DETERMINATION OF THE OPTIMAL MATERIAL FOR PERMANENT MAGNETS USED IN THE MANUFACTURE OF HIGH-POWER AUDIO DEVICES

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Abstract: Crowded permanent magnets of NdFeB -type have the superior properties to those intered as shown by the magnetic circuit modeling using finite element method (FEM). Determination of the optimum material for magnetic circuit of high power audio devices is a complex problem. A very eficiente method, based on the value of the main functional properties, such as technological and material cost analysis method of optimum values developed by Prof. Univ.Emerit Dr. ing. Constantin D. Stanescu. Analysis method of optimum values for material properties present two models: statistical and analytic model . Magnetic materials for permanent magnets of NdFeB-type have superior properties compared to magnetic materials from barium ferrite. In the statistical model, analytical model and results from the experimental data and the importance of ferromagnetic material used for reinforcement, Armco iron magnetic properties with superior steel S235.Using sintered NdFeB permanent magnets instead of crowded NdFeB permanent magnets follows:-the less magnetic induction in the air gap ; -the losses of the magnetic circuit and the extremities of the air gap are greater than in the case of crowded NdFeB permanent magnets, because the sintered magnets require a different configuration of the magnetic circuit. Modeling of magnetic circuit of high power audio device was realized with the finite elements method (FEM) software package ANSYS. It is very important the geometric configuration of the circuit and the optimal choice of materials. Using the same materials, change the shape of the magnetic circuit geometry leads to increased air flow and the losses of magnetic flux are reduced totally . Changing the magnets of barium ferrite, respectively with sintered or crowded NdFeB permanent magnets, the performances of the magnetic circuit grow significantly. The maximum value of magnetic induction in the air gap magnetic circuit in ideal conditions was determined 1,136T. By changing the geometric configuration of permanent magnets, maximum value of magnetic induction can be reached at 1,248T, with about 10% higher than the magnetic reference circuit. Magnetic flux leakage are larger in the magnetic circuit if the magnetic permeability of soft magnetic materials is reduced. The saturation magnetic induction is lower. It is very important that the construction of magnetic circuits to be used with high magnetic permeability materials to prevent their saturation.
Keywords: Air gap, permanent magnets, magnetic flux

1. THEORETICAL CONSIDERATIONS

Crowded permanent magnets of NdFeB -type have the superior properties to those sintered as shown by the magnetic circuit modeling using finite element method (FEM). Determination of the optimum material for magnetic circuit of high power audio devices is a complex problem. A very eficient method, based on the value of the main functional properties, such as technological and material cost analysis method of optimum values developed by Prof. Univ.Emerit Dr. ing. Constantin D. Stanescu. Analysis method of optimum values for material properties present two models: statistical and analytic model.

Magnetic materials for permanent magnets of NdFeB-type have superior properties compared to magnetic materials from barium ferrite.

In the statistical model, analytical model and results from the experimental data and the importance of ferromagnetic material used for reinforcement, Armco iron magnetic properties with superior steel S235.

Using sintered NdFeB permanent magnets instead of crowded NdFeB permanent magnets follows:

– the less magnetic induction in the air gap;

– the losses of the magnetic circuit and the extremities of the air gap are greater than in the case of crowded NdFeB permanent magnets, because the sintered magnets require a different configuration of the magnetic circuit.

Modeling of magnetic circuit of high power audio device was realized with the finite elements method (FEM) software package ANSYS.

It is very important the geometric configuration of the circuit and the optimal choice of materials. Using the same materials, change the shape of the magnetic circuit geometry leads to increased air flow and the losses of magnetic flux are reduced totally. Changing the magnets of barium ferrite, respectively with sintered or crowded NdFeB permanent magnets, the performances of the magnetic circuit grow significantly.

The maximum value of magnetic induction in the air gap magnetic circuit in ideal conditions was determined 1 136T. By changing the geometric configuration of permanent magnets, maximum value of magnetic induction can be reached at 1, 248T, with about 10% higher than the magnetic reference circuit.

2. STATISTICAL OPTIMIZATION MODEL

The statistical model of the optimization of magnetic circuit for material of high power audio devices are:

1) functional analysis of the role of the product;

2) setting main properties considered: physical, thermal, electrical, electronic, mechanical, magnetic, acoustic, technological and cost;

3) the granting of property qualifiers (n) (n = 0 less important property; n = 1 important property);

4) determining the weights of each properties (p) by assessing the percentage p = 1 ... 100% the percentage of participation of a property in relation to its involvement of functional role of the product;

5) compiling the Table 1. with all the data from the 2 ...4;

6) calculation of the product (np) between note and share for each property treated;

7) optimal Material resulting from Table 1determined relationship with

$$\left(\sum_{i=1}^{m} n_i p_i\right)_{\max} = \text{Optimal Material} \tag{1}$$

where: i = 1...m; in this case: i = 1...10.

Table 1. **The data obtained through a statistical model of the studied material optimization**

Properties considered / **Material**			**1. FeB/S235 Without heat treatment of high return**	**2. FeB/S235 With heat treatment of high return**	**3. NdFeB Crowded / S235 Without heat treatment of high return**	**4. NdFeB Sintered / S235 Without heat treatment of high return**	**5. NdFeB Crowded / Armco iron**	**6. NdFeB Sintered / Armco iron**	**Weights p (%)**
Physical	Weight	n	1	1	1	1	1	0	5
		np	0,05	0,05	0,05	0,05	0,05	0	
Thermal	Thermal cond.	n	0	0	0	1	1	1	15
		np	0	0	0	0,15	0,15	0,15	
Electrical	Electrical cond.	n	1	1	1	1	1	1	5
		np	0,05	0,05	0,05	0,05	0,05	0,05	
Magnetic	Magnetic induction	n	0	0	1	0	1	1	15
		np	0	0	0,15	0	0,15	0,15	
Electronic	Rated impedance	n	0	0	1	1	1	1	10
		np	0	0	0,1	0,1	0,1	0,1	

Table 1 (continued)

Properties considered \ Material				1. FeB/S235 Without heat treatment of high return	2. FeB/S235 With heat treatment of high return	3. NdFeB Crowded / S235 Without heat treatment of high return	4. NdFeB Sintered / S235 Without heat treatment of high return	5. NdFeB Crowded / Armco iron	6. NdFeB Sintered / Armco iron	Weights p (%)
Technological	Chipping		n	0	1	0	0	0	0	5
			np	0	0,05	0	0	0	0	
Mechanical	Compliance		n	0	0	1	1	1	1	10
			np	0	0	0,1	0,1	0,1	0,1	
Acustic	Acustic power		n	0	0	1	0	1	1	20
			np	0	0	0,2	0	0,2	0,2	
	Acustic pressure		n	0	0	1	1	1	1	5
			np	0	0	0,05	0,05	0,05	0,05	
Economic	Cost		n	1	1	0	0	1	0	10
			np	0,1	0,1	0	0	0,1	0	
$(\sum n_i p_i)_{max}$				0,20	0,25	0,70	0,50	**0,95**	0,80	100

Analyzing the results in Table 1. material resulting optimal, who has comform relationship 1:

$$\left(\sum_{i=1}^{m} n_i p_i\right)_{max} = 0{,}95 \rightarrow \text{NdFeB crowded / Armco iron} \tag{1}$$

3. THE ANALYTICAL MODEL OF OPTIMIZATION

Steps analytical model for optimization of the magnetic circuit material for high power audio devices are:

1) following the steps 1-5 in the statistical model optimization;

2) matrix calculation of notes Mn , expressed by the relation:

$$M_n = \begin{pmatrix} n_{11} & n_{12} & \ldots\ldots & n_{1n} \\ n_{21} & n_{22} & \ldots\ldots & n_{2n} \\ \ldots & \ldots & \ldots\ldots & \ldots \\ n_{n1} & n_{n2} & \ldots\ldots & n_{nn} \end{pmatrix} \tag{2}$$

3) matrix calculation M_{np}, or the product of the matrix M_n and share notes p for each property, namely:

$$M_{np} = \begin{pmatrix} n_{11}p_1 & n_{12}p_2 & \ldots\ldots & n_{1n}p_n \\ n_{21}p_1 & n_{22}p_2 & \ldots\ldots & n_{2n}p_n \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ n_{n1}p_1 & n_{n2}p_2 & \ldots\ldots & n_{nn}p_n \end{pmatrix} \tag{3}$$

4) drawing program for choosing the optimal organizational structure (Figure 1);

5) drawing theoretical flow chart for running the electronic computer (Figure 2);

6) drawing flow chart and numeric data entry into electronic computer to run the software (Figure 3).

Figures 1 ... 3. present:

– the program organization for choosing the optimum required permanent magnets used in the production of high power audio devices;

– theoretical flow chart for running the electronic computer;
– numerical flow chart and entering data into the electronic computer to run the software.

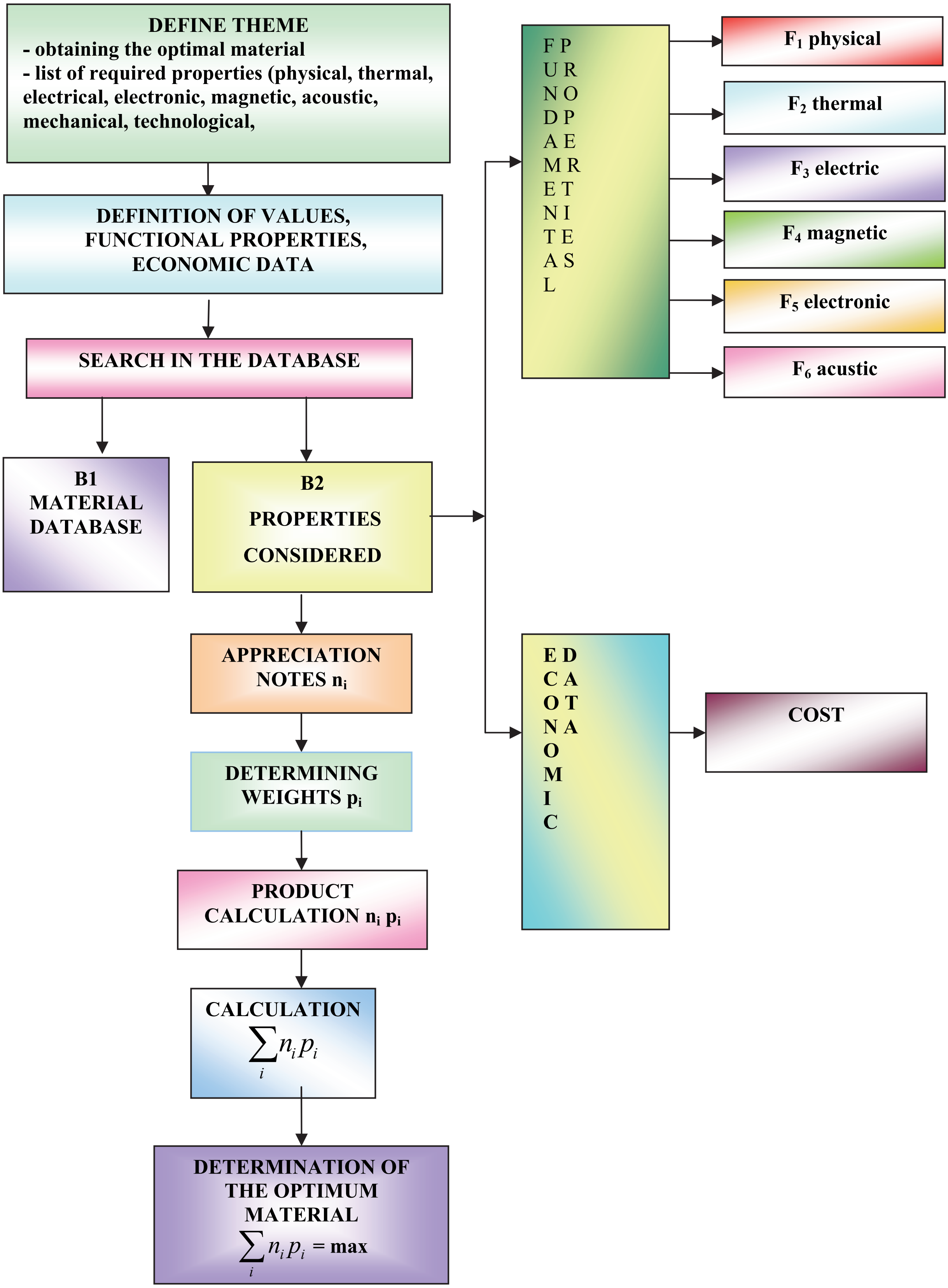

Fig. 1. Organization Programme for the optimal choice of material required for permanent magnets used in the production of high power audio devices.

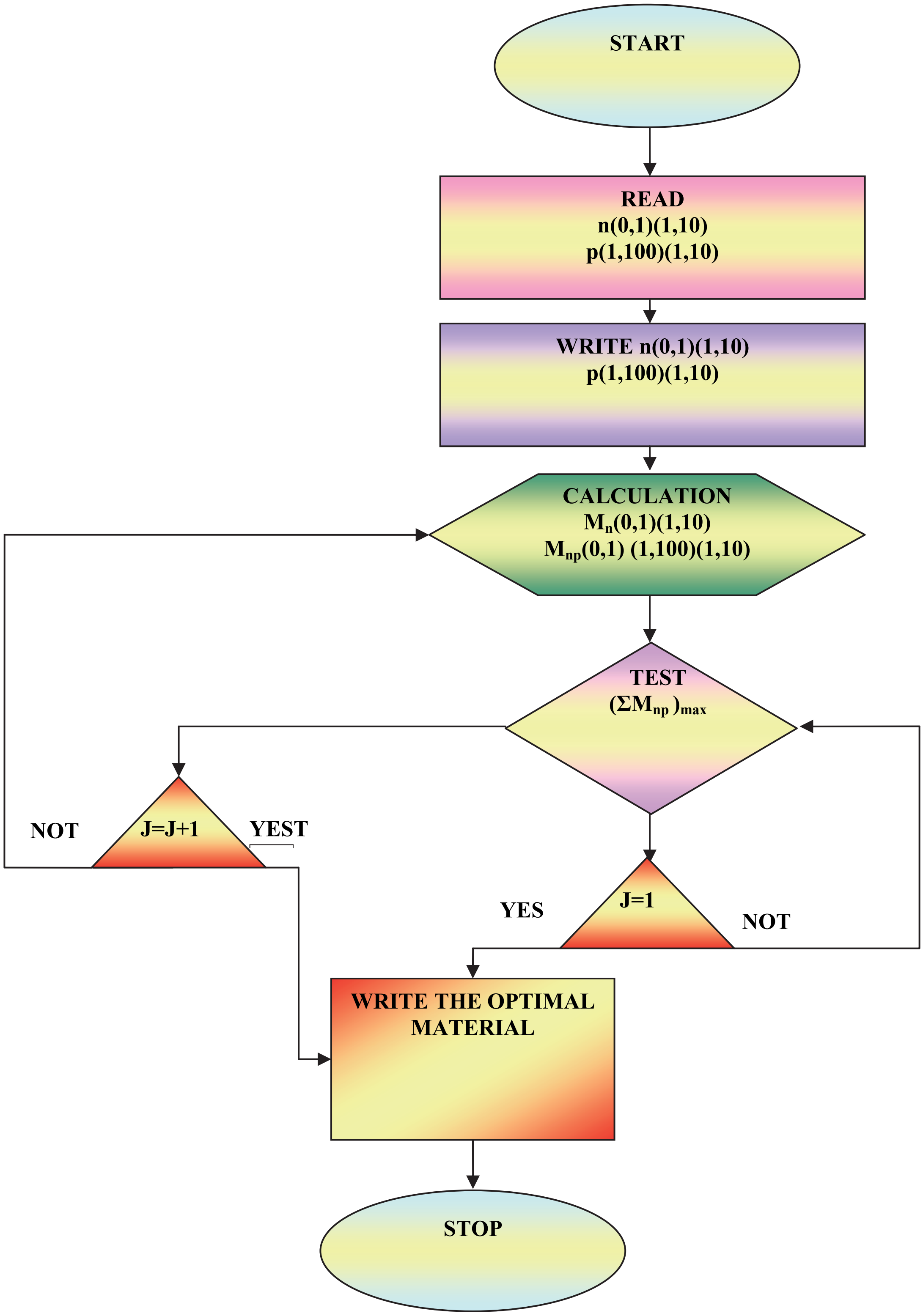

Fig. 2. The theoretical flow chart for running electronic computer program for choosing optimal material.

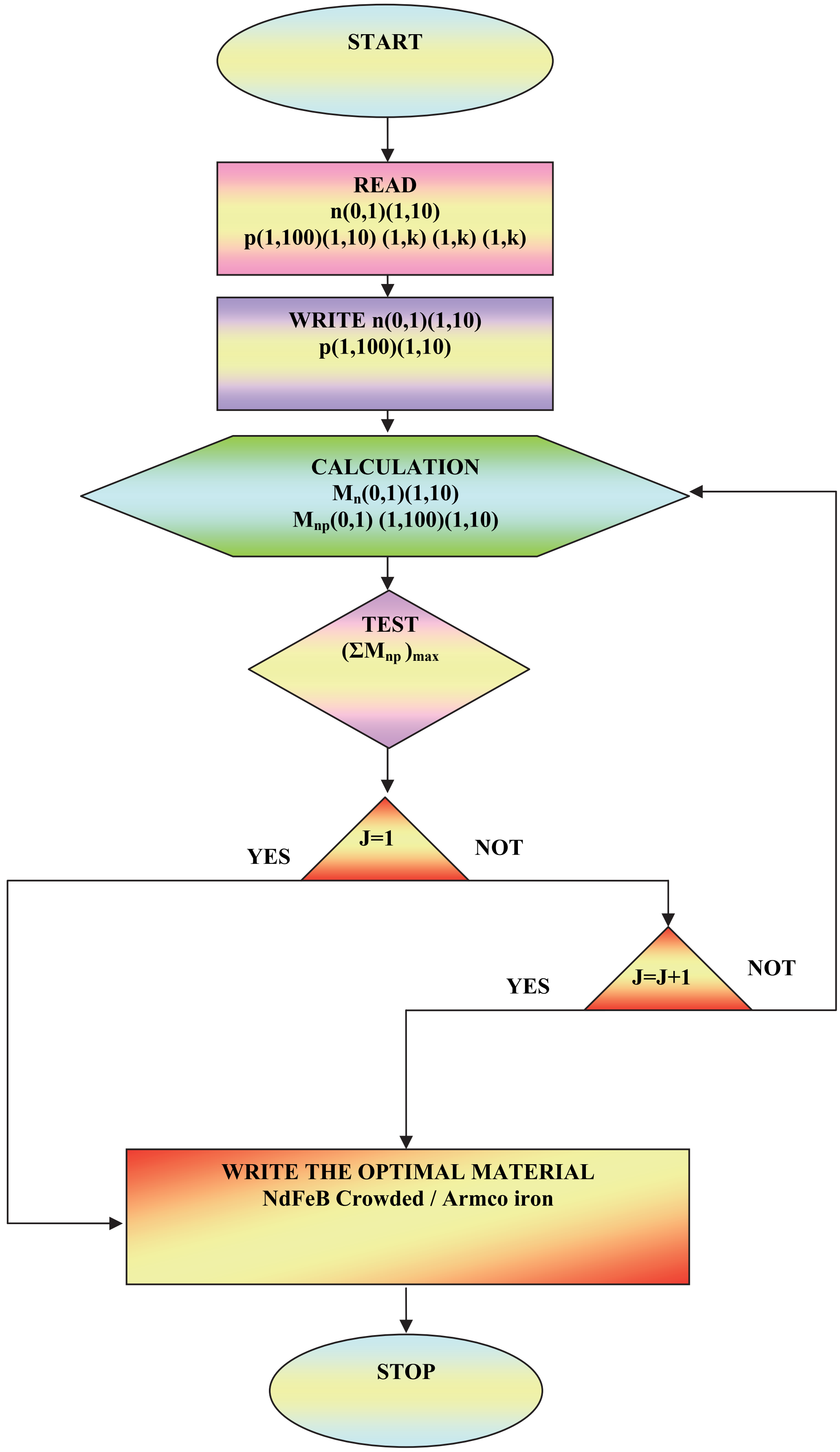

Fig. 3. The flow chart for choosing the optimal material.

4. NUMERICAL CALCULATION MATRIX MATERIAL TO OBTAIN OPTIMUM MATERIAL FOR PERMANENT MAGNETS

The numeric matrix material of the Mn notes is obtained using results from Table 1.:

$$M_n = \begin{pmatrix} 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 \end{pmatrix} \quad (4)$$

Numerical matrix Mnp is constructed by the product of the values for properties valued weights considered in Table 1 and each note given to these properties:

$$M_{np} = \begin{pmatrix} 0,05 & 0 & 0,05 & 0 & 0 & 0 & 0 & 0 & 0 & 0,1 \\ 0.05 & 0 & 0,05 & 0 & 0 & 0,05 & 0 & 0 & 0 & 0,1 \\ 0,05 & 0 & 0,05 & 0,15 & 0,1 & 0 & 0,1 & 0,2 & 0,05 & 0 \\ 0,05 & 0,15 & 0,05 & 0 & 0,1 & 0 & 0,1 & 0 & 0,05 & 0 \\ 0,05 & 0,15 & 0,05 & 0,15 & 0,1 & 0 & 0,1 & 0,2 & 0,05 & 0,1 \\ 0 & 0,15 & 0,05 & 0,15 & 0,1 & 0 & 0,1 & 0,2 & 0,05 & 0 \end{pmatrix} \quad (5)$$

The best result by calculating the matrix material Mnp of expression 1 is:

$$\text{Optimal Material} = \left(\sum_{i=1}^{10} n_{10} p_{10} \right)_{max} = 0,95 \rightarrow \text{NdFeB crowded / Armco iron}$$

5. CONCLUSIONS

The calculation performed using the statistical model optimization and optimization of the analytical model led to the same numeric value expressed by 0.95 corresponding optimal magnetic material NdFeB permanent magnet material crowded with ferromagnetic Armco iron for reinforcement.

Magnetic materials for permanent magnets based on NdFeB have properties superior to barium ferrite magnetic materials.

From the statistical model, the analytical model and experimental data also results the importance of ferromagnetic material used for making the armature, Armco iron superior magnetic properties of steel S235.

Using permanent magnets NdFeB sintered instead of NdFeB crowded permanent magnets results:

– a smaller air gap magnetic induction;

– losses at the ends of the air-gap magnetic circuit and are higher than for crowded magnets, sintered magnets as require another configuration of the magnetic circuit.

Type NdFeB crowded permanent magnets have superior properties of sintered magnets as reflected in the magnetic circuit modeling using finite element method (FEM).

Changing magnetic material of barium ferrite with crowded or sintered NdFeB permanent magnet, the magnetic circuit performance significantly increase.

Maximum flux density in the air gap in the magnetic circuit reference case under ideal conditions was determined 1,136T.

By changing the geometrical configuration of permanent magnets, the maximum magnetic induction can reach 1,248T, value about 10% higher than if the reference magnetic circuit.

The loss of the magnetic flux in the magnetic circuit are greater, as soon as the magnetic permeability soft magnetic material is reduced and therefore their saturation magnetic flux density is low. It is very important that the construction of the magnetic circuit to be used for high magnetic permeability material, in order to prevent their saturation.

The presence of parasite air gap between the pole pieces and the permanent magnet driving while in the air gap flux density decrease due to decrease can not be mitigated by better quality of the ferromagnetic material.

Also, please note that the achievement of a high power electromagnetic audio device equipped with magnetic materials (soft and hard) performance must be interlinked. Computer simulation of the magnetic circuit performance with practical realization of test circuits, leading to a better knowledge of all technological factors that influence the manufacturing serial production of high power audio devices.

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STABILIREA MATERIALULUI OPTIM PENTRU MAGNEŢII PERMANENŢI UTILIZAŢI LA FABRICAREA DISPOZITIVELOR AUDIO DE MARE PUTERE

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Rezumat: Stabilirea materialului optim pentru realizarea circuitului magnetic al dispozitivelor audio de mare putere este o problemă complexă. O metodă eficientă, bazată pe valoarea unor principale proprietăţi funcţionale, tehnologice, cum şi al costului materialului este metoda de analiză a valorilor optime elaborată de Constantin D. Stănescu. Metoda prezintă două modele: modelul statistic şi modelul analitic prin intermediul calculatorului. Materialele magnetice pentru magneţii permanenţi pe bază de NdFeB au proprietăţi net superioare faţă de materialele magnetice din ferită de bariu. Din modelul statistic, modelul analitic şi din datele experimentale rezultă şi importanţa materialului feromagnetic folosit pentru realizarea armăturii, fierul Armco având proprietăţi magnetice net superioare oţelului S235. Utilizând magneţi permanenţi NdFeB sinterizaţi în loc de magneţi permanenţi NdFeB aglomeraţi rezultă: o inducţie magnetică în întrefier mai mică; pierderile de la extremităţile circuitului magnetic şi ale întrefierului sunt mai mari decât în cazul magneţilor aglomeraţi, întrucât magneţii sinterizaţi impun o altă configuraţie a circuitului magnetic. Magneţii permanenţi tip NdFeB aglomeraţi au proprietăţi superioare celor sinterizaţi după cum rezultă din modelarea circuitului magnetic utilizând metoda elementelor finite (FEM). Modelarea circuitului magnetic al dispozitivului audio de mare putere a fost realizată cu metoda elementelor finite (FEM) din pachetul de programe ANSYS. Schimbând materialul magneţilor, respectiv ferita de bariu cu magneţi permanenţi NdFeB sinterizaţi sau aglomeraţi performanţele circuitului magnetic cresc semnificativ. Valoarea maximă a inducţiei magnetice în întrefier în cazul circuitului magnetic de referinţă în condiţii ideale a fost determinată 1,136T. Prin modificarea configuraţiei geometrice a magneţilor permanenţi, valoarea maximă a inducţiei magnetice poate ajunge la 1,248 T, valoare cu aproximativ 10% mai mare decât în situaţia circuitului magnetic de referinţă. Calculul efectuat cu ajutorul modelului statistic de optimizare, cât şi din modelul analitic de optimizare au condus la aceeaşi valoare.