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Contribution to the electro-magneto-mechanic strong coupling in the study of vibration of electrical motors of aeronautic ventilation systems

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1. INTRODUCTION

The noise heard by passengers on airplanes can reach eighty decibels and become a real burden. This noise can come from the ventilation system. The acoustic of such system has become, during the past years, an important requirement of the specifications, and is taken into consideration in the design phase.

In particular, the importance of the coupling between the shaft vibrations and the electromagnetic phenomenon has been highlighted in recent experiments. Here this coupled problem is studied with a simple model able to predict the strong couplings that might produce high level of noise.

This model is divided in 3 steps:

- 1) Model of the electromagnetic forces of a permanent magnet motor. A subdomain model is used to solve the Maxwell equation and calculate the Maxwell forces acting on the rotor.
- 2) Model of the shaft dynamic behavior. A 1D rotating Timoshenko beam is considered to predict the deformed shape of the rotor excited with the Maxwell forces computed in the previous step.
- 3) Strong sequential coupling of these two models.

After convergence, we will be able to say if the eccentricities have created Maxwell Pressure that will that excite our rotor shaft and make it vibrate.

2. ELECTROMAGNETIC MODEL

As explained in the introduction, an electromagnetic model is developed to compute the magnetic forces in the airgap that will generate a rotor dynamic. This forces components, called the Maxwell forces, are directly derived from the magnetic flux density as

$$P_r = \frac{B_r^2 - B_t^2}{2\mu_0}, \quad P_t = \frac{B_r B_t}{\mu_0} \quad (1)$$

where P_r and B_r represent the radial component of the Maxwell Pressure and the magnetic flux density respectively, P_t and B_t the tangential ones. Here the forces depend on the airgap length between the stator and the rotor which might change during rotation. This airgap is related to the flexural deflection of the shaft and/or shaft installation. Therefore, dynamic and/or static eccentricities appear.

The subdomain model [1-5] is used here for its flexibility and speed of execution. It consists of dividing the field domain into three simple subdomains delimited by a specific geometry or material. The Maxwell equation in each domain will be derived using an abstract parameter

called the vector potential. They then will be solved by applying the boundary and interface conditions between subdomains.

In our case, to obtain better computation time and keeping a good precision of results, the simplified geometry of Figure 1 is used with 3 subdomains: permanent magnet (1), airgap (2) and stator slots (3). The blue parts are ferromagnetic ones. They are supposed to be perfect, with an infinite magnetic permeability. That is why they are not considered as a subdomain in the model.

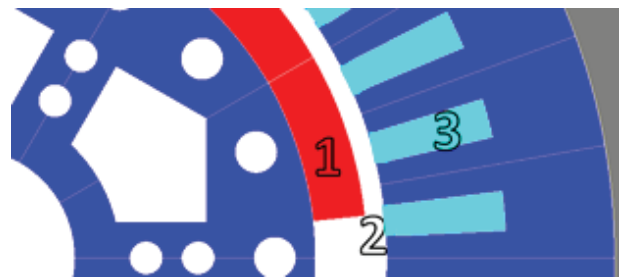


Figure 1. Simplified geometry of a permanent magnet rotor and subdomains

In our study, because we want to see the influence of the rotor dynamics, we must use a model considering the eccentricities of the rotor as in [6-7]. This will allow us to simulate the rotor deformations and compute unbalanced force distributions by introducing an eccentricity perturbation term. There are three types of eccentricity. Static eccentricity means that the rotor is displaced from the rotor center but still rotates about its own axis. In the case of the dynamic eccentricity, it rotates about the axis of the stator while being displaced. The last eccentricity is the combination of these two phenomena.

The study can be pushed even further by adding other defaults to the rotor, such as magnet defaults (bad positioning or magnetization direction) and see their effect on its dynamic. [8]

Electromagnetic computation steps are validated using the 2D Finite Element method software Altair Flux2D [9].

3. MECHANICAL MODEL

The rotor shaft is modeled by a 1D Timoshenko beam [10] with gyroscopic effect to consider its rotation [11]. The finite element method is applied to the weak formulation of the elastodynamics. The final differential system to solve writes

$$\mathbb{M}\ddot{q}(t) + \mathbb{G}\dot{q}(t) + \mathbb{K}q(t) = r(t) \quad (2)$$

where \mathbb{M} , \mathbb{G} and \mathbb{K} are the mass, gyroscopic and rigidity matrixes. The components of r form the exterior forces vector. q is the vector of the rotor generalized

displacements and rotations. The \mathbb{G} matrix is added to the problem to consider the rotation of the rotor.

This equation can be solved in time by applying the external forces from the electromagnetic model with a finite difference scheme [12-13].

4. CONCLUSIONS AND PERSPECTIVES ON THE MULTIPHYSIC STRONG COUPLING

A loop between the two models is used to couple the mechanical and the electromagnetic parts represented by the steps Figure 2.3i and 2.4i. The deformed shape of our shaft is updated at each step in the mechanical model while the air gap angular distribution of the Maxwell forces is updated at each step in the electromagnetic model.

Thus, the airgap will evolve at each step. We will assume that at some point its evolution will be lower than the convergence criteria that will be fixed meaning that equilibrium has been reached. After this step, the vibratory signature of the shaft is obtained. The rotor dynamic and eccentricities will modify the harmonic content of the magnetic forces from the one of Figure 2.1 to the one of Figure 2.2i. This will increase the risk of having a concordance between the Maxwell Pressure exciting frequencies and the modal basis of the stator. This phenomenon can be tested by applying the forces on an equivalent cylinder representing our stator.

That is why this model needs to have fast computation time to be able to deal with the physical problem in real time and allow us to understand the sequence of mechanisms. This software can easily be run during the design phase of every project to detect the defaults early enough.

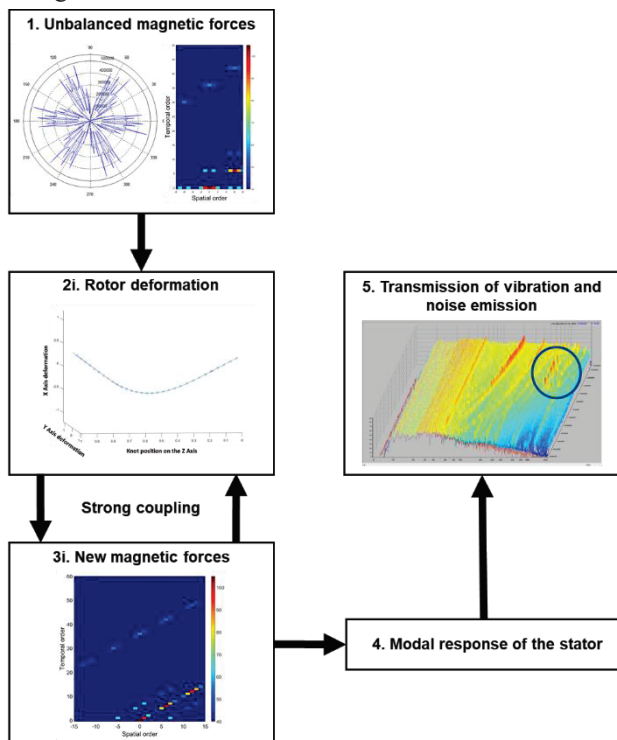


Figure 2. Sequence of physics mechanism leading to noise emission of the motor

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