Determination of the Relative Permeability to Estimate the Efficiency in Energy-Efficient Motors

Victor P. B. Aguiar, Ricardo S. T. Pontes, Tobias R. Fernandes Neto, Renan H. Sousa

Federal University of Ceará, Department of Electrical Engineering, Motor Driven Systems Laboratory, Fortaleza CE, Brazil
victorpba@dee.ufc.br, ricthe@dee.ufc.br, tobias@dee.ufc.br, renansousa@dee.ufc.br

***Abstract*— This paper proposes an iterative method to calculate the equivalent relative permeability (μ_r) of the motor model with closed rotor slots at frequency domain. A brief explanation of the problem is given and the procedure for this approach is presented. Comparison between simulations, with and without new μ_r are performed and compared to experimental data in order to demonstrate the effectiveness of the method. The proposed method is well-suited to estimate the efficiency and the equivalent circuit values.**

***Index Terms*—Time stepping, frequency domain, finite element analysis, iterative method, induction motor.**

I. Introduction

The most energy-efficient Induction Motors (IM) has closed rotor slots and, moreover, they have a different behavior regarding motors with semi-open slots. Therefore, those motors need a computational approach, e.g., an equivalent air gap in the locked-rotor analysis [1]. In Fig. 1, the time stepping transient solver shows the relative permeability (μ_r) distribution map in the iron lamination geometry. Observing the map solved in frequency domain using linear iron permeability [1] [2], depicts a result not suitable for IM with closed rotor slots.

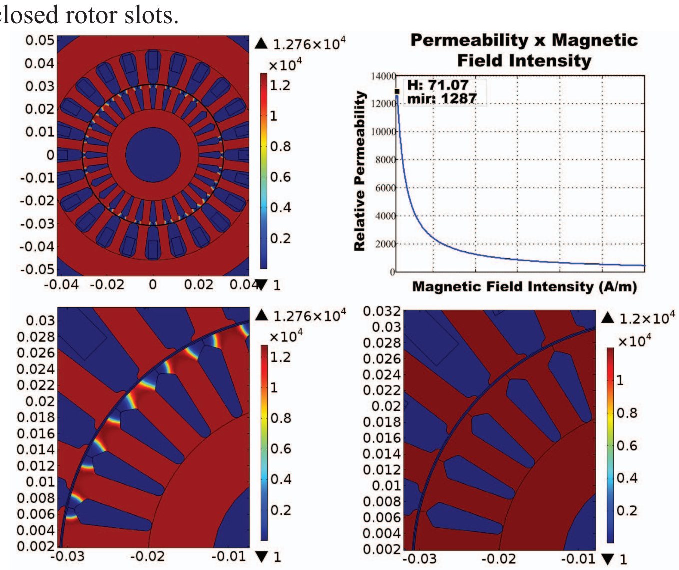

Fig. 1. Relative permeability distribution map in the iron lamination geometry at a time instant (upper left), relative permeability curve (upper right), closed-slots bridges with the relative permeability defined by time stepping transient solver using magnetic material curve (lower left) and defined by frequency domain solver using relative permeability, μ_r=12870 (lower right).

II. Determination of the Relative Permeability

In order to tackle this problem, it is proposed iterative method to calculate the equivalent value of μ_r, as illustrated in Fig. 2. This approach is based on solving the finite element (FE) model within an iterative process. T_k is the calculated torque at each iteration. The rotor circuit is coupled to the 2D model as in [2]. The rated current (I_s) are imposed as field source [1] and T_{ref} is the rated torque.

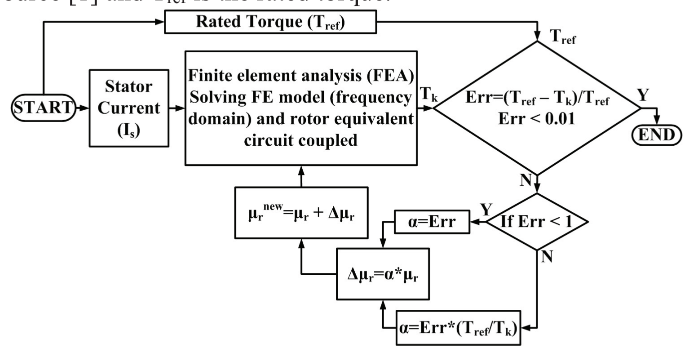

Fig. 2. Flowchart to obtain the equivalent relative permeability μ_r.

III. Experimental Results and Final Remarks

The motor was tested using the IEEE Std. 112/2004 – Method F1 and its rated parameters are 1.5 HP, 380 V/2.32 A, 2 poles and single layer lap winding chorded in 1:10. The 2D FEA is carried out using the determined iron relative permeability. In addition, the 2D FE model is coupled to the stator circuit to locked-rotor analysis [2] [3]. Table I shows the results of the IM equivalent circuit parameters, such as: stator (L_{ls}) and rotor (L'_{lr}) leakage inductances, rotor resistance (R'_r). Furthermore, the calculated efficiency (η) using the linear iron permeability and the permeability determined by the proposed iterative method are compared to the measured efficiency. It can be observed that except the rotor resistance value, the amounts estimated by using the calculated relative permeability have lower errors than the estimated values with linear iron permeability.

TABLE I
COMPARISON AMONG EXPERIMENTAL AND SIMULATED RESULTS

	Meth. F1	Const. μ_r	Error	Calc. μ_r	Error
L_{ls}	17.5 mH	12.5 mH	28.6 %	15.6 mH	10.9 %
L'_{lr}	21.1 mH	40.1 mH	-90.0 %	27.8 mH	-31.8 %
R'_r	4.3 Ω	3.6 Ω	16.3 %	5.3 Ω	-23.3 %
η	82.8 %	84.3 %	1.5 pp	82.9 %	0.1 pp

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