Simulation System for Asynchronous Machines

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***Abstract* –** The worldwide increase of electric energy consumption demands for energy efficient electrical motors. Pumps and compressors in industry and in the private sector consume most of the generated electric energy (Fig. 1). Among other possibilities an appropriate and optimum choice of the electrical steel can give a contribution to the global energy savings. In this paper a simulation software package will be introduced, which is capable to compare various ferromagnetic materials used as lamination of standard induction motors with respect to the efficiency at rated operation as well as at partial load. It is possible to compare material with improved magnetisation behaviour and its influence to the overall efficiency of the induction machine. Industrial motors within the range 1 kW to 100kW can be analysed with the software tool developed.

I. INTRODUCTION

The main technical objectives in improving electromagnetic devices, such as asynchronous machines are:

- To maximize efficiency;
- To have a power factor very close to 1.
- To minimize the volume of the device for the traction applications.

To realize these objectives, a careful machine analysis is required. Induction machines are described by a large number of parameters. The relations that interconnect these parameters are non-linear, like the material law:

$$\vec{B} = m_0 \vec{H} + \vec{J} \qquad (1)$$

with:

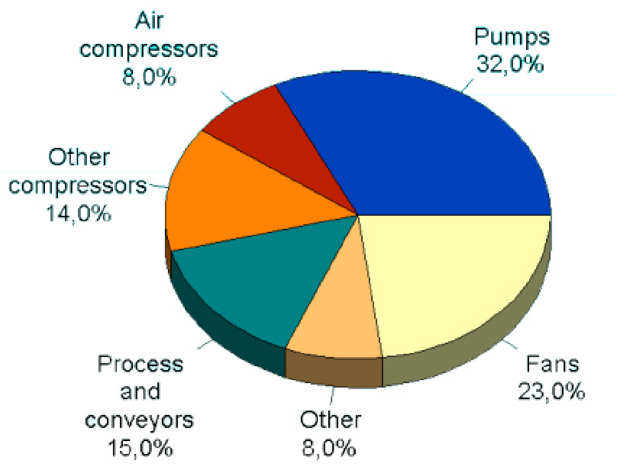

Fig.1. Energy consumption in the industry.

$\vec{B}$	magnetic flux density;
$\vec{H}$	magnetic field strength;
$\vec{J}$	magnetic polarization.

The spatial field distribution (the geometrical shape of the machine) and the non-linear ferromagnetic magnetization characteristic are the reasons for a non-linear model of the machine.

Asynchronous machines can be difficult to describe. The proposed solution is a simulation program that is capable to handle the non-linear equations. The most important requirements from such software programs are:

- To model the machine sufficiently accurate;
- To be fast;
- To be modular;
- To be easy-to-use.

II NUMERICAL CONSIDERATIONS

The magnetization and additional characteristic loss curves are always non-linear. This has a strong influence on every other derived information. They are provided to the software algorithms by lookup tables.

Such lookup tables collect data samples, which require interpolation to evaluate the characteristics in between the given data sets. An appropriate interpolation scheme is a cubic-spline.

Regarding the numerical convergence of the overall non-linear iterations, the spline interpolation involves several advantages.

The resulting curves are continuos and smooth, like the original ones. The smoothness is a property that cannot be obtained by a linear interpolation. With a given set of N distinct points, with the coordinates x_i and y_i in two vectors:

$$X = \{x_0, x_1, \ldots, x_{N-1}\}$$
$$Y = \{y_0, y_1, \ldots, y_{N-1}\} \qquad (2)$$

a lookup table is defined.

To build a cubic spline, the second derivative for each point in X must be calculated. This involves solving a tri-diagonal linear system of order N. The value of any point within the range $x_0 \ldots x_{N-1}$ can then be obtained by using a linear formula [4, 6]. Because the second derivative is stored in the computer memory during the iterations, the interpolation using a cubic spline is a relatively fast method.

III. SIMULATION SYSTEM

Various methods exists nowadays to analyse and to design electromagnetic devices. They can be divided into three major classes: classical methods, which consider characteristic relations for each type of device, numerical methods, which can obtain transparently the potential of the field and mixed methods, which combine the advantages of both classical methods and numerical methods.

The program called Aim@M was developed using the classical approach of asynchronous machine [1, 2, 5]. The model is valid for machines in the range of 1kW up to 100kW operated by a 50 Hz grid. The simplified geometry shown in Fig. 2 is considered, with:

l	machine length;
Da	outer diameter;
D	inner bore diameter;
Di	shaft diameter;
delta	air gap length;
hn1	stator slot height;
bz1	stator tooth width;
bs1	stator slot opening;
hn2	rotor slot height;
bz2	rotor tooth width;
bs2	rotor slot opening;

The chosen language for the software development is C++ [3]. The code assures the following advantages:

- Fast computation time;
- Data abstraction and Object Oriented Programming;
- Portability to other platforms.

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. Two distinct CSpline objects are used for each material to hold the magnetization and specific loss. Each CMaterial entity contains all machine parameters, functions of material properties.

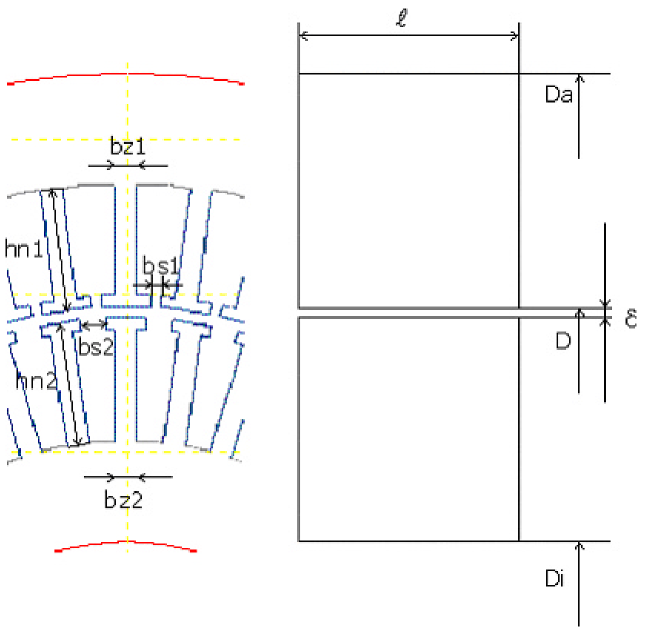

Fig. 2. The considered geometry of the model.

IV. FERROMAGNETIC MATERIAL

The ferromagnetic material has a contribution to the behaviour of the machine (next to copper and mechanical losses). It is interesting to study the influence of the material used in the stator and in the rotor of an induction machine on the overall efficiency, iron losses and on the power factor of the machine, which are depending on the material choice as well. A direct comparison of a simple machine by applying different ferromagnetic laminations (Figs 2, 3) can be performed with the developed software package. Nominal working point and partial load are examined. The iron losses are computed using Steinmetz formula [1]. Iron loss in the stator and rotor are resulting in the overall iron loss:

$$P_{iron\_loss} = P_{stator\_iron} + P_{rotor\_iron} \tag{3}$$

Measurements regarding efficiency, iron loss and power factor were performed on three representative induction motors; a 3 kW, 30 kW and a 90 kW machine with the rotor and the stator manufactured from 700-50A electro-

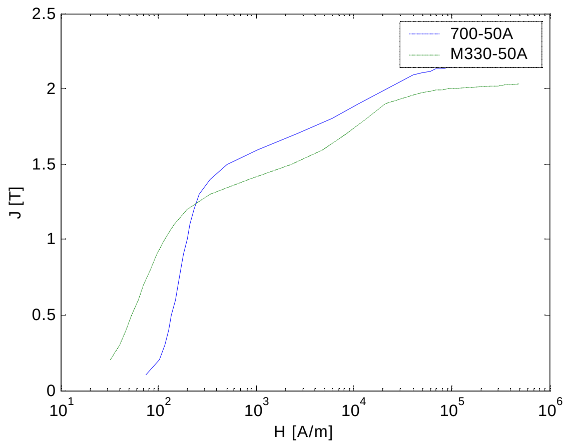

Fig. 3. Magnetization Characteristics.

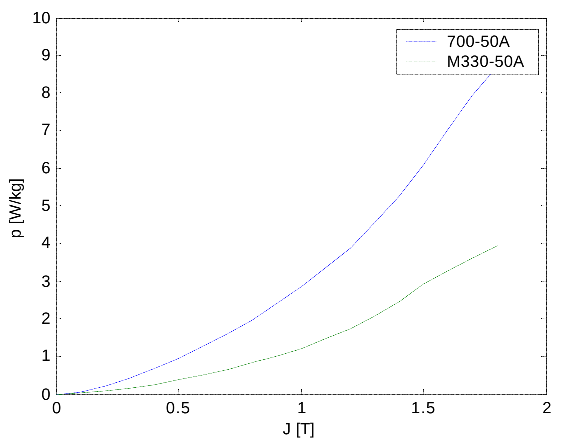

Fig. 4. Loss Characteristic.

laminations.

Changing the ferromagnetic material to M330-50A changes the machine’s behaviour (Figs 5, 6, 7). The following relations were considered:

$$\Delta h = h_{M330-50A} - h_{700-50A}$$

$$\Delta \cos\varphi = \cos\varphi_{M330-50A} - \cos\varphi_{700-50A} \tag{4}$$

$$\Delta Pvu = Pvu_{700-50A} - Pvu_{M330-50A}$$

The value of the specific loss for 700-50A at B=1.5 T is 6.1 W/kg and for M330-50A at B=1.5 T is 3 W/kg (Fig 4.). The saturation flux density of grade 700-50A is higher when compared to the M330-50A laminations.

For the small machine the material with less magnetic losses can make a difference up to 20% in the efficiency under partial load conditions. For rated operations there is still an achievement of 12% for nominal working conditions. But for big machines, this increase reaches a maximum of 2% (Fig. 5). This large difference is due mainly to the iron losses, which are larger for the 3 kW machine. The power factor (Fig x) is better for the 700-50 A.

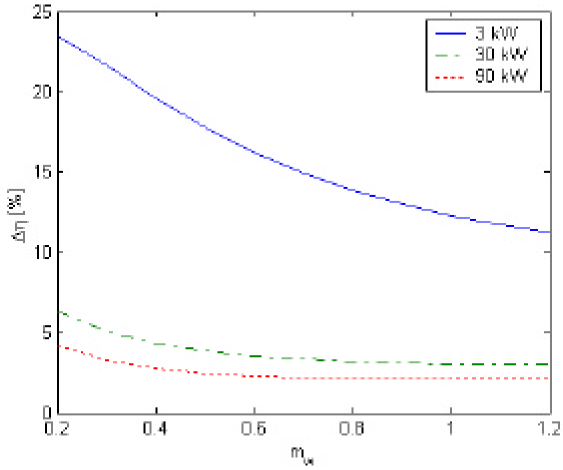

Fig. 5. Efficiency improvement vs. relative load.

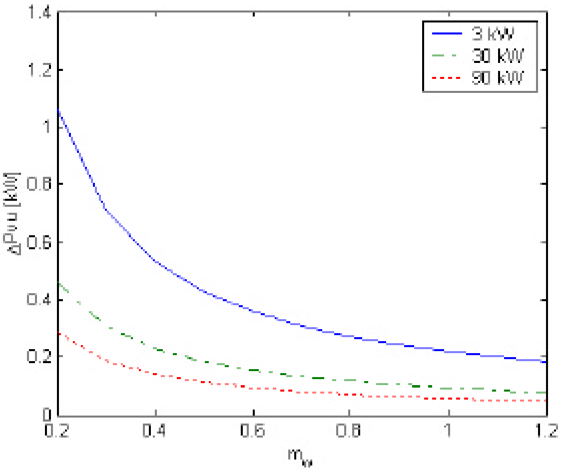

Fig. 6. Iron Losses decrease vs. relative load.

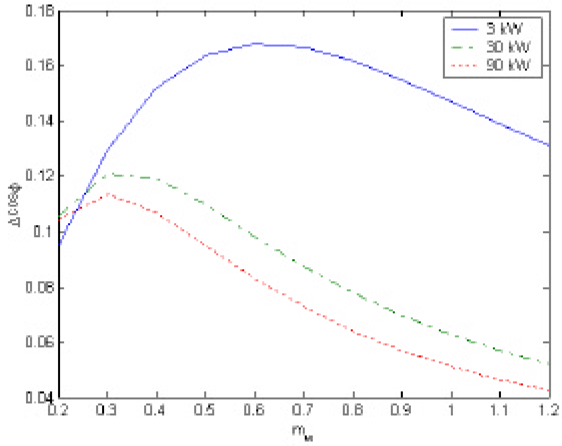

Fig. 6. Power factor variation vs. relative load.

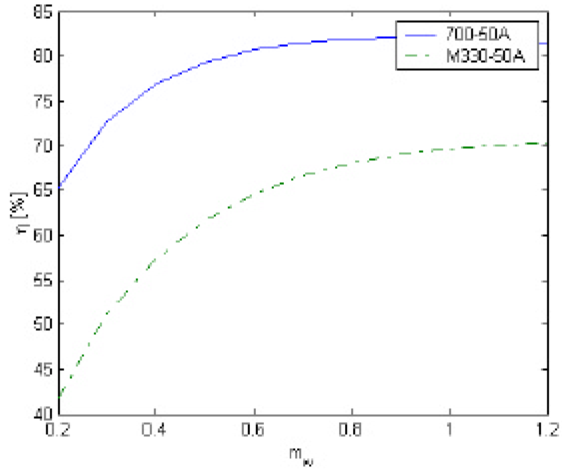

Fig. 7. Efficiency for 3 kW machine vs. relative load.

CONCLUSION

To increase the quality of an induction machine by choosing the most appropriate lamination material an easy to use tool was developed. With this tool, it is possible to simulate the machine behaviour for several ferromagnetic materials. The machine can be analysed in its nominal working point as well as under partial load conditions. Further developments will extend the already implemented loss calculation module. In a future version, harmonics and various supply sources, such as power electronics inverter sources will be implemented.

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REFERENCES

[1] K. Vogt, *Berechnung elektrischer Maschinen*, VCH 1996.

[2] G. Müller, *Theorie elektrischer Machinen*, VCH, 1995.

[3] B. Stroustrup, *The C++ Programming Language*, 2nd ed. Reading: Addison-Wesley Publishing Company, 1992.

[4] R. Belmans, K. Hameyer, *Numerical Modelling and Design of Electrical Machines and Drives*, WIT Press, 1999.

[5] W.H. Middendorf, Marcel Dekker, *Handbook of Electrical Motors*, R. H. Engelmann, Inc, 1995.

[6] S. A. Teukolsky, W. T. Vetterling, B. P. Flannery, *Numerical Recipes in C*, William H. Press.