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Diagnosis of Static Eccentricity in 400 kW Induction Machine Based on the Analysis of Stator Currents

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Abstract. Current spectrums of a four pole-pair, 400 kW induction machine were calculated for the cases of full symmetry and static 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.
Zooms of the current spectrums, around the 50 Hz fundamental harmonic as well as of the main slot harmonic zone, were included.

The spectrums included in this paper are referred to both calculated and measured currents.

Key words

Diagnostic, Harmonic, Induction Machine, Spectrum.

1. Introduction

In an industrialized country, induction machines consume between 40 to 50% of all the generated energy of that country [1].
Hence, it is natural that there is a strong industrial demand for reliable and safe operation of induction machines, as faults and failures of critical electromechanical parts can indeed lead to excessive downtimes and generate costs of millions of dollars in reduced output, emergency maintenance and lost revenues.
That is why the industry is interested in adopting diagnosis techniques to assess and evaluate current condition of electrical machines.
Mature procedures have been elaborated by many researchers [2]-[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 effect of the static eccentricity on the spectrum of the induction machine stator currents. The paper will also present the spectrum in case of healthy machine and demonstrate the difference between the two cases via comparing the harmonics contained in stator current spectrum in each case.
The calculations performed refer to the 400 kW squirrel-cage induction machine, with 4-pole pairs (p=4) and N_S/N_R = 72/88 of stator/rotor slots.
All spectrums refer to steady state operation by full loading torque TL = 5162 Nm.

2. Full Symmetry

As a reference basis, the calculation of the stator current spectrum was performed for full symmetrical machine. The stator current spectrum, shown in fig.1, refers to full symmetrical machine. It contains the 50 Hz fundamental harmonic and the main slot harmonic Slh, of the frequency of about 1139.7 Hz, and its amplitude is about -47 dB. Also, the spectrum contains the second slot harmonic of the frequency of about 2129 Hz but it falls out of our interest. The frequency of the main slot harmonic can be predicted by the following formula [8], [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 number of rotor slots N_R = 88, the slip s = 0.00935, and the synchronous speed $n_s = f_1/p$ = 12.5 revolutions per second.

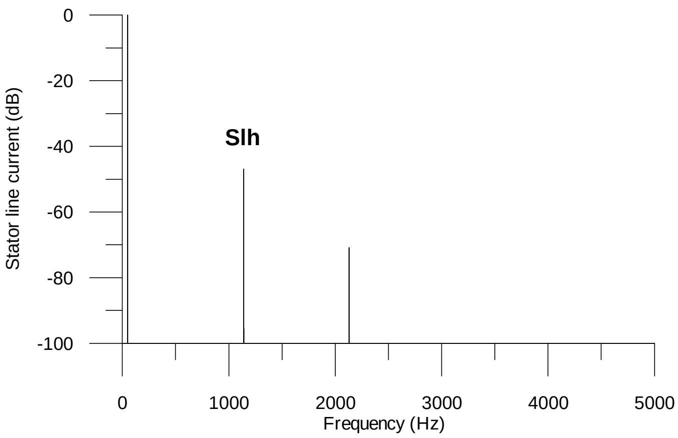

Fig. 1. Spectrum of the calculated stator current (full symmetry)

3. 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].
The spectrum of the stator current of fig. 2 refers to the case of 50% static eccentricity. It does not contain any new harmonics as compared to the spectrum of fig.1, which referred to full symmetrical case. It means that the 50% static eccentricity is not enough to produce any changes to the spectrum of the stator current.

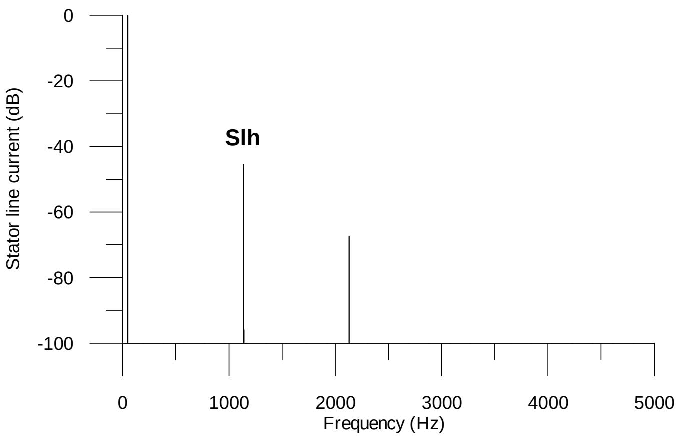

Fig. 2. Spectrum of the calculated stator current (50% static eccentricity)

The next stator current spectrum, shown in fig. 3, refers to the case of 60% static eccentricity. In this spectrum the twin harmonic tw, of the frequency of about 1039.7 Hz is present with quite small amplitude of about -86.5 dB. It is spaced by about 100 Hz to the left of the main slot harmonic Slh, as shown in fig. 4. Normally the presence of the twin harmonic gives an indication for the static eccentricity. However, in the case of this machine, the amplitude of the twin harmonic tw is so small, that diagnosis of 60% static eccentricity is practically not possible. The frequency of the twin harmonic tw, to the left of the main slot harmonic, can be predicted by the following formula [8], [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 number of rotor slots N_R = 88, the slip s = 0.00935, and the synchronous speed $n_s = f_1/p$ = 12.5 revolutions per second.

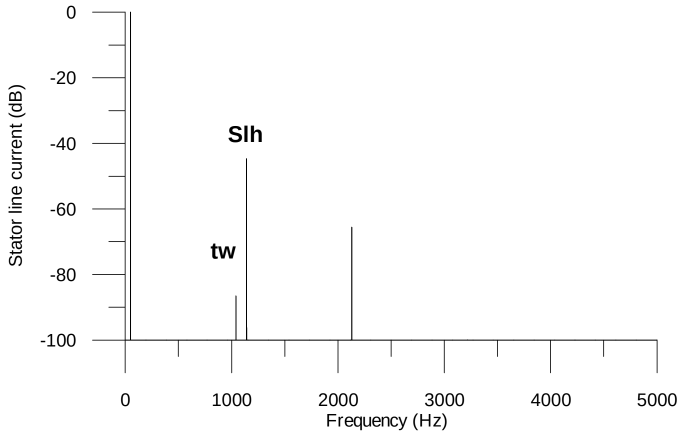

Fig. 3. Spectrum of the calculated stator current (60% static eccentricity)

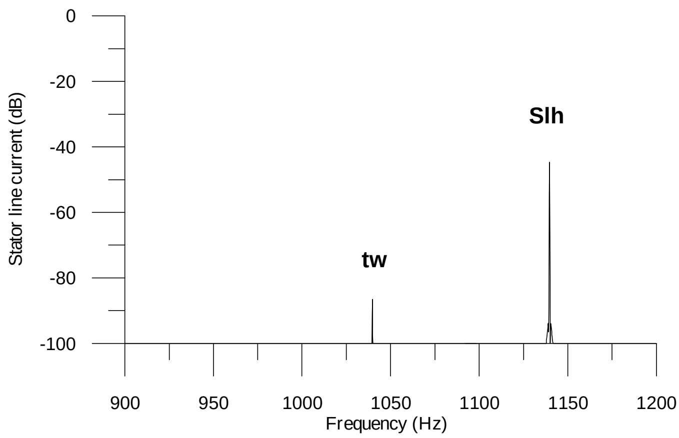

Fig. 4. Zoom of the main slot harmonic zone of the calculated stator current (60% static eccentricity)

The calculations have also been performed for the case of 70% static eccentricity. The spectrum of the stator current, as shown in fig. 5, contains again the twin harmonic tw to the left of the main slot harmonic Slh.
As shown in fig. 6, the amplitude of the twin harmonic tw increased up to about -73 dB, as compared to about -86.5 dB in the previous case of 60% static eccentricity, which means that the amplitude of the twin harmonic is affected positively by the increment of to the static eccentricity degree, higher than 60%, in this case.

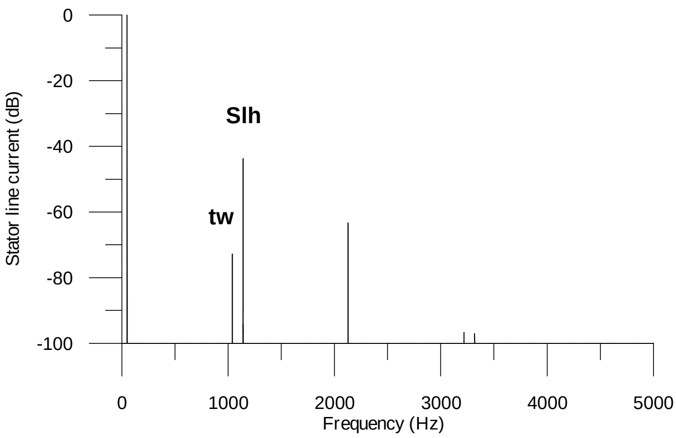

Fig. 5. Spectrum of the calculated stator current (70% static eccentricity)

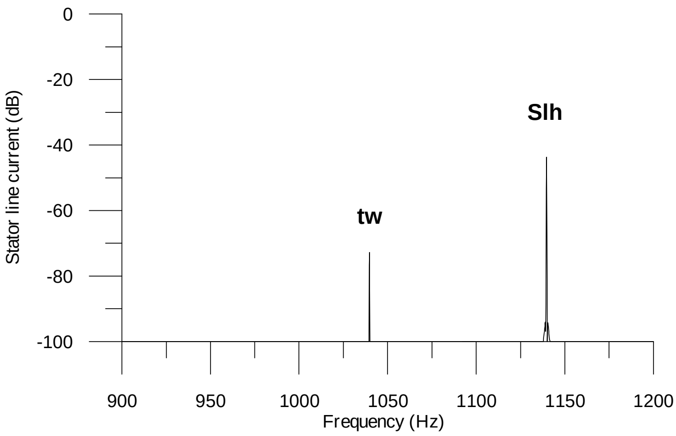

Fig. 6. Zoom of the main slot harmonic zone of the calculated stator current (70% static eccentricity)

4. Case Study

Spectral analyses have been performed for a number of currents really registered in the industry.

The currents analyzed refer to a number of four pole pairs, 400 kW induction machines, labeled in the industry as WP.

Among all the analyzed cases, there were some cases found to show up some static eccentricity.

In the following there are two examples of the really measured currents, referring to the WP, 400 kW, machines, (files names 3WP2U2 and 1WP1U2).

These two cases were classified as static eccentricity ones, due to the presence of the twin harmonic tw, to the left of the main slot harmonic Slh, as shown in figs. 9 and 12.

It delivers clear evidence for the static eccentricity in these cases.

Hence, these two cases were classified as showing up pure static eccentricity.

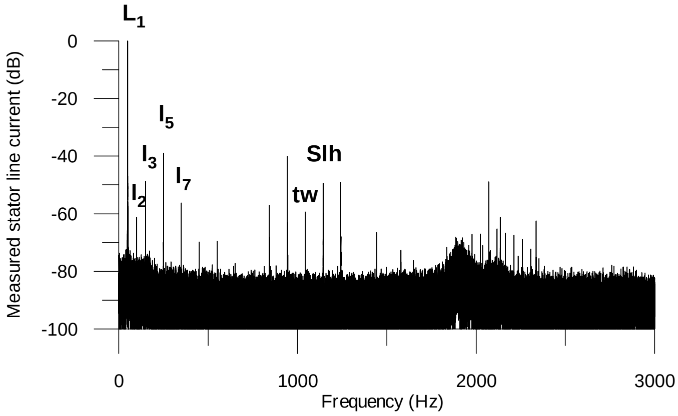

Fig. 7. Spectrum of the measured stator current (3WP2U2)

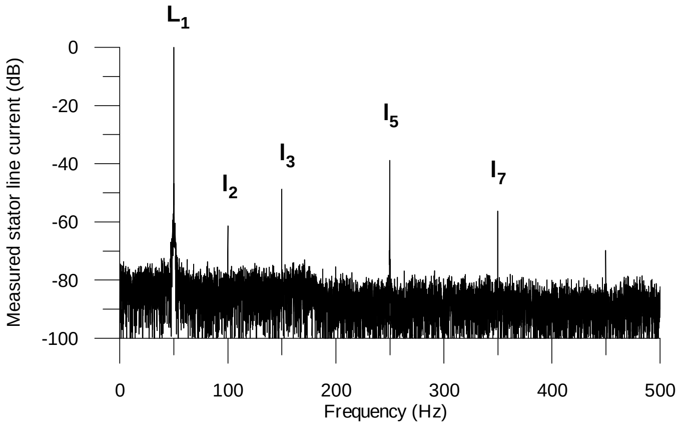

Fig. 8. Zoom around 50 Hz of the measured stator current (3WP2U2)

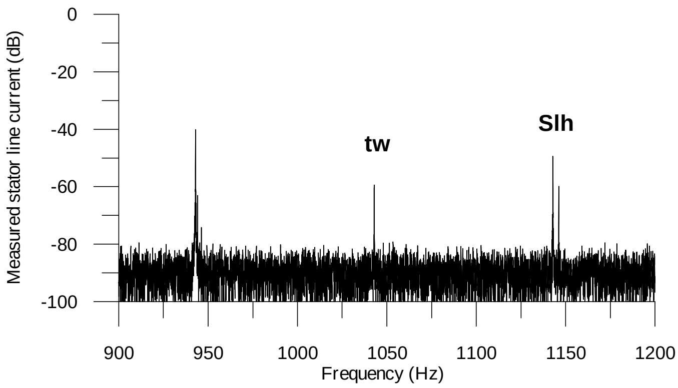

Fig. 9. Zoom of the main slot harmonic zone of the measured stator current (3WP2U2)

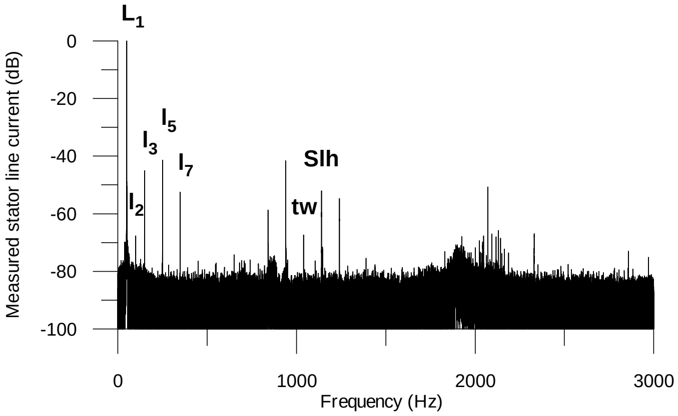

Fig. 10. Spectrum of the measured stator current (1WP1U2)

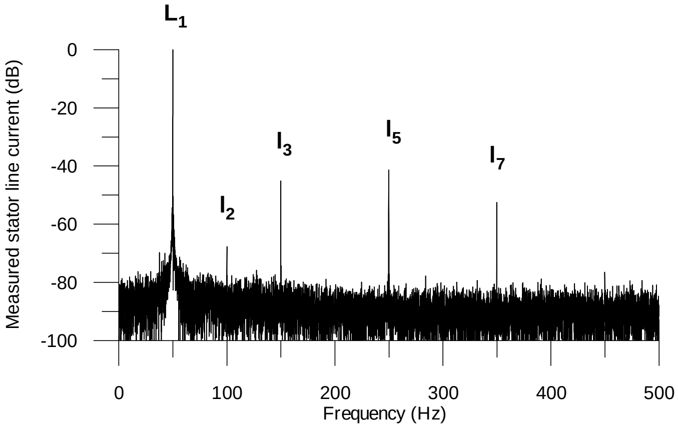

Fig. 11. Zoom around 50 Hz of the measured stator current (1WP1U2)

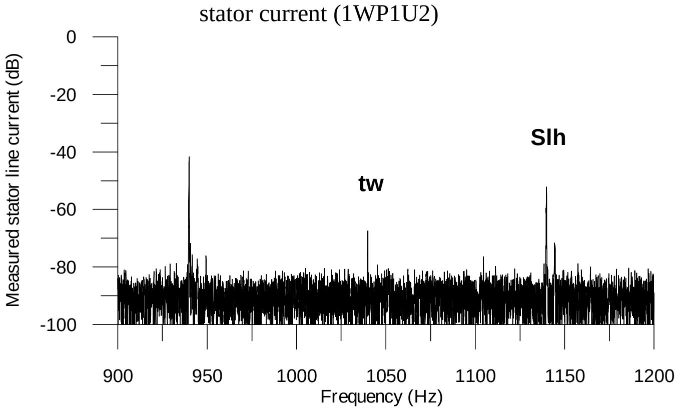

Fig. 12. Zoom of the main slot harmonic zone of the measured stator current (1WP1U2)

5. Conclusion

The Calculations performed and the case study allow concluding that:

1. The visibility of the twin harmonic, as an indication for existence of the static eccentricity, was possible only for higher degrees of static eccentricity, > 60% in this case.
2. The presence of the twin harmonic in the main slot harmonic zone gives clear evidence for the existence of the static eccentricity.
3. Quantitative calculations deliver solid base for reliable diagnosis of induction machines and differentiating between different ailments.

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