On the Improvement of Claw-Pole Generator Performances

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***Abstract*-- In small ratings, direct-driven wind power applications multiple permanent magnet generators have become very attractive. Connected directly to the turbine axis, this type of electrical machine contribute to low price energy (the energy loss is diminished through the conversion, the turbine performance is increased) and to the reduction of the noise – this would be a very important aspect in case the turbine is placed nearby the localities. The present paper approached the magnetic field analysis of a claw pole permanent magnet rotor topology for a synchronous machine, suitable for small wind power application, by means of the 3D finite elements method.**

***Index Terms*-- claw-pole synchronous generator, topology, electromagnetic field analysis.**

I. INTRODUCTION

In wind power applications many types of generator concepts have been used and proposed. Permanent magnet machines are widely used in most of the low speed wind turbine generators, due to their high efficiency and reliability.

Synchronous PM generators can be divided into radial, axial and transversal flux machines. The availability of modern high energy density magnet, such as NdFeB, has made possible to design special topologies.

The replacement of the rotor excitation winding with permanent magnets in a synchronous machine brings the well known advantages of a simple rotor design without field windings, slip-rings and exciter generator, lower heat dissipation and higher overall efficiency. The development in power electronics, enabling energy efficient drives, has increased the interest in permanent magnet synchronous machines, as attractive rivals to the common asynchronous generators, in small and medium systems, both autonomous and parallel connected with the electrical grid configurations. Permanent magnet synchronous machines use three rotor topologies: surface mounted permanent magnets, buried permanent magnets and claw-pole configuration. Claw pole machines are commonly used as automobile, wind and hydro generators due to their simplicity and low manufacturing cost. The permanent magnet replaces the circumferentially wound global excitation coil, increasing the overall efficiency of the machine [7].

The present paper approaches the analysis of claw pole permanent magnet generator performances, by means of the 3D finite elements method. Four claw-pole solutions were considered in order to study the influence of different parameters of the rotor on the machine performances, i.e. magnetic field density, saturation, induced emf.

II. TOPOLOGY AND MAN DIMENSION OF THE MACHINE

The structure presented in this paper is a synchronous claw-pole machine, with permanent magnet excitation on the rotor and thee-phase winding on the stator. The machine has four pairs of poles on the rotor.

The claw-pole machine was obtained by replacing the rotor of a conventional induction machine (Fig. 1), thus obtaining a synchronous permanent magnet machine. The DC rotor excitation is replaced by a permanent magnet, axially magnetized, mounted on the shaft, between two steel plates, carrying, each of them, the claw-pole structure. The module is designed for 72 V output voltage at 750 rpm rated speed.

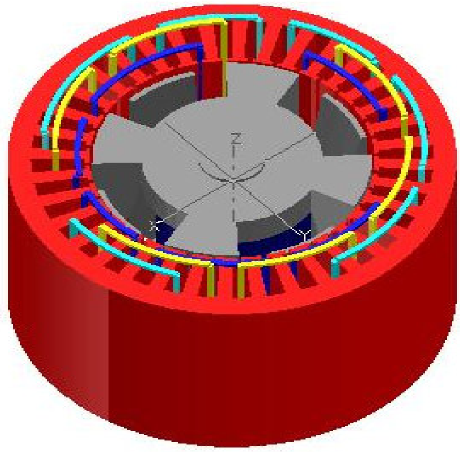


Fig. 1 3D view of the claw-pole PMSM

TABLE I. DIMENSIONS AND MAJOR PARAMETERS

Dimensions and parameters	Quantities
Rated voltage [V]	72
Rated frequency [Hz]	50
Number of phases	3
Number of slots	36
Length of stator [mm]	166
Outer diameter of the stator [mm]	146
Inner diameter of the stator [mm]	92.5
Number of poles	8
Length of rotor [mm]	112.3
Length of pole [mm]	107
Outer diameter of the rotor [mm]	92
Length of magnet [mm]	77
Diameter of the magnet [mm]	57
Diameter of the shaft [mm]	22
Magnet type	NdFeB
Magnetization direction	Axially
Pole material	Iron

The main advantage of using this structure as a generator in energy generation systems, based on renewable sources, is the possibility of obtaining a higher number of poles than in the case of conventional generators. The high number of poles allows the generator to operate both at high and at low speeds.

The overall efficiency of the generator is given by the type of permanent magnets used, that are placed around the shaft [1, 2, 3].

III. 3D FINITE ELEMENT

In contrast to conventional types of electrical machines, where analysis can be conducted in a two-dimensional (2D) plane, the claw pole machine model must take into account all three field components: radial, tangential, and axial, due to the three-dimensional magnetic field in the machine. Due to complex configuration of the machine, the analysis will be made on a pole pairs. The first step was the analysis of basic structure.

The magnetic field analysis using FEM involves three stages: pre-processing, field solution and post-processing.

Development of the geometry, problem definition (choice of the material, ferromagnetic iron non-linear characteristic introduction, magnetizing the magnets in the required direction) and mesh generation are done in the pre-processing phase.

Once the basic structure of the machine was introduced, the mesh was generated and the field equations solved, for no-load regime. In order to obtain more accurate results, a high quality domain discretization will be applied in the important sections of the machine, as air-gap and rotor poles [5, 6].

The results of the computation, in terms of magnetic field density, induced emfs or flux leakage can be extracted in the post-processing stage. For the proposed machine, the maps of the magnetic flux density (Fig. 2), its distribution in the air-gap (Fig. 3) the stator tooth (Fig. 4) and along rotor claw-pole (Fig. 5) are interesting.

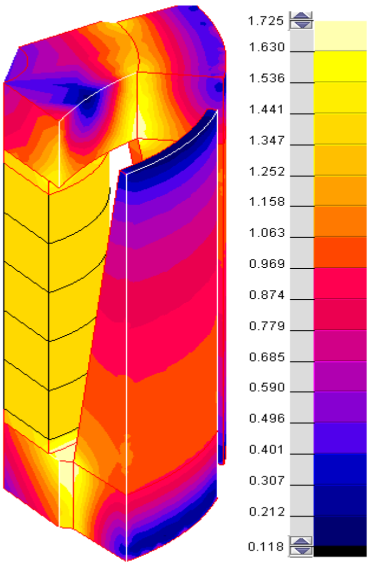


Fig. 2 Magnetic flux density map

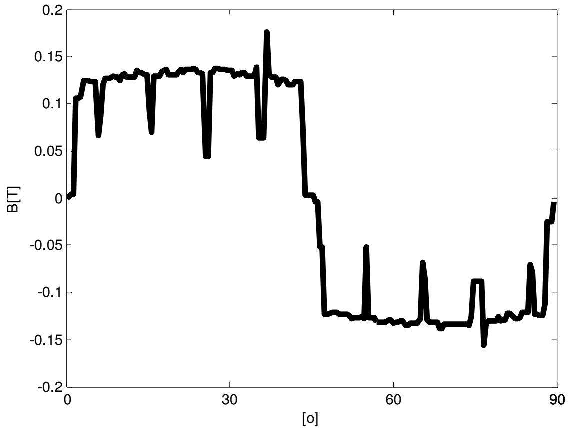


Fig. 3 Magnetic flux density in the air-gap along a pole-pair

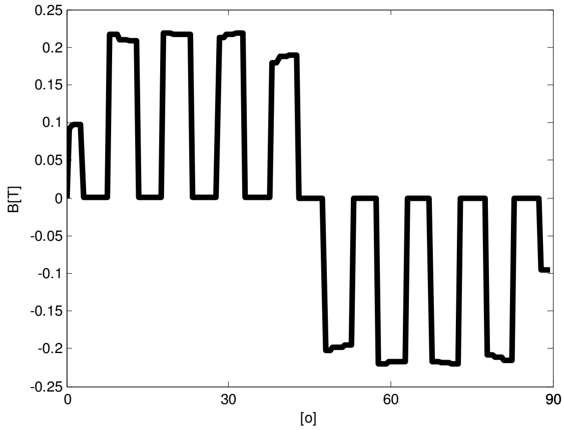


Fig. 4 Magnetic flux density in the stator teeth along a pole-pair

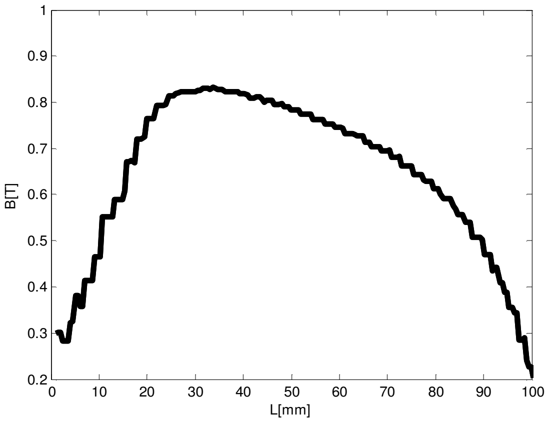


Fig. 5 Magnetic flux density along the rotor pole

As it can be noted, the magnetic flux density value at the basis of the claw-pole, where the direction of the magnetic field path is changing, is close to the saturation value.

The emf in the stator windings of the claw pole synchronous generator is given by:

$$E_f = \frac{\sqrt{2}}{\pi} \cdot \omega \cdot \Phi_p \cdot k_b \cdot w_1 \quad (1)$$

The emf value results 77.8V.

The most important values of flux leakage-Table II- are: between two poles (path1), between poles and magnet (path 2) and at the top of claw pole (path 3)-Fig. 6.

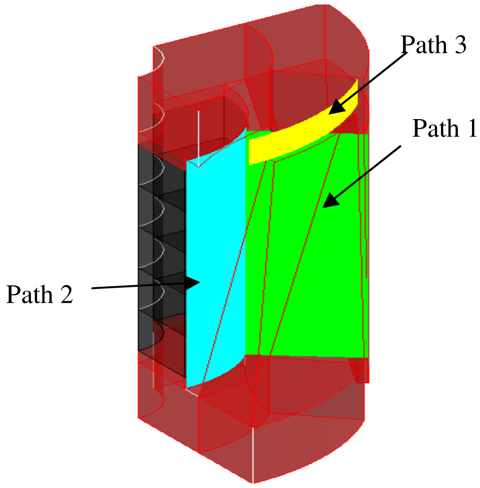


Fig. 6 Magnetic field density in the stator teeth along a pole-pair

TABLE II. FLUX LEAKAGE OF BASIC STRUCTURE

$\Phi_{\sigma pp}$ [Wb]	$\Phi_{\sigma mp}$ [Wb]	$\Phi_{\sigma tp}$ [Wb]
$3.065 \cdot 10^{-5}$	$5.905 \cdot 10^{-6}$	$2.181 \cdot 10^{-6}$

A. Improved the performance of claw-pole generators

For a better distribution of the magnetic induction on the claw pole surface, for a higher value of the "emf" and a lower value of the flux leakage, the claw pole geometry has to be modified. As you can see in Fig. 7, the length of the claw pole is reduced for a better induction distribution over the length of the pole. Also, the width of the pole is reduced at the top of the pole for eliminating the unsaturated zones – see Fig. 7 [1,2,5].

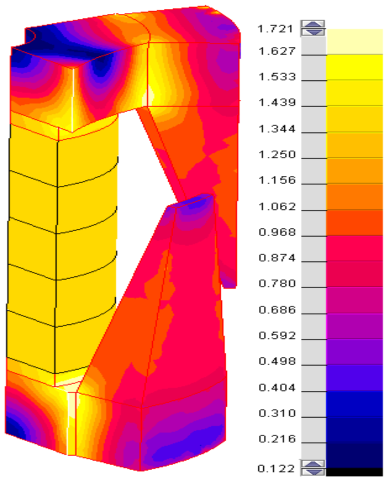


Fig. 7 Magnetic field density map of the second structure

The value of emf obtained in this case is 80.2V, and the flux leakage is presented in Table III.

TABLE III. FLUX LEAKAGE OF THE SECOND STRUCURE

$\Phi_{\sigma pp}$ [Wb]	$\Phi_{\sigma mp}$ [Wb]	$\Phi_{\sigma tp}$ [Wb]
$1.627 \cdot 10^{-5}$	$5.792 \cdot 10^{-6}$	$1.237 \cdot 10^{-5}$

Because the with of poles is reduce, in this case magnetic field in the air-gap, wave is much closer to a sinusoid graphic in contrast with the initial case-see Fig. 8.

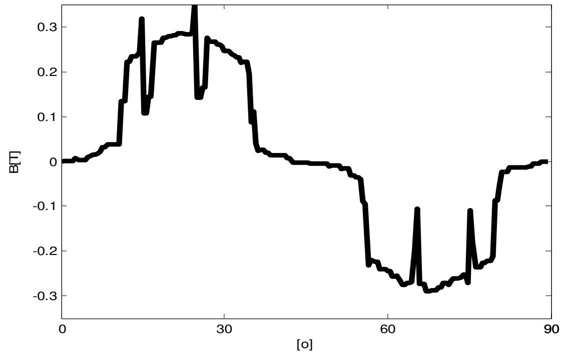


Fig. 8 Magnetic flux density in the air-gap along a pole-pair of the second structure

For eliminating the unmagnetized zones from the base of the poles, their bases have been blunted. That has led to a generator performances improvement - see Fig. 9 and Table IV. The value of emf is 82.2 V.

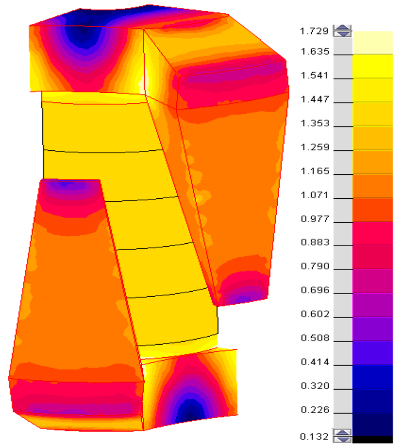


Fig. 9 Magnetic field density map of the third structure

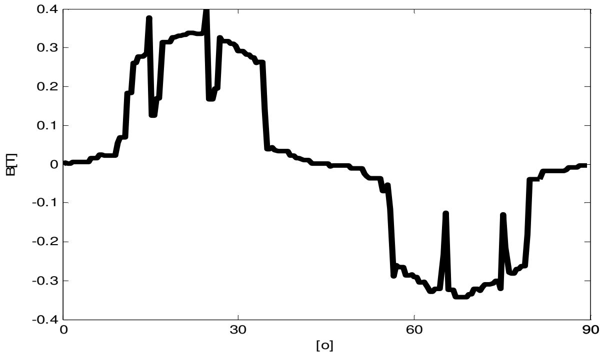


Fig. 10 Magnetic flux density in the air-gap along a pole-pair of the third structure

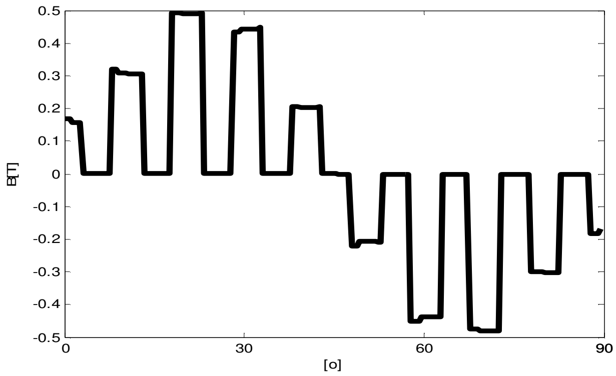


Fig. 11 Magnetic flux density in the stator teeth along a pole-pair of the third structure

TABLE IV. FLUX LEAKAGE OF THE THIRD STRUCURE

$\Phi_{\sigma pp}$ [Wb]	$\Phi_{\sigma mp}$ [Wb]	$\Phi_{\sigma tp}$ [Wb]
$1.365 \cdot 10^{-5}$	$4.656 \cdot 10^{-6}$	$1.095 \cdot 10^{-6}$

B. Space of the magnetic field density in the air-gap

Working as a stand–alone power plant or as a power plant connected to a grid, an important problem to solve in renewable energy sources plants is to produce energy with optimal quality parameters. One of the parameters which define electrical energy from the quality point of view is the content of harmonics products given by the consumers and the generators.

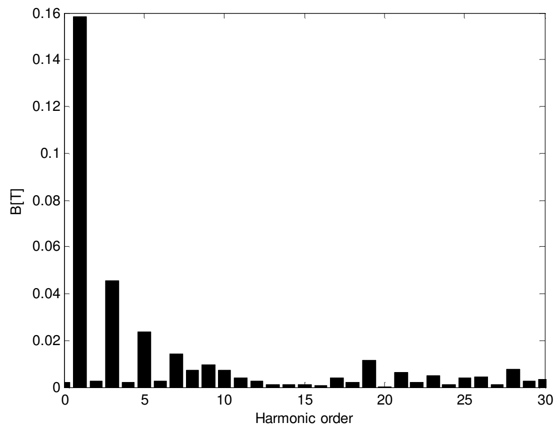
For the synchronous permanent magnet machines, the frequency of the air-gap magnetic field density space harmonics is given by the expression:

$$\nu = 2k \pm 1, k = 0,1,2,... \quad (2)$$

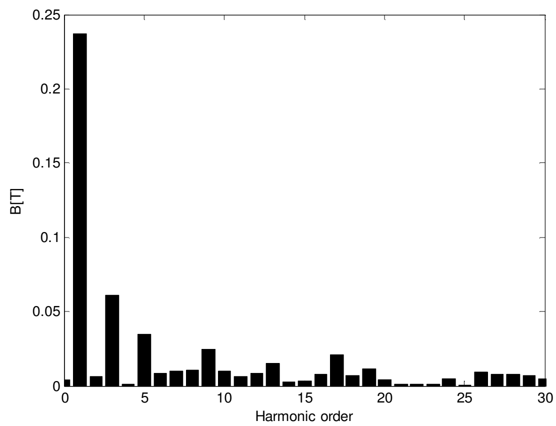
For the analyzed claw-pole machine the frequency of the first harmonic is 13.8 [1/m] and results from:

$$f_1 = \frac{1}{T} = \frac{1}{2\tau_p} = \frac{1}{2\frac{\pi D_{is}}{2p}} \quad (3)$$

The air-gap magnetic field density harmonics are responsible for induced emfs “pollution”. The harmonic spectrum of all analyzed structure is presented in Fig. 12 [1,6,7].



a)



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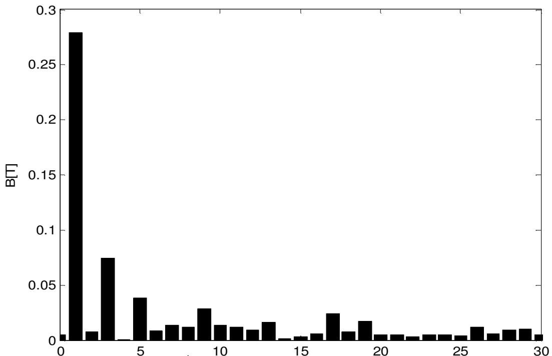

c)

Fig. 12 Air-gap magnetic flux density spectrum: a) first structure, b) second structure, c) third structure

The magnitudes of the harmonics are presented in Table V, the most important space harmonics appear to be the third, the fifth, the seventh and the seventeenth.

TABLE V. AIRGAP MAGNETIC FIELD DESNSITY SPACE HARMONICS MAGNITUDES

ν	Magnitudes[T]		
	First structure	Second structure	Third structure
1	0.158	0.24	0.28
3	0.043	0.065	0.073
5	0.026	0.037	0.038
7	0.018	0.026	0.028
17	0.011	0.022	0.024
19	0.017	0.014	0.02

IV. CONCLUSION

The paper presents the analysis of the magnetic field, using a 3D finite element based software, in a claw-pole permanent magnet synchronous machine for small ratings, direct-driven wind power applications. Air-gap magnetic field density distribution and harmonic content was computed**.** The paper analyzed also three configurations of rotor claw-pole and their influence on the magnetic field density and flux leakage in a claw-pole generator. Future work will be focus to realize the new prototype and analysis of the machine operating as generator in a wind-power conversion.

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