A new investigation on the reduction of the vibrations in PMSM based on magnets segmentation

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Permanent magnet synchronous machines (PMSM) have high efficiency and torque density, and have already been employed in hybrid electric vehicles. However, one of their disadvantages is the inherent cogging torque, which is a kind of torque ripple and it would be better to minimize. This torque, sometimes, can be an important source of noise and vibrations. In this paper, the effect of the geometric characteristics of the magnet on the vibratory behavior of electrical machines is illustrated. The optimum geometry for obtaining a minimum vibration level has been reached. For this purpose, an approach by using the Artificial Intelligent (AI) and the Finite Element Method (FEM) is proposed to solve the magneto-mechanical problem of geometrical parameters identification in the optimization process.

***Index Terms*— Vibration reduction, Permanent magnet synchronous machines, Genetic algorithm, Neural network, Finite element method, Optimal design, Permanent magnet segmentation.**

I. Introduction

In order to reduce the vibratory behaviour caused by electromagnetic forces in the permanent magnet synchronous machines (PMSM), a number of effective methods can be used. One method that imposes the least restrictions on machine performance is segmentation, which can be difficult to implement as magnets need to be cut, insulated and re-glued, which is a laborious and costly process [1]. This paper presents methods of partial segmentation in magnets that aim to improve machine performance by reducing vibrations of magnetic origin, while also suggesting realistic manufacturing possibilities.

In this study a finite element model has been used. So, in this case the resolution of the magneto-mechanical problem is very expensive in terms of computing time. In order to avoid this problem we have proposed to replace the magneto-mechanical problem by the multilayer perceptron neural network (MLPNN) at each iteration of the optimization problem based on genetic algorithm (GA) method.

II. Magneto-mechanical Problem

In electrical machines, vibrations are essentially due to the magnetic forces generated on their ferromagnetic parts.

The magnetic force computation method is based on a local application of virtual works principle [2]. These nodal forces have been calculated on each node, using the following equation:

$$F = -\int_0^A [A]^T \frac{\partial [P]}{\partial s} \, dA \tag{1}$$

where $[P]$ and s represent respectively the magnetic stiffness matrix and the virtual displacement.

Figure 1 and table 1 show respectively the geometry and the characteristics of the studied machine. However figure 2 shows the distributions of magnetic forces on the stator. We can see clearly that the variation of these forces according to the mechanical angle is not uniform. This irregular distribution will generate a vibration behavior of the stator.

The vibration computation is based on the use of the mode summation method where the dynamic equation (2) is solved in the space of eigenvectors [3], [4].

$$[M][\ddot{d}]+[C][\dot{d}]+[K][d]=[F] \tag{2}$$

$[M]$, $[C]$ and $[K]$ are respectively the mass, the damping and the stiffness matrix of the structure, $[d]$ is the displacement vector, and $[F]$ is the magnetic forces vector.

The vibratory response of the structure (displacement) is equal to a linear combination of associated mode shapes as follows:

$$[d] = \sum_{i=1}^{NT} \eta_i \; X_i \tag{3}$$

η_i are the modal coordinates associated to each mode X_i.

The resolution of magneto-mechanical problem based on finite element method is very expensive in term of computing time. In order to avoid this problem a Multilayer Perceptron Neural Network (MLPNN) is used to replace the forward magneto-mechanical modeling in each iteration at the optimization process.

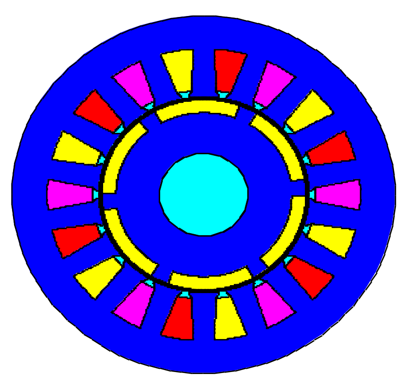

Fig. 1. Studied machine

TABLE I
CHARACTERISTICS OF THE STUDIED MACHINE

Characteristics of the machine	Values
Number of pairs of poles	3
Outer diameter of the stator [mm]	81.60
Air gap diameter [mm]	44.7
Number of stator slots	18
Number of permanent magnets	6
Outer diameter of the stator [mm]	5.3

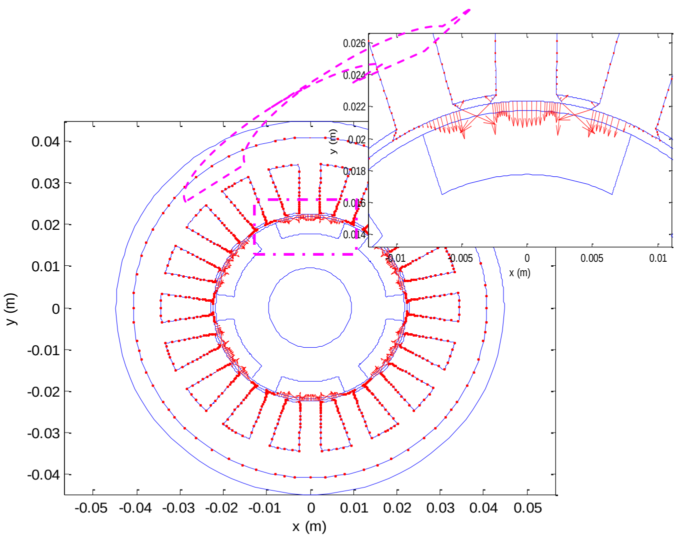

Fig. 2. Magnetic forces distribution

III. OPTIMIZATION PROBLEM

The formulation of the inverse problem has been based on the developed MLPNN model which states a relationship between the dimensions of the magnet, the number of the segments and also the radial displacements. Figure 3 shows the architecture of the MLPNN.

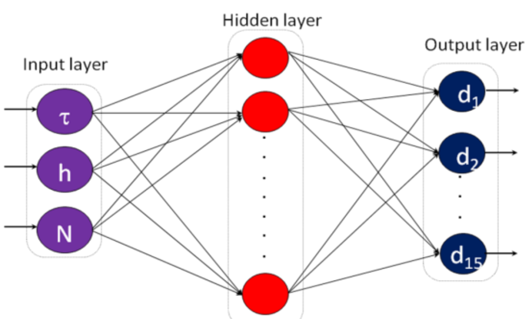

Fig. 3. Architecture of the MLPNN

The proposed MLPNN has three inputs (angle of opening τ and height h of the magnet, and the number of segments N), and 15 outputs (dynamic radial displacements d). Thus, the treated inverse problem (IP) based GA technique returns to solve the following constrained optimization problem:

$$\begin{cases} Min\left(g = \sum_{i=1}^{15} d_i \right) & \begin{bmatrix} [\tau] \\ [h] \\ [N] \end{bmatrix} . [\mathrm{MLP_d}] = [\mathrm{d}] \\ 1.9 \le C \le 3.8 & \\ 27.5994 \le \tau \le 57.5994 & \\ 3\ 10^{-3} \le h \le 6.5\ 10^{-3} & \begin{bmatrix} [\tau] \\ [h] \\ [N] \end{bmatrix} . [\mathrm{MLP}_c] = [C] \\ 1 \le N \le 10 & \end{cases} \quad (4)$$

Where

τ, h, and N: optimization parameters to find,

C: inequality constraint to respect, on magnetic torque

MLPd, MLPc: neural networks defining displacements d_i in each node i of the structure and the torque respectively

Table II shows the optimal obtained parameters and the corresponding computing time. These parameters have been reached for a reducing computing time.

TABLE II
OPTIMAL OBTAINED PARAMETERS

Parameters	Initial values	Optimal values	Computing time (min)	Magnetic torque (N.m)
τ (Deg)	43.05	42.21		
h (mm)	4	3	14	1.97
N	1	6		

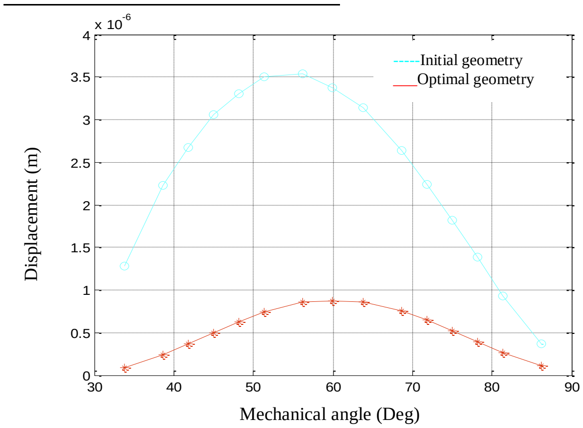

Fig. 4. Obtained displacements

Figure 4 shows the obtained displacements on the frame of the machine for the optimal and initial geometry of the machine. We can say a significant diminution of displacement after the segmentation of the magnets.

IV. CONCLUSION

In this paper a new investigation on the reduction of vibrations in PMSM has been presented. The proposed optimization method allows showing clearly the significance of the segmentation of the magnets on the vibratory level. The combination finite element-neural network allowed a significant reducing of computing time. In the extended paper more details and more results will be presented considering another parameters of the magnet. Experimental realization will be included.

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