Integration of the eccentricity effect in the field computation by finite element methode of a variable reluctance machine

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***Abstract*— In this paper, a reluctance machine under eccentricity fault is modeled and analyzed by two dimensional Finite Element Method. The calculation of the field in a variable reluctance machine (VRM) tells us clearly and extensively on the evolution of the field at the air gap. Knowing that changing the thickness of the airgap (eccentricity) may possibly is caused after a certain period of operation of the machinery during the manufacturing processes. Specifically, we consider the analysis of the results the magnetic vector potential and magnetic field. Simulation results of healthy and faulty case are discussed and illustrate the effectiveness of the proposed approach.**

Keywords-Reluctance machine; modelisation; eccentricity; finite element; simulation.

I. INTRODUCTION

The variable reluctance motor is based on the principle that an unrestrained piece of iron will move to complete a magnetic flux path with minimum reluctance, the magnetic analog of electrical resistance. The reluctance motors can deliver very high power density at low cost [1-3], making them ideal for many applications. The advantages of the VRM have a simple construction, no brushes, commutator, permanent magnets and no conductors in the rotor. They have a high efficiency, reliability compared to conventional AC or DC motors and high starting torque [4]. The cost of VRM is effective compared to brushless DC motor in high volumes. They are adaptable to very high ambient temperature and they have a low cost accurate speed control possible if volume is high enough. Disadvantages are high torque ripple [5] when operated at low speed, and noise caused by torque ripple. Until the early twenty-first century their use was limited by the complexity of designing and controlling them [6]. These challenges are being overcome by advances in the theory, by the use of sophisticated computer design tools, and by the use of low-cost embedded systems for control. The displacement effect of the rotor (eccentricity) directly affects the course of the magnetic flux (magnetic reluctance) [7].According to the model developed in this work, we could introduce and study the consequences of the eccentricity phenomenon on the magnetic quantities of the machine through the magnetic vector potential. The complexity related to the spatial distribution of local forces [8-9-10] to calculate a resultant force has been surmounted due to the flexibility of our program allows us to consider the effect of changing the rotor position by adjusting its coordinates in the program.

In the following sections, we consider the development of the model and the magnetic vector potential formulation. Then, we present the simulation results and their interpretations.

II. VARIABLE RELUCTANCE MACHINE

A. Operating principle

When a stator coil pole pair is energized, the rotor will move to the lowest magnetic reluctance path (see figure.1). A switched reluctance motor is also known as a variable reluctance motor. The reluctance of the rotor to stator flux path varies with the position of the rotor [11].

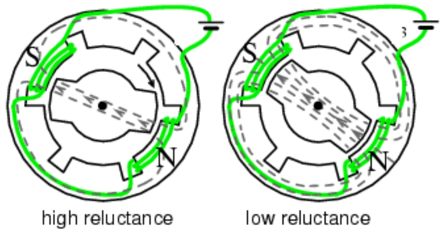


Figure.1. Reluctance path.

B. Model of VRM

To determine the field distribution at each time-step, a tow dimensional transverse section spanning a pole pitch of the VRM is represented [12]. In reducing the problem to two dimensions. The transient magnetic field in terms of magnetic vector potential(A),the permeability of air ($\mu_0 = 4.\pi.10^{-7}$ H/m), conductivity (σ), and current density (J_s), can be expressed by following equation[13-14]:

$$\sigma \cdot \frac{\partial A}{\partial t} + curl\left(\frac{1}{\mu_0} \cdot curl(A)\right) = J_S \qquad (1)$$

The constitutive linear relationship of ferromagnetic material is:

$$B = \mu_r \cdot H \qquad (2)$$

Where

B: flux density;

H: magnetic field;

μ_r: permeability relative.

To solve the general diffusion equation (1) a classical weighted residual method with first order shape functions we obtain the following integral form [15]:

$$\iint_\Omega \omega_i \cdot \left[(curl(curl A)) + \mu_0 \cdot \sigma \left(\frac{\partial A}{\partial t}\right) \right] d\Omega = \iint_\Omega \omega_i \, \mu_0 \cdot \vec{J_s} \, d\Omega \qquad (3)$$

With ω_i is the ponduration function.

With the following linear approximation for the vector potential:

$$A = \sum \omega_i . A_i \qquad (4)$$

Then, we obtain the following algebraic form:

$$[K] \cdot \left[\frac{\partial A}{\partial t}\right] + [M] \cdot [A] = [F] \qquad (5)$$

$$\begin{cases} K_{ij} = \iint_\Omega \sigma \, \mu_0 \, \omega_i \, \omega_j \, d\Omega \\ M_{ij} = \iint_\Omega \left(\frac{\partial \omega_i}{\partial x} \cdot \frac{\partial \omega_j}{\partial x} + \frac{\partial \omega_i}{\partial y} \cdot \frac{\partial \omega_j}{\partial y} \right) \\ F_i = \iint_\Omega \omega_i \cdot \mu_0 \cdot J_s \cdot d\Omega \end{cases} \qquad (6)$$

III. RESULTS OF SIMULATION

The purpose of this investigation is to use the finite element model [16] described above to evaluate the effects of rotor eccentricity on the magnetic vector potential and magnetic field.

The figure.3 shows the geometry of the VRM with 2 poles, 36 slots in the stator and the rotor is made of a ferromagnetic material.

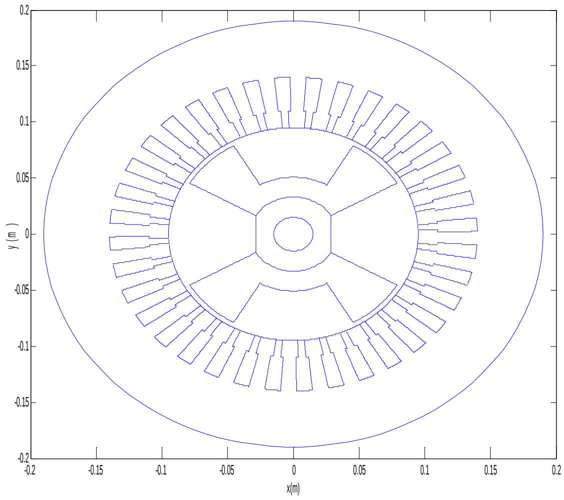


Figure.2. VRM geometry.

The discretization of the geometry with finite element is shown in figure 3.

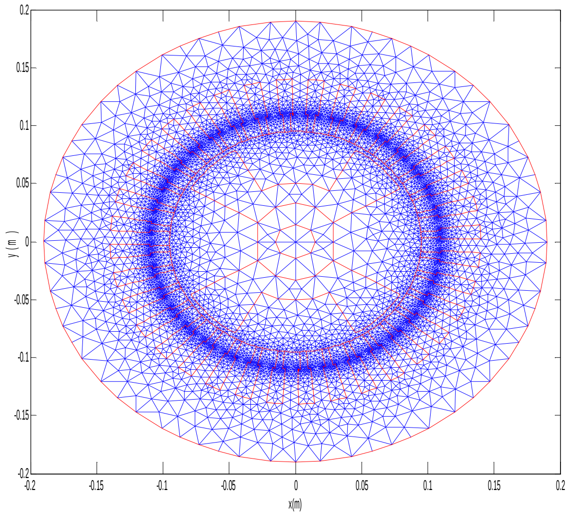
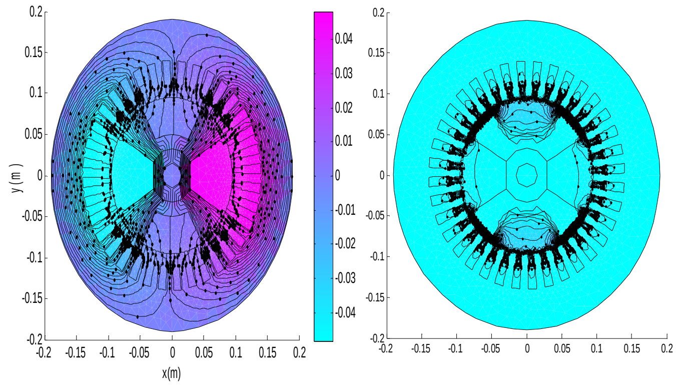


Figure.3. Grid of the domain.

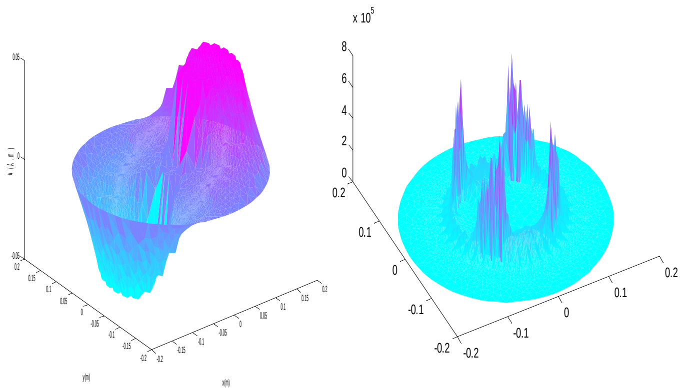
The equipotentials of potential vector magnetic (figure4.a) and magnetic field (figure4.b) is shown by the figure.4.



-a- **-b-**

Figure.4. Equipotentiel of potential vector magnetic (a) and magnetic field (b).

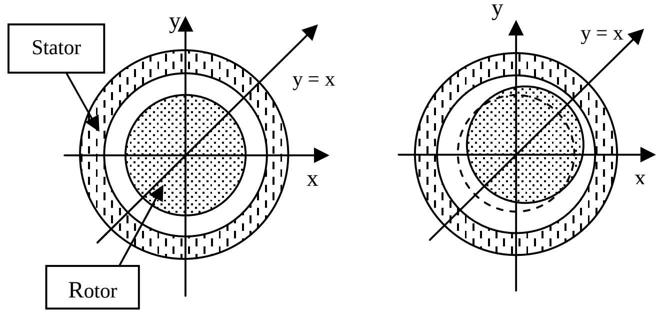
The figure.5 shows the spatial distribution of potential vector magnetic (figure5.a) and magnetic field (figure5.b) for each element of the geometry.



a. potential vector. **b**. magnetic field.

Figure.5. Spatial distribution.

- **Statement of the Problem**



a- Healthy case b- Case with balanced of the rotor.

Figure.6. Schema explicative.

Our study, to see the evolution of magnetic variables (magnetic vector potential and the magnetic field) along the axis of movement (y = x) of the rotor for 25% of the value of the gap. Comparing the simulation results in the default case (with eccentricity) with those of the healthy case, we can see the impact of eccentricity on the magnetic quantities of the machine.

The figures 7 and 8 show the projection of the spatial distribution of magnetic vector potential presented in Figure 5.a on the plane (zx) in the healthy case and with default respectively.

The change in the position of the rotor (eccentricity) occurs with the change of magnetic reluctance. Indeed, when the air gap reduces, so, the magnetic reluctance also reduces, therefore the amplitude of the magnetic vector potential increases. By against, when the air gap increases we see the opposite effect.

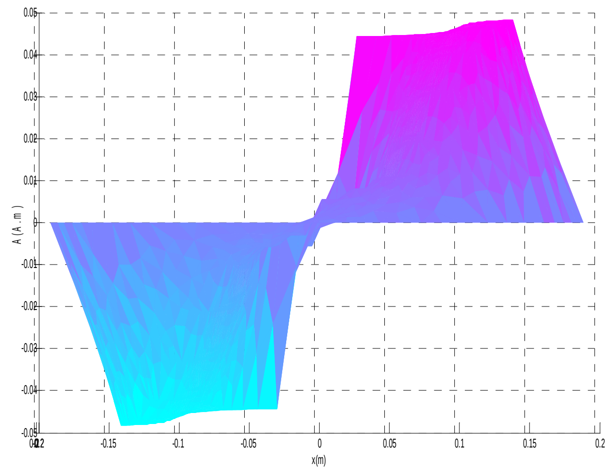


Figure.7. Potential vector (healthy case)

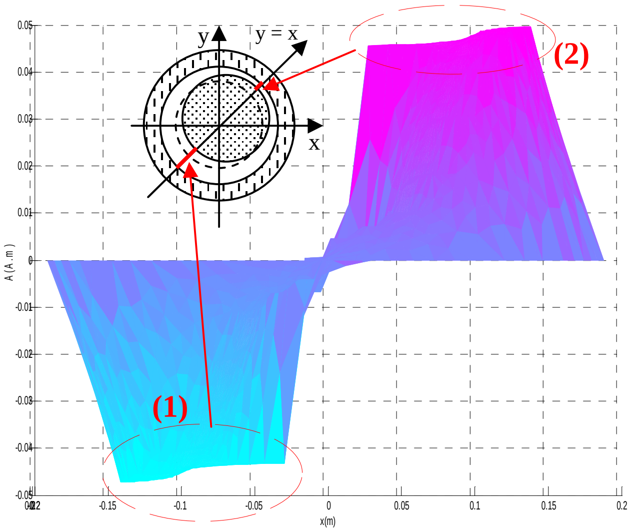


Figure.8. Potential vector: the rotor balanced in axis y=x (25%).

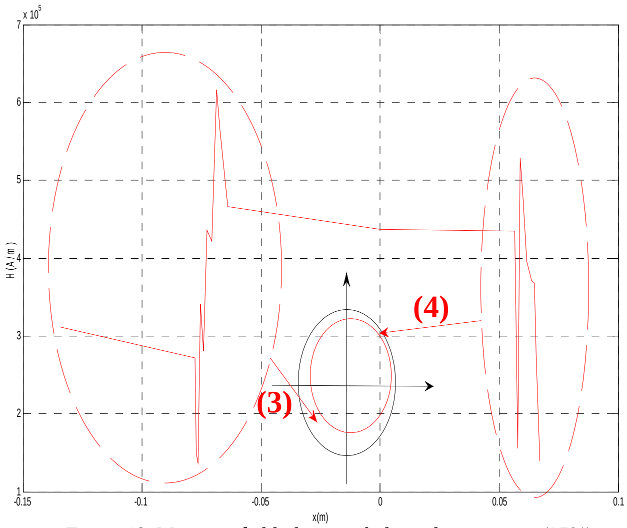


Figure 10. Magnetic field: the rotor balanced in axis y=x (25%).

(1): represents the South Pole (figure.8), comparing with the healthy case (figure 7), since the thickness of the air gap increases meant that the magnetic reluctance increases, so the magnetic potential decreases.

(2): represents the North Pole (figure.8), comparing with the healthy case (figure 7), since the thickness of the gap decreases meant that the magnetic reluctance decreases, so the magnetic potential increases.

The figures 9 and 10 show the evolution of the magnetic field along the diagonal (y = x) in the healthy case and with default respectively.

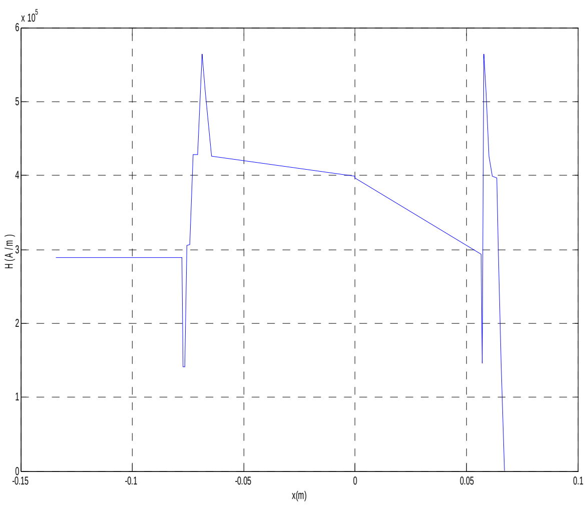


Figure 9. Magnetic field (healthy case).

(3) : the thickness of the air gap increases (figure.10) which serve to increase the magnetic reluctance, then the magnetic field increases, comparing with the healthy case (figure 9).

(4) : the thickness of the air gap decreases (figure.10) which serve to decrease the magnetic reluctance, then the magnetic field decreases, comparing with the healthy case (figure 9).

IV. Conclusion

In order to analyze the effect of eccentricity on the magnetic behavior of the machine, we have begun to appear in figure 7 and 9, respectively, the vector potential and magnetic field when the machine is saint, the results of simulations enables us to introduce and clearly see the impact of the eccentricity on the magnetic machine behavior (magnetic vector potential (Fig.8) and magnetic field (Fig.10)) for a 25% from the value of the air-gap, they are compared to the healthy case (magnetic vector potential (Fig.7) and magnetic field (Fig.9)) of the VRM. The change in the position of the rotor (eccentricity) occurs with the change of magnetic reluctance. Indeed, when the air gap reduces, so, the magnetic reluctance also reduces, therefore the amplitude of the magnetic vector potential increases. By against, when the air gap increases we see the opposite effect.

By against, we see the opposite effect of eccentricity on the magnetic field comparing to that of the magnetic vector potential.

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