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Original article

Induction machine magnetic noise: Impact of a new stator magnetic circuit design

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Abstract

The main topic of this paper is to examine the impact on induction machine magnetic noise of a new stator magnetic circuit design. This new design was developed in order to increase AC machine energetic performance by assembling non-segmented shifted grain-oriented steel sheets which make it possible to reduce iron losses. Experimental results on induction machine efficiency increase are presented and justified using reluctance network simulations. An analysis, finally, shows and explains how this structure behaves considering acoustic magnetic noise in a Pulse Width Modulation supply case.

Keywords: Magnetic circuit; Grain oriented steel; Iron losses; Induction machine; Reluctance network; Magnetic noise reduction

1. Introduction

Induction machines are widely used in industry because of their reliability and simple construction, so their efficiency increase is of some interest [1]. In the same time, the problem of magnetic noise have become more significant and of concern in industry applications. Standards are becoming more stringent. Consequently, it is absolutely necessary to be sure that this efficiency increase is not accompanied by a magnetic noise increase.

The study presented in this paper concerns small or medium induction machine operating at variable speed drives by using pulse width modulation (PWM) voltage supply. The considered induction machine has its Stator magnetic circuit (SMC) designed with non-segmented shifted grain-oriented (GO) sheets in order to reduce the iron losses [4,14]. The target is to analyze the impact of this new assembly on the magnetic noise [6,8].

First of all, theoretical considerations on the magnetic noise in rotating machines are exposed. The second part is devoted to a brief recall of the theoretical basis concerning the GO steel and the new SMC design. The redesigned induction motors are also presented as well as some results on efficiency. A reluctance network (RN) is proposed in the third part in order to explain the involved phenomena taking place inside the proposed SMC structure submitted

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Abbreviations: GO, grain oriented; NO, non-oriented; RD, rolling direction; SMC, stator magnetic circuit; SRE, slotting resonance effect.

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to a unidirectional field. The noise spectra obtained on the previous machines are presented in the fourth part. As an important result, it appears that not only the noise does not increase but that it is reduced. The last part is dedicated to a discussion on the possible causes which lead to this noise decrease; a physical interpretation of the results to justify the anisotropy impact on noise is also suggested.

2. Induction machine magnetic noise

The induction machine magnetic noise mostly comes from different harmonic sources.

(1) The spatial distribution of the windings in a finite number of slots (space harmonics) and the reluctance effects due to the slotting.
(2) The possible eccentricity of the rotor.
(3) The saturation of the magnetic circuit.
(4) The supply harmonics.

This magnetic noise results from the non-static F Maxwell force [12,18] expressed per area unit as:

$$F = \frac{b^2}{2\mu_0} \tag{1}$$

where $\mu_0 = 4\pi e^{-7}$ H/m. b is the air-gap flux density which can be defined as the product of the ε air-gap mmf and the Λ permeance per area unit:

$$b = \Lambda\varepsilon \tag{2}$$

In the next, saturation and eccentricity are neglected and the following notations are used:

- p: pole pair number,
- ω: fundamental angular frequency (frequency f),
- k: supply harmonic rank (upper index),
- h: mmf harmonic rank (lower index),
- N^s, N^r: stator and rotor total slot numbers,
- k_r, k_s: slotting harmonic ranks (lower indexes),
- d^s, d^r: statoric and rotoric spatial references,
- α^s: spatial angle which locates any air-gap point relatively to d^s,
- θ: spatial angle between d^r and d^s: $\theta = (1 - s^{(1)})\omega t/p$,
- $s^{(1)}$: slip relative to the fundamental term ($k = 1$).

Neglecting the phase angles which intervene in the variable definitions and denoting $\hat{x}$ the maximal x value, it comes:

$$\Lambda = \sum_{k_r,k_s} \Lambda_{k^s k^r} \cos[(k_s N^s + k_r N^r)\alpha^s - k_r N^r \theta] \tag{3}$$

$$\varepsilon = \sum_{k,h} \hat{\varepsilon}_h^{(k)} \cos[k\omega t - ph\alpha^s] \tag{4}$$

So, b can be expressed as:

$$\left.\begin{aligned} b &= \sum_k b^{(k)} \\ b^{(k)} &= \sum_{h,k_r,k_s} b_{h,k_r,k_s}^{(k)} \\ b_{h,k_r,k_s}^{(k)} &= \hat{b}_{h,k_r,k_s}^{(k)} \cos[\Delta_{k_r}^{(k)}\omega t - P_{h,k_r,k_s}\alpha^s] \end{aligned}\right\} \tag{5}$$