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Analytical Field Calculations of Skewed Magnets

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***Abstract*—Iron core permanent magnet linear actuators are applied in high precision systems and transport applications where a low force ripple is required. Force ripple can be reduced by applying skewing. This paper develops analytical expressions for the magnetic field of skewed magnets. These expressions are used to calculate the magnetic flux density distribution in the air gap and determine the EMF of the actuator.**

I. Introduction

Iron core linear permanent magnet synchronous motors are often applied in high precision positioning systems and transportation applications where a high mean force must be combined with a low force ripple. In order to reduce the force ripple produced by such actuators, several techniques can be applied such as using quasi-Halbach magnetization, pole shifting or skewing. This paper focusses on permanent magnet skewing. Although this method allows reduction of the force ripple, it also affects the mean output force. In order to effectively predict the effects of key design parameters on the performance of the linear actuator shown in Figure 1, accurate and fast models are necessary in order to select the appropriate machine topology. In literature, three dimensional analytical expressions for the magnetic field are available for magnet assemblies with cylindrical [1], triangular [2], or cuboidal [3] permanent magnets. However, there are no analytical expressions available for the field induced by skewed permanent magnets.

II. Magnetic surface charge model

In the magnetic surface charge method, 3D analytical expressions for the magnetic field induced by a permanent magnet are deducted from Maxwell's equations. Under the assumption that the magnetization of a magnet is uniform and the relative permeability $\mu_r = 1$ in the whole model, a scalar potential which imposes a virtual charge distribution on the magnet surfaces is introduced. The analytical magnetic field expressions are obtained using

$$\mathbf{B} = \frac{\mu_0}{4\pi} \oint_S \frac{\sigma\left(\mathbf{r} - \mathbf{r}'\right)}{|\mathbf{r} - \mathbf{r}'|^3} \mathrm{d}S'. \qquad (1)$$

These highly accurate field expressions are used to calculate the air gap flux density and the EMF of the actuator. Figure 2 shows the magnetic field component of a permanent magnet which is magnetized along the z-axis.

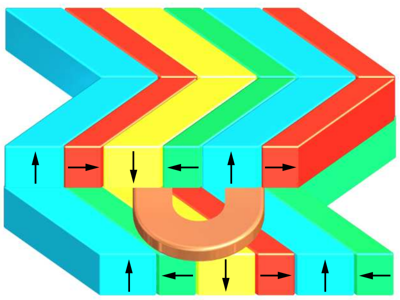

Fig. 1. A v-shape skewed quasi-Halbach ironless linear actuator

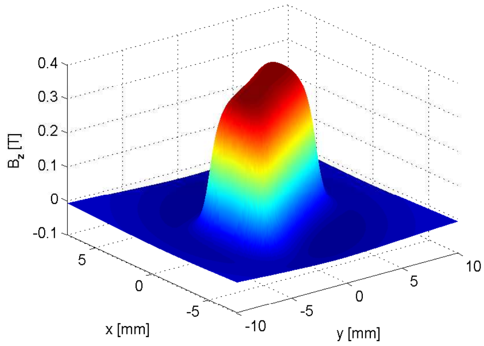

Fig. 2. Analytically calculated magnetic field component along the z axis at 0.5 mm above the skewed magnet magnetized in the z-direction

III. Conclusion

Three-dimensional analytical expressions are derived for the magnetic field density of a skewed magnet along the x-, y-, and z-axis. The obtained expressions are used to calculate the flux density distribution in the air gap of the machine and can be used to quickly determine the performance of a skewed actuator design.

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