

STUDY OF AN ELECTROMAGNETIC LEVITATION SYSTEM

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Abstract: There are two different forces applying on a sample that determine its equilibrium position in an electromagnetic field; the Lorentz force, which is a natural consequence of alternating electromagnetic field, and the gravitational force of the sample. These two forces are both body force types, which mean they all act with the same value all over the domain of the sample, i.e. in all nodes of the finite element mesh. The finite element analysis was conducted to determine the sample position in the electromagnetic field.

Keywords: electromagnetic field, levitation, numerical modeling

1. INTRODUCTION

Electromagnetic levitation is an established technique for containerless positioning and heating of metallic melts by means of high frequency alternating magnetic fields [1,2]. The levitation field induces eddy currents in the sample. On the one hand these currents heat the sample due to ohmic losses. On the other hand, their interactions with the original field produce Lorentz forces in the direction of decreasing magnetic field strength, which support the sample against gravity and residual forces without any mechanical contact.

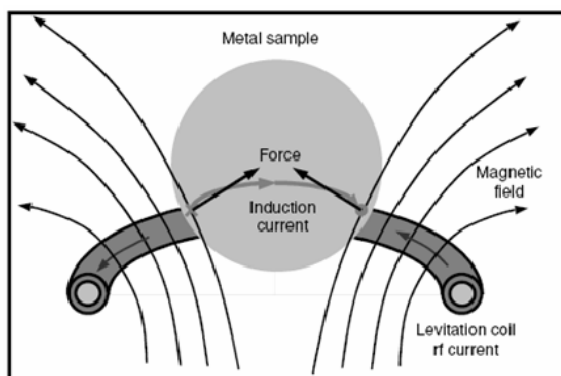


Fig.1: Principle of electromagnetic levitation

The main advantage of levitation melting is that the metal is molten without contact. The applications of this technique are based on this advantage: measurement thermophysical properties of liquid metals, elaboration of materials that require a high degree of purity, processing of strongly reactive metals or

alloys, and investigation of solidification of undercooled melts.

This paper presents a 2D finite element model for the study of levitation of a conductive spherical sample in the alternating magnetic field of induction \vec{B} created by a coil carrying the a.c. current i_1 . The coil represents the inductor of electromagnetic levitation system and the spherical sample its induced. The heating is not study.

Through the numerical model the values of coil current intensity and frequency are correlated with the electromagnetic force and sample position in respect with the coil.

2. ELECTROMAGNETIC FIELD MODEL

The inductor turn, Fig.2, made of a stranded conductor in the first studied case, hence a constant current density on its section, has the dimensions:

- average diameter, 24 mm;
- outer diameter, 10 mm;
- inner diameter, 6 mm.

The sphere made of aluminum has a diameter of 20 mm. In the reference position the sphere center is at a distance of 11 mm in respect with the sphere symmetry horizontal plane.

The supply frequency is within the range (1, ..., 300) kHz.

The electromagnetic field model of the levitation system is quasistatic magneto-harmonic.

The physical model, Fig.2, is characterized by rotational symmetry and the associated field model is 2D axisymmetrical in cylindrical

coordinates (r, z) . The current density \vec{J}_1 in coil and the magnetic vector potential \vec{A} are normal to the plane rOz .

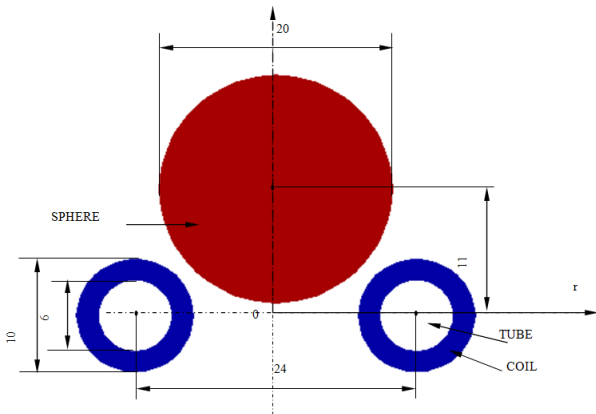


Fig.2. Physical model

The differential model of quasistatic magneto-harmonic field expressed in complex phasors is given by the equation:

$$\nabla \times \left(\frac{1}{\mu} \cdot \nabla \times \vec{A} \right) + \frac{j\omega \vec{A}}{\rho} = \vec{J}_1 \quad (1)$$

where $\omega = 2\pi f$, f is the frequency, ρ is the resistivity and μ is the magnetic permeability. The second term from the left member of equation (1) represents the density of induced currents, which is different from zero only in conducting regions.

The electromagnetic field computation domain, Fig.3, represents half of a cross section within the levitation system physical model and it consists of the following regions with distinguished physical properties:

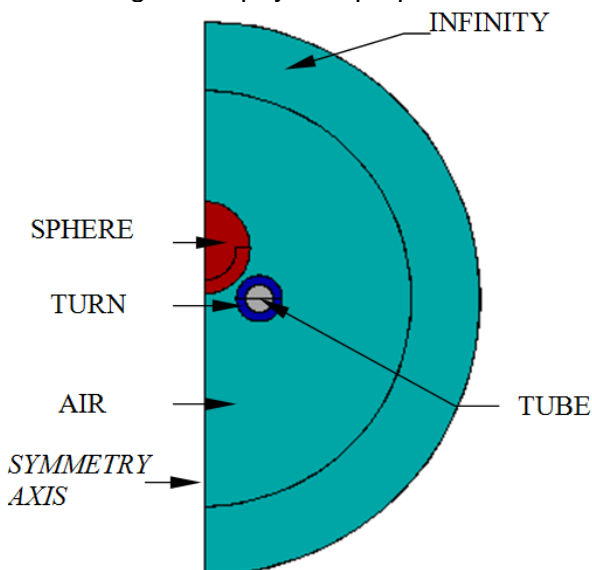


Fig.3. The computation domain

- TURN, region where current density is known, J_1 ; in the first studied case it is represented by a stranded conductor where no eddy currents occur and a non-conductive, non-magnetic material is assigned; in the second studied case it is represented by a solid conductor and eddy currents occur and a conductive, non-magnetic material is assigned;
- TUBE, the turn inner part, non-conductive and non-magnetic region
- SPHERE, solid conductor region;
- AIR, non-conducting and non-magnetic region;
- INFINITY, non-conducting and non-magnetic region; it represents a transformation of infinite region exterior to region AIR through which the field problem is one with unlimited extension.

The finite element model is developed in FLUX software.

The finite element mesh, Fig.4, is very important for the results accuracy and it is designed in such a manner that on the sphere surface there are two elements on a thickness approximately equal to penetration depth for the highest assumed frequency.

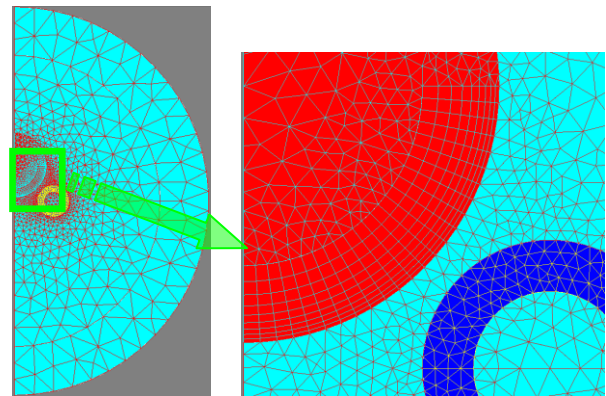


Fig.4. The finite element mesh

The sphere to be levitated is made of aluminum having resistivity $\rho = 0,035 \cdot 10^{-6} \Omega m$, density $\gamma = 2700 \text{ kg/m}^3$ and gravity $G = 0,1109 \text{ N}$. The value of magnetic permeability in whole computation domain is $\mu_0 = 4\pi 10^{-7} \text{ H/m}$. The current density in the inductor turn is $J_1 = 15 \text{ A/mm}^2$.

The magnetic vector potential satisfies a boundary condition of Neuman homogenous type on the symmetry axis and the electromagnetic field vanishes at infinity.

The influence of frequency within the range (1,...,300) kHz on the spatial distribution of magnetic field and induced current density and on electromagnetic levitation force for given inductor current and sphere position in respect to the turn is studied.

3. NUMERICAL MODEL RESULTS

The magnetic induction charts for the two extrema values of supply frequency, 1 kHz respective 300 kHz, are presented in Fig.5.

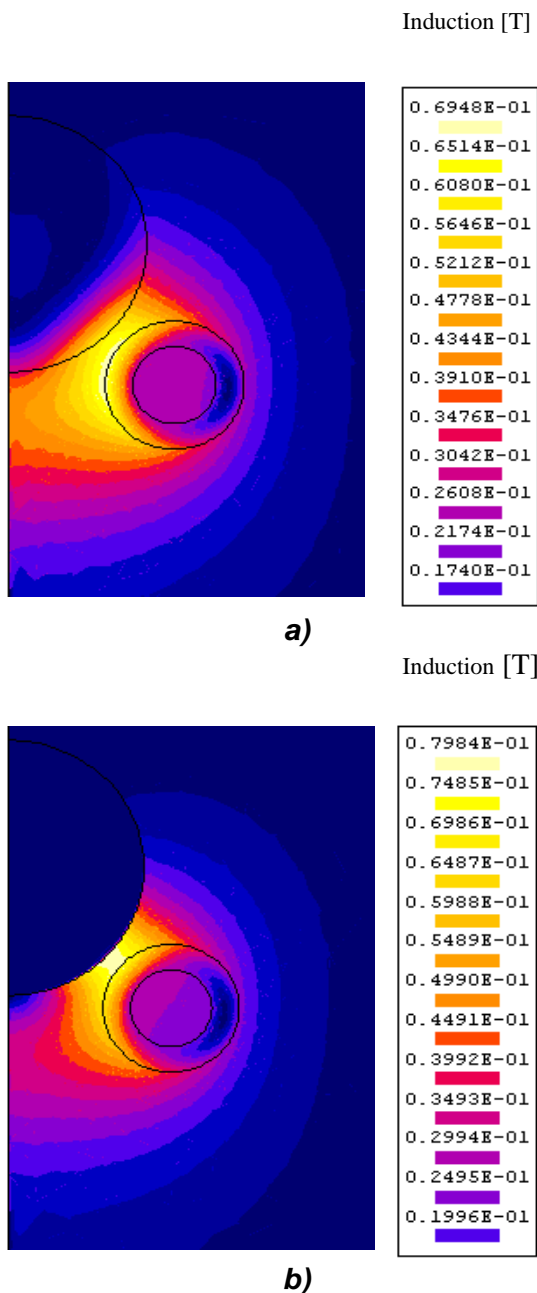


Fig.5. Magnetic induction
a) 1 kHz; b) 300 kHz

The induced current density charts for the two extrema values of supply frequency, 1 kHz respective 300 kHz, are presented in Fig.6.

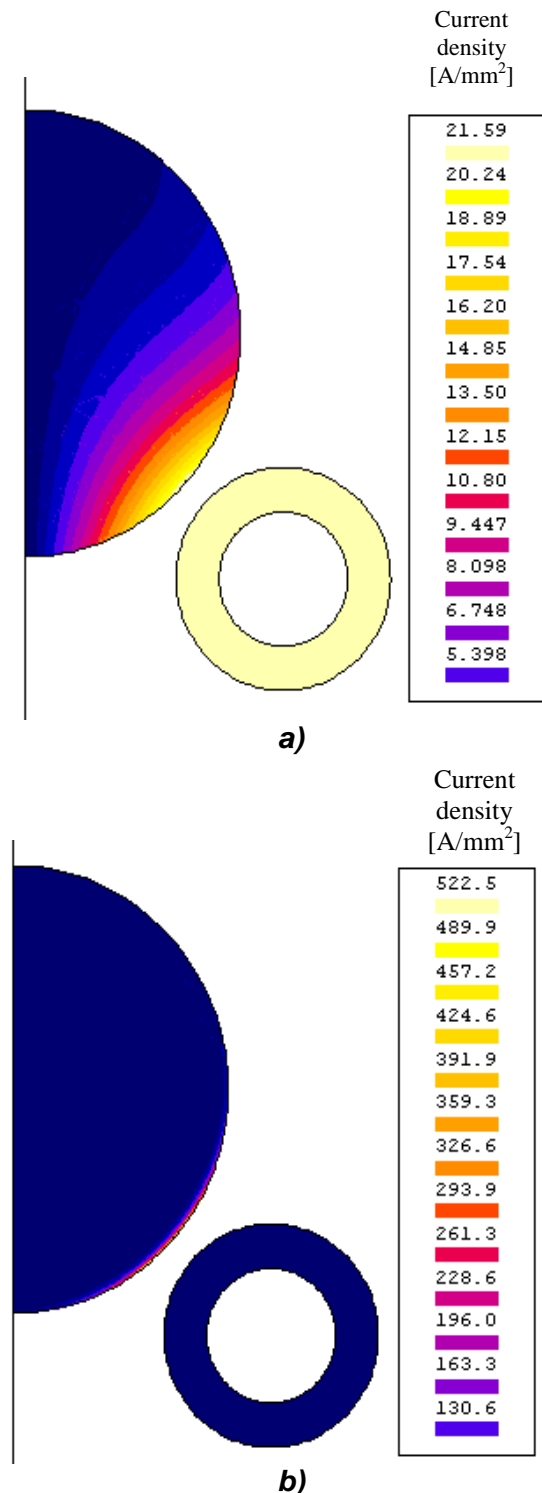


Fig.6. Induced current density chart (peak value)
a) 1 kHz; b) 300 kHz

The frequency increasing results in a increasing of the maximum value of induced current density within the sphere and the thickness of superficial zone where the

induced currents have significant values decreases. Therefore, as the frequency decreases the electromagnetic force F (proportional with J_2) decreasing, Fig.7, is smoother than the decreasing of power induced within the sphere P_{J_2} (proportional with J_2^2), Fig.8.

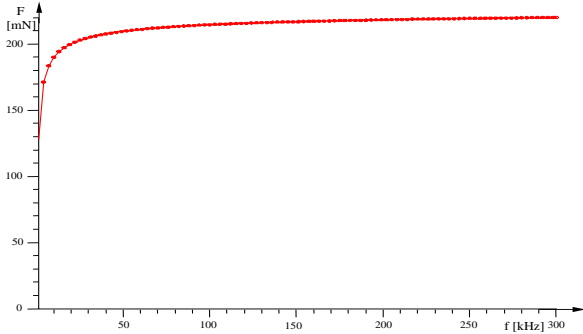


Fig.7. Variation of electromagnetic force with frequency

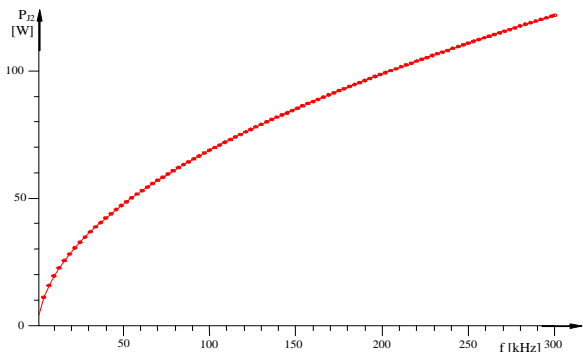


Fig.8. Variation of induced power with frequency

Analyzing the results, the frequency of 10 kHz is observed to be suitable for an application of levitation. For frequencies greater than the stated value the increase of electromagnetic force is insignificant, as the induced power strongly increases.

The study of electromagnetic levitation force in respect to parameter h_{cs} – the distance between sphere center and the turn horizontal symmetry plane, for the supply frequency of 10 kHz results in the graphic shown in Fig.9. The position for which the electromagnetic force is equal to sphere gravity G , which stands for the sphere levitation, corresponds to distance $h_{cslev} = 13,467$ mm.

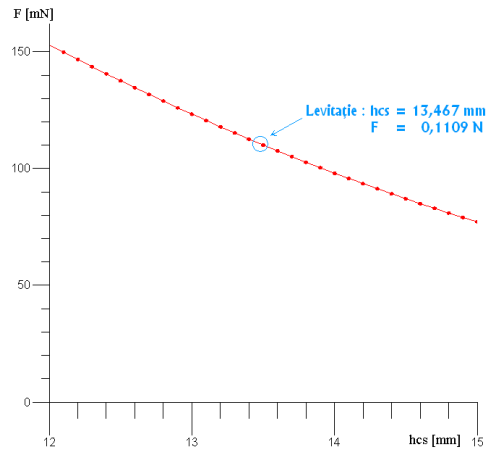


Fig.9. Variation of electromagnetic levitation force with distance h_{cs}

In the case when the region TURN is assumed to be a solid conductor with a resistivity of $0,02 \mu\Omega m$ a circuit model is coupled with the numerical model in FLUX.

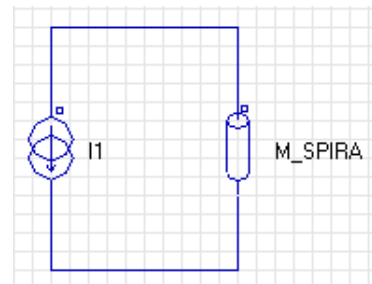


Fig.10. The circuit model

In Fig.11 is presented the current density chart in the case of solid conductor assumption for supply frequency of 1 kHz.

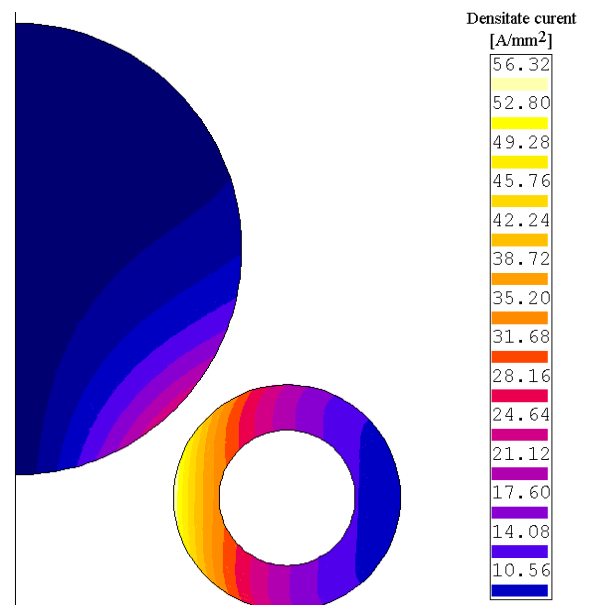


Fig.11. Induced current density chart

The active power produced by Joule effect in the solid conductor type turn is $P_{J1masiv} = 19,35 \text{ W}$, and it results through simulation results postprocessing. In the case of stranded conductor type turn, characterized by the filling factor $F = 0,7$, this power has the value: $P_{J1filiform} = RI^2 = \rho L / (FS) (J_1 S)^2 = \rho L J_1^2 S / F = 24,36 \text{ W}$, where L is the turn average length and S is the cross section of region TURN. It can be noticed a 20% decreasing of Joule losses in case of solid conductor type turn. Due to the loop effect, the current is distributed mainly on the turn inner side and the current lines are shorter.

In case of solid conductor type turn, Fig.12, the levitation force is approximately two times greater than in case of stranded conductor type.

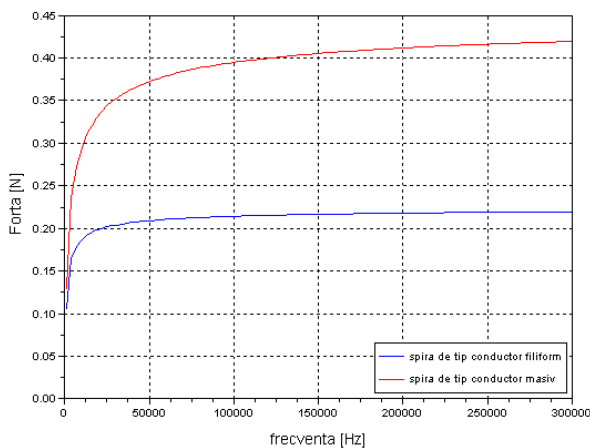


Fig.12. Variation of electromagnetic force with frequency for the two studied cases

4. CONCLUSIONS

Numerical model is a useful tool in defining the coil parameters, sample weight (size) and lifting force exerted on sample. The sample weight should be in a specific range for having a successful levitation process. The electromagnetic analysis was conducted to determine the sample position in the electromagnetic field.

A meshing of computation domain adapted to the distribution of electromagnetic field for a parameterized geometrical study is definity.

Further work will involve a coupled-field electromagnetic transient thermal analysis in order to calculate temperature distribution in the levitated sample.

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