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## NONLINEAR MAGNETIC CIRCUIT ANALYSIS FOR A NOVEL STATOR-DOUBLY-FED DOUBLY-SALIENT MACHINE

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Purpose

The doubly-salient permanent-magnet (DSPM) machine takes the advantages of high power density and high efficiency, but still suffers from limited constant-power speed range and high PM material cost [1]. This paper proposes a novel topology, namely the stator-doubly-fed doubly-salient (SDFDS) machine, which not only solves the problems of the DSPM machine, but also offers the flexibility to on-line optimize the efficiency. In order to effectively analyze and efficiently optimize the proposed machine, a new nonlinear magnetic circuit (NMC) analysis approach is also proposed.

Proposed topology

As shown in Fig.1, the proposed machine consists of two types of stator windings – polyphase armature winding and dc field winding. The polyphase armature winding operates like that for a DSPM machine, whereas the field winding not only works as an electromagnet but also as a tool for flux weakening and/or flux optimization.

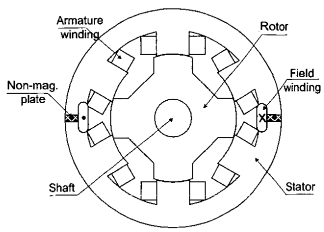


Fig.1. Proposed SDFDS machine topology.

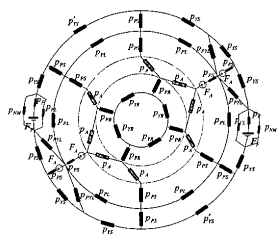

Fig.2. Proposed NMC model.

Proposed analysis

A NMC model is proposed for effective analysis and efficient optimization of the SDFDS machine as shown in Fig.2, in which the non-idealities in both the airgap and pole permeances are also taken into account. The resulting static characteristics, including back EMF (Fig.3), self-inductance and mutual inductance, are verified by experimentation.

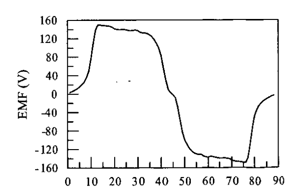


Fig.3. Back EMF characteristic.

[1] M. Cheng, K.T. Chau and C.C. Chan, "Design and analysis of a new doubly salient permanent magnet motor," IEEE Trans Magnetics, 2001, pp. 3012-3020.



## COGGING TORQUE MINIMIZATION FOR SMALL SPINDLE MOTOR THROUGH REDUCED-ORDER FINITE ELEMENT OPTIMIZATION

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Introduction

The optimization objective is to find a combination of magnet parameters (radial length, magnetic strength) which minimizes the cogging effect in a spindle motor (Figure 1). Reduced order finite element technique provides an accurate means to predict the cogging effect while keeping computational overhead low.

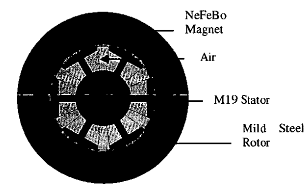


*Figure 1: Spindle Motor Structure*

Reduced-Order Formulation

Reduced-order finite element formulation [1] reduces computation time by extrapolating a new solution of vector potential A from a solution set previously obtained (for various parameter combinations) when small changes to magnet parameters are made in the optimization iteration process. The problem then reduces to solving the linear system $A_N u_N = b_N$ with $A_N = W_N^T A_n W_N$, $b_N = W_N^T b_n$. $u_n$ is the original n-order A vector (finite element problem with n nodes), $u_N$ the reduced order A vector, and $W_N$ is the *n x N* set of previously calculated solutions of A. The computation is faster as it involves lower order matrix computation. The A values are then used to obtain the torque value [2] and the process repeated until a combination of magnet parameters is found to minimize the cogging torque. Typical torque profiles for various magnet properties are shown in Figure 2.

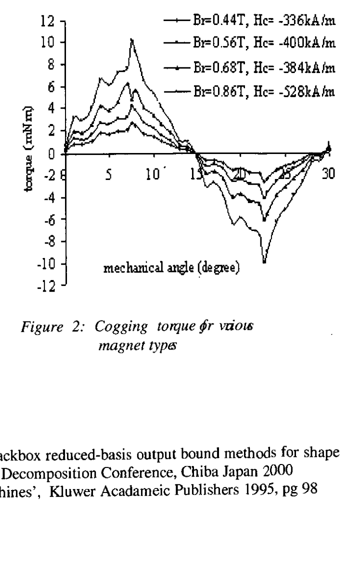


*Figure 2: Cogging torque for various magnet types*

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[2] Salon S.J., 'Finite Element Analysis of Electrical Machines', Kluwer Acadameic Publishers 1995, pg 98

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