Study of the influence of the fabrication process imperfections on the performances of a claw pole synchronous machine using a stochastic approach

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In mass production, fabrication processes of electrical machines are not perfectly repeatable with time leading to dispersion on the dimensions which are not equal to their nominal values. The issue is then to evaluate the influence of these dispersions on the performances of the electrical machines. In this communication, a stochastic approach coupled with a 3D Finite Element model is used to study the influence of the fabrication process imperfections like the rotor eccentricity and the stator deformation. The novelty of this paper relies on the fact that a stochastic approach has been applied to evaluate the influence on the behavior of an electrical machine of the dispersions on the dimensions, which have been characterized from a measurement campaign.

***Index Terms*— Claw Pole Machine, Finite Element Method, Eccentricity, Stator Deformation, Uncertainty Quantification**

I. Introduction

Claw pole machines are commonly used as automotive generators due to their simplicity and low manufacturing cost. These machines are produced in mass. Due to the variability of the manufacturing and assembling processes with time, dispersions on the machine dimensions occur. These imperfections, which introduce parasitic effects on the behavior of the electrical machine should be studied [1,2]. Generally, this study is carried out for some typical values of the input parameters which doesn't take into account the dispersion. The probabilistic approach enables to evaluate the impact of the dimension dispersions on the performances of the electrical machine [3]. The issue is then to be able to model the uncertain parameters with random variable because experimental data are often not available. Until now, the stochastic approach is generally applied with random parameters modelled from expertise and almost no measurement to characterize the dispersion.

In this paper, we propose to quantify the influence on the torque and the back EMF of the dimension dispersions in the case of claw pole synchronous machine. The dispersion on the dimensions is modelled using a probabilistic model extracted from measurements on 40 machines [4]. It appears that the most significant imperfections are the eccentricity of rotor and the deformation of the stator inner surface which can not be considered as a cylinder. A 3D non linear finite element model of the machine with a parameterized geometry has been developed to account for any eccentricity and complex inner shape of the stator. To propagate the uncertainty, a stochastic non intrusive approach based on sparse polynomial chaos expansion has been applied. Then, statistics has been extracted in order quantify the influence of the imperfections on the performances of the electrical machine.

II. Modelling of the imperfection of the claw pole machine

A measurement campaign has been made on parts of 40 electrical machines. As expected, the measured dimensions were not equal to the nominal dimensions and the dispersions have been studied [4]. It appeared that the major imperfections were the eccentricity of the rotor (static and dynamic) and also the deformation of the inner surface of the stator. The eccentricity has been modeled by four parameters (α,sr,βs,βr). The parameters βs and βr are two angles, sr is the distance between the rotor and the stator axis and α a coefficient in [0,1] characterizing the eccentricity type (static $\alpha=0$, dynamic $\alpha=1$ and mixed $0<\alpha<1$). The deformation of the stator inner surface has been modelled by the following expression [5,6]:

$$r_i = h_0 + \sum_{j=1}^{18} h_{jsin} \sin\left[j\frac{i}{18}\pi\right] + h_{jcos} \cos\left[j\frac{i}{18}\pi\right] \qquad (1)$$

With r_i the radius of the tooth i ($1 \leq i \leq 36$). For each of the 40 machines, the previous parameters have been identified leading to a sample of 40 realizations for each parameter α,sr,βs,βr and h_i's. Statistical tests showed that α can be modeled by a gaussian Random Variable (RV), sr by a lognormal RV and βs and βr by uniform RVs. A statistical analysis showed that the most significant modes h_i's were 0, 2, 3,6,12 and 18. The last three modes were strongly correlated and we had $h_{6sin}=h_{12sin}$ and $h_{6cos}=h_{12cos}=h_{18cos}$. The inner shape of the stator is then parameterized by h_0, h_{2sin} ,h_{2cos} ,h_{3sin},h_{3cos}, h_{6sin} and h_{6cos}. Statistical tests showed that the variability of the coefficients could be modelled by gaussian RV. It should be noted that the previous parameters can be related to a stage of the fabrication process. For example, h_{2sin} and h_{2cos} are related to the assembling of the lamination stack and the housing with 4 screws. The harmonics 6,12 and 18 related to the term h_{6sin} are due to the six welding bands on the side of lamination stack leading to the retraction of six teeth over the 36 stator teeth which are regularly distributed.

III. Model of the Claw Pole Synchronous Machine

The eddy current effect in the stator and in the rotor has been neglected. Under this assumption the claw pole synchronous machine has been modeled using a non linear magnetostatic model accounting for the movement. The scalar potential formulation coupled with the Finite Element method has been used to solve the problem. In Fig. 1, the mesh of the electrical machine is presented. The numbers of nodes and tetrahedral elements of the mesh are respectively equal to 152865 and 832514. To account for the modification of the geometry (eccentricity and stator deformation), a node displacement method has been chosen instead of a remeshing method. The position of the rotor is then parameterized by the parameters (α,sr,βs,βr) which is very convenient to simulate any configuration of eccentricity. In the same way, the radius of each tooth is calculated according to the deformation of the stator inner surface given by the parameters (h_0, h_{2sin}, h_{2cos}, h_{3sin}, h_{3cos}, h_{6sin}) and the expression (1). A transformation has been implemented in order to move adequately the nodes to account for the deformation of the stator and the eccentricity.

IV. Results

We have studied the EMF and the torque when the rotor is supplied by a current I of 0.5A and 4A and the stator winding is at no load. At I=0.5A, the machine behavior is almost linear whereas at 4A the machine is very saturated. In the following, we will focus mainly on the torque. We have first quantified the effect of the uncertainties on the stator deformation. We have generated a sample of 200 realizations of the input parameters (h_0, h_{2sin}, h_{2cos}, h_{3sin}, h_{3cos}, h_{6sin}). We have calculated the evolution of the torque in function of the position for each realization. In Fig. 2, the superposition of the 200 torque wave shapes are compared to the one of the ideal machine (the dimensions are equal to the nominal ones) for I=0.5A. We can see that the stator deformation introduced a low frequency effect. To characterize it, the harmonics of torque have been calculated for each realization. The influence of the parameters on the variability these harmonics has been studied by calculating the Sobol indices. The harmonics 36 and 72, which exist with the ideal machine, are not much influenced by the stator deformation. However, new harmonics of order 12 and 24 appear. In Table 1, we have reported the value of Sobol indices for I=0.5A and 4A for the harmonic 12. It should be noted that only the term h_{sin6} is the most influential meaning that the variability (and the magnitude) of the harmonics 12 and 24 can only be reduced by acting on h_{6sin}. As mentioned previously, the term h_{6sin} is closely related to the welding process. Consequently, the reduction of the harmonics 12 and 24 requires acting on this stage of the fabrication process. In the same way, the effect of the eccentricity has been also studied. It appears that the variability of the eccentricity has almost no influence on the magnitude of the harmonics 36 and 72. A parasitic harmonic of order 1 appears. The variation coefficient of the magnitude of this harmonic is equal to 70% and 64% for I=0.5A and I=4A respectively meaning that this harmonic is really dispersive. However, the ratio between the mean of the magnitudes of the harmonic 1 and 36 is equal to 3.8% and 0.9% for I=0.5A and I=4A respectively showing that even though the variability of the eccentricity is quite large it has a small impact on the machine behavior. The stochastic approach presented here enables to segregate among all the dispersive input parameters, characterizing from a measurement campaign, which ones are the most influential. Thus, it has been shown that the dispersion on the stator deformation has a greater influence on the behavior electrical machine than the eccentricity.

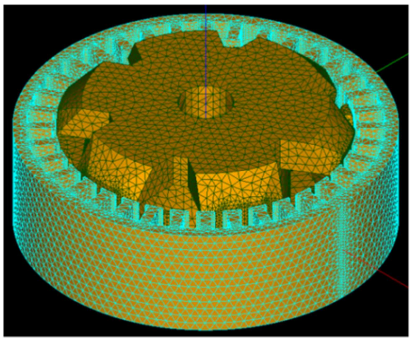

Fig.1. Mesh of the claw pole machine

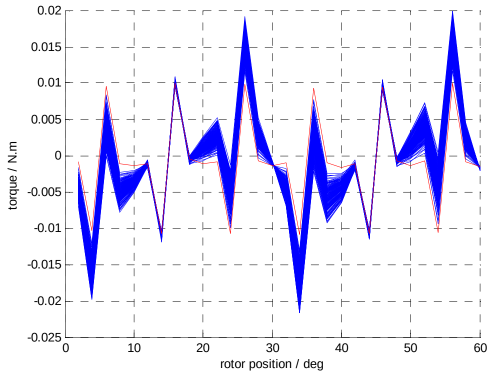

Fig.2: Superposition of the 200 torque wave shapes (in blue) compared to the torque of the ideal machine (in red)

TABLE I
Sobol Indices (%) calculated for the harmonic 12 when considering the stator deformation

I (A)	h0	h_{sin2}	h_{cos2}	h_{sin3}	h_{cos3}	h_{sin6}
0.5	1.75	0.07	0.08	0.03	0.02	97
4	0	0.02	0.06	0	0	97

V. References

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