Simulation of A Reluctance Actuator

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Abstract **– The reluctance actuator is an electromagnetic actuator widely used in industrial applications. The main objective of this study is to create a model capable of simulating the attractive force between the armature and a ferromagnetic mover. EMS is used to solve the simulation through magneto-static analysis and to evaluate the reluctance force based on the Virtual Work Method.**

I. Introduction

IN today's world, there is an increase demand for electromagnetic actuators capable of producing high forces with high levels of precision and efficiency. The Lorentz force actuator has several limitations that a reluctance force actuator overcomes, making the use of this type of actuators advantageous. Especially when a short stroke is required, reluctance actuators are highly recommended. Short-stroke actuation is often obtained through designs with small air-gaps between the armature and the mover: it can be proved that the smaller is the gap, the higher is the efficiency of these actuators [1]. Moreover, the reluctance actuator has a quadratic function of the current to the force generated [2].

In this study the dimension of the actuator are constrained by other design factors, therefore the aim is to find, for the given dimensions, the configuration that insure the highest reluctance force. In order to achieve the objective, a series of three-dimensional magneto-static analysis is performed for various gaps and currents. For each gap and current, the force obtained from EMS is postprocessed and compared with the theoretical model.

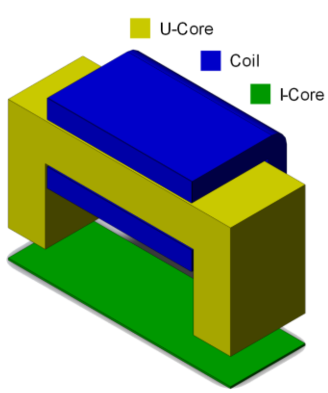


Figure 1. Schematic diagram of the reluctance actuator

II. Geometry and Model

The cross-sectional view of the model geometry is provided in Fig. 1. The model mainly consists of a UI-iron core and a coil of wire wound around the U-core. The coil, which has a cross-section of 5mm x 39mm, is composed by 860 turns copper wire with a diameter size similar to that of an AWG 24 resulting in 90.31% of the Fill factor. The rest of domain is modeled as air.

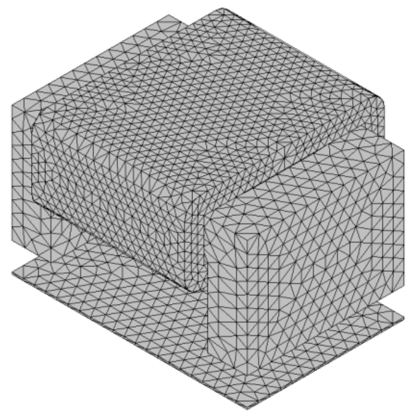


Figure 2. Meshed model

An automatic generated mesh, shown in Fig 2, is used in the model allowing EMS to control element size and mesh tolerance for a faster solution. For our study, a sequence of magneto-static simulations is carried out using various values of current, ranging from 0.5-1.5A and for different gap values, ranging from 1-7mm. Reluctance forces are, therefore, calculated as a function of electric current and gap. Figure 3 shows the current direction and rigid body force calculation indicated by green and red arrows, respectively. The detailed material properties are presented in Table 1.

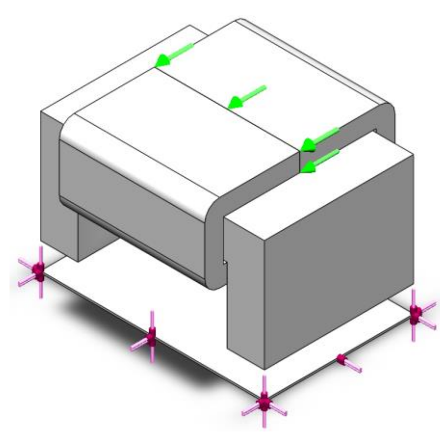


Figure 3. Loads and boundary conditions

	Conductivity [Mho/m]	Relative permeability
Copper	57e6	1
Iron	10.3e6	5000
Air	0	1

Table 1. Material properties

III. THEORETICAL MODEL

By neglecting the fringing effects and assuming a homogenous magnetic field, by using Maxwell's equations [3], we can evaluate the values of magnetic field,

$$H_C.l_m + 2H_g.g = N.i \tag{1}$$

where H_C is the magnetic field in the ferromagnetic material, l_m is the lumped magnetic circuit, H_g is the magnetic fields in the air gaps, g is the air gap value, N and i are the number of turns and the current, respectively.

By considering $B_c = B_g = B$, the relation between the magnetic field and the magnetic flux can be drawn using a linear relationship $B_g = \mu_0 H_g$ and $B_c = \mu_0 \mu_c H_g$, which yields,

$$B = \frac{\mu_0.N.i}{(l_m/\mu_c) + 2g} \tag{2}$$

where μ_0 is the magnetic permeability of free space and μ_c is the relative permeability of the ferromagnetic material.

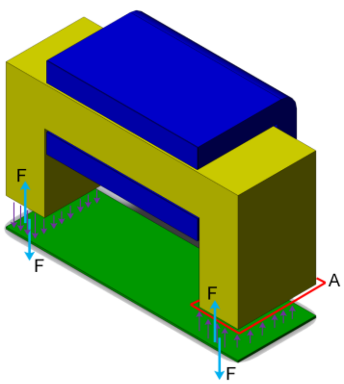


Figure 4. Magnetic flux density for current of 1.5A and air gap of (a) 1mm, (b) 3mm and (c) 5mm

Using the symmetry of the model, the reluctance force is evaluated only on half of the ferromagnetic mover, as shown in the Fig. 4,

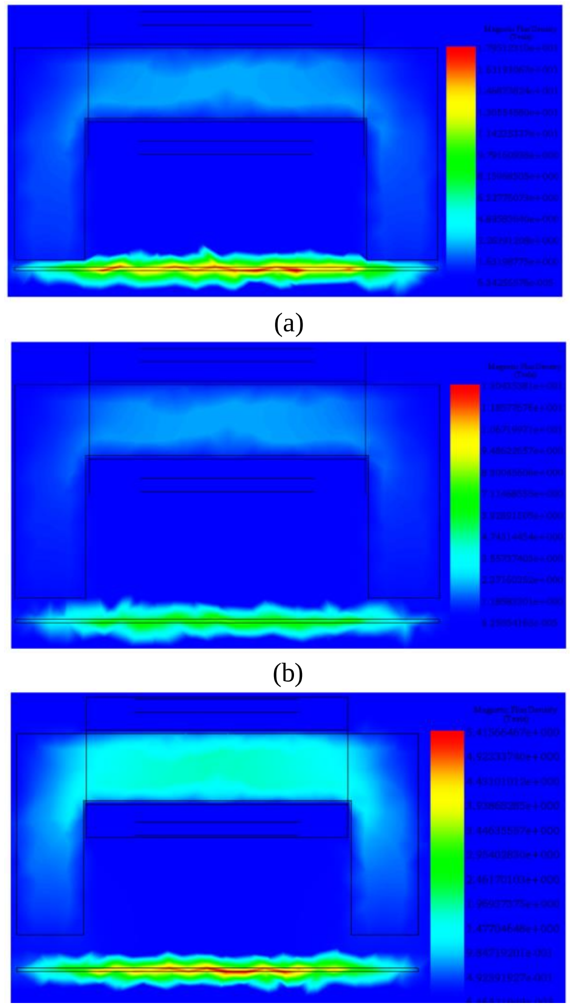
$$F = \frac{1}{2}\iiint_V \frac{B^2}{\mu^2}\nabla\mu.dx\,dy\,dz = \frac{1}{2\mu_0}\iint_A B^2\,dA \tag{3}$$

where A is the total cross-section area of the air gap. Since B is assumed to be homogenous throughout the circuit and $(l_m/\mu_c) \approx 5l_m.10^{-6} \ll g$ in Eq. (2), Eq. (3) yields,

$$F = \frac{A}{2\mu_0}B^2 = \frac{\mu_0 A N^2 i^2}{4g^2} \tag{4}$$

IV. SIMULATION RESULTS

Figure 5 shows the contour plot of magnetic flux density for three different gaps and a current of 2 A. The total attraction force on the core for various values of current and gap is plotted in Fig. 6. Overall, both the analytical model and the EMS model are in good agreement. It is commonly accepted that there is a discrepancy between the two, since force generated by EMS is calculated by the Virtual-Work Method and the other one is based on a linearized model based on Maxwell's equations.



(a)

(b)

(c)

Figure 5. Magnetic flux density for current of 1.5A and air gap of (a) 1mm, (b) 3mm and (c) 5mm

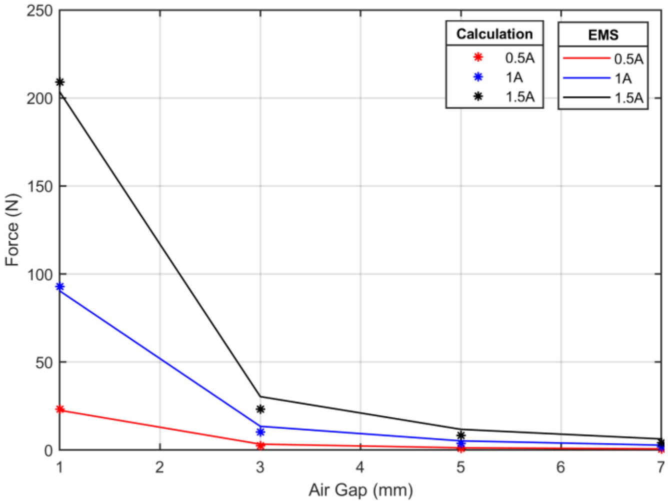


Figure 6. Computed force versus air gaps for various values of electric current

V. Conclusion

In this study, the force in the function of air gap and electric current have been presented and compared with two different methods. Both finite element and theoretical models were derived and studied. The force showed a close match between the two.

References

[1] Hiemstra, David. "The design of moving magnet actuators for large-range flexure-based nanopositioning" Master Thesis, The University of Michigan (2014).

[2] Wiedemann, Daniel. "Permanent magnet reluctance actuators for vibration testing" PhD Thesis, Technische Universitat Munchen (2012).

[3] Katalenic, Andelko. "Control of reluctance actuator for high-precision positioning" PhD Thesis, Technische Universiteit Eindhoven (2013).