Design of a Linear Electromagnetic Actuator Based on Finite Element Modeling

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Abstract — Electromagnetic actuators are employed in many applications. It is desired to have a fast and accurate process of development of the actuators. As Finite Element Modeling (FEM) deals well with nonlinearities, present in magnetic systems, a fast and good approach can be achieved making use of this technique.

This paper presents the steps of the design of a linear tubular electromagnetic actuator to be employed on an elevator active suspension system. Measurements were carried out on site to assess required specification of the device. Based on these measurements, a linear electromagnetic actuator was proposed, modeled, and results were evaluated.

I. INTRODUCTION

Recently, due to the construction of very high skyscrapers, it is becoming more and more important the development of high speed elevators system to provide rapid access within the premises of the building. In order to cope with that, elevators have to operate at higher speed levels, which leads to problems such as vertical oscillation and horizontal swing [1].

Solutions have been proposed using ropeless elevators [2] and electromagnetic guided systems [3]-[4], though feasibility may be compromised because of the cost. Alternatively, active electromagnetic suspension systems can be implemented to deal with the problems [5].

An electromagnetic actuator can be used in the active suspension system in order to produce force to attenuate horizontal swing due to unbalanced weight, irregularities of the structural alignment and oscillations due to the long length of the suspension cable.

II. ELECTROMAGNETIC ACTIVE SUSPENSION

A complete active electromagnetic suspension system has many components, such as power electronics, control system, sensors and actuators among others. Despite the complexity, it provides a full solution for the problem which is a great motivation for the development of technologies to enhance the system.

Figure 1 shows where to install the main elements of the active electromagnetic suspension. Spring, damper and actuator must be placed between the roller guides and the cabin in four positions denoted by A, B, C and D.

The electromagnetic actuator is placed parallel to the spring and the damper. It must be able to produce force F_a horizontally in two directions as shown. The correct design of the actuator has to obey certain specifications which will be treated in the next section.

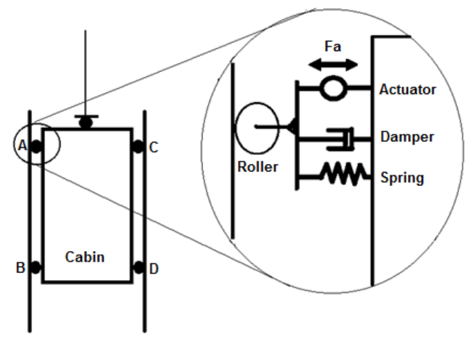

Fig. 1. Elevator's active suspension location.

III. ACTUATOR

The design of the actuator for the elevator active suspension system has a certain number of requirements.

Measurements were made on site to verify dimensions, necessary force, and frequency of vibration. Physically it has to fit into the designated space, which has basically a length of 155 mm. Operation is preferable in DC with no more than 4 A current. Stroke has to be up to 15 mm. It has to be able to attenuate frequencies of up to 30 Hz. The nominal produced force must be up to 90 N.

After studies of possibilities, a topology was developed. Figure 2 shows a 3D view of a proposed linear tubular actuator. It has four permanent magnets (PM) made of Neodymium-iron-boron (NdFeB), two coils, a yoke made of Steel AISI 1010 and two back irons made of the same material as the yoke.

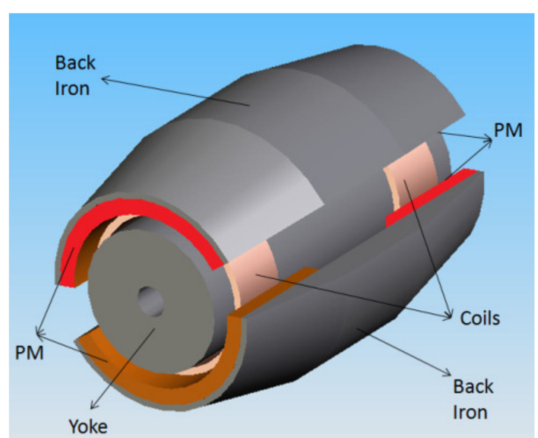

Fig. 2. 3D view of the tubular actuator.

The permanent magnets are oriented in opposite direction, forcing the magnetic flux to follow the path shown in Fig. 3 by the arrows.

Either the yoke or the set, back iron and PM, can be fixed while the other is free to move.

The tubular shape provides a good use of the coil active length, as practically the full length of the winding is submitted to a perpendicular magnetic flux density.

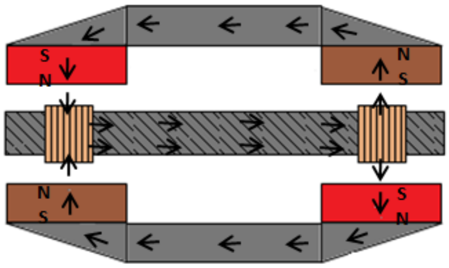

Fig. 3. 2D view representation showing the direction of the magnetic flux.

The resulting produced force is giving by the Laplace force (1), where: bold letters indicate vectors; the force is $\boldsymbol{F}$; $\boldsymbol{B}$ is the magnetic flux density on the coils; the active length per turn is $\boldsymbol{l}$; the electric current per coil is I and it passes through the N turns of both coils.

$$\boldsymbol{F} = NI \int \boldsymbol{B} \times d\boldsymbol{l} \qquad (1)$$

The current in the windings has to be positive in one and negative on the other coil for a giving reference to produce force in a desired direction.

IV. MODEL AND RESULTS

The mentioned topology was modeled considering a 2 A current DC applied to the coils. First, it was verify magnetic flux density distribution. This step considers the nonlinearity of the magnetization curves; and electric conductivity was also considered so the eddy currents can be evaluated.

Figure 4 shows the modulus of magnetic flux density at a section of the actuator, and Fig. 5 shows a graph with the y component of the vector magnetic flux density $\boldsymbol{By}$ at region of the coils.

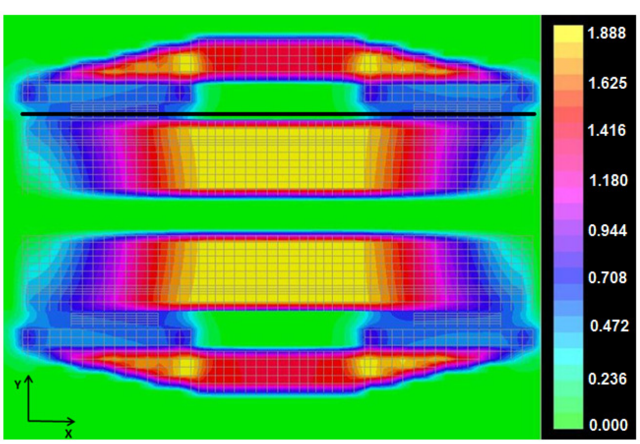

Fig. 4. Modulus of magnetic flux density at a section of the actuator.

The component $\boldsymbol{By}$ has a maximum value of approximately 0.65 T at the region of the coils (black line in Fig. 4).

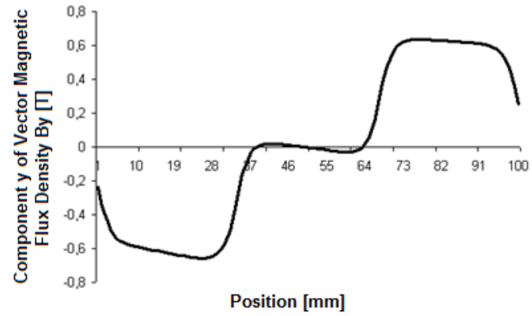

Fig. 5. Component y of magnetic flux density at the region of the coils.

The produced static force was computed based on the Maxwell stress tensor resulting on the graph shown in Fig. 6. Displacement zero corresponds to the alignment of the coil with the left side of the PM while displacement 30 mm corresponds to the alignment with the right side. A mean force of 96 N was observed with a low variation on the 30 mm stroke.

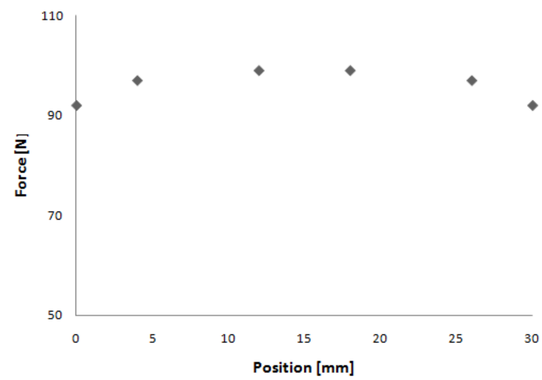

Fig. 6. Simulated force profiles.

V. CONCLUSION

Following the steps of specification, analysis of possibilities, design, finite element modeling and result evaluation it was possible to develop a linear electromagnetic actuator that meets all requirements to be employed as an actuator for elevator active suspension system.

VI. REFERENCES

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