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A fast semi-analytical model for the slotted structure of induction motors

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Highlights

- We have developed an harmonic modeling technique for the analysis of slotted induction motor structures.
- We have examined two different methods to represent the slots and slot opening in the model.
- The results of the model have been compared to 2D FEA simulations for a set of four test motors.
- The obtained magnetic field solution is in relatively good agreement with the magnetic field predicted by linear 2D FEA simulations.
- The electromagnetic torque calculated from the harmonic model is in very good agreement with linear 2D FEA simulation results.

Abstract

A fast, semi-analytical model for induction motors (IMs) is presented. In comparison to traditional analytical models for IMs, such as lumped parameter, magnetic equivalent circuit and anisotropic layer models, the presented model calculates a continuous distribution of the magnetic flux density in the air gap and both the stator and rotor slots of the IM. Due to its semi-analytical nature, the computation time of the model is short in comparison to finite element analysis (FEA) simulations. However, the curved shapes of typical IM slots require a suitable representation of each slot in polar coordinates. Two different polar slot representations are investigated and it is shown that a double region representation is favorable to a single region representation. Finally, the model is implemented for four different benchmark motors. The calculation results are shown to be in good agreement with linear 2D FEA simulation results. This makes the model a suitable candidate for fast design tools.

Keywords: Harmonic modeling; Induction motor; Semi-analytical; Slotting

1. Introduction

A crucial element in the design of induction motors (IMs) is the availability of a suitable electromagnetic model to predict the performance of the motor. Typical demands for such a model are short computation times, high accuracy

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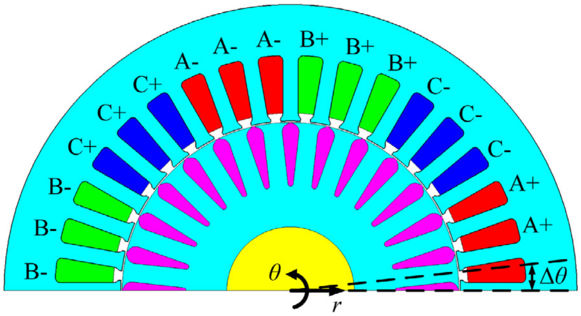

Fig. 1. Typical circumference of a low-power, three-phase IM.

and flexibility with respect to parameter variations. Historically, the lumped parameter model is very extensively used for IM analysis and design [1,2,12]. This method generally has a short computation time, but the accuracy is limited due to its dependence on the model parameter calculation. Many of these effects are estimated by correction factors, which means that the physical effects, such as leakage and fringing flux, are not modeled in detail. On the other hand, a more accurate and detailed analysis of IM performance is often obtained using Finite Element Analysis (FEA) [13]. This method can take non-linear soft-magnetic materials and complex geometries into account, but at the price of a much longer computation time. Also, parameter variation requires re-meshing, which further increases computation time.

Alternative methods that have been investigated for IM analysis include Magnetic Equivalent Circuit (MEC) modeling [10,11] and Anisotropic Layer Theory (ALT) modeling [7,9,16,20]. Both these methods can have relatively short computation times and are able to take global saturation effects into account. However, for MEC modeling, the magnetic flux paths should be known a-priori to avoid very complex and detailed model implementations. This is not practical for a design tool. Furthermore, the ALT method takes the effect of the stator and rotor slots into account globally, but the local magnetic flux distribution is neglected.

In this work, a semi-analytical model for IMs is presented. The model is based on the harmonic method described in [3,19] and predicts the static magnetic field distribution in the air gap and both the stator and rotor slots. However, due to the curved shape of typical IM slots, a suitable polar slot representation is required. Two polar slot representations are investigated, namely the single region polar slot and the double region polar slot. It is shown that the double region polar slot is favorable to the single region one. Then, the magnetic field solution in each region is derived and the model is implemented for four benchmark motors. The total computation time for each model is in the order of tenths of a second, including the generation of the equation matrix. Finally, it is shown that the results of the developed magnetic field model are in good agreement with linear FEA results.

In future prospect, the presented work is the first step towards an advanced semi-analytical design tool for IMs. Methods to apply and extend the model to calculate induced rotor currents are presented in [6,15,18]. Furthermore, the biggest limitation of the model is the assumption of infinitely permeable soft-magnetic material. This limitation might be overcome by implementing a hybrid coupling between the presented model and a model based on ALT or MEC [4]. However, the implementation and performance of such a coupling should be further investigated in future research. Finally, it should be noted that an extension of slotted harmonic modeling to 3D is successfully reported in [8,14].

2. Model assumptions and definition

2.1. Model assumptions

Fig. 1 shows one periodic half of a typical circumference of a low-power, three-phase IM. To implement a slotted harmonic model for such IMs, several assumptions are made. Firstly, the permeability of the soft-magnetic material in the IM is assumed to be infinite. Secondly, the geometry is assumed to be infinite and invariant in the axial direction, such that the 2D polar coordinate system can be used. Since the harmonic model requires a division of the geometry into regions having constant radial height and angular width, a polar representation of each stator and rotor slot is