3D field effects in tubular permanent magnet actuators with quasi-Halbach magnetization

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Abstract—To improve the performance of permanent magnet (PM) machines, quasi-Halbach PM arrays are used to increase the magnetic loading in these machines. In tubular PM actuators, these arrays are often approximated using segmented magnets resulting in a 3D magnetic field effect. This paper describes the results of this segmentation obtained from an analytical model.

I. INTRODUCTION

In literature, several papers describe tubular permanent magnet actuators (TPMAs) with quasi-Halbach magnetization, as shown in Figure 1a, with radial and axial magnetized PMs. However, the radial magnetized ring magnet shown in Figure 1b is difficult to magnetize especially for small radii. Therefore, in practice this PM is often approximated by diametrically magnetized segments as shown in Figure 1c,d. This segmented PM results in a 3D effect; hence, for the exact magnetic fields in the actuator, a 3D analysis is required. To date, papers describing tubular actuators with Halbach magnetization consider the 2D problem with perfect radial magnetized magnets [2]. Figure 2a shows the flux density in the airgap of a TPMA with a diameter of 18 mm where the radial magnetized magnet ring is made of four diametrically magnetized segments as shown in Figure 1c. The radial component of the flux density is dependent on both the radial and the angular position. In [3], the authors presented two analytical 3D models which provide the magnetic field expression for quasi-Halbach arrays. This paper presents results from these new models as well as a comparison between the number of magnets and the effective radial component of the flux density.

II. MODELING

To calculate the magnetic fields, a semi-analytical formulation for the magnetic scalar potential in the 3D cylindrical coordinate system is derived. Although the model is quite complex to derive, it avoids the use of time consuming 3D Finite element analysis (FEA). Using this model, the rms value of the radial component of the flux density in the airgap is calculated. Additionally, a 2D model is obtained to calculate the radial component of the flux density having an ideal ring magnet inside the quasi-Halbach magnet array. Different topologies, i.e., inner magnet, outer magnet, soft- or non-magnetic core, with several dimensions are investigated and the effect of the approximation is calculated for different numbers of segments. Figure 2b visualizes the effect of the segmentation on the rms value of the radial component of the flux density for a certain geometry.

III. SLOTTED ACTUATORS

The created model describes a slotless TPMA, however the results are also applicable to slotted actuators. A (non-skewed) slotted TPMA has slots in the radial direction over the whole circumference resulting in a field distortion in the radial component of the flux density as function of translation ($z$). On the other hand, the segmentation of the radial ring PM affects the radial component of the flux density as well however, as a function of the angular position ($\theta$). Hence, the slotted TPMA can be modeled as a slotless actuator with a smaller airgap due to the absence of a coil in the airgap.

IV. REFERENCES