Software Tool For The Optimum Material Choice For Induction Machines

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***Abstract* — Electromagnetic devices such as induction machines are widely used in industry. Increasing their efficiency is an optimisation process with three aspects: shape optimisation, waveforms of imposed currents and voltages, and material choice. This paper describes a program intended to help choosing the best ferromagnetic material in induction machine design. The aim is to evaluate the effects of applying different magnetic materials with different magnetizing behaviour on the iron as well as on the copper losses determining the efficiency of induction motors.**

I. Introduction

In general, induction machines are designed for a particular point of operation. At this working point efficiency, current density and other important parameters are determined. However, the knowledge of the behaviour of the machine at non-nominal load (partial load) is important to determine the overall efficiency. The behaviour of the non-linear ferromagnetic material and the point of operation determine the ratio between iron losses and copper losses in that point. The material characteristics of various iron laminations have to be analysed to optimise the machine's behaviour. A mathematical model for induction machine to evaluate the effects by using different electrical steels was developed by Müller et al. [1]. The model is valid for standard induction motors in the range between 1 kW and 100 kW. A basic data-set describing the machine is used for the model calculation to compare the resulting losses and efficiency of the machine constructed with different lamination.

II. Software Framework

Optimisation processes in general need time to analyse all implications of each parameter. To increase the speed of the analysis of the machine, a program called Aim@M, based on the model of Müller [1], was developed. The main requirements for such programs are:

1) to model all important effects sufficiently accurate;
2) easiness of importing data and exporting the results;
3) user friendliness.

These programs work with particular algorithms to model the machine and to process various data-sets describing different magnetic materials. Different working conditions can be analysed in this way. In the program described here, material, loss and supply models are implemented in a modular way, allowing the exchange of already implemented models (e.g. loss models) with others, hence the flexibility of the overall program.

An important feature of this program is that there are no time-consuming online finite element simulations involved. This results in a rather short time for each analysis. However, particular effects may in a general way be computed beforehand using finite element solvers and can be handled by the algorithms as look-up tables.

III. Machine Model

At a first stage of the calculation within the model of Müller [1] the magnetizing currents using different electrical steels for a given machine are considered. For the modelling of the induction machine a classical approach was chosen [2,3]. The magnetic circuit of the machine is assumed to consist of three parts: the stator yoke, the stator teeth and the rotor teeth for which a non-linear material characteristic is considered. The iron losses are evaluated employing Steinmetz's formula (1) [3, 6].

$$P_{Fe} = \left[s_h k_h \frac{f}{50\text{Hz}} + s_e k_e \left(\frac{f}{50\text{Hz}} \right)^2 \right] \left(\frac{B}{T} \right)^2 m_{Fe} \qquad (1)$$

with:

P_{Fe}	iron loss;
f	the frequency;
B	the magnetic flux density;
m_{Fe}	the mass of the magnetic material;
σ_e, σ_h	specific magnetic loss due to eddy currents, respectively to hysteresis;
k_e, k_h	experimental additional factors.

In the case that experimental data for the specific losses at the desired frequency are available, a seperation into eddy current and hysteresis losses can be avoided.

The air gap of the machine is assumed to be constant and the slotting effect is considered by Carter's factor for the stator, respectively for the rotor.

In order to show the differences in the machine's behaviour by applying different ferromagnetic materials, the results may be given as relative values with respect to the initial design material, defined as reference material "one".

For example, the iron losses are calculated resulting in the ratio:

$$\left(\frac{P_{loss\ Fe\ II}}{P_{loss\ Fe\ I}}\right) = f(B_1) \tag{2a}$$

and are given as a function of the stator air gap flux density B_1.

The ratio of the magnetizing currents is given by

$$I_{mII} / I_{mI} \tag{2b}$$

The second step of calculation considers the energetic quantities of the machine, such as the efficiency η and the power factor cosφ.

IV. SOFTWARE METHODOLOGY

The flexibility of the program is crucial because it is desired to be able to easily modify the various parts which model different effects of the electrical machine.

To ensure the already mentioned modularity of the overall programming package and the possibility of object oriented programming, C++ language [4, 5] is used. The following conceptual properties, on which this programming language is based, are useful in our case:

1) *Abstraction*. In order to solve a particular problem the following terminology must be defined:

- Data-sets: input data, output data, temporary

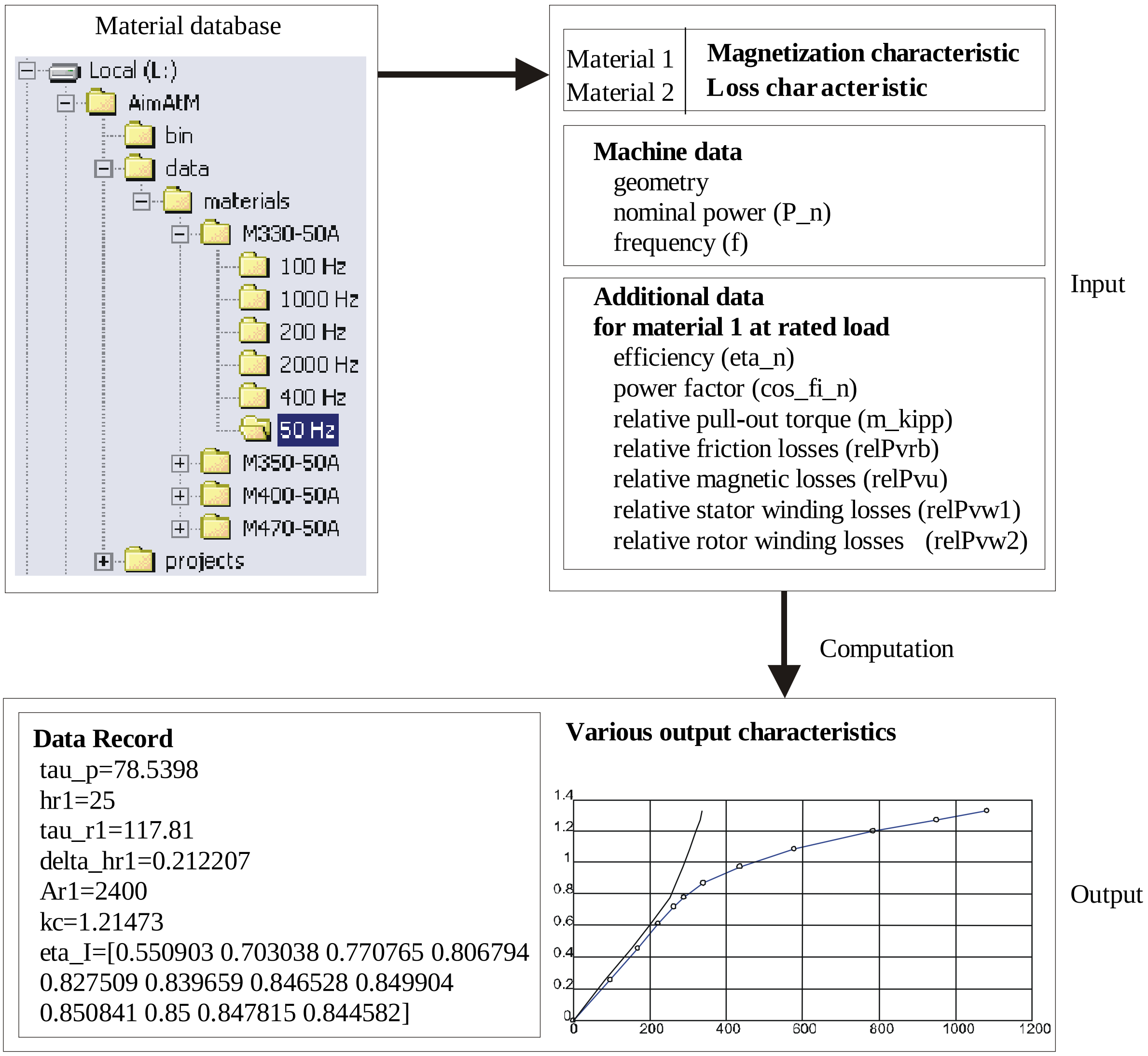

Fig. 1. Data structure description.

status data;

- Methods or routines: ways to operate or to modify existing datasets;
- Algorithms: ways to define the order of the operations on input data or intermediary data, to obtain further intermediary or output results.

2) *Function overloading*. Several methods interact in a similar way or they have the same purpose. For example there are different methods to estimate the losses in a machine. A simple model can be chosen. Several others can be integrated as a build-in extension later on.

3) *High computational speed*. Due to some inner properties of the electrical machines (such as non-linear continuous characteristics), several numerical aspects (such as interpolation, root finding, evaluating large double precision expressions) may be time consuming. Therefore, a high execution speed is always desired, no matter how powerful nowadays processors are.

4) *Portability*. Designing a user-friendly and efficient environment requires a large amount of time and experience. C++ assures an easy way for software modules exchange.

V. EXAMPLE

The program data structure is shown in Fig. 1.
The material database is designed by paying particular attention to the way information is extracted and the way new fields can be added to the database. In general, due to the fact that characteristics have not a fixed number of data samples (pairs of double-precision values) it is difficult to create a visual inter face to edit them. For this reason a system of directories is proposed

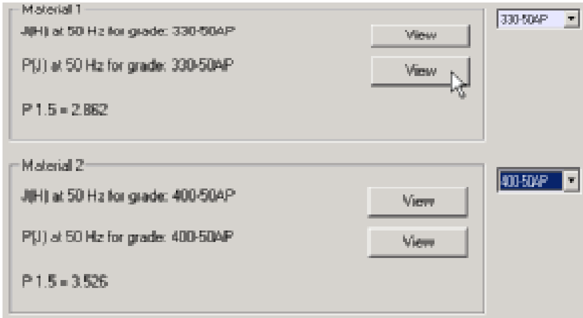

Fig. 2. The way of choosing the material in Aim@M.

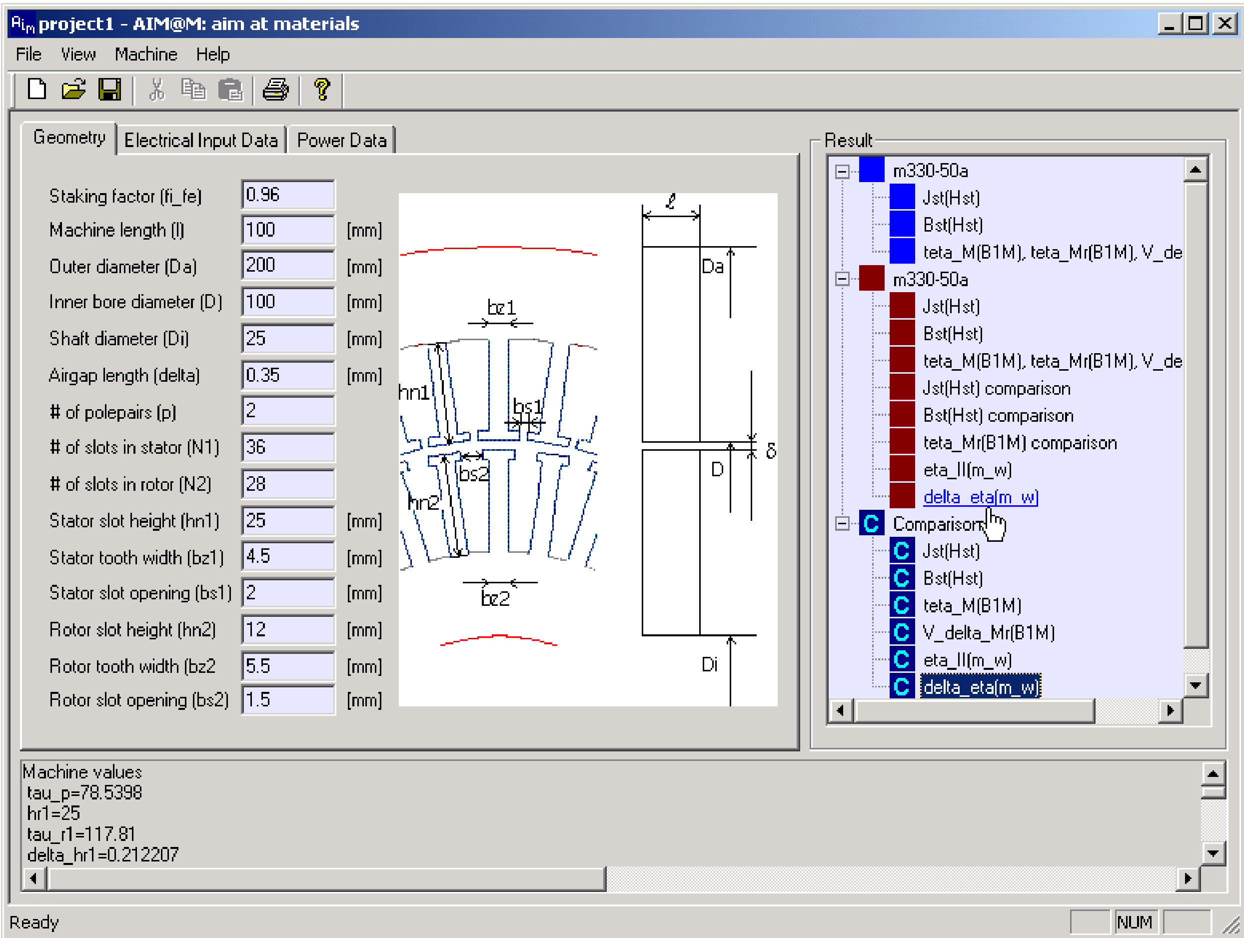

Fig. 3. Aim@M main window.

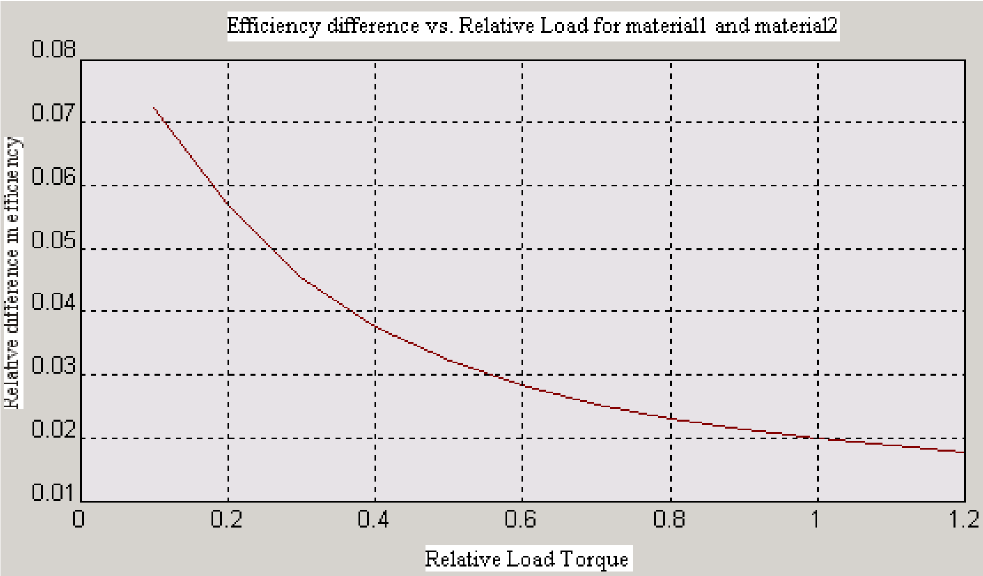

Fig. 4. Relative Efficiency vs. Relative Torque.

as solution. Each directory represents a single material with a particular name. In each directory, there are several other subdirectories corresponding to different frequencies (e.g. 50Hz, 100Hz, 200Hz, 400Hz, 1000Hz, 2000Hz or others). All pieces of data are collected in look-up tables stored in text files. In order to add a new material, a new directory must be created in the existing tree.

The use of a material in Aim@M is done by just selecting it from a "combo-box" (Fig. 2). For other input information such as: geometry, frequency, etc, regular "edit-boxes" are used (Fig. 3).

In Fig. 3 the main window is shown. On the left side several panels (Geometry, Electrical, Input data) were created in order to input the required information, including the choice of the material (Fig. 2.). On the right side a "list-box" containing the output characteristics for each considered material is displayed. Double-clicking on an item in this list will automatically plot the specified characteristic in a separate window (Fig. 4.). The result information is displayed on the bottom side of the main window (Fig. 3.). If some input data is changed (e.g. a material, frequency, stack-length) the influence on the results can be seen immediately.

Internally, the following classes are defined: CMaterial, CGeometry, CSpline, CPlot, CGraph and CMachine. The program has internally one CMachine object which keeps track on all modifications. This object contains non-material data (including a CGeometry object) and an array of several CMaterial objects.

VI. CONCLUSION

To check the possibilities to improve the quality of an induction machine by choosing the most appropriate lamination material an easy-to-use software tool was developed. With this tool it is possible to evaluate the effects by choosing different electrical steels for a given machine. The machine can be analysed in its nominal working point as well as under partial load conditions.

ACKNOWLEDGMENT

The work was financial supported by EBG Bochum. In addition the authors I. Podoleanu and K. Hameyer are grateful to the Belgian "Fonds voor Wetenschappelijk Onderzoek Vlaanderen" for granting project G.0420.99 and the Belgian Ministry of Scientific Research for granting the IUAP No. P4/20 on Coupled Problems in Electromagnetic Systems.

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