentricity, the calculations were performed also for the cases of 60% and 70% static eccentricity.

The stator current spectrum of fig. 3 refers to the case of 60% static eccentricity. In this spectrum the twin harmonic tw is clearly visible having amplitude of about -70 dB as compared to about -74 dB in case of 50% static eccentricity. Similarly, in Fig. 4, referring to the case of 70% static eccentricity, the amplitude of the twin harmonic tw increased up to about -67 dB which proves that the twin harmonic amplitude is sensitive enough to the level of static eccentricity.

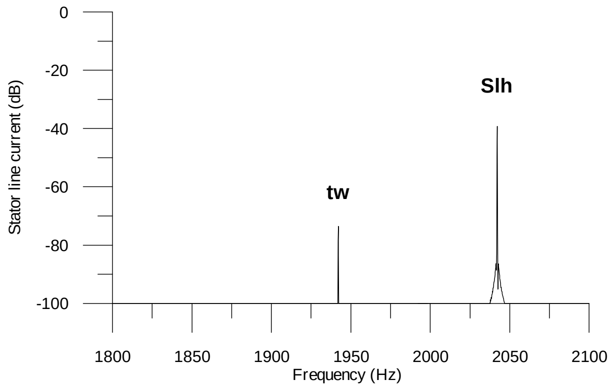

Fig. 2 (b) Zoom of the main slot harmonic zone (50% static eccentricity)

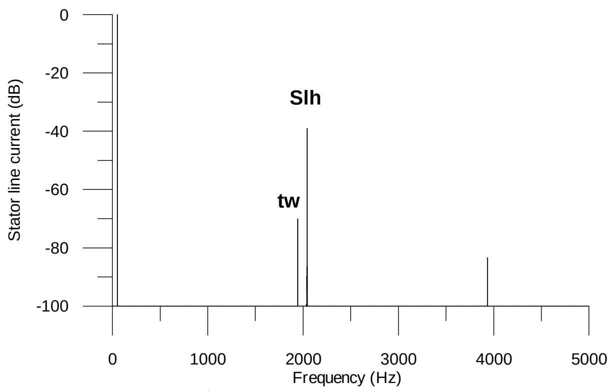

Fig. 3 Spectrum of the calculated stator current (60% static eccentricity)

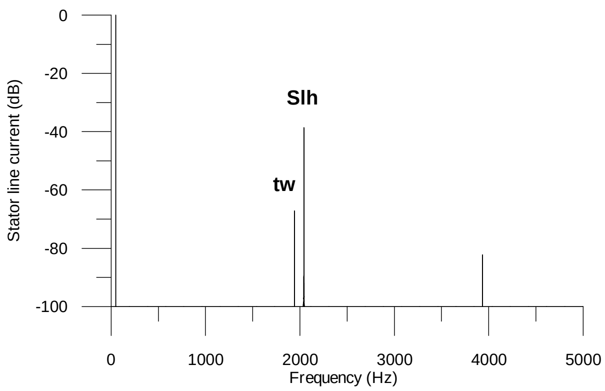

Fig. 4 Spectrum of the calculated stator current (70% static eccentricity)

IV. Dynamic Eccentricity

The dynamic eccentricity was simulated considering a certain displacement from the geometrical center to the axis of rotation, toward specified rotor tooth [11].

The stator current spectrum of fig. 5 (a) refers to the case of 50% dynamic eccentricity. The spectrum does not contain any harmonics around the 50 Hz fundamental harmonic.

By contrast to this, the main slot harmonic zone contains two harmonics around the main slot harmonic. They are labeled as dt_{-2} and ds_{+2} as shown in fig. 5 (b).

The zoom of the main slot harmonic zone, shown in fig. 5 (b), indicates that the harmonic dt_{-2} is spaced by about $2(1-s)f_1/p$ to the left of the potential twin harmonic.

(The potential twin harmonic is the one which could appear if there were some static eccentricity).

It has a frequency of about 1842.5 Hz and its amplitude reaches the level of about -82 dB. Whereas, the harmonic ds_{+2} is spaced by about $2(1-s)f_1/p$ to the right of the main slot harmonic. It has a frequency of about 2142 Hz and its amplitude reaches the level of about -80 dB.

The stator current spectrum shown in fig. 6 refers to the case of 60% dynamic eccentricity. It again does not contain any important harmonics around the 50 Hz fundamental harmonic, a part of the harmonic of the frequency of about 250 Hz, which has practically negligible amplitude.

Whereas, the main slot harmonic zone contains practically the same harmonics dt_{-2} and ds_{+2} to the left of the potential twin harmonic and to the right of the main slot harmonic, respectively.

These harmonics possess the same frequencies as in the previous case of 50% dynamic eccentricity, fig. 5 (a), but their amplitudes are magnified as shown in fig. 6.

That proves that these harmonics dt_{-2} and ds_{+2} represent quite good indication of the dynamic eccentricity.

The spectrum of fig. 7 refers to the case of 70% dynamic eccentricity. The fundamental harmonic zone does not contain important harmonics, except for the harmonic of the frequency of about 250 Hz, to the right of the fundamental one, but its amplitude is practically negligible.

In similar manner, as in the previous cases of dynamic eccentricity, the main slot harmonic zone contains the dynamic eccentricity harmonics dt_{-2} and ds_{+2}, as shown in fig. 7.

It is to be noted that the amplitudes of these harmonics, dt_{-2} and ds_{+2}, increased to the levels of -75 dB and -73 dB, as compared to -82 dB and -80 dB, respectively, in the previous case of 50% dynamic eccentricity. That proves the sensitivity of these harmonics to the degree of the dynamic eccentricity.

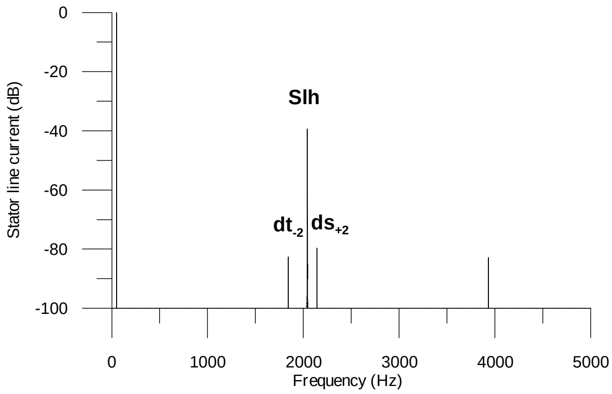

Fig. 5 (a) Spectrum of the calculated stator current (50% dynamic eccentricity)

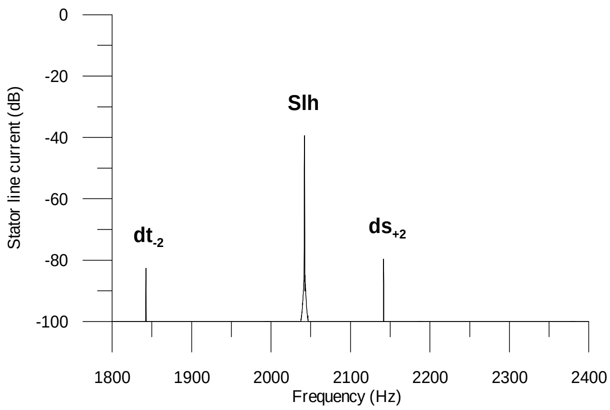

Fig. 5 (b) Zoom of the main slot harmonic zone (50% dynamic eccentricity)

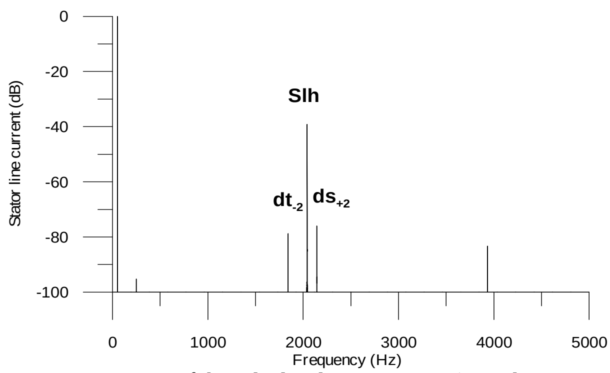

Fig. 6 Spectrum of the calculated stator current (60% dynamic eccentricity)

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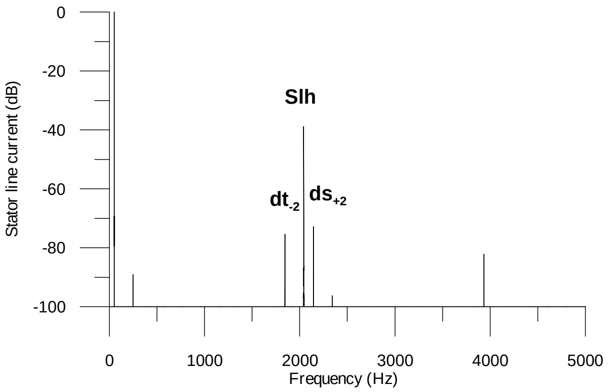

Fig. 7 Spectrum of the calculated stator current (70% dynamic eccentricity)

V. Case Studies

Spectral analyses have been performed for a number of currents really registered in the industry. The registered currents are referred to the one pole pair, 3.15 MW, induction machines.

Among all the cases analyzed there were some cases found to show up some degree of dynamic eccentricity.

In the following there is one example of dynamic eccentricity.

The full spectrum of the measured stator current is shown in Fig. 8 (a). The zoom around the 50 Hz fundamental harmonic is shown in fig. 8 (b). It contains the 2nd, 3rd, 5th and 7th harmonics of the supply system.

The zoom of the main slot harmonic zone is shown in Fig. 8 (c). The spectrum does not contain the twin harmonic, of the frequency of about 1942 Hz, to the left of the main slot harmonic. That proves the lack of static eccentricity in this case. Whereas, the dynamic eccentricity harmonics, dt_{-2} and ds_{+2} of the frequencies of about 1842 and 2142 Hz, are clearly visible to the left and to the right of the main slot harmonic, respectively. That gives clear indication for the dynamic eccentricity in this case.

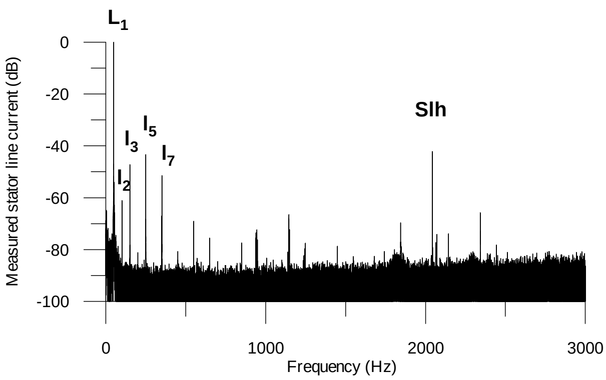

Fig. 8 (a) Spectrum of the measured stator current

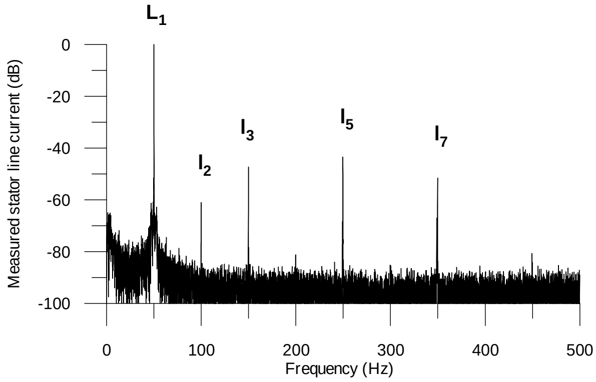

Fig. 8 (b) Zoom around 50 Hz of the measured stator current

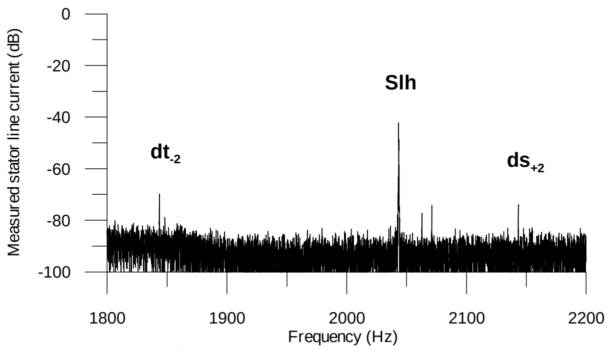

Fig. 8 (c) Zoom of the main slot harmonic zone of the measured stator current

VI. Conclusion

1. Pure static eccentricity is characterized by a pair of 100 Hz spaced harmonics in the main slot harmonic zone. This pair of harmonics consists of the main slot harmonic which is always present, independently of the static eccentricity, and the twin harmonic which gives evidence for the static eccentricity.
2. The amplitude of the twin harmonic is affected by the degree of the static eccentricity.
3. Pure dynamic eccentricity is characterized by the following harmonics:

- One harmonic spaced by two times rotational speed to the right of the main slot harmonic.
- One pair of harmonics around the potential twin harmonic. They are again spaced by two times rotational speed above and below the potential twin harmonic.

In this case of the 3.15 MW machine (p=1& h=1) the harmonic to the right of the potential twin harmonic was interfered with the main slot harmonic. So, only the one to the left of the potential twin harmonic was visible.

4. Quantitative calculations deliver solid base for reliable diagnosis of induction machines and differentiating between different ailments.

References

[1]. V. Devanneaux, H. Kabbaj, B. Dagues, and J. Faucher, "A versatile model of squirrel cage induction machines for design, monitoring and diagnosis purposes," *9th European Conference on Power Electronics and Applications*, Auguest, 2001.

[2]. A. Bellini, F. Filippetti, G. Franceschini, and C. Tassoni, "Towards correct quantification of induction machines broken bars through input

electrical signals", *International Conference on Electrical Machines*, ICEM'2000, 28-30 August 2000, Espoo, Finland, pp. 781-785.

[3]. A. Bellini, F. Filippetti, G. Franceschini, and C. Tassoni, "Quantitative evaluation of induction motor broken bars by means of electrical signature analysis", *IEEE, Transactions on Industry Applications*, vol. 37 No. 5, pp. 1248-55. 2001.

[4]. A. Lebaroud, A. Bentousi, A. Kkhezzar, M. Boucherma. "Effects of broken bar of induction motor with stator asymmetry and distorted supply ", *International Conference on Electrical Machines*, ICEM'2004, 5-8 September 2004, Cracow, Poland, pp. 795-796.

[5]. Saleh Elawgali. "Effect of combined eccentricities on the spectrum of induction machine currents", *XL International Symposium on Electrical Machines*, SME'2004, 15-18 June 2004, Hajnowka, Poland, pp. 457-462.

[6]. Saleh Elawgali. "Current spectrums of a 3.15 MW induction machine based on diagnostic oriented calculations ", *Elektrotechnika i Elektronika, AGH Uczelniane Wydawnictwa Naukowo-Dydaktyczne*, tom 23. zeszyt 1, pp. 14-26, Krakow 2004.

[7]. Saleh Elawgali. "Effect of eccentricities and cage asymmetry on the induction machine currents, considering deformation of supply voltages", *International Conference on Electrical Machines,* ICEM'2004, 5-8 September 2004, Cracow, Poland, pp. 443-444.

[8]. J. Rusek, "Computer implementation of induction machine dynamical model accounting for broken bars, eccentricities, slotting and parallel branches", *International Conference on Electrical Machines*, ICEM'2000, 28-30 August 2000, Espoo, Finland, pp. 868-872.

[9]. J. Rusek, "Category, slot harmonics and the torque of induction machines", *The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, COMPEL, vol. 22 no. 2, pp. 388-409, 2003.

[10]. J. Rusek, "Categorization of induction machines resulting from their harmonic-balance model", *Electromagnetics*, vol. 23, No. 3, April 2003, Taylor & Francis, pp. 277-292.

[11]. V. Devanneaux, H. Kabbaj, B. Dagues, and J. Faucher, "An accurate model of squirrel cage induction machines under static, dynamic or mixed eccentricity", *IEEE International Symposium on Diagnostics for Electric Machines, Power Electronics and Drives*, SDEMPED, 1-3 September 2001, Grado, Italy, pp. 121-126.

[12]. W. T. Thomson, and A. Barbour, "On-line current monitoring and application of a finite element method to predict the level of static air gap eccentricity in three-phase induction motors", *IEEE Transaction on Energy Conversion*, vol. 13, No. 4, December 1998, pp. 347-354.