New Axial Field Electric Machine for Energy Storage.

Olivier Gergaud, Bernard Multon, Hamid Ben Ahmed, LÉSiR - Antenne de Bretagne de l'ENS de Cachan.

Introduction

Since 1996, the Conception of Actuators team of *Antenne de Bretagne* of LESiR (*Laboratoire d'Electricité Signaux et Robotique*) has worked on an electromagnetic energy storage device in cooperation with the LMT (*Laboratoire de Mécanique et Technologie of the ENS of Cachan*) and the LEG (*Laboratoire d'Electrotechnique of Grenoble*). A special electric machine satisfying the set of constraints of storage by inertia wheel on semi-passive magnetic bearings (low stiffness) has been imagined, modeled [1] and conceived by this team.
This original device [2] consists of two cogged rotating disks, figure 1, made of a magnetic and non-conductive material, a fix three-phase induced winding placed in the air-gap between the two disks, which produce a magnetomotive force the most sinusoidal possible, and a fix inductor coil, around the axis of two disks. We will note that the stored energy will be the rotor kinetic energy.

In order to minimize the mechanical losses, the rotating parts of the device are designed to operate in partial vacuum and semi-passive magnetic bearings will ensure the supporting of the whole device. These magnetic bearings are studied and made at LEG [3].

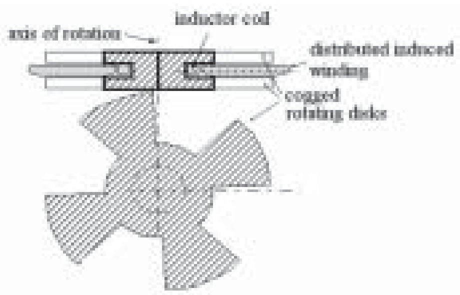

Figure 1: Structure of the new axial field machine.

For a good cohabitation between the magnetic bearings and the actuator, it is necessary to evaluate the parasitic efforts created by the machine.
In such a machine structure, with windings in the air-gap (without slots), there are two types of

Figure 2: Mock-up for validation made at LESiR.

efforts. On the one hand, the reluctant efforts due to the interaction between the induced magnetic field and the reluctance of the rotor disks and, on the other hand, the Laplace efforts generated by the interaction between the inductor magnetic field and the currents of the induced winding (denoted by J). We carried out a study of these efforts, especially in the situation of non-alignment of the rotor due to possible displacements of the rotor disks with respect to the stator winding.

Since the magnetic circuit operates is practically linear and the induced winding is in air, the evaluation of the first component of the Laplace efforts can be done by the relation $\overrightarrow{dF} = \vec{J} \wedge \overrightarrow{B_e}$ (figure 3). In this case, it is enough to determine the distribution of the magnetic flux density B_e due only to the inductor coil, starting from a 3D finite element computation (FLUX3D [4]). As to the induced current distribution J, it is expressed, starting from an analytical model, as a function of a certain number of electric and geometric parameters, taking into account the particular geometry of the induced winding.

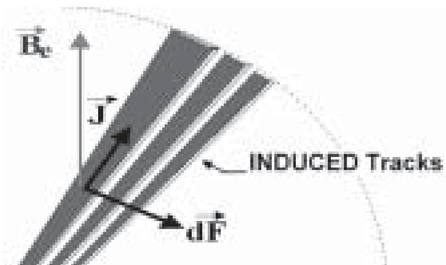

Figure 3: Laplace efforts

Evaluation of the magnetic flux density due to the inductor coil

3D finite element computations are used to evaluate the magnetic flux distribution in the space between the disks, due to the inductor coil. This distribution is then expressed by means of three matrices representing the radial, orthoradial and normal components of flux density.
The complete structure is shown in figure 5. Axial and azimutal symmetries can be noticed. The inductor coil is placed in the center. Taking into account these symmetries, as well as the possibilities offered by FLUX3D, the processed structure is shown in figure 4.

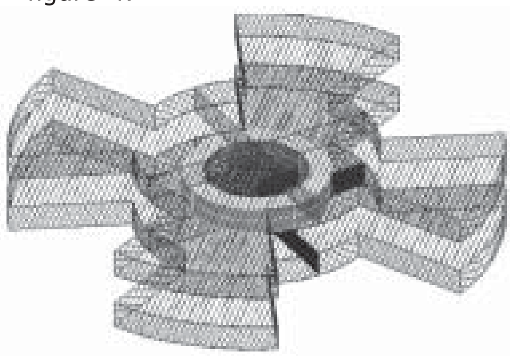

Figure 4: Complete structure of the machine with inductor.

The obtained magnetic field density in the air-gap is shown in figures 6 and 7.
The components of the radial and orthoradial magnetic flux density are the main causes of the parasitic efforts. The latter ones are due to the leakage flux going out from the edges of the teeth (internal part of the slot, teeth extremities and teeth edges). A qualitative image can be seen in the figures below.

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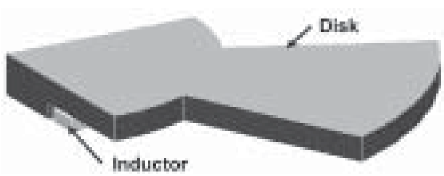

Figure 5: Elementary pattern for 3D magnetic computations.

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Conclusion

The 3D finite element computation allowed us to evaluate the distribution of the magnetic flux density in the air-gap, due to the inductor coil. The interaction between the inductor magnetic field and the induced currents, allowed an appropriate evaluation of the parasitic efforts that are exerted on the magnetic suspension that operates perfectly centered (vertical, axial and angular), but also in the case of various non - alignment. Finally, a 2D finite element computation allowed us to evaluate the efforts of the reluctant type.

When applied to the validation mock up (0.1 Nm at 10,000 rpm), the computations showed that at rating operating conditions of the machine, the magnetic bearings should be dimensioned in order to support:

- A radial and axial stiffness of the order of magnitude of Newton per millimeter,
- An effort of the radial moment of the order of magnitude of milli-Newton-meter for Laplace efforts,
- An axial stiffness of 5 N/mm for reluctant efforts.

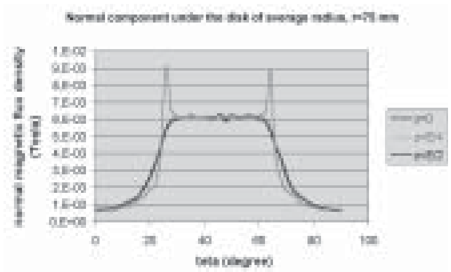

Figure 6: Normal component of the magnetic flux density under the disk of average radius, at different heights.

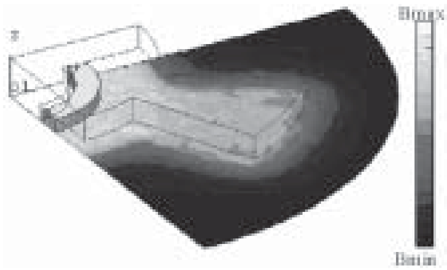

Figure 7: Normal component of the magnetic flux density under the disk.

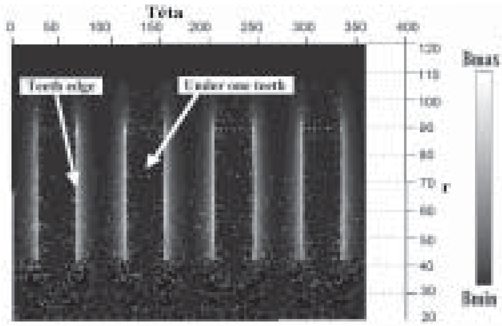

Figure 8: Orthoradial component of the magnetic flux density in the air-gap.

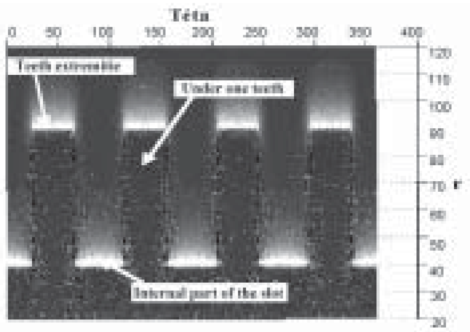

Figure 9: Radial component of the magnetic flux density in the air-gap.

Current Transformer Modelling. (continue)

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[(3)] Schneider Electric, Grenoble, France.

To avoid the problems linked to air-gap geometrical descriptions and meshing, a new computation of t_{0k} is introduced which allows to take into account both circuit equations and surface air-gaps with thickness. This contribution strongly improves problem description (geometry and mesh of thin volume regions), computation times (4 times faster) as well as the smoothness of the isovalue results.

References

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(a)

(b)

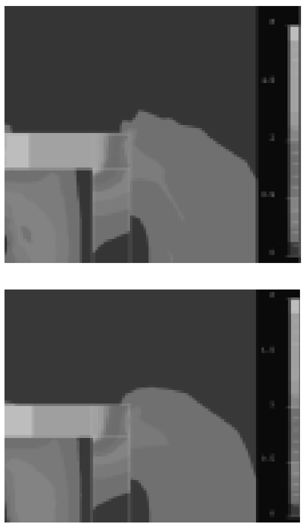

Figure 8: Flux density (Tesla) at time t=0.033s with volume air-gap (a) and with surface air-gap (b).