3D Thermal Study of a Low Power Electric Motor with FLUX3D.

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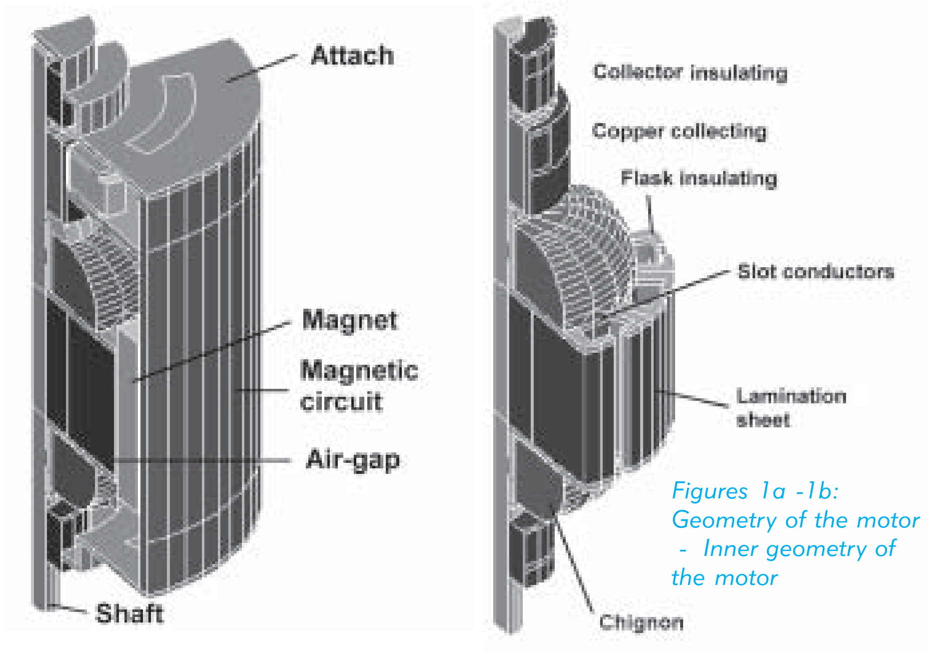
Introduction

The design of rotating electric machines requires that the inner heating be taken into account. Indeed, they prejudice the lifetime of machines by deteriorating the windings and the bearings. The cause of overheating could be a new supply source that determines supplementary losses, an increase of the load, or a high temperature of the environment. The use of a numerical simulation tool such as FLUX3D during the design stage is determinant in order to anticipate a priori the temperature level. However, the numerical model has to be validated. Therefore, experiments and numerical simulations are carried out during this stage.

The experiments allow the assessment of the boundary conditions and give the inner temperatures useful for the validation of parameters integrated in the model. It is quite dificult to obtain the set of thermal conductivities and we have obtained them by means of the FLUX2D thermal module used for heterogeneous structures.
For these thermal models we used the non-linear heat equation. This is a rigorous approach in solid domains, but it requires to be adapted for fluid domains. Indeed, the heat is transferred through fluids by the three fundamental ways of thermal transfers. The use of thermal conductivity of fluids would highly underestimate the heat fluxes through them. Therefore, it is convenient to increase this value artificially, in order to consider the sum of the 3 fluxes expressed in a conductive form.

This study refers to a D.C. electric motor with permanent magnets, and a rated power of 120 W. At this power range, we note that the external radiation is not negligible with respect to the convection. Finally, the thermal model was developed by means of the FLUX3D finite element software for an original design of a machine, having a different geometry but the same topology as the 120 W motor.



Figures 1a -1b: Geometry of the motor - Inner geometry of the motor

Studied motor

The study concerns a low power (120W) D.C. motor with permanent magnets. The geometric symmetry and the boundary conditions allowed us to consider only a quarter of the machine. The geometry of the motor is shown in figures 1a and 1b.

The whole structure is parameterized by means of several coordinate systems linked ones to the others. This parameterization allows a possible modification of the structure without having to create a new geometry from the beginning. This is particularly interesting for conceiving a new structure starting from the origin ones. However, it is convenient not to change the topology. The whole motor is split into different regions. These regions differ from one another by the inner thermal sources, their thermo-physical properties or the conductivities and/or heat transfer modes.

Presentation of the motor testing facility:

The installation for motor testing in figure 2, consisting of thermal and electrical components, has got a triple role. It must quantify, locate and separate the thermal losses of the motor, which are as many thermal sources that have to be known. It should also provide the inner

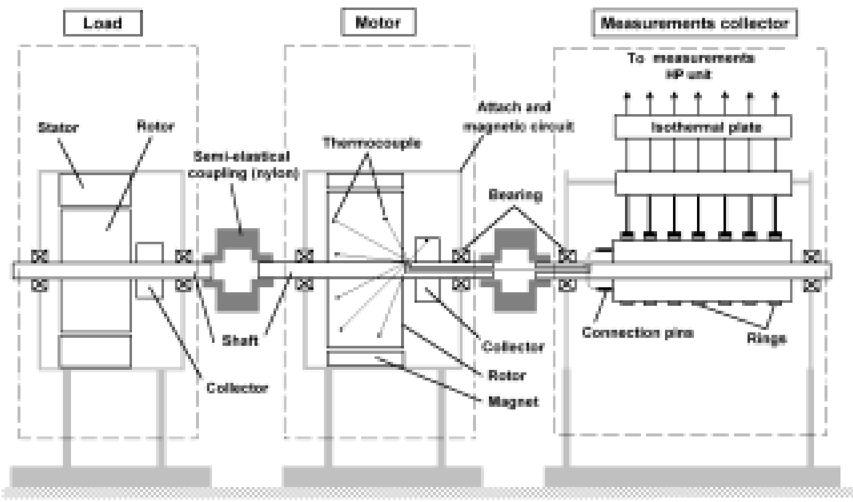


Figure 2. Scheme of motor testing facility.

(continued on page 11)

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reference temperatures of the stator and the rotor, as well as the surface temperatures (Dirichlet boundary conditions). The latter are obtained by means of an infrared short waves thermograph camera and it shows that they are relatively uniform. All the inner temperatures are obtained by means of standard thermocouples of 100 µm diameter. The rotor has got 23 thermocouples coupled to a data acquisition system of high technology.

The first module is the load, which is a D.C. machine operating as a generator. The second module is the studied motor equipped with thermocouples on the rotor and on the stator. The wires of rotor thermocouples pass through the quill shaft and they are connected to the rotating multiple connector (third module).

Loss separation

In order to model a machine or to study its thermal behavior, it is necessary to know the different losses that are as many thermal sources. They are mechanical losses P_m, magnetic losses P_{iron} and Joule losses P_J. Since the studied machine has a commutator and brushes, the Joule losses on the brushes - commutator contacts have to be separated from the ones in the coils. The loss separation obtained for a load operating conditions test is given in table 1.

Localization of temperature sensors

40 thermocouples are introduced in the device in zones with high thermal flux and high temperature gradient (contact thermal resistance). 23 thermocouples are placed in the rotor on 3 axial planes at 120° angular distance between them.

Used method

The lock and the validation of the set of the thermo-physical parameters require at least 2 experimental tests with different heating conditions. The first test allows the evaluation of the set of thermal conductivities in different zones of the machine, while the second test confirms these values. The validation of parameters always includes the comparison between measured temperatures and computed temperatures by numerical simulation at the same reference points.

Test	Characteristics	Pm [W]	Piron [W]	Pm+Piron [W]	PJ total [W]	PJ comm. [W]	PJ coil. [W]	P total [W]
N°1	N=1780 rpm I=8.4 A Tamb=24.6 °C	2 3.5%	3 5.3%	5 8.8%	51.8 91.2%	20.2 35.6%	31.6 55.6%	56.8 100%

Table 1: Synthesis of different losses for on load test.

Geometric parameterization and mesh

The structure of the motor is relatively difficult to be handled. It consists of approximately 1000 points, 1900 lines, 1000 faces, 90 volumes and 28 volume regions. The set of this data is parameterized in order to carry out possible modifications of the geometry, but with the same topology. The final mesh is constituted by 194 256 nodes of second order.

Comparison between experimental and numerically computed temperatures in inner reference points

The experimental and computed temperatures (1st order) are compared in 19 reference points. Absolute and relative differences are computed and analyzed. The convergence of numerical simulation is obtained after 40 iterations in which the thermo-physical parameters are changed unitarily. The most important differences between the computed and experimental temperatures are obtained inside the left chignon (- 6.4°C for an experimental value of 99°C), while the less important difference was obtained close to the left windings, in the iron (- 0.1 °C for an experimental value of 89.2 °C). For all inner reference points, the absolute and relative average values obtained with a least square method are 3°C and 3.2% respectively.
Figure 3 shows the 3D color map of the temperatures in the winding in the case of a test under overload operating conditions.

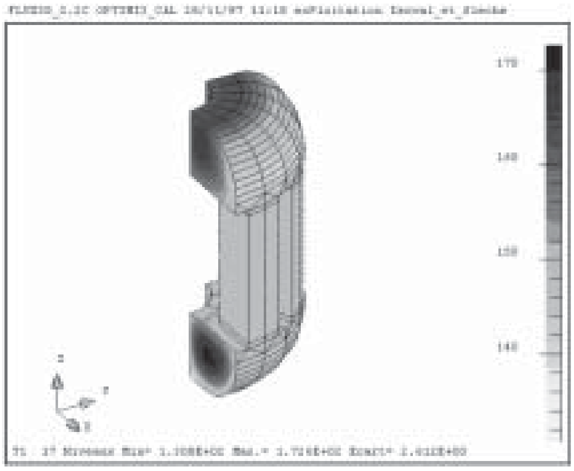

Figure 3. 3D color map of temperature in the winding

Conclusions

The FLUX3D thermal module proved to be well adapted for the developed methodology. The parameterization of the structure allowed the study of a different geometry having the same topology. This feature is very important for the industry, which often conceives the design of motors starting from already existing machines. The software proved to be useful in the use of boundary conditions that are changing with the ambient temperature. Simulations that take into account the speed were also carried out. In this case the treated equation which is non-linear (some parameters depend on the speed) has been solved with good results, without a considerable increase of the computational effort.