Optimization Of Permanent Magnet Linear Force Motor Design & Force Output Using COMSOL Multi-Physics

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Abstract

Introduction:
The Linear Force Motor (LFM) is permanent magnet motor which develops the axial force and movement linearly with respect to the input current. The major applications of LFM in servo hydraulic actuators is to drive the Main Control Valve spool. Majority of the existing design are based on solid magnet or ring magnet configuration (Figure 1) This work focuses on modelling, simulation, and optimization of force of solid magnet LFM within the given envelope and to arrive at configuration of Ring Magnet LFM which produces higher force than possible from solid magnet LFM using COMSOL Multi-physics software. The force output of solid magnet LFM can be increased by optimization of geometric parameters by about 40% within the identical envelope and electrical parameters of an existing design. This can be achieved by reducing saturation while in magnetic circuit, while minimizing fringing, leakages and magnetic path reluctance. Ring magnet configuration LFM produces higher output force due to higher area of permanent magnets and working air gap, which is further optimized to produce higher force. Experimental and theoretical results are compared for both types of LFM are in good correlation.

Use of COMSOL Software:
LFM is modelled in the Multi-Physics COMSOL software using axi-symmetric geometry for initial magnetic and heat transfer analysis. The geometry is sub divided into domains to assign material and properties. The magnetic flux density is estimated by solving Ampere's circuit law. Permanent magnets are modelled using B-H correlations. The magnet operating point is arrived by creating a separate COMSOL model with magnet and airgap reluctance. The non-linear B-H characteristics of permandur are modelled using interpolation function. The multi turn coil node of COMSOL is used for coil modelling. The coil conductivity is modelled in terms of domain temperature using linearized resistivity relations. Final validation is done using full 3D model catering for any geometric irregularity not captured in 2D approximation. The Maxwell's and heat equations along with linearized relations with appropriate boundary conditions are solved in COMSOL AC/DC module.

Results and Discussion:
Contour plots of axial magnetic flux density along with magnetic field vectors for final configuration of solid magnet LFM & ring magnet LFM is shown in Figure 2. Optimization of configuration, geometric parameters, leads to elimination of the saturation in fixed iron, magnetic housing and fringing in tractive air gap. It also reduces the flux leakage, producing higher force output and improved magnetic stiffness.

The temperature contour of the LFM with worst case qualification requirements of ambient temperature of 135°C is shown in Figure 3. The maximum temperature is about 165°C, is well within coil allowable limits.
After the optimization of both LFM configuration and geometric parameters, the force output increases by 40 % as shown in Figure 4. However, the ring magnet configuration, produces 67% higher than solid magnet LFM with about 20 % higher weight. Hence, the ring magnet LFM has a much higher power to weight ratio as compared to solid magnet LFM, but at cost of added intricate mechanical design and assembly.

Figures used in the abstract

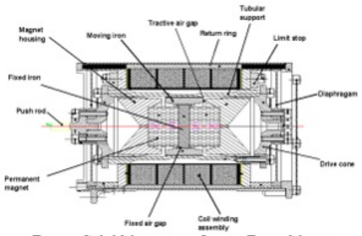


Figure: Solid Magnet type Linear Force Motor

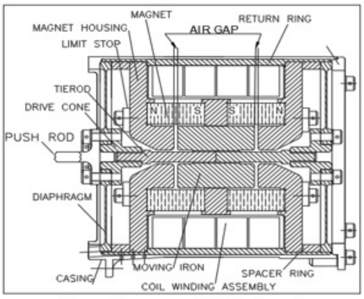


Figure: Ring magnet LFM Configuration

Figure 1 : Figure 1 Solid & Ring Magnet LFM

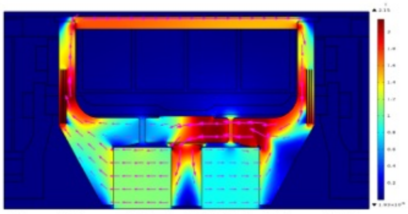


Figure: Axial magnetic flux density for final solid magnet LFM configuration

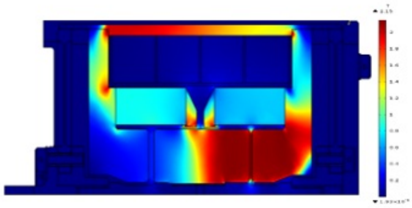
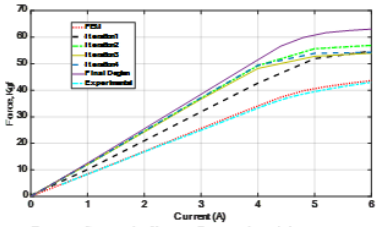


Figure: Axial magnetic flux density for final ring magnet LFM configuration

Figure 2 : Figure 2 Contour plots of axial magnetic flux density



Force vs Current for Various Designs for solid magnet configuration

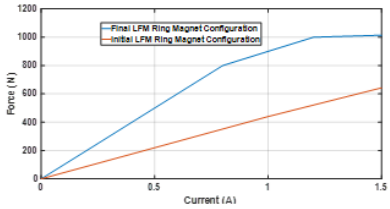


Figure: Force Vs Current for ring magnet LFM configuration

Figure 3 : Figure 3 Force comparison for Solid magnet and Ring magnet LFM

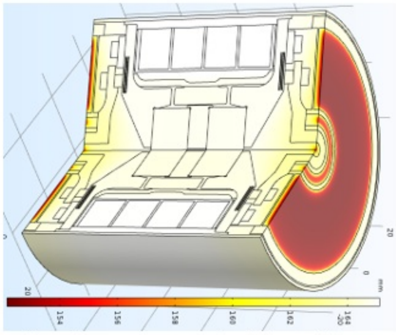


Figure: Temperature contour plot for solid magnet LFM

Figure 4 : Figure 4 Temperature contour plot for solid magnet LFM