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Novel moving coil tubular actuator with double sided PM array.

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To increase the magnetic loading in linear actuators, double sided magnet arrays are widely used in flat ironless (U-shaped) linear actuators [1]. This type of linear actuators has the disadvantage that the end-windings reduce the efficiency of the actuator. On the contrary, in tubular permanent magnet actuators (TPMA) the complete winding is producing effective force, hence an improved efficiency [2]. In most TPMAs, either the permanent magnets or the coils with soft-magnetic back-iron are moving. Both these topologies exhibit parasitic forces due to the finite length of the back-iron and the relatively high moving mass. To avoid these, a moving coil actuator with two airgaps could be implemented, where both the permanent magnets and soft magnetic back-iron are stationary, as illustrated in Fig. 1a. In this paper, a further improvement is proposed by means of a novel double sided PM array, as shown in Fig. 1b, which significantly increases the magnetic loading. To enable fast and accurate calculations of the magnetic fields inside the actuator, comprehensive analytical models of the two configurations are created [3]. A comparison is then undertaken by selecting a volumetric envelope and optimizing the corresponding RMS value of the flux density in the coil.

Fig. 2 shows the flux lines within both configurations, where the right image clearly shows the self-shielding property of the outer Halbach array, which focuses the flux in the airgap of the TPMA. Firstly, the force density of the tubular actuator with stationary soft-magnetic back iron (Fig. 1a) is optimized by selecting a maximum outer diameter and axial length, where the other dimensions are varied taking the geometrical constraints into account, the total copper losses in the windings and the flux density in the back-iron. This provides an actuator with the highest possible force within the pre-determined volume. Secondly, a new parametric search is performed on the novel tubular actuator with the double sided PM array by fixing the dimensions in the radial direction using the results of the previous optimization to achieve the highest magnetic loading. This magnetic loading is given by the RMS value of the flux density in the coil and is significantly increased compared to the moving coil actuator of Fig. 1a by the replacing the back-iron with a Halbach PM array and varying the respective magnet pitches of both the inner and outer PM arrays. Indeed both the magnet pitches need to be varied, since the optimization resulted in two completely different optimal magnet ratios of the two PM Halbach arrays, 0.3 and 0.4 respectively for the inner and outer PM array. More specific, the radial magnetized permanent magnet in the outer PM array is wider than the radial magnet of the inner PM array. This is dependent on the volumetric constraints, where the full paper will illustrate to which extend the optimal PM ratio varies with respect to the outer diameter. As an example, for a fixed outer diameter of 27.0 mm shows Fig. 3 the flux density that can be achieved by optimizing both actuator configurations, where clearly can be seen that the flux density in the coil is significantly increased, i.e., the RMS value by approximately 7 %, which equates to a significant copper loss reduction of 14 %.

[1] M. G. Lee and D. G. Gweon, "Optimal design of a double-sided linear motor with a multi-segmented trapezoidal magnet array for a high precision positioning system," J. Magn. Magn. Mater., vol. 271, pp. 336–346, Jun. 2004.

[2] N. Bianchi, S. Bolognani, and F. Tonel, "Design consideration for a tubular linear PM servo motor," EPE J., vol. 11, no. 3, pp. 41–47, Aug. 2001.

[3] J. Wang, G. W. Jewell, and D. Howe, "A general framework for the analysis and design of tubular linear permanent magnet machines," IEEE Trans. Magn., vol. 35, no. 3, pp. 1986–2000, May 1999.

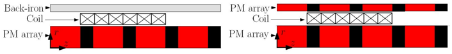

Figure 1 Moving coil TPMA with (a) soft magnetic back iron (b) double sided magnet array

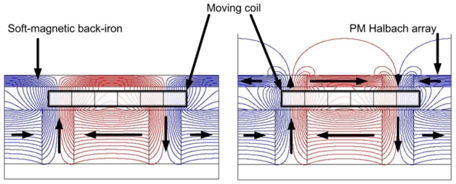

Figure 2 Actuator with soft-magnetic back-iron and actuator with two Halbach arrays

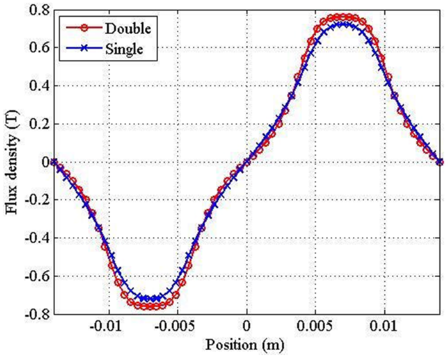

Figure 3 Flux density inside the airgap for the topology with a single PM array with soft-magnetic back iron and the topology with a double PM array