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3D Analytical and Numerical Modeling of Skewed Tubular Magnet Arrays

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Abstract— **This paper considers analytical and numerical techniques to model the magnetic field distribution in a tubular actuator with skewed permanent magnets (PMs). The analytical solution is obtained by solving the magnetostatic Maxwell equations in terms of the scalar potential for the 3D geometry. The 3D analytical solution is compared with 2.5D analytical solutions as well as 3D finite element solutions. Various skewing topologies will be considered and the accuracy of the 2.5D analytical solution on the skewing angle will be given.**

I. INTRODUCTION

Tubular actuators are ever more used in the industry due to their high force density, excellent servo characteristics and no need for end windings due to their cylindrical structure [1, 2]. Skewing of the permanent magnets, shown in Fig. 1, or skewing the stator slots decreases the force ripple, however also reduces the mean output force. Hence, modeling of the skewing effect is necessary in order to make an appropriate choice for the skewing topology and the angle of skewing. Quasi 3D or 2.5D analytical solutions were considered in [3], however, if the skewing angle is increased, the 2.5D assumption is not valid anymore and 3D modeling becomes necessary. This paper considers the 3D analytical solution of the magnetic field solution for various skewing topologies as well as the 3D finite element verification.
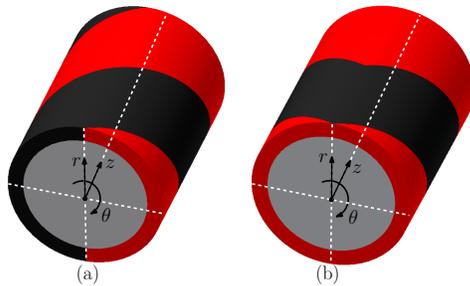

Fig. 1. Translator with skewed permanent magnets for (a) linear skewing and (b) triangular skewing

II. ANALYTICAL MODELING

The 3D analytical model is based on Fourier analysis where the skewed magnetization profile is described by a Fourier series in the 3D cylindrical coordinate system [4]. A linear recoil permeability curve of the PMs is assumed. Only radial magnetized magnets are considered, however, the procedure for a (quasi) Halbach array is identical. The geometry is divided into radial regions and the magnetostatic

Maxwell equations in terms of the scalar potential are solved for every region. Boundary conditions are considered at the interface between the various regions. End effects are excluded and only one pole-pair is considered with periodic boundary conditions. The solution of the flux density in the center of the airgap for triangular skewing is shown in Fig. 2.

III. FINITE ELEMENT VERIFICATION

The 3D analytical solution will be verified with 3D finite element analysis. Furthermore, the 3D analytical solution will be compared with 2.5D solutions [3] for various skewing topologies and skewing angles. A conclusion on the validity of the 2.5D analytical solutions will be made.
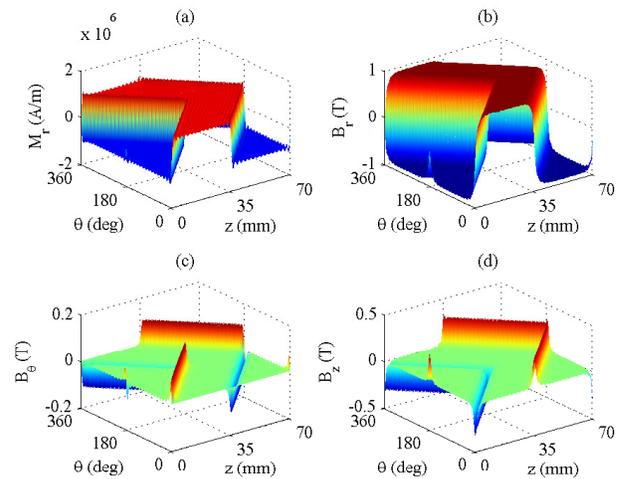

Fig. 2. (a) Magnetization profile for triangular skewing and flux density in the airgap (b) radial, (c) angular and (d) axial component

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