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The Effect of Dynamic Eccentricity on the Stator Current Spectrum of 550 kW Induction Motor

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***Abstract*— In order to present the effect of the dynamic eccentricity on the stator currents of squirrel cage induction machines, the current spectrums of a 550 kW induction motor was calculated for the cases of full symmetry and dynamic eccentricity. The calculations presented in this paper are based on the Poly-Harmonic Model accounting for static and dynamic eccentricity, stator and rotor slotting, parallel branches as well as cage asymmetry. The calculations were followed by Fourier analysis of the stator currents in steady state operation. The paper presents the stator current spectrums for full symmetry 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.

***Index Terms*—Current spectrum, dynamic eccentricity, harmonics, induction machine, slot harmonic zone.**

I. INTRODUCTION

Induction machines play a very important rule in the world's industrial life. Among them, the squirrel cage induction motor which is frequently used because of its relatively simple, robust construction and its low price. Design and analysis of new induction motors remain an important topics in electrical engineering [1]. Besides, the strong industrial demand for reliable and safe operation of induction 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. Many calculations have been performed by the author [2], [3], [4] dealing with diagnosing rotor asymmetries. These calculations, as well as the one presented in this paper, 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 [5] 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 and different degrees of dynamic eccentricity and demonstrate the effect of dynamic eccentricity ailment via predicting the harmonics contained in stator current spectrums in this case. The spectrums presented in this paper rely on calculations performed using a special software AS [6], owned by the Chair of Electrical Machines, AGH University of Science and Technology, Cracow, Poland. 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 550 kW squirrel-cage induction machine, possessing four pole pairs (p=4), N_S/N_R = 72/88 of stator/rotor slots. All current spectrums refer to the steady state operation, by full loading torque TL = 7051 Nm.

II. PFULL 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 1140.7 Hz and amplitude of about -33 dB. The spectrum contains also the second slot harmonic of the frequency of about 2130 Hz. The frequency of the main slot harmonic can be predicted by the following formula [7], :

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

Where: the supply frequency f_1 = 50 Hz, the parameter h = 1 [8], the no. of rotor slots N_R = 88, the slip s = 0.0084558, and the synchronous speed $n_s = f_1/p$ = 12.5 revolutions per second.

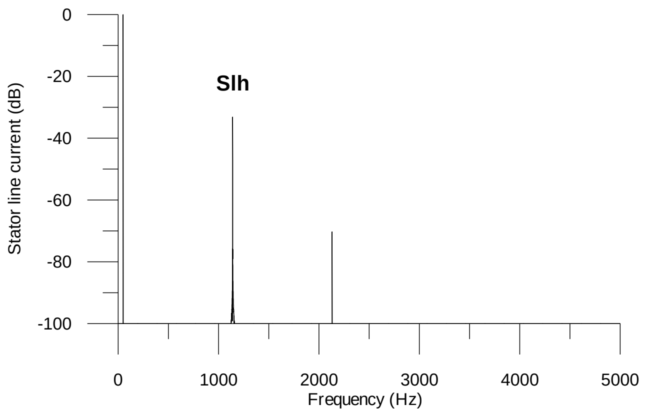

Fig. 1 Spectrum of the calculated stator current, (Full symmetry)

III. DYNAMIC ECCENTRICITY

The dynamic eccentricity was simulated considering a certain displacement from the geometrical center to the axis of rotation, toward specified rotor tooth [9], [10]. The stator current spectrum of fig. 2 (a) refers to the case of 50% dynamic eccentricity. The zoom of this spectrum around the 50 Hz fundamental harmonic is shown in fig. 2(b). It does not contain any important harmonics, except the harmonic of the frequency of about 25 Hz, to the left of the 50 Hz harmonic, but it has practically negligible amplitude. Whereas, the main slot harmonic zone, as shown in Fig.2(c), contains the dynamic eccentricity harmonic $ds_{+2,}$ that is the one spaced by about $2(1\text{-}s)f_1/p$ to the right of the main slot harmonic Slh. The frequency of the dynamic eccentricity harmonic ds_{+2} is about 1165.5 Hz and its amplitude is about -69 dB. Also, the spectrum contains the dynamic eccentricity harmonics dt_{+2} and $dt_{-2,}$ which are spaced by about ± $2(1\text{-}s)f_1/p$ around the potential twin harmonic. (The potential twin harmonic is the one which could appear if there were some static eccentricity). The frequencies of these dynamic eccentricity harmonics are about 1065.5 and 1016 Hz, and their amplitudes are about -74 and -78 dB, respectively. Similarly, another pair of dynamic eccentricity harmonics appeared around the potential twin harmonic, those are the harmonics which are labeled as, dt_{+4} and dt_{-4}. They are spaced by about ± $4(1\text{-}s)f_1/p$ above and below the potential twin harmonic, but their amplitudes are practically negligible.

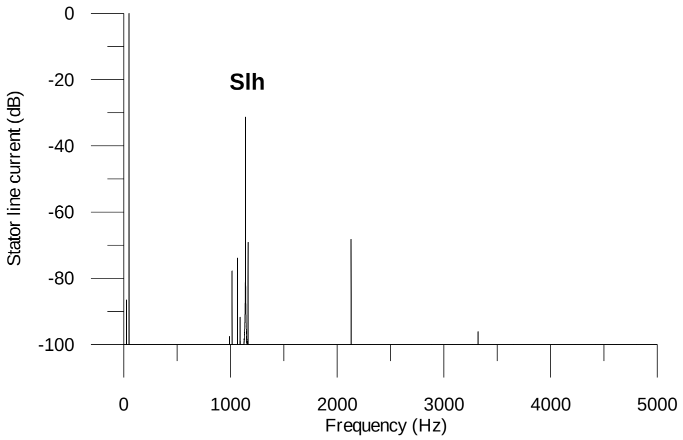

Fig. 2 (a) Spectrum of the calculated stator current, (50% dynamic eccentricity)

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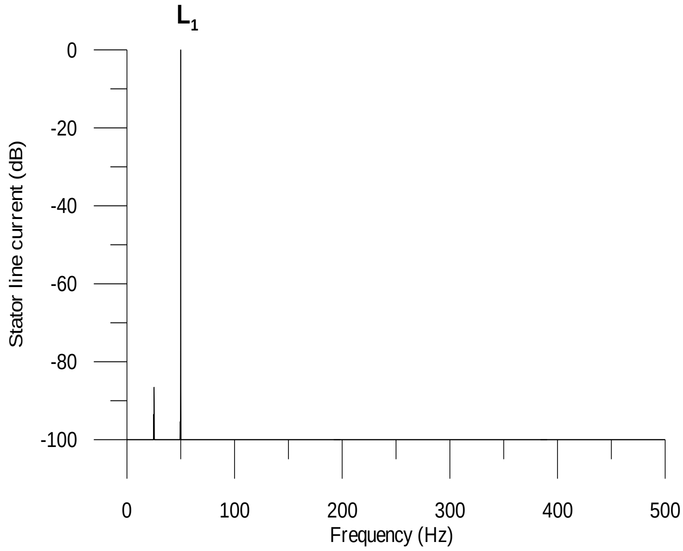

Fig. 2 (b) Zoom around 50 Hz, (50% dynamic eccentricity)

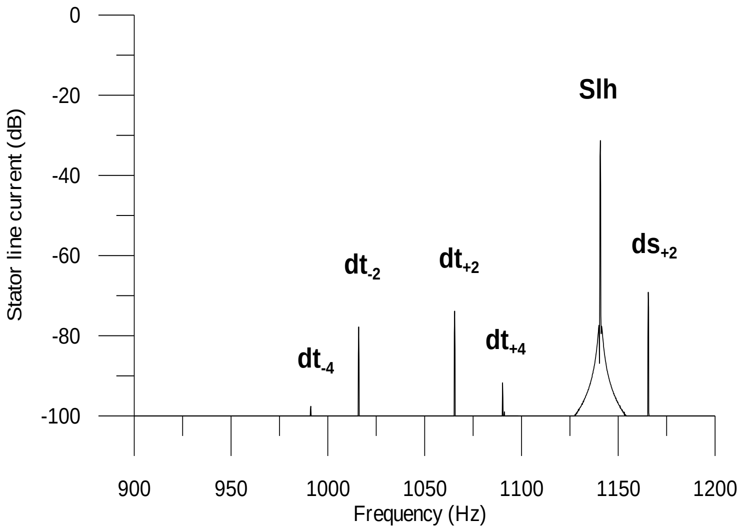

Fig. 2 (c) Zoom of the main slot harmonic zone, (50% dynamic eccentricity)

The next spectrum of fig. 3(a) refers to the case of 60% dynamic eccentricity. The zoom of this spectrum around the 50 Hz fundamental harmonic is shown in fig. 3(b). It contains the harmonic of the frequency of about 25 Hz, to the left of the 50 Hz one, but it is of minor importance for the diagnostic purposes.

In the zoom of the main slot harmonic zone, shown in fig.3(c), the dynamic eccentricity harmonic ds_{+2} is quite conspicuous to the right of the main slot harmonic Slh. It has the same frequency as in the previous case of 50% dynamic eccentricity, whereas its amplitude magnified to the level of about -66 dB, as a result of increment of the dynamic eccentricity degree to 60% in this case. That proves the sensitivity of this harmonic to the dynamic eccentricity degree.

Similarly, the dynamic eccentricity harmonics dt_{+2}, dt_{-2}, dt_{+4} and dt_{-4} are present around the potential twin harmonic. It should be noted that their amplitudes are magnified as compared to the previous case of 50% dynamic eccentricity.

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That gives clear indication that the amplitudes of these harmonics are affected by the increment of the dynamic eccentricity degree.

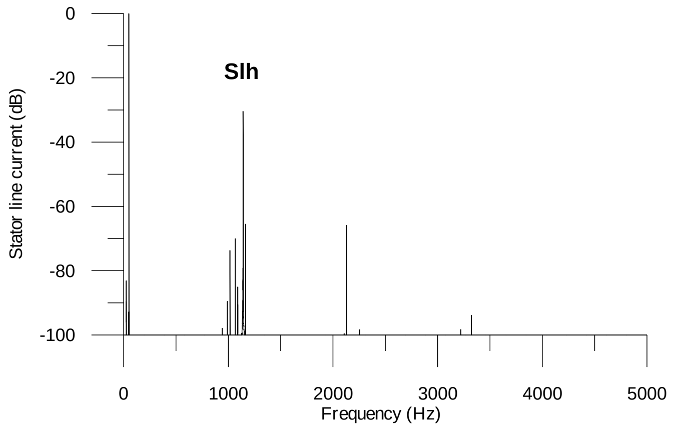

Fig. 3 (a) Spectrum of the calculated stator current, (60% dynamic eccentricity)

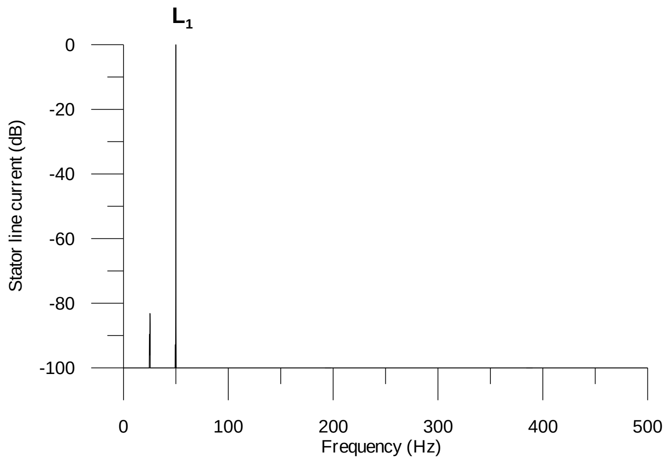

Fig. 3 (b) Zoom around 50 Hz, (60% dynamic eccentricity)

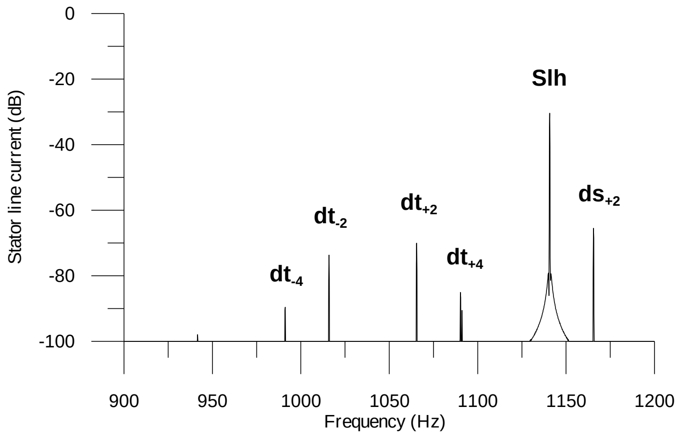

Fig. 3 (c) Zoom of the main slot harmonic zone, (60% dynamic eccentricity)

The spectrum of fig.4 (a) refers to the case of 70% dynamic eccentricity. The zoom of this spectrum around the

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50 Hz fundamental harmonic is shown in fig. 4(b). It contains the harmonics of the frequencies of about 25 and 100 Hz, to the left and the right of the 50 Hz, respectively, but both are of no importance for the diagnostic purposes.

In the zoom of the main slot harmonic zone, shown in fig. 4(c), all the dynamic eccentricity harmonics, whether to the right of the main slot harmonic or around the potential twin harmonic, are present with higher amplitudes as compared to the previous cases of 50% and 60% dynamic eccentricity.

The amplitude of the dynamic eccentricity harmonic ds_{+2}, of the frequency of about 1165.5 Hz, is now reaching the level of -62 dB, as compared to -69 dB in the case of 50% dynamic eccentricity. That proves that, this harmonic is very promising for diagnosing the dynamic eccentricity.

Also, the amplitudes of the dynamic eccentricity harmonics dt_{+2} and $dt_{-2,}$ of the frequencies of about 1065.5 and 1016 Hz, are now reaching the levels of -67 and -70 dB, as compared to -74 and -78 dB, respectively, in the case of 50% dynamic eccentricity. That allows relying on these harmonics, too, as additional signs for dynamic eccentricity.

The amplitudes of the second pair of dynamic eccentricity harmonics dt_{+4} and $dt_{-4,}$ around the potential twin harmonic, do not trespass the level of about -80 dB, even for high degree of dynamic eccentricity (70%). That makes these harmonics of lower priority in diagnosing dynamic eccentricity.

The spectrum of fig. 4(c), that refers to the case of 70% dynamic eccentricity, contains another harmonic of the frequency of about 942 Hz, but it is of no diagnostic importance.

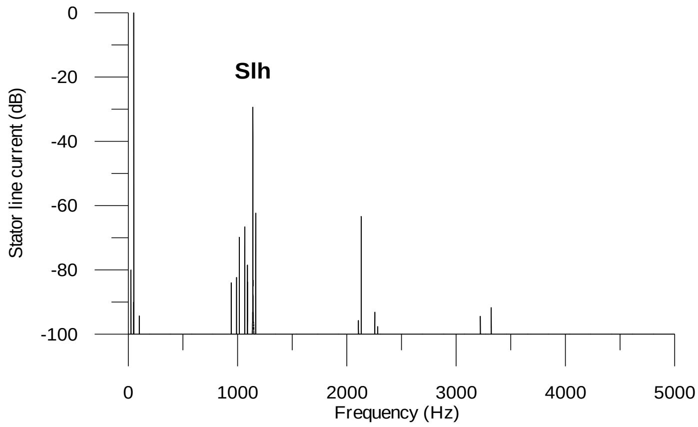

Fig. 4 (a) Spectrum of the calculated stator current, (70% dynamic eccentricity)

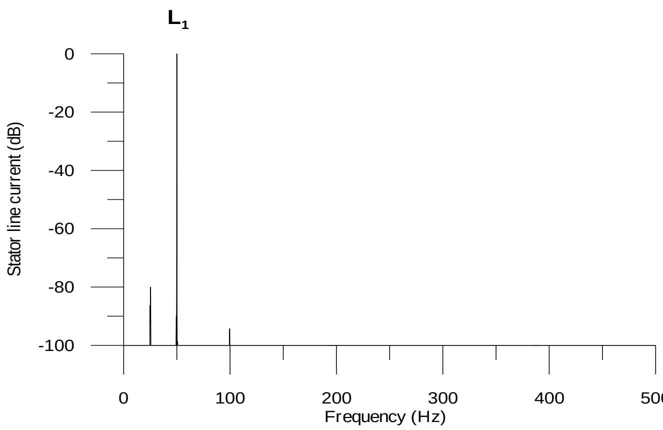

Fig. 4 (b) Zoom around 50 Hz, (70% dynamic eccentricity)

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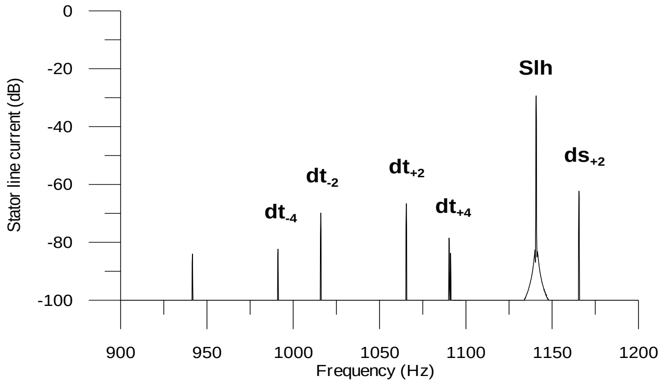

Fig. 4 (c) Zoom of the main slot harmonic zone, (70% dynamic eccentricity)

IV. CONCLUSION

1. Pure dynamic eccentricity is characterized by the following harmonics:
- One harmonic spaced by about 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 about two times rotational speed above and below the potential twin harmonic.
2. The calculations proved that the main slot harmonic zone is, from diagnostic point of view, the most important one, as it contains diagnostic information, in form of important diagnostic harmonics.
3. Quantitative calculations deliver solid base for reliable diagnosis of induction machines and differentiating between different eccentricity ailments.

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