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► **To cite this version:**

Sijie Ni, Grégory Bauw, Raphael Romary, Cassoret Bertrand, Jean Le Besnerais. Damper winding for noise and vibration reduction of permanent magnet synchronous machine. 20th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering (ISEF), Sep 2021, Cracow, Poland. hal-04289962

HAL Id: hal-04289962

<https://univ-artois.hal.science/hal-04289962>

Submitted on 10 Jan 2024

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Damper winding for noise and vibration reduction of Permanent Magnet Synchronous Machine

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Abstract—In this paper, a new passive method for noise reduction of Permanent Magnet Synchronous Machine (PMSM) is presented: the principle is to add an auxiliary three-phase winding into the same slots as the initial stator winding, in short circuit via three capacitors of suitable values. The aim is to create a damping effect for stator flux density harmonic components in the air gap in order to reduce the noise and vibration of PMSM. The method can significantly reduce the sound pressure level and vibrations for specific frequencies. Because of passive features, the additional winding effectively mitigates magnetic noise without greatly increasing the complexity of design and manufacturing, which also extends its applicability to different PMSMs.

Index Terms—PMSM, damper winding, noise, harmonic, passive

I. INTRODUCTION

As electrical machines are used more widely, magnetic noise and vibration are getting more and more attention. As a result of flux density harmonics, magnetic noise is sometimes harsher and rougher than mechanical noise. Its acoustic features vary according to the mechanical structure, power source and rotational speed. Lots of previous researches propose how to design and optimize a silent machine. As more and more various machines and PWM strategies appear, active and passive methods are proposed in order to reduce the noise. A few years ago, the laboratory LSEE proposed a new passive method which allows damping flux density harmonics and magnetic noise in induction machines [1]. Inspired by this study, this paper extends the approach to PMSMs. Firstly, magnetic noise and its origin on AC rotating machines are recalled. Then, the principle of the passive method is presented, explaining the installation and disposition of the auxiliary winding within stator slots. Finally, simulation results based on finite element method (FEM) are given.

II. ORIGINS OF NOISE AND VIBRATIONS

A. Flux density harmonics

Generally, AC machine creates a rotating field in the air gap that interacts with the magnetic field generated by Permanent Magnet (PM)s which leads to the rotation of the rotor. Actually the fields are not perfect on account of several reasons, such as the spatial distribution of coils in slots (space harmonics), variable distance of the air gap (permeance harmonics), eccentricity, magnetic saturation, distribution of

PMs and voltage harmonics from the power supply [1]. The flux density harmonics can be decomposed as [2], [3]:

$$B_{\delta}(\alpha, t) = [\Theta_s(\alpha, t) + \Theta_r(\alpha, t)] \cdot \Lambda_{\delta}(\alpha) \quad (1)$$

Where B_{δ} is the flux density of the air gap, Θ_s/Θ_r are the stator/rotor magnetomotive forces versus position and time, Λ_{δ} is the relative permeance of the air gap. To simplify, the radial component of a flux density harmonic can be characterized by its order h , angular position α , amplitude $\hat{B}_{\delta rh}$, pulsation ω_h and initial phase ϕ_h in the $2p$ poles machine:

$$B_{\delta rh}(\alpha, t) = \hat{B}_{\delta rh} \cos(\omega_h t - hp\alpha - \phi_h) \quad (2)$$

$h=1$ $B_{\delta r1}$ corresponds to the fundamental radial component. But there are countless harmonics in the air gap, which induce electromotive forces in the stator winding. These electromotive forces generate other current harmonics and flux density harmonics.

B. Maxwell forces and noise

The interaction between the magnetic field of PMs and the stator winding creates forces in the air gap. With Maxwell stress tensor approach, the article [4] explains how to deduce and simplify the expression of Maxwell force in the air gap, considering several hypotheses. Different from tangential forces generating torque, radial forces are much stronger and are the main source of vibrations and noise. The radial component of a force of order h can be expressed as:

$$f_{rh}(\alpha, t) = \frac{1}{2\mu_0} [B_{\delta rh}^2(\alpha, t)] \quad (3)$$

Noting μ_0 is the vacuum magnetic permeability ($4\pi 10^{-7}$ H/m). The force waves excite the variation of attraction between the stator and rotor, resulting in noise and vibrations.

III. PRINCIPLE OF THE DAMPER WINDING

A. Auxiliary winding in stator slots

The principle of the proposed approach is to install an auxiliary winding, superimposed to the initial winding, in stator slots. All secondary stator coils of the same phase are in series with each other and with a capacitor. Star connection without grounded is used to link different phases. There is no modification on the rotor nor the air gap. Fig.1 shows the

position of the auxiliary winding in a PMSM with interior magnets.

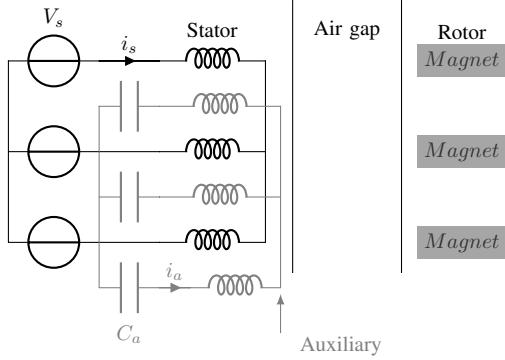


Fig. 1: Representation of the auxiliary winding

The resistance and leakage inductance of the auxiliary winding, as well as the capacitor, form a series RLC circuit in the equivalent single-phase diagram. Depending on the application, the chosen capacitors allow us to adjust or change the resonant frequency of the auxiliary winding, thus affecting the filtering of current harmonic components.

B. Principle of harmonic reduction

According to Fig.1, the position of the auxiliary winding is given. The purpose of connecting capacitors is to allow flux density harmonic components ($B_{\delta rh}$) to easily generate induced currents (i_a) in the auxiliary winding while maintaining a high impedance for low frequency components, especially the fundamental component, whose induced currents are weaker and don't impact the average torque. The high frequency induced currents can easily be carried by the auxiliary winding and can generate flux density components in opposition to those which create them, according to the Lenz law. Therefore, specific flux density components at the origin of magnetic noise are damped and reduced, but the opposed component should keep the same polarity as the initial one. Fig.2 illustrates interactions between flux density components and currents in interior PMSMs.

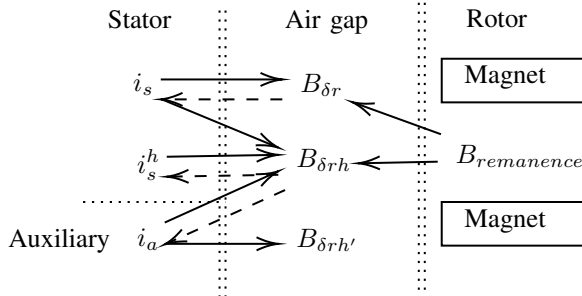


Fig. 2: Interactions between stator and rotor

IV. FINITE ELEMENT METHOD SIMULATION

In the simulation, the studied machine is a interior PMSM Leroy-Somer (LSRPM) with 12 slots and 8 PMs. The transient simulation based on the FEM is carried out in *Altair Flux2D*.

The fundamental frequency f is 100 Hz, the switching frequency f_{swi} is 3 kHz.

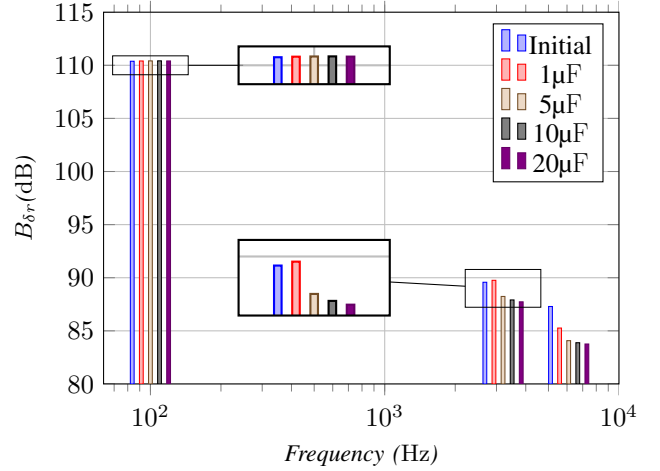


Fig. 3: Radial flux density spectrum; initial system; with different capacitors C_a in the auxiliary winding

Fig.3 shows the spectrum of radial flux density (magnitude in dB) on a fixed point in the air gap with or without the auxiliary winding. The harmonic components, especially high frequency components from PWM signals (e.g. 3200 Hz [$f_{swi} + 2f$], 6100 Hz [$2f_{swi} + f$]), are strongly impacted by the addition of the auxiliary winding. Different capacitors also affect the reduction effect on different harmonic components. There are also some harmonics that are amplified by the presence of the damper with specific capacitors (e.g. $C_a = 1\mu F$). In general, the damper has a beneficial effect for the harmonic reduction, while its impact on the fundamental component is negligible.

V. CONCLUSION

This study has shown that the damper winding allows reducing the flux density harmonics effectively in PMSMs. It can be deduced from the Maxwell tensor that the method mitigates radial force harmonics, thus reducing the noise and vibrations of PMSMs. A suitable capacitor needs to be used, otherwise the damper winding could have a reinforcing effect on specific harmonics. In a subsequent study, the resonant frequency of the auxiliary winding can be adjusted by changing capacitors to reject specific harmonics.

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