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[1.] Alexandra BOBU, [1.] Alecsandru SIMION, [1.] Adrian MUNTEANU, [1.] Leonard LIVADARU, [1.] Bogdan VIRLAN, [1.] Ionut NACU, [1.] Ion NASTAS

USING GRAIN-ORIENTED ELECTRIC STEEL IN A DOUBLE ROTOR FRACTIONAL-SLOT CONCENTRATED-WOUND PERMANENT MAGNET SYNCHRONOUS MOTOR

[1.] Department of Electrical Engineering, Gheorghe Asachi Technical University of Iasi, ROMANIA

Abstract: For this paper, the possibility of using grain-oriented electric steel for the stator lamination in a double rotor fractional-slot concentrated-wound permanent magnet synchronous motor it was studied using FEM simulations. The results were compared with the ones of the non-oriented electric steel machine having two different stator lamination topologies. The purpose of this study was to estimate the influence of the stator yoke discharge for the proposed structure and to check the possibility of compensating some of its negative effects by using grain-oriented electric steel for stator lamination. The proposed solution gives the advantage of a modular construction of the stator lamination which simplifies the fabrication technology and reduces the production costs, at the same time, without major impact over the machines performances.

Keywords: grain-oriented electric steel, fractional-slot concentrate-wound permanent magnet synchronous machine, FEM simulation, double rotor electrical machine

1. INTRODUCTION

Double rotor electrical machines, frequently used in different axial flux configurations, but applicable in radial flux machines as well, are intensely studied lately due to the major advantage of ensuring higher power density values of an electrical machine, a requirement that can't be overlooked, especially in certain application areas, where dimensions or weight constraints are imposed. [1-15]

Fractional-slot concentrated-wound (FSCW) permanent magnet synchronous machines (PMSM) are currently used in a large variety of industrial applications such as automotive, air-space, naval, household, military, energy and many others, being preferred to other of electrical machines due to their significant advantages such as the high torque density and efficiency, low cogging torque, torque ripples and fabrication costs. [16-28]

Grain-oriented electrical steel (GOES), commonly used for electrical transformers lamination as well as for high-power electrical machines, has an internal structure that ensures greater magnetic saturation and flux density, having less core losses, when the field has the same direction with the oriented grains of the material, in compared with non-oriented electric steel (NOES). However, when the magnetic field direction is different from the one of the grains, GOES loses this advantage in front of NOES laminations, limiting the use of such materials to certain applications. [29-39]

Starting from these three premises, and using 2D Finite Element Method (FEM) simulations, a double rotor fractional-slot concentrated-wound permanent magnet synchronous motor using GOES and NOES stator laminations has been analyzed and the compared results are presented in this paper.

2. MOTOR DESIGN

A radial flux double rotor fractional-slot concentrated-wound permanent magnet synchronous motor with 20 poles on each rotor and 18 coils for each stator was designed and studied, at first for two different poles alignment configurations using usually NOES. Its main working parameters and dimensions are provided into Table 1 and Table 2 respectively.

Table 1: Electrical machine working parameters

Parameter name	Abbreviation	Value
Rated power	P_N	1500 W
Rated voltage	U_l	72 V
Rated current	I_l	14 A
Nominal speed	n	1000 rpm
Power supply frequency	f	166,66 Hz

The cross section through the machine is shown in Figure 1, separately for the stator (a) and the two rotors (b), while in Figure 2 the stator windings layout is presented.

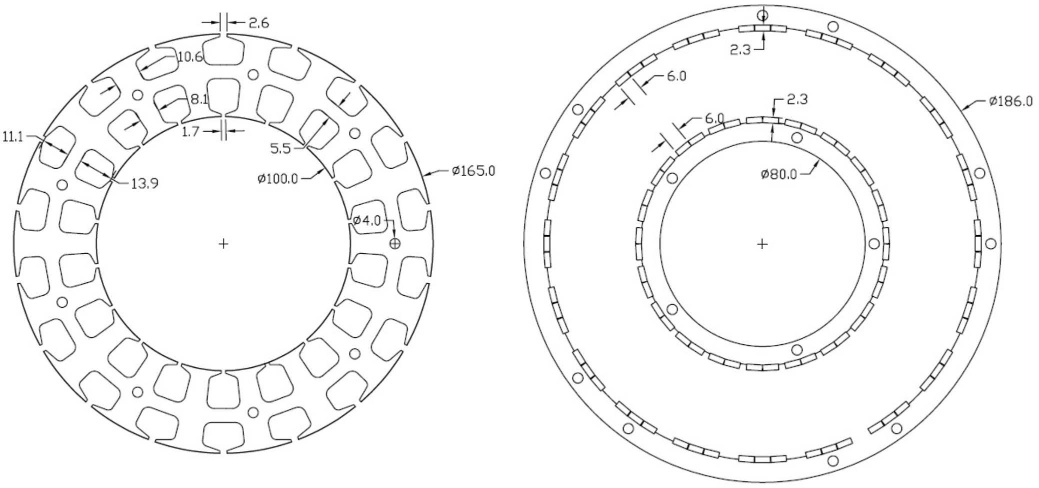
Table 2: Electrical machine main dimensions

Parameters name	Abbreviation	Value
Stator inner diameter	D_{is}	100 mm
Stator outer diameter	D_{es}	165 mm
Stator core length	l_i	30 mm
Inner stator slot height	h_{di}	13.9 mm
Outer stator slot height	h_{de}	11.1 mm
Inner stator tooth average width	b_{di}	8.1 mm
Outer stator tooth average width	b_{de}	10.6 mm
Stator yoke width	h_j	5.5 mm
Inner rotor inner diameter	D_{iri}	80 mm
Outer rotor outer diameter	D_{ere}	186 mm
Magnets length	l_m	30 mm
Magnets width	b_m	6 mm
Magnets thickness	g_m	2.3 mm
Phase number of turns	w_1	114
Conductor cross section	S_{Cu}	2x0.7088 mm^2
Inner rotor weight	m_{ri}	0.562 kg
Outer rotor weight	m_{re}	1.046 kg

The proposed structure allows us to use the machine in two different configurations as regarding the alignment of the magnetic poles of the two rotors, resulting two variants for the machine:

- V1 (N-N/S-S) - the opposing permanent magnets of the two rotors create the same magnetic poles at the airgaps level for both rotors,
- V2 (N-S/S-N) - the opposing permanent magnets of the two rotors create the different magnetic poles at the airgaps level for both rotors.

The change between these two configurations can easily be made only by shifting one of the two rotors with one pole (18 geometrical degrees), together with a change in the electric circuit connections of the two sections of the stator winding.



(a) stator geometry (b) rotors geometries

Figure 1: Electrical machine cross section

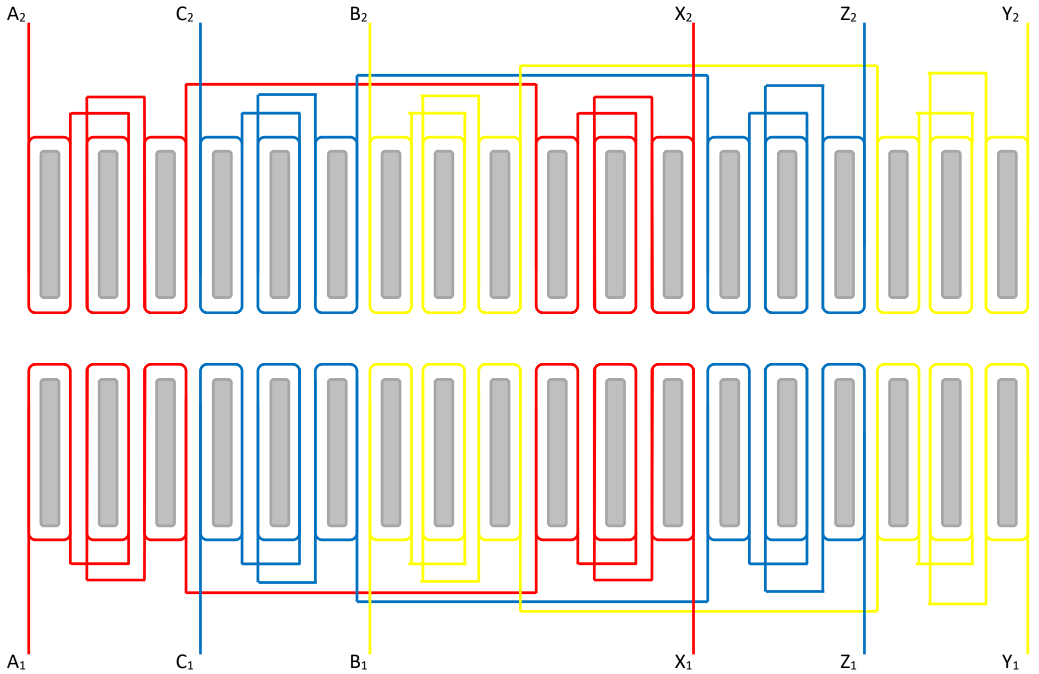


Figure 2: Stator winding

As a second step of the study, for the V2 motor configuration for which the magnetic flux closes from the two rotors poles mainly passing through the stator teeth, the stator yoke of the machine has been defined with no magnetic material proprieties. This modification, ensure the possibility of using a modular construction of the stator, building motor teeth independently and assembling the final structure after coils were placed on them. This solution is not applicable for V1 motor configuration for which the stator yoke is mandatory for the machine to work.

In the end, for this proposed solution it has been studied the possibility to use GOES for stator lamination in order to reduce losses and increase motor performances. The material proprieties of the NOES and GOES laminations used for simulations are presented in Table 3.

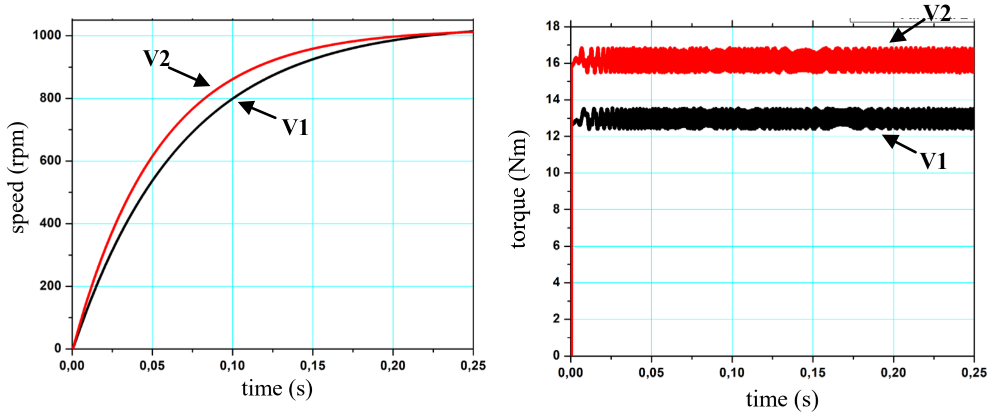
Table 3: Laminations material proprieties

Material specifications	NOES	GOES
Thickness of the lamination	0.35 mm	
Core stacking factor	0.95	
Material density	7650 kg/m^3	
Magnetic induction @ 2500 A/m	1.56 T	1.87 T
Magnetic induction @ 10000 A/m	1.76 T	1.97 T
Core loss @ 50Hz & 1.5 T	1.3 W/kg	1.05 W/kg
Core loss @ 50Hz & 1.7 T	3.3 W/kg	1.5 W/kg
Material conductivity	2.38 · 10^6 S/m	3.23 · 10^6 S/m

3. SIMULATIONS RESULTS

A 2D FEM model has been created for simulations and adjusted in respect with the analyzed configuration, and problems defined according considered setups described above. Transient start-up and constant speed operation for motor duty were investigated on all analyzed configurations for results comparison.

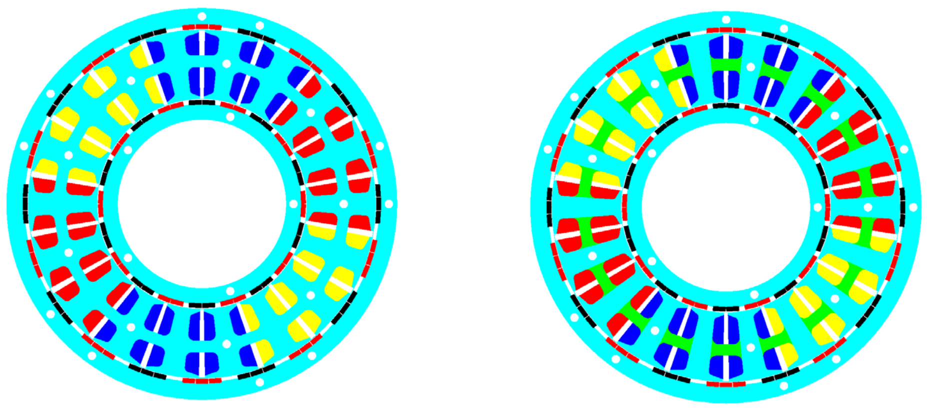
Figure 3 presents the motor start-up characteristics of the NOES stator lamination for the two motor variants. As can be observed, the electromagnetic torque developed by the V1 is inferior to the one of V2 configuration at the same power supply rated current values.



(a) speed characteristics (b) torque characteristics

Figure 3: Star-up characteristics

In Figure 4 the 2D FEM models for V2 motor configuration are presented for (a) the original geometry of the magnetic circuit and (b) for the new proposed modular geometry that was considered, which excludes stator yoke (nonmagnetic material).

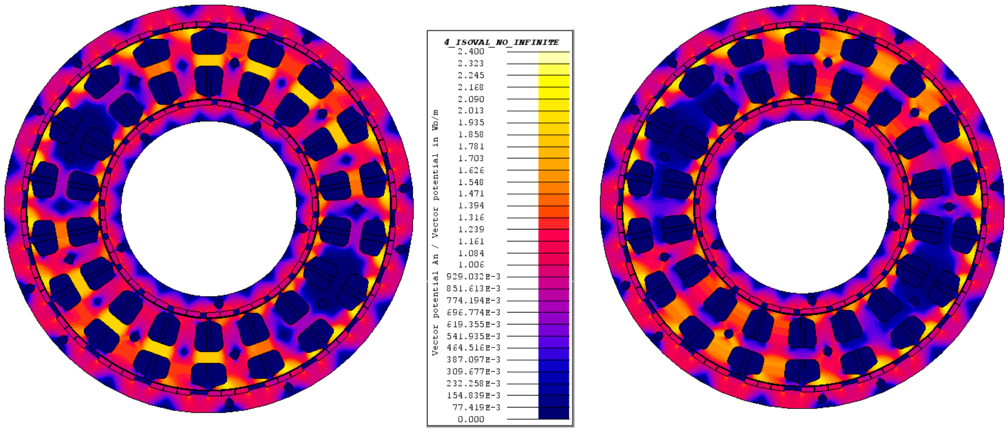


(a) original geometry (b) new proposed geometry

Figure 4: 2D FEM models for V2 motor configuration

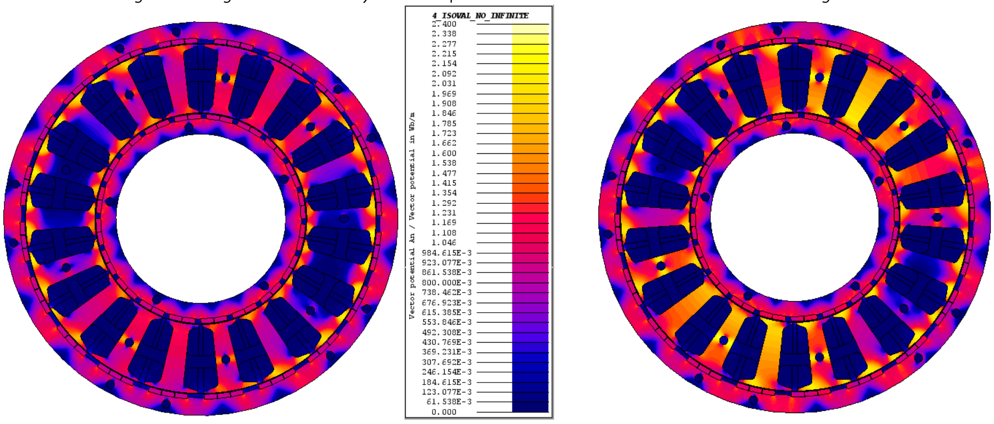
Figure 5 presents the magnetic flux density color maps for the NOES (a) V1 motor configuration and (b) V2 initial motor configurations, while Figure 6 presents the same flux density color maps for the proposed modular geometry of V2 motor configuration (a) with NOES, respectively (b) GOES stator laminations, giving useful information regarding the magnetic load.

For these four different analyzed structures, the angular characteristics, presented in Figure 7, were computed and compared. The results showed that original V2 motor configuration is capable to produce a higher electromagnetic torque than V1 motor configuration at the same working conditions.



(a) **V1** motor configuration (b) **V2** motor configuration

Figure 5: Magnetic flux density color maps for the NOES initial **V1** and **V2** motor configuration



(a) NOES lamination (b) GOES lamination

Figure 6: Magnetic flux density color maps for the NOES and GOES **V2** motor configuration

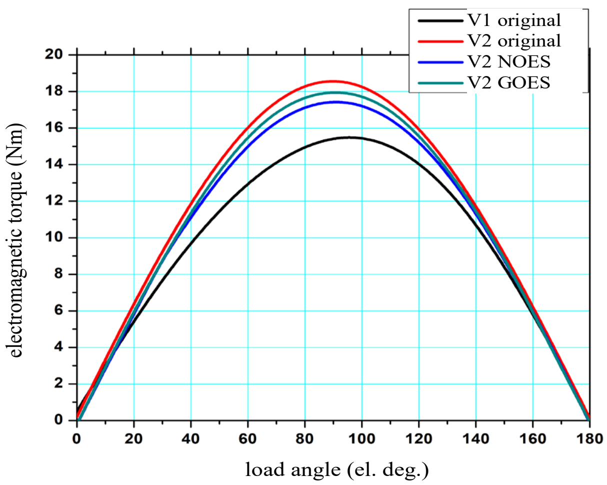


Figure 7: Electromagnetic torque versus load angle characteristics

As for the proposed structures that consider the stator yoke as nonmagnetic material for V2 motor configuration, the results are, in both cases (NOES and GOES), inferior to the original V2 but better then V1 structure. However, when GOES lamination is used an increase value of the electromagnetic torque is achieved for the same motor layout.

4. CONCLUSIONS

In this paper, a double rotor fractional-slot concentrated-wound permanent magnet synchronous motor with two different rotor poles alignment configurations has been presented. For the motor variant having superior performances, an additional investigation has been done in order to find an optimal solution for a modular fabrication technology of the stator assembly with minimum impact over motor behavior. Grain oriented electric steel has been considered for the stator lamination to reduce loses and increase the efficiency of the machine. Simulation results showed that the motor achieved higher electromagnetic torque when the corresponding poles of the two rotors have opposite polarities. In this case the magnetic field is closing mainly through the stator teeth, offering the possibility of reducing or even excluding the stator yoke from the magnetic circuit of the machine. However, this measure had a negative impact on motors performances.

The negative effect of the stator yoke elimination can be for the most part compensated by using grain oriented electric steel for stator lamination.

The fabrication cost reduction is one of the major decisional factors in industry and different solutions for modular design and automated production are always investigated in this regards.

Note: This paper was presented at CNAE 2022 – XX[th] National Conference of Electric Drives, organized by University POLITEHNICA Timisoara, Faculty of Faculty of Electrotechnics and Electroenergetics (ROMANIA), in Timisoara, ROMANIA, in 12-13 May, 2022.

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