A Benchmark Problem of Vector Magnetic Hysteresis for Numerical Models

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Abstract— **In this paper we present a benchmark problem for the validation of numerical models of vector magnetic hysteresis. The problem geometry and the measurement system are described. The materials considered are both oriented grain and not oriented grain Si-Fe steels. A series of experimental data to use for the numerical model identification and for the comparison of the data reproduced by the numerical model are presented.**

Index Terms— **Magnetic hysteresis, Si-Fe magnetic steels, Benckmark Problem, Measurements.**

I. Introduction

Generally, the complete modeling of hysteresis for magnetic materials at macroscopic scale is a difficult task, being the material behavior influenced by different factors such as the grain size, the structural stress, the presence of enclosures, etc. [1][2].Vector modeling of hysteresis has many applications in the analysis of practical devices and components, such as transformers, electric motors, magnetic transducers etc. However, the state of the art of the modeling of magnetic hysteresis has not reached yet the desired capabilities of prediction. The Stoner-Wohlfarth [3] model has some very attractive magnetic features, but its use is limited to ellipsoidal, single-domain, uniaxial magnetic particles. Although many other physical approaches were tried at micro- and even at nano-magnetic scale (see for example [4]-[6]) they are not usable in practice for bulk materials. Owing to the extremely large amount of computer time and memory required to compute the behavior of practical devices, the approaches suggested have limited usefulness. Phenomenological approaches [7]-[12], on the other hand, have been proposed on a macro-magnetic scale for the modeling of magnetic materials with hysteresis. They have been used almost successfully for the vector analysis of magnetic hysteresis problems of bulk materials, because real devices are three-dimensional. Some of the models above mentioned have the advantage of great generality; they obey the so called saturation property, that means that the magnetization goes to the saturation value for any path of the magnetic field to infinity and that the magnetization value is always less than the saturation value. The models obey also the vector loss property, that means that the magnetic losses of any applied rotating magnetic field tends to become zero when the magnitude of the applied rotating increases. Anyway, it is almost difficult to reproduce with accuracy the magnetic hysteresis and the magnetic losses for several magnetic materials, included the Si-Fe magnetic steels, extensively used for the production of electrical machines. This is particularly true when transient or not sinusoidal modeling is required. In this paper we propose a benchmark problem for the validation of computer codes for the vector modeling of magnetic hysteresis in electrical machines.

II. The Benchmark Problem

In Fig. 1 the block diagram of the benchmark problem proposed is illustrated.

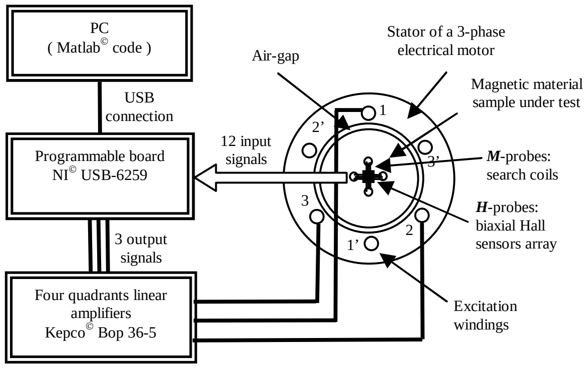
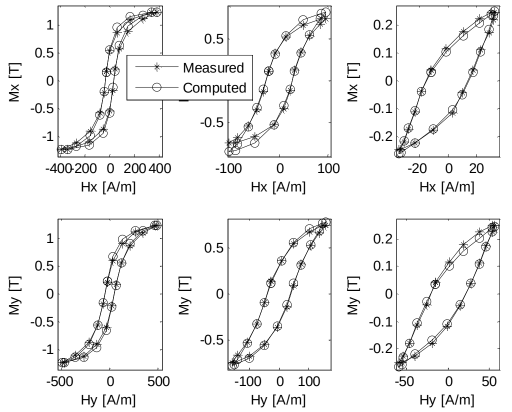


Fig. 1 - Working principle of the benchmark problem for vector hysteresis.

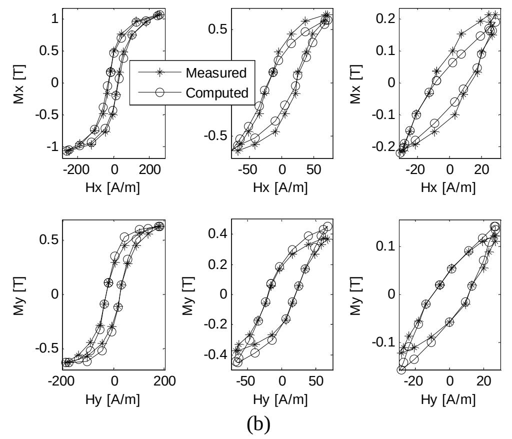
In the stator of a three phase induction motor suitably wired and electrically connected is centered a disk of Si-Fe magnetic steel. Three identical linear power amplifiers supply the excitation coils and a programmable waveform generation board pilots the power amplifier system [13]. The magnetic field is measured via a biaxial Hall sensors array designed and realized in our laboratory. The array is a sandwich of three biaxial Hall sensors with a total thickness of 6.6 mm. Each biaxial Hall sensor is a commercial chip. The chip contains a Complementary-Metal-Oxide-Semiconductor CMOS with a couple of Hall cells inside, each oriented 90° respect to the other. The device has an offset compensation circuit and a chopper stabilized amplification circuit: this allows a very stable output vs temperature fluctuations and mechanical stresses. The biaxial Hall sensor used have a typical sensitivity factor of 50 V/T, supply voltage of 5 V, supply current of 16 mA, linear range up to 63000 A/m. The thickness of a single integrated sensor with the printed circuit board PCB is almost small, about 2.2 mm, so the magnetic field components Hx and Hy can be measured at the same time on three points close to the sample surface. The magnetic field components Hx and Hy inside the disk of the material sample are evaluated by extrapolating the measured data of the three couples of sensors. For the static measurements the excitation frequency used is 5 Hz: this is because we are mainly interested in vector hysteresis model and try to make negligible any dynamic effect in the measurements. A preliminary analysis, either numerical, or experimental shows that the eddy current effects are negligible. The sample thickness used (always < 0.2 mm) is larger than the typical dimension of the magnetic grains of commercial Si-Fe steels. In consideration of that and of the previous statement about the frequency rate the additional losses are negligible. The voltage noise of the signals of the biaxial Hall sensors is treated using a suitable software filter with a frequency cut-off at 25 Hz. The biaxial Hall sensors array is applied on the material sample in an almost uniform field zone (the maximum deviation of the M- and H strength from the average value is less than 10%). This has been proved by a dedicated FEM numerical calculation and the uniformity has been experimentally verified [14]. The system is supplied with a three phase voltage system by means of a suitable feed-back control procedure that gives sinusoidal magnetizations; the x- and y- components of the measured magnetizations presented in this work have a shape factor between 1.11 ± 0.2 %, less than the ± 1 % required in the standard [15].

III. Some Results

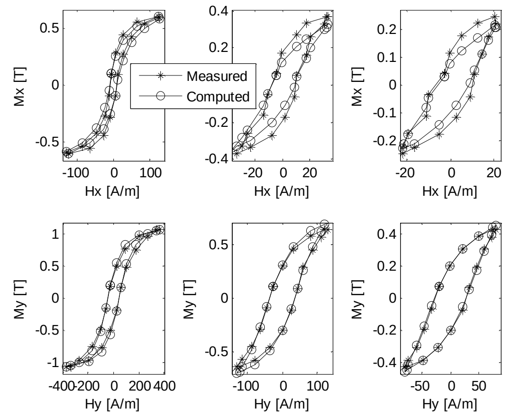
In this sections are pictured some results (see Fig. 2). The disk diameter is 65 mm, and the disk thickness is 0,65 mm for the not oriented grain (NOG) Si-Fe steel and 0,27 mm for the oriented grain (OG) one. In the full paper we will present the complete set of values to calculate for the problem solving.



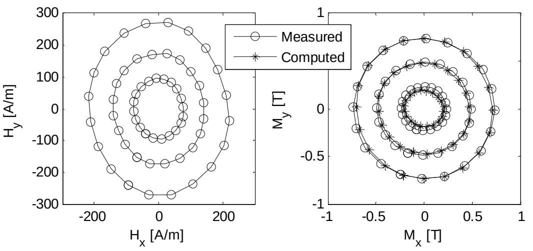
(a)



(b)



(c)



(d)

Fig. 2 – Comparison between computed and measured values for static field to NOG. (a) 0 and 90 degree, (b) 30 degree, (c) 60 degree, (d) rotational.

In conclusion we can say that the benchmark presented can be a useful tool for the magnetic steel measurement and for the hysteresis modeling evaluation. The uncertainties about the comparisons presented in the preliminary results above will be analyzed and improved on the final work where higher magnetic flux density above 1 T will be used.

References

[1] A. Aharoni, *Introduction to the Theory of Ferromagnetism*, Oxford Press, 1998.

[2] W.F. Brown, Micromagnetics, Krieger, New York, 1978.

[3] E.C Stoner, E.P. Wohlfarth, Philos. Trans. R. Soc. London A240 pp. 599-642, 1948.

[4] A. Giordano, G. Finocchio, M. Carpentieri, L. Torres, and B. Azzerboni, J. Appl. Phys. 111(7), 07D112, 2012.

[5] L. Torres, L. Lopez-Diaz, E. Martinez, M. Carpentieri and G. Finocchio, J. Magn. Mag. Mat. 286, 381, 2005.

[6] L Lopez-Diaz, D Aurelio, L Torres, E Martinez, M A Hernandez-Lopez, J Gomez, O Alejos, M Carpentieri, G Finocchio and G Consolo, J. Phys. D: Appl. Phys. Vol. 45, 323001, 2012.

[7] I.D. Mayergoyz, Mathematical Models of Hysteresis, Springer Verlag, New York, 1991.

[8] E. Della Torre, Magnetic Hysteresis, IEEE Press: Piscataway, NJ, 2000.

[9] E. Cardelli, E. Della Torre, A. Faba, IEEE Trans. on Magn., Vol. 46, n. 12, pp. 3990-4000, 2010.

[10] D.C. Jiles, and D. L. Atherton, J. of Magnetism and Magnetic Materials, Vol. 61, pp. 48-60, 1986.

[11] H. Shimoji, M. Enokizono, J. of Magn. And Magn Mat. 254-255, 290, 2003.

[12] J. V. Leite, P. A. Da Silva Jr., N. Sadowski, N. Batistela, P. Kuo Peng, J. P. A. Bastos, IEEE Trans. on Magn., 44, 6, 906, 2008.

[13] E. Cardelli, A. Faba, *Physica B*, Vol. 372, pp. 143-146, 2006.

[14] E. Cardelli, E. Della Torre, A. Faba, IEEE Transaction on Magnetics, 45, 11, 5243, 2009.

[15] International Electrotechnical Commission, Magnetic Materials — Part 3, IEC 60404-3 ed 2.2, 2010.