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A REVIEW OF PERFORMANCE AND CHARACTERISTICS OF CLAW POLE ALTERNATER USING VECTOR MODEL AND FEM

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Abstract

By solving 3d non linear magnetostatics problems design a claw pole synchronous machine which makes the computation time very long . In our model, the mesh is refined to reach the desired level of precision on global quantities such as torque. Since the airgap is very thin (around 0.3 mm for a 100 mm diameter) and require a newton raphson algorithm to cover a several iteration ,the time of the cpu may be too high . To reduce the cpu time many researches are going on ,while preserved an acceptable accuracy. Permeance networks is one of the most efficient methods . But this method is not appropriate for complex geometries. Our main role is to use a permeance network in the zones where flux lines are easy to guess and to solve a 3d fem problem in complex geometry zones of the magnetic device: the claw poles and the air gap for example. Additionally, current sources belong to the permeance network model, therefore there are no current sources in the 3d fem problem. Then, a 3d scalar magnetic potential formulation can be used easily. The two classical magnetostatic formulations (magnetic scalar potential formulation (um – hs) and vector potential formulation (a – j)) are presented in this paper. Then, the formulation of 3d fem hybridization and the permeance network, is obtainable. Numerical results are compared with experimental measurements and a good arrangement is obtained while reducing the cpu time.

Introduction

The claw-pole synchronous machine (cp-sm), shown in fig. 1 is widely used in the automotive industry thanks to its low-cost price and robustness compared to other electrical machines. The complex geometry of claws in the rotor makes it difficult to model with accuracy the cp-sm, whatever the method (numerical or analytical). It cannot be considered as a 2d geometry and it has to be kept unaltered. Besides, the 3d effects due to the claw poles cause local high magnetic saturation, mainly in the rotor claws and stator teeth. These two characteristics lead to solve a difficult nonlinear 3d magnetostatic problem. Reducing the cpu time is a real challenge. There are many strategies to obtain the optimum balance between cpu time and accuracy. The main idea is to mix an analytical method based on a permeance network with a numerical one based on 3d finite element (FE) method. On one hand, the 3d FEM takes into account the real motor shape without geometric approximations, and gives accurate results. But computation time is high. On the other hand, the analytical method uses less computing resources, at the expense of accuracy [1], [2]. Our main contribution is to take advantage of these two complementary approaches for a 3d problem. To do this, a coupling between permeance networks and fe is carried out with free finite element softwares but it could be implemented in any other computation tool allowing a coupling of electric circuits with nonlinear resistances and fem. The machine is cut into two areas. A permeance network is built from the ferromagnetic areas where the field lines are two dimensional (the upper stator armature and the central part of the rotor). The air gap and the areas where flux leaks are important (claws and slots) will be the area modeled fem.
In section ii, the choice of magneto-static formulation is presented as well as the hybridization of 3d fem with permeance network. Then, in section iii, the hybrid model and experimental results are compared.

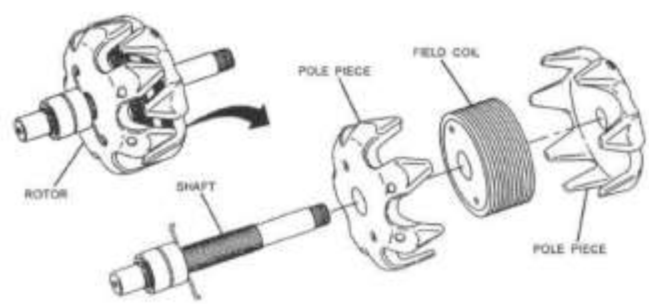

Figure. 1. Synchronous Claw-Pole Machine

I. Magnetic Modelling

To compare the performances of the different approaches, we use global quantities: the no-load electromotive force (emf) and the torque (Γ). To obtain these different global quantities, two types of models are possible: a casual fe model on the whole

A. Classical FE 3D Models

Both conventional models rely on the use of magnetic Potentials: the scalar potential (*um*) or the vector potential (***a***). These two potentials bring us either to a b-conforming or to a h-conforming formulation, which provide two variational formulations related to (1) and (2).with ***j*** the current density, the reluctivity and ***Br*** the reminisce, □□the studied domain, □s the source domain and □*m* the permanent magnet domain with ***Hs*** the source field (***Hs*** = ***curl(j)***), ***Hc*** is the coercive field, □ the permeability

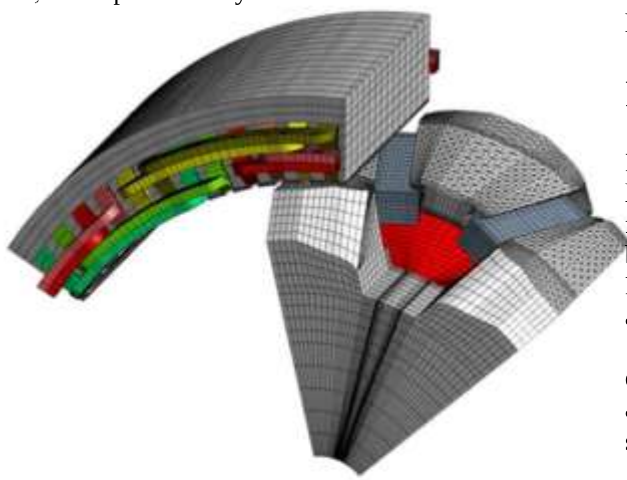

Figure. 2. FE Model Of Claw Pole Synchronous Machine [3]

The studied machine, shown in fig. 2, is purely three dimensional. In the case of (***a*** – ***j***) formulation, a spanning tree gauge [5] is implemented to ensure the magnetic vector potential uniqueness. The current density is imposed by analytic formulas for the rotor coil and computed by a current-flow preresolution for the stator coils. However, for (*UM-Hs)* formulation, we must replace the current sources by an equivalent source field. Among the various methods to evaluate this source field, we choose an indirect method proposed by dular et al. In [6]. It can be applied to any shape of inductor while reducing cpu time. The scalar formulation has fewer unknowns than the vector formulation. However, computing the source field in a periodic geometry with complex coils is difficult and causes cumulative errors, because of an additional step. We note that the calculation of the emf by the flux derivative is easier with the (***a*** – ***j***) formulation than with the (*UM-Hs*). In return, the (***a*** - ***j***) formulation needs more computing resources due to the size of the system. To show objectively that the hybrid-method presented later is efficient, we did our best to speed up the convergence of (***a*** **–** ***j***) and (*UM-Hs*) formulations. Therefore, we use two different solvers with the same convergence criterion. A newton- raphson method with a convergence criterion of ||***b***-***h***|| in the air-gap with a relative accuracy of 10-3 is selected for the (***a*** – ***j***) formulation. According to the literature, the newton-raphson method is not the most suitable for (*UM-Hs)* formulation [8]. The choice of solvers and convergence criterion results from our previous works to reduce CPU time in the case of a nonlinear magnetostatic problem

B. Hybrid Formulation

The hybrid formulation is based on additional assumptions. It can be understood as the mix of fem and permeance network. The 3d fem unknowns are either ***a*** or *Um* Depending on the chosen formulation. The permeance network unknowns are the flux (φ) or the magnetomotive force (*vp*). As usual, we assume that the flux density ***b*** is oriented along the length such as *leq* and uniform throughout a flux tube.

RESULTS

In this section, we will discuss about a no-load and a full load operations. We can provide experimental measurements for the no-load operation and we will compare the emf given by two numerical formulations and experimental results. For the full-load operation, as our test bench does not have any torque sensor yet, three numerical models are compared.

The emf are calculated by derivating the magnetic fluxes. In the hybrid model, the fluxes in the network branches are directly available after the resolution and it only has to sum them to obtain the total flux (ϕ) through the coil

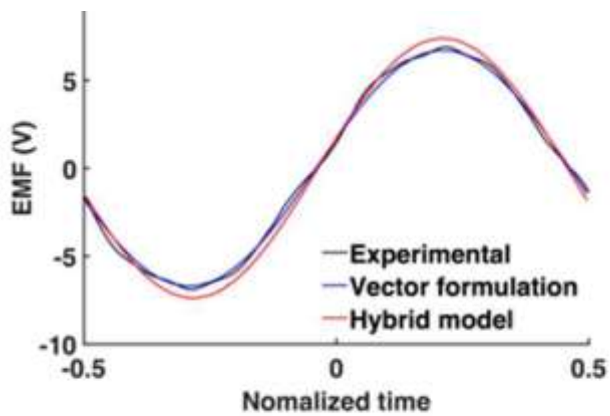

Figure. 3. EMF Over One Period [3]

Figure. 3.shows the no-load emf waveform and figure. 4. Graph indicates EMF versus field coil. The rms value of emf versus excitation current (*if*), for a constant rotor speed. For *if* = 0, emf is non zero because the machine includes both wounded inductor and magnets.

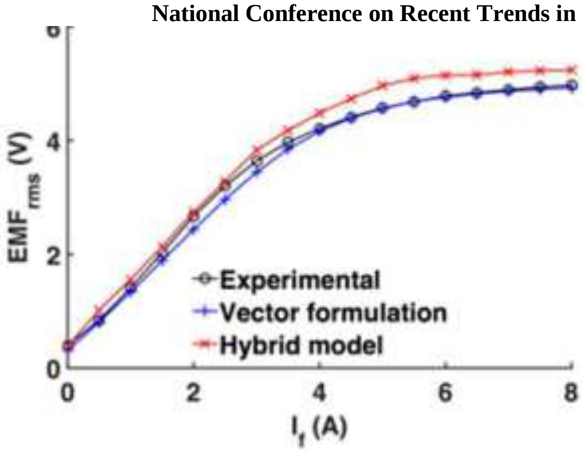

Figure. 4. EMF Versus field coil[3]

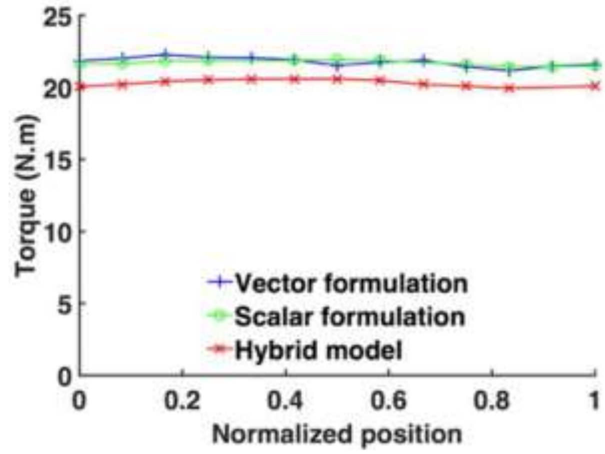

Figure. 5. Torque Waveform Over Slot Pitch [3]

As expected, > wo19-2 < 4 ($\boldsymbol{a} - \boldsymbol{j}$) formulation gives emfs very close to measured ones because this model uses the least simplifying assumptions. The relative difference for the no-load emf is less than 8% in the worst case compared to both experimental and full 3d results.

In the case of full-load operation, the torque is calculated by the volume integral of the maxwell stress tensor in the moving band using the hybrid model underestimates the average torque (under 10% of difference) due to the different assumptions of permeance network model. This type of models allows us to take into account the real 3d effect inside the claw. In a future work, this model will be used for the optimization of claw shape for a given stator geometry.

As shown in figure. 5, the hybrid model underestimates the average torque (under 10% of difference) due to the different assumptions of permeance network model [3]. This type of models allows us to take into account the real 3d effect inside the claw. In a future work, this model will be used for the optimization of claw shape for a given stator geometry the (UM-VP) hybrid model, even if it is based on strong assumptions, gives a quite good approximate value of the average torque. Moreover, cpu time is divided by 2. Besides, dofs number is at least divided by 4. The gain with the (UM –Hs) formulation is much higher: cpu time is divided by 8.6 . Cpu time is more or less the same for no-load emf and full load torque. Our hybrid model will really improve the convergence speed of optimization processes, without damaging the accuracy. Our work began with a simpler device(electromagnet) and we drew the same conclusions. This example proves the robustness of the (UM-VP) formulation even in the case of a complex geometry.

CONCLUSION

The purpose of this work is to optimize processing. An original model based on hybridization of 3d fe and permeance network is applied to a claw-pole machine. The (UM-VP) formulation has been chosen for several reasons. First, the scalar potential um and VP are easier to connect together at the common boundary because grad (UM)is similar to a potential difference VP. Moreover, current sources are transferred in the permeance network which avoids calculating any source field for the scalar potential formulation. It provides accurate results and cpu time is reduced, which makes it suitable for pre-design and/or optimization purposes

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