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Defaults Modeling due to Demagnetization in Permanent Magnet Synchronous Machines Using 2D FEM

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***Abstract*— This paper presents a model using 2D finite element method (FEM) to study defects due to the demagnetization in permanent magnet synchronous machines (PMSM). To take into account the defects due to the demagnetization in our model, the magnets will be considered as small elements. The defaults are diagnosed mainly through the visualization of the magnetic induction in the air gap and the electromagnetic torque. Two types of defaults are considered symmetrical and asymmetrical defaults.**

***Keywords*— Finite element method, Permanent Magnet Machines, Demagnetization.**

I. INTRODUCTION

Permanent magnet synchronous machines (PMSM) contain permanent magnets on the rotor, they are either placed on the surface or buried [1]. These produce a constant rotor magnetic flux. The flux paths vary according to several factors such as the armature reaction due to the load, the temperature [2], [3] etc. In some cases and when operating at high speeds the permannt magnets can be deteriorated. This desintegration can lead sometimes to the disruption of the flux flow in the airgap causing imbalances between the rotor and the stator magnetic fields which generate vibrations. The investigation of the effects of the defects due to demagnetisation is performed through the solution of the electromagnetic problem which will allow determination of the flux density distribution in the air-gap and hence calculating the electromagnetic torque.
Several models have been used to study the phenomena of demagnetization in electrical machines namely analytical methods based on Maxwell's equations [2] and permeance network methods [2],[5],[6]. In this paper, we have proposed a model based on the resolution of the electromagnetic equations expressed in terms of magnetic vector potential (MVP) using a 2D Finite element method, .
This model is developed to characterize the phenomenon of demagnetization in PMSM with burried magnet. Simulation results using the FEMM software helps significanly in the understanding of the effects of these defects on the PMSM performances.

II. ELECTROMAGNETIC FORMULATION

The system considered is a permanent magnet rotating synchronous machine and is given by Fig.1 [7]. This machine comprises a stator composed of conductors Ω_c and ferromagnetic Ω_{fs} and a ferromagnetic rotor Ω_{fr} having permanent magnets on the surface Ω_{pm}.

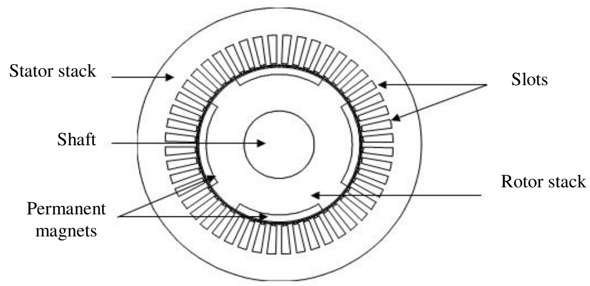

Fig.1. Geometry of the considered PMSM

Table I. shows the characteristics of the Permanent Magnet synchronous machine parameters

Designation	Value
Stator exterior diameter (mm)	189
Stator interior diameter (mm)	110
Rotor exterior diameter (mm)	107.1
Core stack length (mm)	231
Stator slot hight (mm)	0.9
Stator slot width (mm)	1.5
Stator tooth width (mm)	3.5
Stator tooth hight (mm)	20.7
Width of the maintaining ring (mm)	0.75
Permanent magnet hight (mm)	5
Magnet width (mm)	20.7
Number of slots	48
Remanence of the permanent magnet (T)	1.07
Coericevity (kA/m)	812
Terminal current (A)	170
Shaft power (kW)	49
supply frequency (Hz)	201 Hz
Rotationnel speed (rpm)	6021

Considering the two-dimensional Cartesian coordinates with only the azimuthally component of PVM $\vec{A}(0,0,A_z(x,y))$ and the current density $\vec{J}_s(0,0,J_z(x,y))$, the 2D diffusion equation is given as follows:

$$-\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial A_z}{\partial x}\right)-\frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial A_z}{\partial y}\right)=\begin{cases}0 & in\ \Omega_{fs}\\ 0 & in\ \Omega_{fr}\\ J_z & in\ \Omega_c\\ \frac{\mu_0}{\mu}\left(\left(\frac{\partial M_y}{\partial x}\right)-\left(\frac{\partial M_x}{\partial y}\right)\right) & in\ \Omega_{pm}\end{cases} \tag{1}$$

Where μ is the magnetic permeability and μ_0 the magnetic permeability of the air. M_x and M_y are respectively the magnetization components along x and along y.

Using the Galerkin method (FEM) with the substitution of the boundary conditions, equation (1) is written for each node in discretised form as follows:

$$\sum_{j=1}^{n}\left[\frac{1}{\mu}\iint_{\Omega}\vec{\nabla}N_m\ \vec{\nabla}N_n\ d\Omega\right]A_j=\begin{cases}0 & in\ \Omega_{fs}\\ 0 & in\ \Omega_{fr}\\ \iint_{\Omega}N_m J_z d\Omega_c & in\ \Omega_c\\ \iint_{\Omega}\frac{\mu_0}{\mu}\left(N_m\left(\frac{\partial M_y}{\partial x}\right)-N_m\left(\frac{\partial M_x}{\partial y}\right)\right)d\Omega_{pm} & in\ \Omega_{pm}\end{cases} \tag{2}$$

Where N_m is the shape function of element *m* and N_n is the approximation function of the magnetic vector potential at node *n*.

By re-writing equation (2) for all nodes in each region, the following algebraic equations are obtained:

$$[M]=\begin{cases}0 & in\ \Omega_{fs}\\ 0 & in\ \Omega_{fr}\\ [F] & in\ \Omega_c\\ [G] & in\ \Omega_{pm}\end{cases} \tag{3}$$

Where,

$$M_{ij}=\sum_{j=1}^{n}\left[\frac{1}{\mu}\iint_{\Omega}\vec{\nabla}N_m\ \vec{\nabla}N_n\right]d\Omega \tag{4}$$

$$F_i=\iint_{\Omega}N_m J_z d\Omega_c \tag{5}$$

$$G_i=\iint_{\Omega}\frac{\mu_0}{\mu}\left(N_m\left(\frac{\partial M_y}{\partial x}\right)-N_m\left(\frac{\partial M_x}{\partial y}\right)\right)d\Omega_{pm} \tag{6}$$

A defect of a magnet may occur due to armature reaction or fissure. This means that the defect of a magnet can be classified as a type of defect that is uniformly distributed over the entire surface, or located at a specific location of the pole. To take account his non-uniformity in our model, the magnet is considered as being constituted of several small elements as shown in Fig.2.

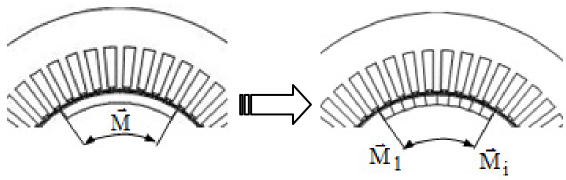

Fig.2.Subdivision of the magnet into en 'i elements'

- The small magnets are alike and are magnetized evenly in the radial direction.
- The effects of edges are ignored.
- The permeability of the rotor and stator yoke is considered infinite.

A. Electromagnetic torque calculation

The electromagnetic torque is calculated by the method of the Maxwell tensor. This method calculates the torque directly from the distribution of the electromagnetic field. The torque is estimated by the integration over a contour bounding the moving part. The electromagnetic torque is given as follows:

$$T=\frac{l_i}{\mu_0}\oint r\ B_n\ B_t\ dl \tag{7}$$

Where, l_i is the stack length. B_n and B_t are respectively the normal and tangential induction.
This method is used to determine the shape of the static torque of the machine.

A finite element simulation was conducted in sever degraded conditions. Six elements of one pole (one pole is divided into ten elements) were supposed to be demagnetized. The residual induction of the magnet is less than its normal value.
Fig.3 and Fig.4 show the two considered defects due to demagnetization, respectively symmetric and asymmetric.

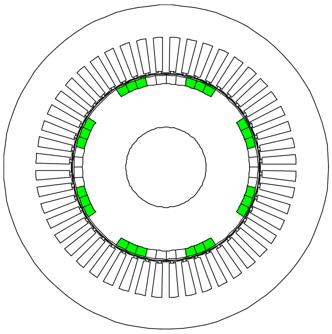

Fig.3. Symmetrical defaults

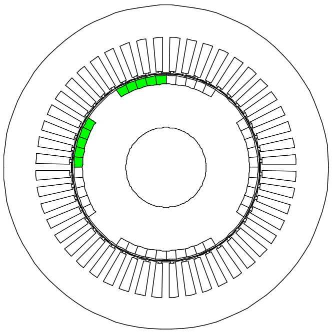

Fig.4.Asymmetrical default

III. RESULTS AND DISCUSSION

Fig5 shows the finite element mesh of the machine with permanent magnets. The mesh in the air gap is very thin because of the importance of information at this level to know the accuracy of the distribution of the magnetic induction.

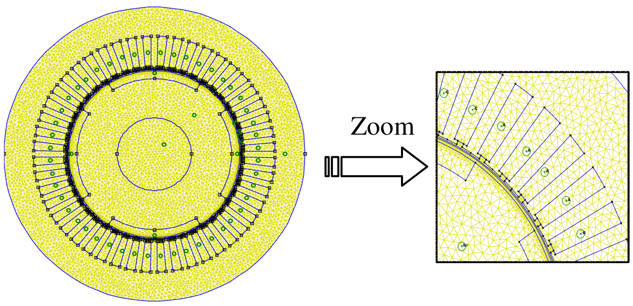

Fig.5. finite element meshing of the PMSM

The Fig.6, Fig.7 and Fig.8 show the magnetic field distribution for the permanent magnet machine in sound condition and in the presence of symmetrical and asymmetrical fault.

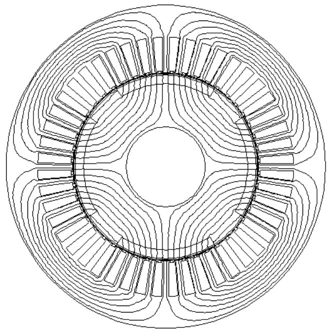

Fig.6. Iso-values of the magnetic potential vector for a machine without defaults

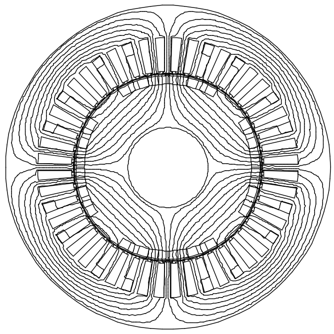

Fig.7. Iso-values of the magnetic potential vector for a machine with symmetrical defaults

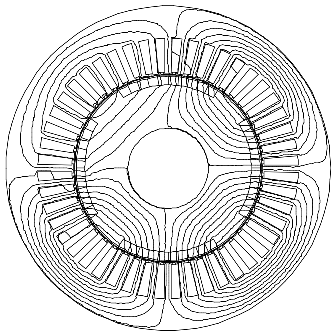

Fig.8. Iso-values of the magnetic potential vector for a machine with an asymmetrical default

The field solution has led to the determination of the variation of the magnetic potential vector and the magnetic flux density for both cases, machine with and without defaults.

Fig. 9 and 10 show respectively the waveform of the magnetic vector potential and the normal component of the magnetic induction in the air gap in the healthy machine and in the presence of a symmetrical default. Note that in both cases the waveforms have a sinusoidal shape. It can be seen that the value of the magnetic potential vector has decreased in the case of a symmetrical default. The value of the normal component of the magnetic induction in the healthy machine is about 0.8 T, and it is around 0.2 T in areas where the default is present. Fig.11 gives electromagnetic torque in the healthy machine and in the presence of a symmetrical default. By comparing the curves of Fig.11 we can state that the maximal torque has decreased significantly with the presence of a default (from 80 Nm in a health machine to 40 Nm in a machine with default).

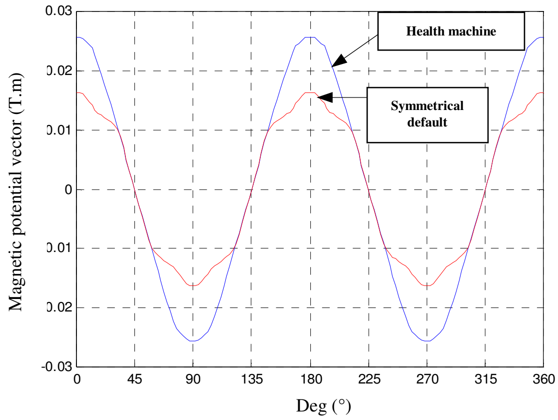

Fig.9. Magnetic potential vector for machine with and without default

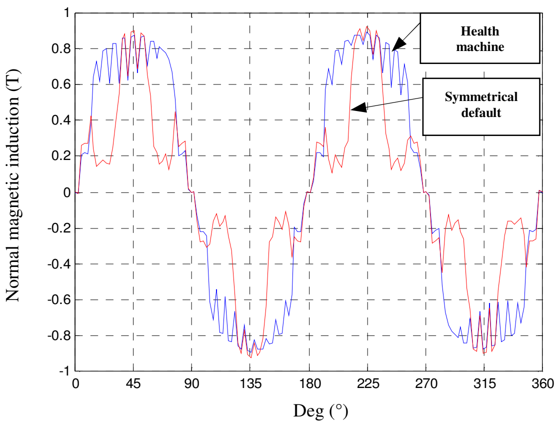

Fig.10. Magnetic flux density with and without default

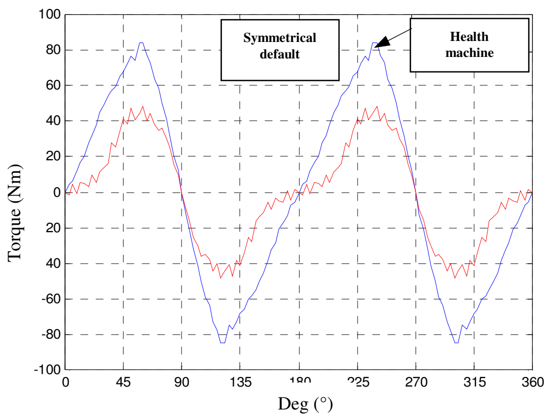

Fig.11. Static torque with and without default

Fig.12 and 13 show respectively the waveform of the magnetic vector potential and the normal component of the magnetic induction in the air gap in the healthy machine and in the presence of an asymmetrical default. Note that in both cases the waveforms have a sinusoidal shape. It can be seen that the value of magnetic potential vector has decreased in the case of unsymmetrical default. The value of the normal component of the magnetic induction in the healthy machine is about 0.8 T, and it is around 0.2 T in areas where the default is present. It is clearly seen that the effect of the asymmetrical default is from zero to 180 degree.

Fig.11 gives the electromagnetic torque in the healthy machine and in the presence of asymmetrical default. By comparing the curves of Fig.14, we can state that the maximal torque has decreased significantly with the presence of a default (from 80 Nm in a healthy machine to 72 Nm in a machine with asymmetrical default).

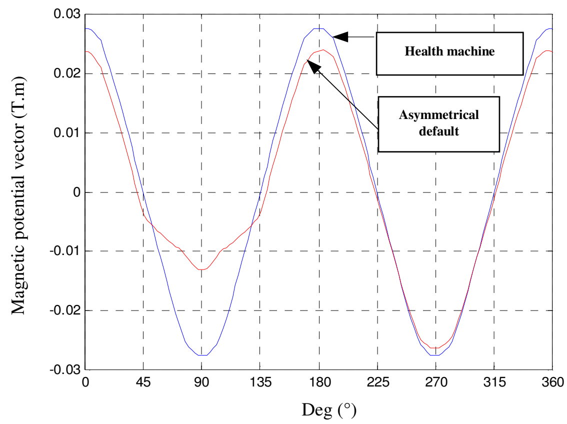

Fig.12. Magnetic potential vector with and without default

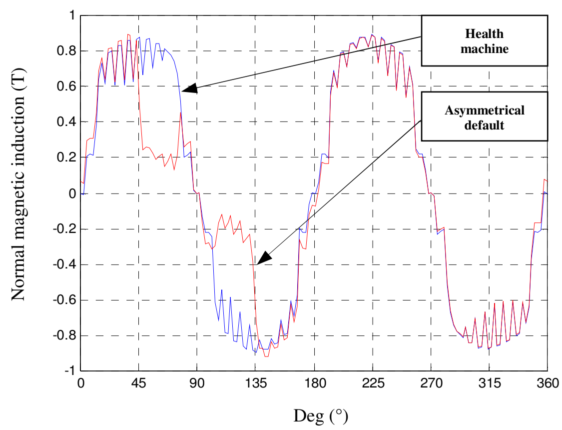

Fig.13. Magnetic flux density with and without default

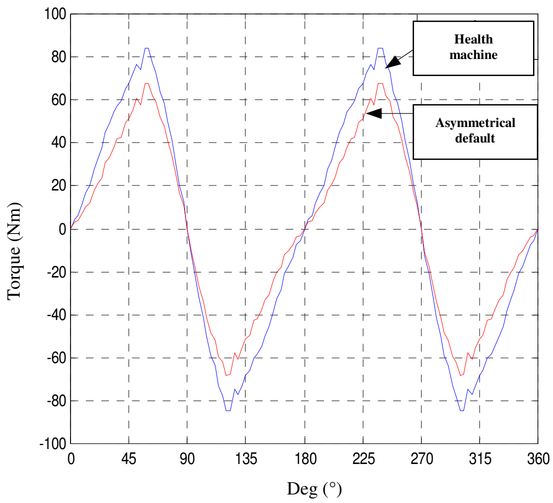

Fig.14. Static torque with and without default

IV. Conclusion

In this paper a model based on the resolution of the electromagnetic equation in terms of potential magnetic vector using 2D finite element method is presented. This model is used to study the behaviour of permanent magnet synchronous machines while subjected to a default due to demagnetization. The simulation conducted using this model have permitted the determination of the flux density distribution in the airgap and hence the calculation of the static torque produced by the machine. In order to take into account the demagnetization effects, the magnetic poles are subdivided into several small elements. Two types of defaults are considered symmetrical and unsymmetrical faults. Both these defaults have a significant influence on the torque produced by the machine and hence on its performances.

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