8th International DAAAM Baltic Conference
"INDUSTRIAL ENGINEERING -
19-21 April 2012, Tallinn, Estonia

SINGLE-STAGE ELECTROMAGNETIC ELEVATOR MODELLING IN FEMM SOFTWARE

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Abstract: In present paper an electromagnetic elevator (conveying device) designed in Riga Technical University (Latvia) is described. Modelling of single-stage electromagnetic elevator in FEMM software is suggested. Analysis of electromagnetic field distribution created by multi-turn coil used as propulsion mean for conveying of ferromagnetic materials by electromagnetic field is presented. Use of different coil materials and coil dimensions is evaluated.

Key words: electromagnetic elevator, FEMM software, coil

1. INTRODUCTION

There are many specific industrial applications of electromagnetic fields: sensors, actuators, valves, vibration agitators, particulate filters and a great many other technical applications. Amongst them there is a place for specific application of pulsed electromagnetic field, namely for conveying of ferromagnetic materials in tubes. A millisecond impulse of electromagnetic field is acting as a propulsion mean for moving of ferromagnetic materials inside a tube. Ferromagnetic powders manufacturing industry is one of the end-users of presented approach [1].

Nowadays manufacturers of ferromagnetic powders are using a traditional screw [2] , belt conveyors, bucket elevators, chain tubular conveyors [3] or pneumatic conveying systems [4] for powder handling. Due to extensive wear of construction materials, a periodic maintenance of such conveyors is required. Moreover, powder raw materials are becoming contaminated of wear products (particles). The electromagnetic conveyor can be considered as a solution for certain industrial applications, and especially in powder metallurgy.

One of the most demanding tasks is a conveying of ferromagnetic powders in vertical pipes for further processing. As a possible solution the Powder Materials Laboratory of Riga Technical University has designed a laboratory-scale single-stage electromagnetic system for powder conveying on short distances (up to 5 meters) in pipes [5]. Scheme of laboratory equipment EMC-05 [6] for ferromagnetic powder conveying by impulse electromagnetic fields is shown in Fig. 1. In our laboratory setup a power unit is produced by HBS Bolzenschweiss-Systeme GmbH [7] has been used.

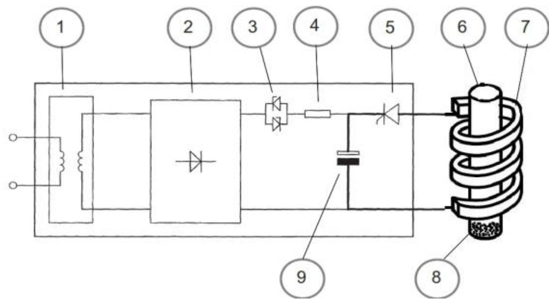


Fig. 1. Schematic of the equipment used for ferromagnetic powders conveying by impulse electromagnetic field.
1 – transformer, 2 – rectifier, 3 – triac (thyristor), 4 – charging resistor, 5 – discharging thyristor, 6 – conveyor tract, 7 – coil, 8 – ferromagnetic powder, 9 - capacitor battery.

Schematically the approach for conveying by electromagnetic fields is shown in Fig. 2.

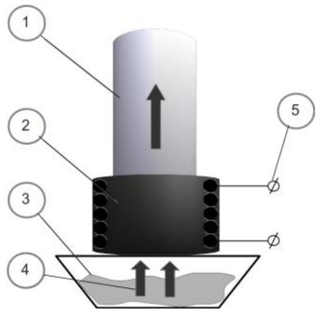


Fig. 2. Schematic ferromagnetic materials conveying in vertical pipe.
1 – pipe (conveyor tract), 2 – electromagnetic coil, 3 – reservoir filled with ferromagnetic powder (iron powder), 4 – gripping of ferromagnetic powder by impulse electromagnetic field applied, 5 – coil connection to the generator of electromagnetic currents (power unit).

Industrial iron powders have iron content 96.5-99.5%. Specifications of iron powders suitable for transportation by electromagnetic field are presented in Table 1.

Particle size range, μm	45-200
Fe content in powder (by weight), %	96.5-99.5
Apparent density of powder, g/cm^{-3}	2.3-3.9

Table 1. Iron powders used for conveying by impulse electromagnetic field.

2. ELECTROMAGNETIC CONVEYOR MODEL IN FEMM

We have chosen the FEMM - a powerful free software for electromagnetic problems modelling [8], [9]. FEMM is a 2D FEA software package developed by Eng. D. Meeker [10].
There are different models of accelerator devices where pulsed electromagnetic fields are used [11]. In case of fine particles (or iron powders) the reluctance conveying approach was used [12]. A selected approach is based on the attractive ferromagnetic properties of the transportable material which provoke acceleration. FEMM modelling is realised for the computation of the force on a mass of iron powder at various positions relative to a wound air-cored coil.

For modelling of electromagnetic field distribution a set of wound air-core coils has been used (Table 2.). A cross-sectional view of coil is shown in Fig. 3.

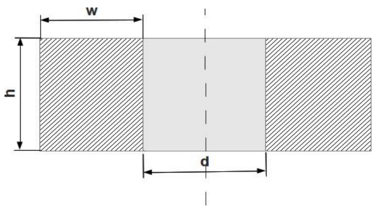


Fig. 3. Coil cross-sectional view.
w – winding thickness, mm; h – winding height, mm; d – coil's internal (wound) diameter, mm

Coil No.	Winding material	w, mm	h, mm	d, mm
Coil(01)	Copper	25	25	50
Coil(02)	Aluminium	25	90	50
Coil(03)	Copper	40	75	50

Table 2. Electromagnetic coils used for modelling in FEMM.

In order to evaluate an electromagnetic lifting force for current model a set of ferromagnetic powder bodies (cylindrical powder fillings) has been defined (Fig. 4., Table 3.)

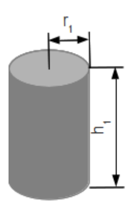


Fig. 4. Powder bodies used for the modelling of electromagnetic elevator.

Label of powder body	h_1, mm	r_1, mm
a	35	25
b	25	25
c	15	25

Table 3. Dimensions of ferromagnetic powder bodies used for modelling.

A schematic of electromagnetic elevator input geometry is shown in Fig. 5. Initially, the powder body is located underneath the coil.

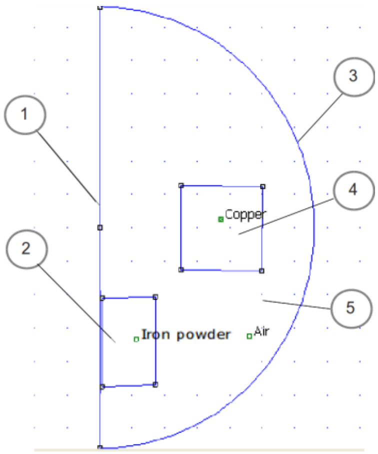


Fig. 5. Electromagnetic elevator: axisymmetric model set-up in FEMM.
1 - symmetry axis, 2 – iron powder, 3 – outer boundary of interior region, 4 – coil cross-section, 5 – interior region (air).

It was established experimentally that for the laboratory device the minimal voltage of impulse current source when it is possible to observe and register a lifting phenomenon of fine ferromagnetic materials is 50 V. Thus, for the FEMM model the similar conditions have been chosen. Coil electrical input parameters [13] for the model are shown in Table 4.

Coil No	Calculated source current density, MA/m^2	Electrical conductivity of wire material, MS/m
Coil(01)	0.608	59.6
Coil(02)	0.158	35
Coil(03)	0.123	59.6

Table 4. Power source current density, and electrical conductivity of coils.

The following assumptions of FEMM model have been taken into account: steady current (in coil), no eddy currents, simulation for every position (shift) of powder body along the z-axis is calculated for the steady-state conditions. Example of magnetic field density plot for Coil(01) is shown in Fig. 6.

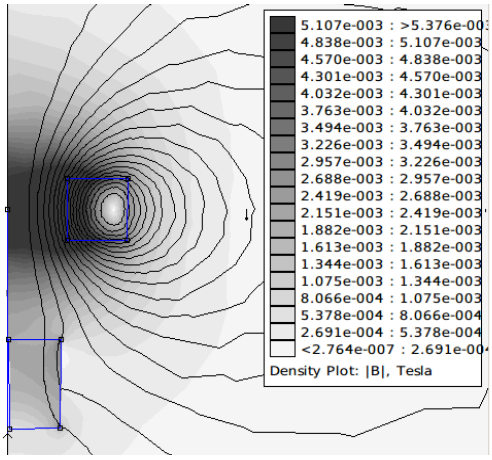


Fig. 6. Magnetic field density plot for Coil(01).

For evaluation of electromagnetic interaction between coil and powder body, a programme written in Lua language [14] has been used. The following actions are performed during an execution of Lua script:

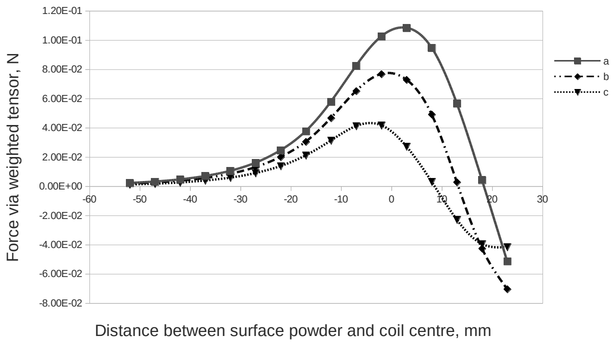
a) Shifting a powder body along z-axis,

b) Performing a numerical analysis of the model,

c) Calculating z-directed component of force for every position of powder body.

3. RESULTS

Output results of force vs. distance between powder body and coil centre modelling are presented below in Fig. 7, 8,



9.

Fig. 7. Force vs. distance between powder body and coil centre modelling output for Coil(01) calculated for powder bodies (a), (b), (c).

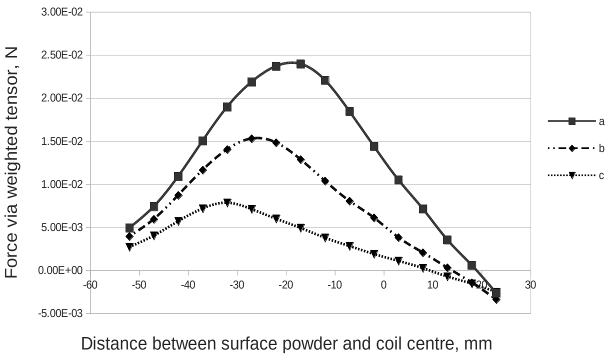


Fig. 8. Force vs. distance between powder body and coil centre modelling output for Coil(02) calculated for powder bodies (a), (b), (c).

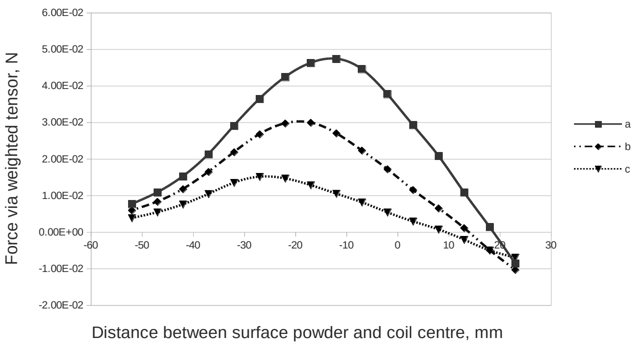


Fig. 9. Force vs. distance between powder body and coil centre modelling output for Coil(03) calculated for powder bodies (a), (b), (c).

It is evident that coil's geometry plays an important role in conveying model. For Coil(02) and Coil(03) the maximum of force is achieved at the entrance of coil wound or in the first half of coil's height. In the same time the highest force values have been shown by Coil(01). In fact, the experiments confirm the effectiveness of Coil(01) [15]. The best simulation results have been shown by coil made of copper wire e.i. Coil(01).

4. FURTHER RESEARCH

Further research is necessary for pilot equipment construction, which can be used in real manufacturing facilities. The modelling procedure can help in design of low-energy pilot equipment for conveying of ferromagnetic materials. Meanwhile, it is important to evaluate an influence of electromagnetic impulse fields on powder segregation, especially in case of continuous exploitation. FEMM software will be used for modelling of different mixing equipment based on electromagnetic phenomena [16].

5. CONCLUSIONS

The FEMM software is useful instrument for evaluation of different geometries and materials used in design of electromagnetic elevator.

Modelling approach has confirmed a previous research on construction of electromagnetic conveying equipment.

The following modelling is necessary for evaluation of combination of factors influencing on the effectiveness of electromagnetic elevator.

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7. AKNOWLEDGEMENTS

EIROPAS SOCIĀLAIS FONDS

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This work has been supported by the European Social Fund within the project "Support for the implementation of doctoral studies at Riga Technical University"

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