International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 3, Issue 10 (October 2014), PP.40-48

Numerical Analysis of Magnetic Compounds used to Make Induction Planar Actuator Core with Two Degrees Of Freedom

João Mota Neto[1], Ana Paula Volpato[1], Carlos Antonio Ferreira[1],Lirio Schaffer[2]
[1]*(Department Industrial Automation, Faculty SATC, Brazil)*
[2]*(DepartmentMetallurgical Engineering/ Ufrgs, Brazil)*

Abstract:- Research exposes the electric planar actuator as an element of traction which can be employed for bidirectional movement performed by a single mechanism as an alternative to the usual composed disposition of mechanical components and rotary motors used in industrial applications. Considering the capacity of the surface motors to produce kinetic energy with minimum mechanical contact between the stator and the translator, thus it reduces the friction and consequently eliminates this and other nonlinearities present in other drive technologies normally used. When the process of powder metallurgy is used, it is possible to build unique massive blocks cores with high magnetic permeability and advantages can be obtained when compared to conventional cores, such as motors with lower energy consumption and higher efficiency. Therefore the focus of this paper concentrates on simulations of magnetic compounds and alloys through analysis by the Finite Element Method with support for three-dimensional models applied in the confection of magnetic circuits used in planar actuator. The performance of the cores was analyzed by magnetic field density spectral with numerical information of the maximum magnetic flux density and the influence of the variation of the supply frequency.

Keywords:-Induced electrical currents, magnetic materials, powder metallurgy, relative magnetic permeability.

I. INTRODUCTION

In the last few years, has been verified a substantial increase in the study, research and development of linear electric machines, mainly for industrial and transportation applications. Based on electromagnetic phenomena, the increasing interest in these devices is intimately connected to the emergence of new materials and constant modernization of control techniques dictated by electronics that is more and more efficient [1].

In this scenario, it is detached the progresses achieved by powder metallurgy regarding to soft magnetic composites (SMC). They are materials utilized in electromagnetic applications and they can be described as iron powder particles, or its iron alloys, circled by isolated material. SMC components can be normally produced by conventional techniques of powder metallurgy (PM) with or without applications of new methodologies such as, double compacting, hot compaction and thermal treatments [2].

The continuous advances in research of materials makes a reality the capacity of producing a high quality material with magnetic proprieties, competing, thus, with laminated steel, with a similar production cost. Thereby, since the mid-80s of last century, soft magnetic composites materials (SMC) appeared on the market as new perspectives for electric projects of motors. These materials are adequate for use in alternated magnetic fields where the establishment of Foucault currents is undesirable. This fact allows the utilization of soft magnetic composites materials in the construction of core of AC electric motors.

Surrounded by these technological evidences, the main focus of this article concentrates in simulations of magnetic composites and alloys by means of Finite Element Method analysis with support for three-dimensional models applied in the confection of magnetic circuits applied on the three-phase planar actuator. Thus, the structure of the induction planar actuator (I.P.A.) taken on this paper for the development of simulations of the I.P.A. car **core** were materials that favor the magnetic flux for the creation of the traveling field necessary for the primary's movement. Will be objects of study in this article the materials Somaloy500 (developed by the Swedish company Höganäs), Ferrita, Mu-Metal (materials of interest developed through powder metallurgy), Aluminum and Steel1020 (materials with easy access and machining).

II. THEORETICAL OF MATERIALS

Due to constant improvement of the powder consolidation technique, as sinter-forging, also the constant innovations in the powder production, so that they result in powder with superior compaction characteristics, it made the powder metallurgy a competitive technique with the traditional metallurgical processes, not only under economic point of view, but also with the fact that is obtained, in the final product, mechanical properties compatible with the ones in molten materials, mechanically shaped or machined, in the same time that operations with superficial thermal treatments can be successfully applied [3].

2.1 Somaloy 500

The Somaloy 500, produced by the Swedishcompany Höganäs, is a magnetically soft ferromagnetic composite material applied in low frequencies of until 400 Hz, because it presents low magnetic total loss in this order of magnitude. This material is composed by metallic powder, lubricants and agglutinants. The quantity of addition of lubricants and/or agglutinants to the metallic powder followed by compaction in thermal treatment, determinate the magnetic, electric and mechanical proprieties of the material [4][5].

This material, made from powder metallurgy, does not present the sintering phase, which limits the relative magnetic permeability and, because of the addiction of agglutinant, presents a high electric resistivity. These characteristics may be interesting in some magnetic applications, where the induced currents present losses to the device, being classified as Foucault Currents.

The magnetization curves, fundamental data in the analysis of magnetic proprieties of the materials, relate the magnetic flux density, B, with the magnetic field, H, and they are important for the definition of the operation point of the material, the saturation values and the magnetic permeability. The Figure 1 presents the data of the discussion material. The compactions that generated the three different specific weights are: 400MPa, 600MPa and 800MPa, and higher pressure results in higher density.

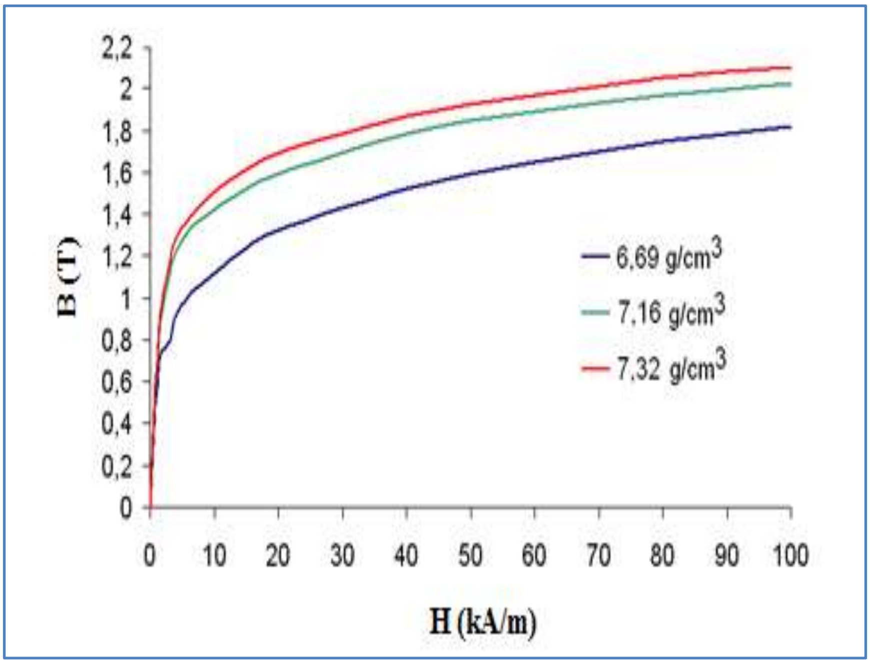

Fig. 1. Magnetic curve of Somaloy 500 + 0,5% Kenolube, with thermal treatment at 500ºC for 30 minutes in the air, due to the density [5].

With regard to the maximum relative magnetic permeability of the material, the Somaloy 500 with 0,5% of Kenolube (500° C for 30 min. in the air) has a maximum relative permeability of 500 and coercive force of 250 A/m.

2.2 MuMetal

MuMetal is an alloy of four elements based on Cr-Permalloy, composed by 75% Ni, 18% Fe, 5% Cu and 2% Cr. The losses by hysteresisin function of flux density are represented in the Fig. 2, and it represents one fourth of the alloy Fe-Si. In the TABLE 1 are represented the total losses of the MuMetal alloy as a function of thickness and frequency, to induction of 0.5T [6].

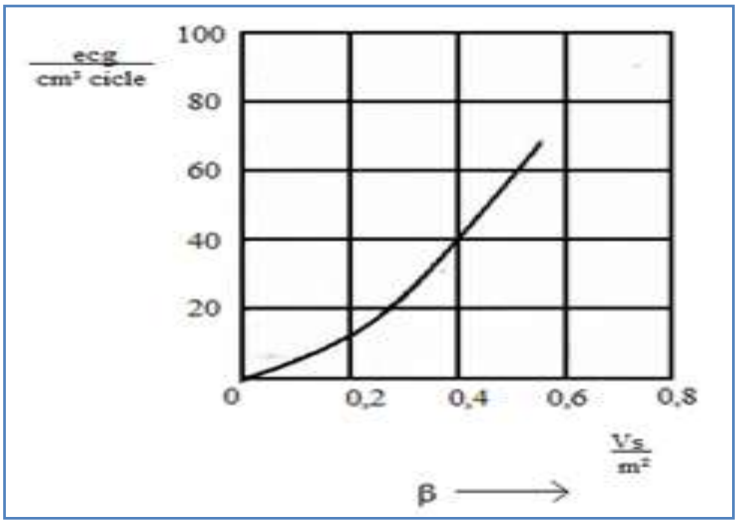

Fig. 2. Losses by hysteresis as a function of magnetic induction for the alloy MuMetal [7].

If a Permalloy alloy is composed by 78% of Ni, 18% of Fe and it is added 4% of Cr, its electrical resistivity will increase from 20 μΩ cm to 65 μΩ cm. The maximal permeability of commercial alloys which contain 3.8% chromium somewhere around 35.0000μo, although they have been achieved in the laboratory, the values in the order of 65.0000μo.In comparison with the MoPermalloy, this alloy presents worse results in the permeability level, however it presents better results when compared with the FeNi alloy, with only 1,45% of Ni [6].

Table 1. Total losses of the MuMetal alloy, for magnetic inductions of 0.5T, as a function of thickness and frequency [7].

PlateThickness (mm)	Frequency (Hz)	$W_{o.g}$ (mW/kg)
0-37	50	150
	600	9000
0-2	5000	18
0-1	5000	5-5

2.3 ISA 1020 Steel

The relative magnetic permeability of this material tends to be high; nevertheless it is lower when compared to others ferromagnetic materials utilized in electric machines' core (e.g., limited steel). Therefore, the massif steel is more susceptible to the establishment of parasite electric currents when exposed to variation of magnetic flux density, which represents a limitation in the use of this material in the construction of magnetic circuits in function of the losses that these parasite currents might represent [8][9].

To increase the magnetic permeability of the steel, the traditional procedure is the annealing (thermal treatment). In this technique, the steel is submitted to a controlled heating during the time, inert to a gas (not oxygen or air). After that, the piece is put in room temperature so it returns to its initial temperature. This technique not only improves the permeability by the relief of intern stresses of the material, but also increases its mechanical resistance. The performance is nonlinear in relation to the magnetization, as can be verified in Fig. 3.

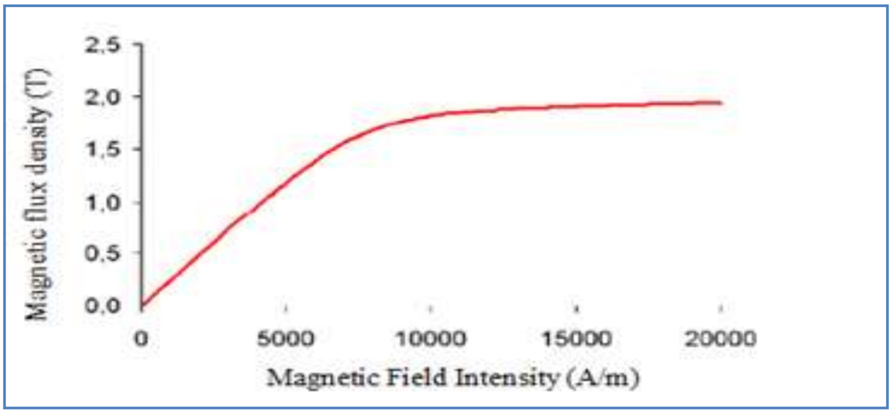

Fig.3. Normal magnetization curve of Annealed Massif Steel AISI 1020 [10].

III. ANALYSIS METHODOLOGY

In this chapter it will presented the conception referring to the Three-phase Planar Actuator **(T.P.A.)**, as well as the procedure related in order to demonstrate the sequence of obtained results in the simulation of the object of study.

3.1 Three-phase Planar Actuator Structure

The conception of the I.P.A.'s structure in study consists in a motor composed by a primary block denominated car it is constituted by nine teeth in form of 3X3 matrix. Each tooth has two coils, one referred to the winding that provides traction in the x axis and the other one that will move by traction the y axis. The set of three parallel teeth for each axis makes feasible the balanced sinusoidal three-phase feed available in the energetic system.

The secondary of the motor is composed by a stator metal sheet of ferromagnetic material that will be the means of low reluctance to the magnetic flux lines. The ferromagnetic sheet is recovered by a plate of paramagnetic (or diamagnetic) material with high electric conductivity, which provides a low electric resistance way to the induced currents. Thus, it is allowed a substantial increase of linear force of the planar actuator's car. (See Fig. 4)

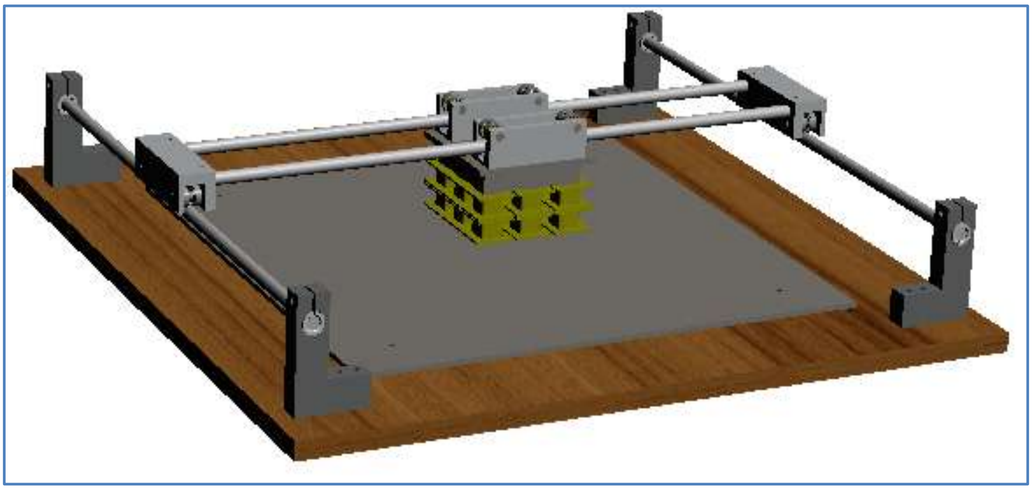

Fig. 4. Induction Planar Actuator.

The car is supported by a suspension system composed by linear axis and plain bearings and windings systems, which allows movement in two degrees of freedom, which is characteristic and the goal of the Induction Planar Actuator at issue. The characteristic of planar movement with two degrees of freedom attributes to the Induction Planar Actuator a wide applicability in the industry, where the applications with this setup use a rotating electric motor as source of motive force, for transformation of rotated movement to linear movement; it makes necessary the use of a complex mechanical system made by gears, axis and endless threads of screw. These mechanical systems for energy transmission produce high losses, accented abrasion due to the mechanical parts friction, even with the utilization of fluids with low viscosity for lubrication, increase the operational costs, mainly the ones related to maintenance. Therefore, the use of electric planar actuator as element of traction passable of being employed in bidirectional movements executed by only one mechanism would result in lower operational cost, higher reliability and lower maintenance [4].

3.2 Characteristics of the Simulated model

The proposal of this article is founded in the analysis of electromagnetic performance parameters of the composites passable of being employed in the fabrication of the I.A.P. This analysis objectifies studying the static performance focusing on the distribution of the magnetic flux density, the originally electromagnetic forces produced, issues about induced electric currents in the primary and secondary of the device. For this analysis will be utilized the Finite Elements Method (FEM) through a specific software for simulations.

The model was inserted in the software, being the machine's primary denominated carformed by only one block in which the coils are allocated and isolated from the primary. The coils fabricated in copper, with 250 turns in each winding, being three coils each phase. As a result, there are a total of eighteen winding identical to each other, disposed in a form that allows the balanced sinusoidal three-phase feed by means of the star linkage for each set of coils. The machine's secondary, a statorflat structure with dimensions of 500 x 500 mm, was transported to the software being constituted by 1020steel sheet of 8mm superposed by an aluminum plate of 1mm, respectively. Thus, the relative position of the core in relation to the secondary was fixed in 100mm of each corner (X and Y), and the distance referred to the Z coordinate between the secondary and the tooth's surface of the car was defined in 1mm, according to what can be seen in Fig. 5.

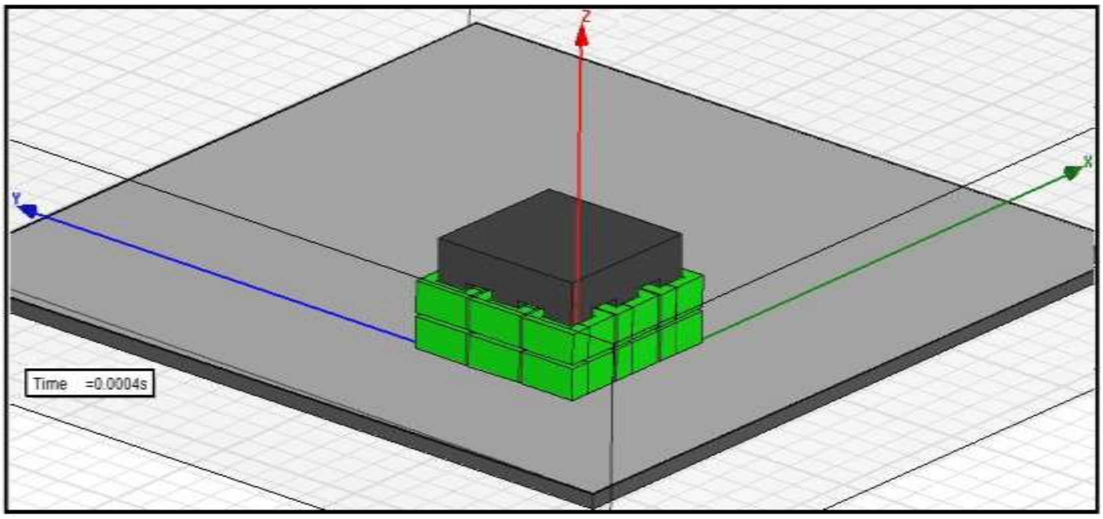

Fig. 5. Simulated Model in Finite Element Method.

With respect to the electric current in which the coils are submitted, was defined in 5 Amperes, in sinusoidal form and 120° gap, so in this way it characterizes a balanced system. It was analyzed in the range of 30 to 600Hz. In this range it is verified the magnetic flux density response in the core of car (Wb/m²-T), the induced current density spectrum in the secondary's aluminum plate (A/m²) and the density of ohmic losses in the core (W/m³).

Based on previous mentioned aspects, the instant of the analysis values was determined based on the electric current peak of phase A, being this parameter defined by equation 1.

$$t[s] = \frac{f^{-1}}{4}$$

The setup for analysis is changed for each applied frequency, and the simulation time was stipulated in two complete periods of frequency referred to the IPA's feed. The TABLE 2 presents the inserted data in the software for each defined frequency.

Table 2. Description of analysis parameters inserted in the FEM software.

Frequency (Hz)	Peak time ofPhase 1 [s]	Simulation total time [s]	Pass time [s]
30	0,008	0,07	0,001
60	0,004	0,03	0,0006
120	0,002	0,017	0,0003
180	0,0014	0,011	0,0002
240	0,0010	0,008	0,00014
300	0,0008	0,007	0,00011
420	0,0006	0,005	0,00008
600	0,0004	0,003	0,00006

IV. RESULTS AND DISCUSSION

With main focus in the zone that embodies the car, one of the goals of the analysis using the software is to predict the performance of the magnetic flux density distribution in the planar actuator. Besides that, to predict the effects of planar propulsion force that act over the car, when the three-phase windings are excited with alternated three-phase electric tension, in static regime.

Under the proposed conditions, were obtained results in spectrum of magnetic flux density (B), induced current density in the secondary (J) and volumetrical density of ohmic losses in the core (OL – ohmic loss). Parameters used for better IPA's performance: High flux density, high induced current and low ohmic loss [1][5].

The obtained results are in visual and numerical order, according to what was seen in Fig. 6 to Fig. 8. For the three situations, it is possible to verify homogeneity in the spectrum of magnetic induction magnitude inside the material. Thus, it is allowed to state that the medium induction is close to the value of 1,5636E-1 T with frequency of 30Hz.

In the analysis of Fig. 7 and Fig. 8, it is possible to verify the maintenance of the induction homogeneity in the core. With values close to 1,5660E-1 and 1,5668E-1 in frequencies of 300 and 600Hz, respectively. The observed performance in the results delegates with the theoretical prediction and with the available literature upon the SMC's frequency variation performance [5].

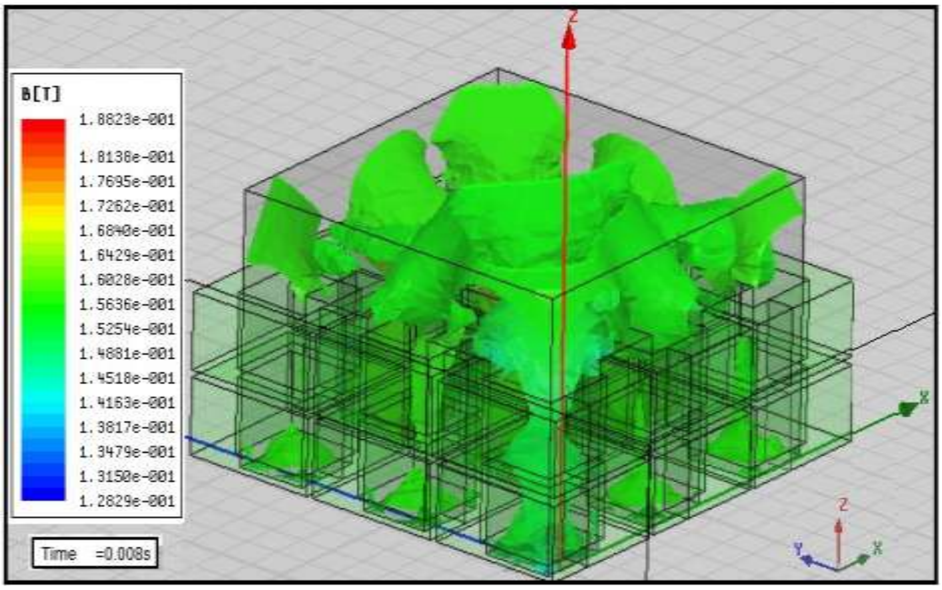

Fig. 6. Result of Magnetic Flux Density Spectrum B (T) simulated with core of Somalloy500 with frequency of 30Hz.

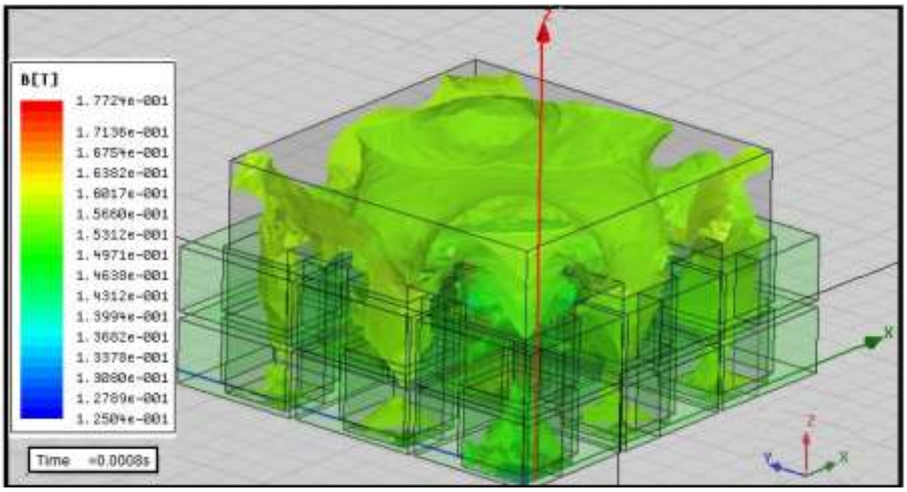

Fig. 7. Result of Magnetic Flux Density Spectrum B (T) simulated with core of Somalloy500 with frequency of 300Hz.

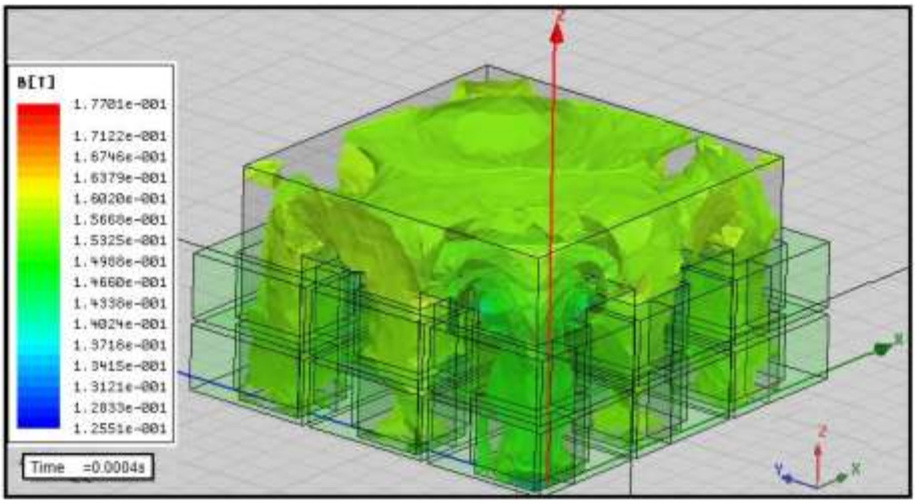

Fig. 8. Result of Magnetic Flux Density Spectrum B (T) simulated with core of Somalloy500 with frequency of 600Hz

It was aimed to compare the performance of mechanical materials of easy machining with the new developed materials through powder metallurgy. With the right data and information grouping and it was possible to obtain performance graphics of the evaluated parameters in function of the primary's material frequency (car).

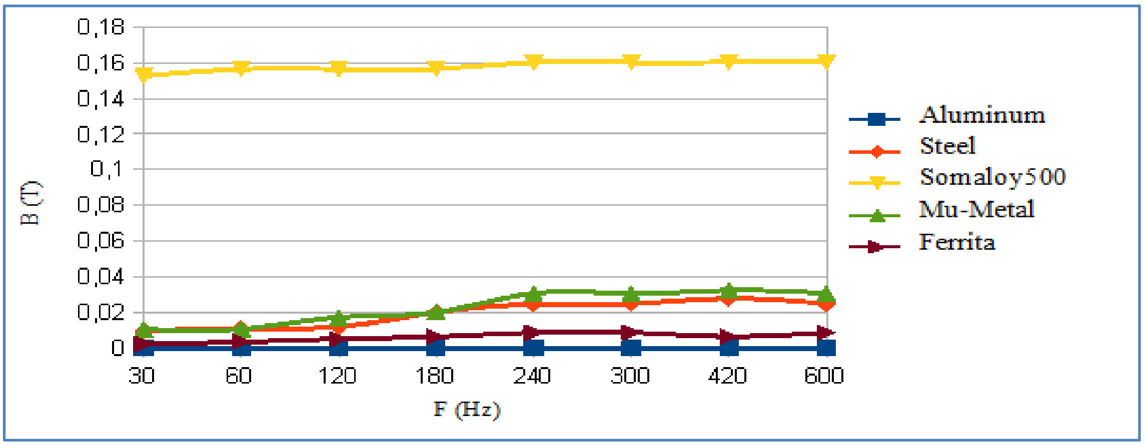

Fig. 9. Resulting Magnetic Flux Density (Magnetic Induction) in the core in function of frequency.

The magnetic flux density observed in Somaloy500 is noticeably superior to other materials, especially because of its high magnetic permeability, deriving from the high purity degree inherent to the SMC's composition.

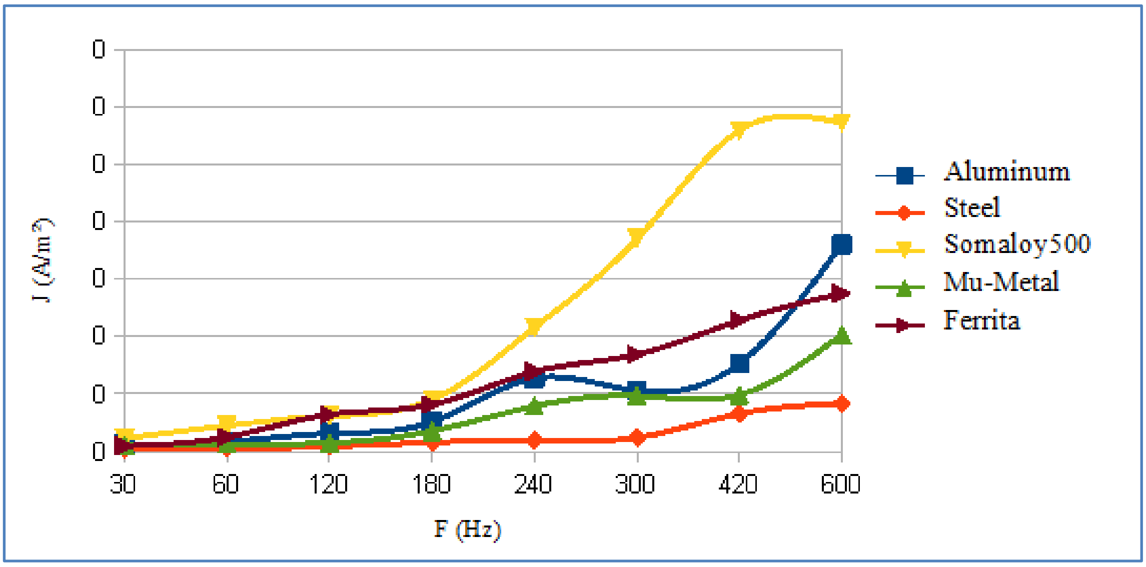

Fig. 10. Resulting Induced Current Density in the aluminum plate of the Secondary in function of frequency.

As a consequence, the induced current curves in the secondary follow the same optimist tendency with the use of Somaloy500. The expressive increase of the current's density magnitude in the secondary incurs of the frequency increase followed by a good flux density in the magnetic circuit [12].

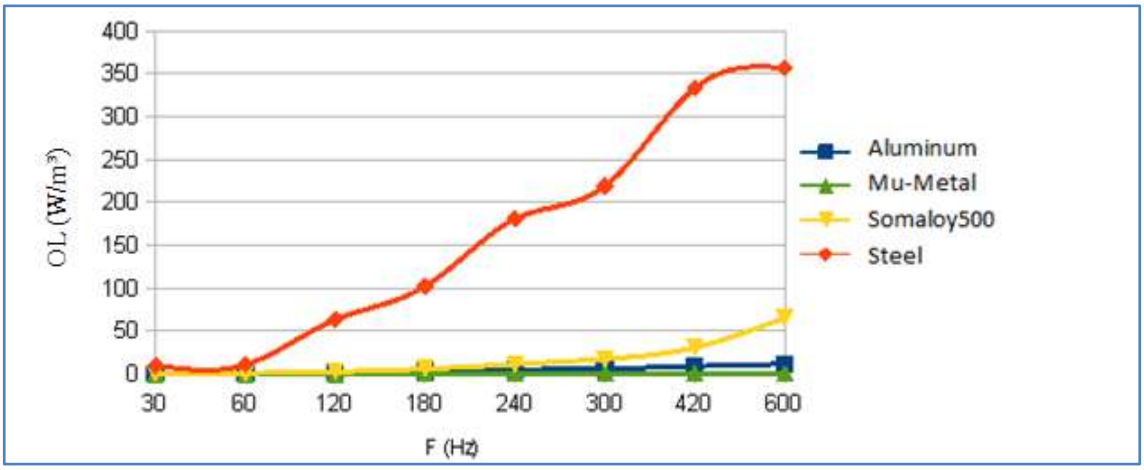

Fig. 11. Volumetrically density of Ohmic Losses resulting in the core of car in function of frequency.

The losses in the iron are substantially higher in the steel core, especially because of the high relative magnetic flux and the Foucault induced currents in the primary [6], derived of the high electric conductivity and the disposition in unique block.

V. CONCLUSION

The Induction Planar Actuator performance referred to the parameters of magnetic flux performance in the car region, main point analyzed in this study, it was obtained results that are favorable to the application of Somaloy500 as an adequate material for confection of the IPA core.

The Somaloy500 allowed the establishment of magnetic flux density considerably eight times more than other studied materials (Ferrita, MuMetal, Aluminum and Steel1020), enabling the occurrence of a good density of induced current in the secondary and with density of ohmic losses in acceptable boundaries. The aluminum, because of its paramagnetic characteristic, presented an infamous flux density, and this performance makes it not viable for the core construction.

Even though the MuMetal presented superior results compared to aluminum in the magnetic induction analysis, it has a similar performance compared to steel in these enquiries: flux density and induced current. For an eventual prototyping, its easy obtainment and machining favor the utilization of steel in relation to MuMetal, even if its losses are considerably high.

In relation to the frequency variation, in the ferrita it increases when occurs the performance develops, even with disadvantage to the Somaloy500; this one, on the other hand, maintained stability in response with all analyzed frequencies of flux density. Thus, Somaloy500 is, among all analyzed materials in this study, the most adequate to be applied in the IPA in a control structure based on modulation of the operation frequency.

REFERENCES

[1] BAGGIO FILHO, N. F. *Estudo de Um Atuador Planar de Indução.* 2012. 249 f. Tese Universidade Federal do Rio Grande do Sul, 2012.

[2] SHOKROLLAHI, H. & JANGHORBAN, K. 2007. *Soft magnetic composite materials Journal of Materials Processing Technology, London (UK), Vol. 189*,1-12 (Classificação SMC)

[3] ESSWEIN JUNIOR, Jorge Alberto Lewis.Desenvolvimento de Compóstivos Magnéticos Macios Utilizados em Núcleos de Máquinas Elétricas. 2009. 117 f. Dissertação - Departamento de Pós-graduação Em Engenharia Minas, Metalúrgica e de Materiais - Ppgem, Universidade Estadual De Campinas, Porto Alegre, 2009.

[4] FLORES FILHO, Aly F.; BAGGIO FILHO, Nolvi F.. *Analysis of an Induction Planar Actuator*. XIX International Conference On Electrical Machines, Rome, p.978-984, 2010.

[5] SHOKROLLAHI, H. & JANGHORBAN, K. 2007. *Soft magnetic composite materials Journal of Materials Processing Technology, London (UK), Vol. 189*,1-12 (Classificação SMC)

[6] PINHO, Lucas Carlos Almeida.*Materiais Magnéticos e suas Aplicações.* 2009. 100f. Dissertação – Faculdade de Engenharia da Universidade do Porto, Portugal 2009.

[7] HECK, C., *Magnetic Materials and their Applications,* ButterWorths, Londres (1974).

[8] FLORES FILHO, A. F.; SUZIM, A. A.; SILVEIRA, M. A. Produção de Movimento Bidirecional Através de um Novo Atuador Planar. In: SEMINÁRIO NACIONAL DECONTROLE E AUTOMAÇÃO - SNCA, 2001, Salvador. Anais... Salvador: AINST/IEEE /UFBA , 2001. TT-041.

[9] FLORES FILHO, A. F.; SUZIM, A. A.; SILVEIRA, M. A. 3D Analisys and Simulation of a Novel Planar Actuator. In: INTERNATIONAL CONFERENCE ON ELECTRICAL MACHINES, 2000, Espoo. Proceedings... Espoo: Helsinki University of Techonology, 2000.v.3, p. 1379-1383.

[10] SILVEIRA, M. A. *Estudo de um Atuador Planar.* Porto Alegre.2003. 225f. Tese, Programa de Pós Graduação em Engenharia de Minas, Metalúrgica e Materiais, Porto Alegre: UFRGS, 2003.

[11] GUO, Youguang; ZHU, Jianguo; LIU, Dikai; LU Haiyan; WANG, Shuhong. Application of Multi-level/Multi-domain Modeling in the Design and Analysis of a PMTransverse Flux Motor with SMC Core. Power Electronics and Drive Systems. PEDS '07. 7th International Conference, Bangkok, P 27-31, 2007.

[12] BASTOS, João P. A. *Eletromagnetismo para engenharia: Estática e quase estática.*3 ed. rev. Florianópolis: Ed. da UFSC, 2012