Electric Power Systems Research 142 (2017) 20–28

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Study of eddy-current loss in the sleeves and Sm–Co magnets of a high-performance SMPM synchronous machine (10 kRPM, 60 kW)

N. Boubaker[a,*], D. Matt[a], P. Enrici[a], F. Nierlich[b], G. Durand[b], F. Orlandini[c], X. Longère[c], J.S. Aïgba[c]

[a] *Institut d'Electronique et des Systèmes—Groupe Energie et Matériaux, 34095 Montpellier, France*
[b] *SAFRAN Messier-Bugatti-Dowty, 78140, Vélizy-Villacoublay, France*
[c] *SAFRAN Technofan, 31702, Blagnac, France*

ARTICLE INFO

Article history:
Received 3 April 2015
Received in revised form 21 April 2016
Accepted 30 August 2016
Available online 18 September 2016

Keywords:
Composite sleeve
Experimental tests
Eddy current losses
Finite-element model
Inconel718 sleeve
High-speed surface mounted PMSM

ABSTRACT

The goal of this paper is to analyze and evaluate the eddy-current losses due to stator slotting in conductive and non-conductive retaining sleeves mounted on the rotor of a high-speed SMPMSM: 60 kW, 10 kRPM, designed for an aeronautical application. Roughly speaking, there are two groups of sleeves: composite sleeves (carbon-fiber or fiberglass + resin) and metallic sleeves (Inconel718, titanium, stainless steel). For both types of sleeves losses are estimated by two means: a 2D finite-element model (AnsysMaxwell) and experimental tests. According to test bench results, the use of a composite sleeve reduces losses by 330 W (370 W found with the FEM), showing reduction equal to 0.6% of the machine's rated power. The eddy-current losses in the magnets are equal to 60 W. The final section of the paper proposes an optimization study of eddy-current loss and an analysis of the shielding effect induced by the high-conductivity sleeve (aluminum, etc.).

Contents

1. Introduction 21
2. Presentation of the studied machine 21
   2.1. Characteristics 21
   2.2. Finite-element model (FEM) 21
3. Analyze of magnetic flux density 21
4. Study of eddy-current losses with an inconel718 sleeve 22
   4.1. Losses at 10,000 RPM 22
   4.2. Losses as a function of rotational speed 23
5. Study of eddy-current losses with a composite sleeve 23
6. Experimental results 23
7. Experimental and finite-element thermal analysis 24
8. Optimization study 25
   8.1. Optimization parameters 25
   8.2. Effect on harmonic spectrum of the magnetic flux density 25
9. Magnetic shielding effect 26
10. Study at full-load 27
11. Conclusion 27
Acknowledgment 28
References 28

* Corresponding author.
E-mail addresses: boubaker_nadhem@live.fr (N. Boubaker), florent.nierlich@safranmbd.com (F. Nierlich), fabien.orlandini@technofan.com (F. Orlandini).

http://dx.doi.org/10.1016/j.epsr.2016.08.045
0378-7796/

1. Introduction

In recent years, permanent magnet synchronous machines (PMSM) are increasingly employed in several technological fields (transport: AGV train; aeronautical: air-craft, as in our case, etc.) for their high reliability and power-to-weight ratio (up to a few kW/kg). A number of rotor topologies are available for the radial field, such as: spokes, insets, buried and surface-mounted (SM) permanent magnets. We chose SMPM topology for our application, in particular because of the simple manufacturing process. However, for high-speed applications (some hundred RPM), the SMPMSM often requires banding with a sleeve (also called banding-band or hoop) to fix the PMs [1–3].

Indeed, banding consists of retaining the magnets (bonded to the surface of the rotor iron core) in order to increase mechanical strength and consequently avoid serious damage that could be caused by the detachment of magnets under strong centrifugal effects. The sleeve is made of non-magnetic material that may be conductive (Inconel718 etc.) or non-conductive (composite). The major advantage of non-conductive sleeves is the low electrical conductivity that limits eddy-currents and consequently decreases the sleeve's Joule loss [3,4]. However, at the same time, they present low thermal conductivity, which means that they behave as a good thermal insulator that prevents heat flux-flow. Thereby, non-conductive sleeves can cause rotor overheating and require the use of a cooling system [5]. For this reason, manufacturers prefer metallic sleeves, commonly using an Inconel718 material [6,7,9,10].

In the case of conductive sleeves at high speeds, losses may increase considerably and cause heating due to the circulation of eddy-currents.

This paper presents a study of the losses in two sleeves mounted on the rotor of a high-speed PM synchronous machine: 60 kW, 10,000 RPM, designed for an aeronautical application.

The first tested sleeve is based on Inconel718, it is a metallic alloy with high electrical conductivity (8×10^5 S/m at 20 °C). The second sleeve is manufactured with carbon-fiber and epoxy resin (composite and anisotropic material).

The study consists to estimate the eddy-current loss in the sleeve for the two cases, by both means of finite-element model (AnsysMaxwell) and experimental tests (test bench).

The last part of the paper presents an optimization study of eddy-current loss as well as an analysis of the shielding effect linked to a very highly conductive sleeve (aluminum, copper, etc.).

Table 1
Main characteristics of the machine.

Property	Value
Speed (kRPM)	10
Power (kW)	60
Pole-pair number	4
Phase number	3

2. Presentation of the studied machine

2.1. Characteristics

The stator core is made of low-loss Cobalt-Iron lamination sheets of 0.1 mm (49% Co). The sheets have 45 slots.

We used CoFe material in order to minimize iron loss and stator weight (the stator yoke is thin), because this material presents high saturation magnetization up to 2.35 T. Consequently, the machine's performance is increased significantly. That is why the CoFe is a more expensive alloy than SiFe and NiFe.

However, the rotor is made of thicker Silicon-Iron lamination sheets (SiFe M400-50A) of 0.5 mm, because flux density variation is negligible, thereby without risk of substantial eddy-current in the magnetic rotor core.

The machine (Fig. 1) has four pole-pairs, thus eight surface-mounted Samarium–Cobalt magnets (Sm2Co17).

The permanent magnets are retained with a sleeve of 1.3 mm (Inconel718 or composite).

The main characteristics of the machine are presented in Table 1.

2.2. Finite-element model (FEM)

Machine modeling and simulation were performed with Ansys-Maxwell software, in 2D (eddy-current, iron-loss...) and 3D (flux density).

Fig. 2 shows the 3D finite-element model of the machine with the distribution of magnetic flux density in the rotor and stator.

3. Analyze of magnetic flux density

The spatial magnetic flux density in the different rotor parts (at this stage, regardless of the sleeve material) calculated with the finite-element model is given in Fig. 3. Evidently, this includes

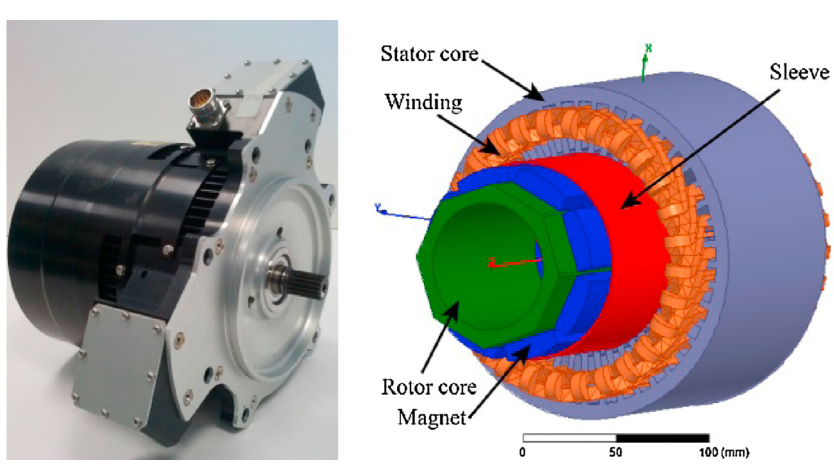

Fig. 1. Picture/3D view of the studied machine.