Designing a Virtual laboratory for Simulating to Production of Nanocomposite NdFeB Magnets

Musa Faruk Çakır[1], İlhan Tarımer[2], Osman Gürdal[3]

[1]*Technical and Business College, Çankırı Karatekin University, Çankırı, Türkiye*
[2]*Muğla Sıtkı Koçman University, Kötekli Kampüsü, Muğla, Turkey*
[3]*Department of Electrical Electronics Engineering, Orhangazi University, Bursa, Türkiye*

***Abstract* – The talent figure for a permanent magnet is the multiplication of the maximum energy (BH_{max}). Less volume magnet is required for the production of magnet flux density if the BH_{max} value is higher. Mathematical functions are obtained from the data related to resiudal flux density, magnetic coercitivy, permanent magnet flux product capability, Curie temperature and density which were obtained as a result of the studies on different NdFeB alloys in the laboratory. Besides this, mathematical functions of NdFeB hard magnet's resiudal flux density are obtained by adding elements. In this study, a virtual laboratory for producing nanocompositedNdFeB magnet has been designed. The virtual laboratory software has been used to simulate NdFeB hard magnets for industrial utilities.**

***Keywords* – Designing NdFeB hard magnets, simulation software, permanent magnets.**

1. Introduction

Permanent magnets have talented to give magnetic flux to air gap of magnetic circuit without continuous energy loss. This magnetic flux may change its properties such as smooth, stable, no stable or can vary with the time by Gürdal [1, 13]. Permanent magnet applicants can be classified due to their physical properties and usage area. The most important thing of a permanent magnet is its maximum energy value (BH_{max}), this means in that smaller magnets volume the more magnetic flux values. However there were natural magnets which had 10 kJ/m^3 energetic values in the beginning of the century nowadays, NdFeB permanent magnets can produce 400 $kJ/m^3 BH_{max}$energetic values by Rodewald[2].It has stated [3] that NdFeB hard magnets can produce 1090 $kJ/m^3 BH_{max}$energetic values at laboratory conditions.

NdFeB magnets have a wide utility area today likely they are being used in designing motors and generators. Especially, they have a great importance on the new design of synchronous generator. Recent technological developments have led the design of axial flux permanent magnet motors and NdFeB magnets are used on that type motors as a permanent magnet. On the other hand, one of the researchers has showed that using NdFeB magnets on the construction of synchronous motors has increased motor efficiency by Tarımer [4].

A reasonable effort had been spent to develop the magnetic and physical features of the magnets since the development of NdFeB magnets. Ferromagnetic elements such as iron and cobalt are used widely. These magnets have anisotropic properties and high coercivety values. Sm-Co and Nd-Fe-B permanent magnets have significantly importance in magnet technology, because of their high BH_{max} values. As it is well-known, coercivity values of the sintered NdFeB hard magnets can be increased by adding small amount of substantial elements (for example Ti, Zr, Co, Mo, Mn, Ni) by Herbst and by Sagawa, et.all.[5, 6].

Ferromagnetic metals such as Co and Ni of transition elements increase the magnetization and TC Curie temperature. Mo, Nb, Ti, V and W have high melting temperature and non-magnetic properties, Ga, Al, Cu and Sn have low melting temperatures elements that product phase in grain boundary, thus they avoid growing grain size and increase coercivety values by decreases magnetic interaction between grains by Vial, et.all4, and by Yan5. In many researches, it is seen that the permanent magnet coercivity values are increased by adding the elements of Nb, Mo, W, Ti which have high melting points by Otaniandet.all. [7]. In order to obtain optimum magnetic and physical properties, the magnets should be sintered between 650◦C – 1160◦C and should be cooled immediately by Raggand Harris, and Vial et. all.[8, 14]. Sintering is a high temperature process which provides the unification of material powders the effect of high temperature through diffusion and decreases the grain volume among the powders step by step by two separate works [13, 14]. In much alloying systems, sintering temperature point is determined under metal melting point. Sümerhas stated that sintering time is decreased when sintering temperature is increased[9].

In this study, the effects of Nd and B elements to the production of nano–composited NdFeB magnets have been investigated. In order to do this, several mathematical functions for different kinds of alloyed material magnets regarding to these magnetic materials have been obtained. All of these functions (permanent magnet flux producing capability 'BH_{max}' (Pe), coercivity 'Hc' (*C*) and residual flux density 'B_r' (*R*) have been taken place during the development of the virtual laboratory software. By means of that several simulations of producing nanocompositeNdFeb magnets have been made by the developed virtual laboratory.

2. Data Tables and Mathematical Functions of Nanocompsited Nd-Fe-B Alloys

It has stated in that [12] the composite materials are generated by combining the best features of materials that are in the same or different groups on a new and unique material on macro level. Nano composites are new kinds of materials which are mineral fillet and consist of nano dimensioned mineral less than 10%. As the surface area of used nano participles are very high, their mechanical, thermal and magnetic properties have been improved well. The mathematical functions and the data are extracted from the 5–183–516 numbered work with the United States' Patent Office by Sagawa et.all.[10, 11].

The influence Boron on 15Nd-xB-Fe alloy to obtain Br and Hc functions have investigated and also the influence of Nd on xNd-8B-Fe have investigated as well. Moreover Nd% and B% have presented as graphically in the study. Once the supplement materials are added into alloys, remainance of magnet has been changed. Tables 1 and 2 show the data of alloys by Sagawa et.all.[10, 11].

Table 1.The Data of xNd-(92-x)Fe-8B alloys.

Alloy name: xNd-(92-x)Fe-8B			
%Nd	B_r (KG)	H_c(KOe)	BH_{max}(kGOe)
6	0	0	0
13	13.1	4.8	29.3
14	12.8	7.8	36.5
17	11.6	9.2	31.1
19	10.9	11.4	28.0
25	5.8	12.6	8.8
35	**1.9**	**14.6**	**≤1**

The mathematical functions of xNd-(92-x) Fe-8B alloys are given in Eq. 1–2–3.

$$F_{Nd}(xBr) = 2{,}059.10^{-6}.x^6 - 0{,}000181.x^5 + 0{,}005228.x^4 - 0{,}03569.x^3 - 0{,}916.x^2 + 17{,}01.x - 66{,}81 \quad (1)$$

$$F_{Nd}(xHc) = -8{,}242.10^{-5}.x^3 - 0{,}01436.x^2 + 1{,}217.x - 6{,}966 \quad (2)$$

$$F_{Nd}(xBH_{\max}) = 0{,}0139.x^3 - 0{,}9633.x^2 + 19{,}09.x - 83{,}15 \quad (3)$$

where; $F_{Nd}(xB_r)$ – Function of remaining flux change as % values of Nd (neodymium) element, $F_{Nd}(xH_c)$ – Function of coercivity changing % values of Nd (neodymium) element, $F_{Nd}(xBH_{max})$ – Function of permanent magnet flux producing capability change as % values of neodymium element.

The Br functions are directly being affected by a factor for alloys to determine energetic values of $BH_{max}$and it has to be defined as a joint value for different alloys. And also Br as a means of the residual magnetic flux density of permanent magnets has got one characterization of different permanent magnet alloys. The functions of remaining flux are obtained if they are pressed under 10 KOemagneticfields when M% (M=Ti, Zr, Hf, V, Ta, Nb, Cr, W, Mo, Mn, Ni, Sb, Sn, Ge, Al, Bi) are added into 15Nd-Fe-8B-xM as addition materials [15].

Table 2 – The Data of 15Nd-(77-x)Fe-8B-zM alloys.

Alloy name: 15Nd-(77-x)Fe-8B-xM								
AdditionmaterialsB$_r$Values, M=Additionmaterials								
%M	Ti (KG)	Zr (KG)	Hf (KG)	V (KG)	Ta (KG)	Nb (KG)	Cr (KG)	W (KG)
0.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
0.5	12.3	11.9	11.9		11.6		11.6	11.6
1.0	12.0	11.7	11.7	11.5	11.6	11.,9	11.4	11.4
1.5	11.8	11.4	11.4					
2.0	11.2	10.7	10.7	11.0	11.4	11.7	10.9	11.0
3.0	8.7	9.2	9.2	10.3				
4.0	6.0	7.5	7.5	9.8	10.5	11.0	9.5	9.8
5.0	2.4	5.3	5.3					
6.0		2.2	2.2	8.5	9.5	10.2	7.6	8.0
7.0								
8.0				7.0	8.4	9.4	5.2	5.9
9.0				5.7	7.5	9.0		
10.0				3.5	6.0	8.2	2.3	3.5
11.0					3.7			
12.0						5.4		

The mathematicalfunctions of 15Nd-(85-x)Fe-xBalloysaregiven in sample Eq.4–6.

$$F_{Ti}(xB_r) = -0{,}02969.x^6 + 0{,}4061.x^5 - 2{,}03.x^4 + 4{,}555.x^3 - 5{,}048.x^2 + 2{,}181.x + 12 \quad (4)$$

$$Fzr(xB_r) = 0{,}002656.x^6 - 0{,}04875.x^5 + 0{,}3254.x^4 - 0{,}9443.x^3 + 0{,}8405.x^2 - 0{,}4438.x + 12 \quad (5)$$

$$FTa(xB_r) = 9{,}06.10^{-5}.x^6 - 0{,}003284.x^5 + 0{,}04315.x^4 - 0{,}02561.x^3 + 0{,}6518.x^2 - 0{,}8792.x + 12 \quad (6)$$

where; $F_M(xB_r)$ – Function of remainingfluxchange as % values of addingelements (M= Ti, Zi, Ta, …).

In order to obtain math functions, seven tables like Table 1 and 2 have been used in the study. As result of this, thirty mathematical functions have been obtained by method of curve fitting. There are 30 functions, and those have been used for creating virtual laboratory software.

3. Preparation Software and Implementation

Virtual laboratory software and animations have been developed by using Adobe Flash 8®. The software codes and scripts have been written by Action Script 3.0. A part of these codes are given in the below lines. A part of virtual laboratory is presented as shown in Fig. 2. The meanings of the icons seen in the Fig. 1 from 1–11 are given in the screen shot.

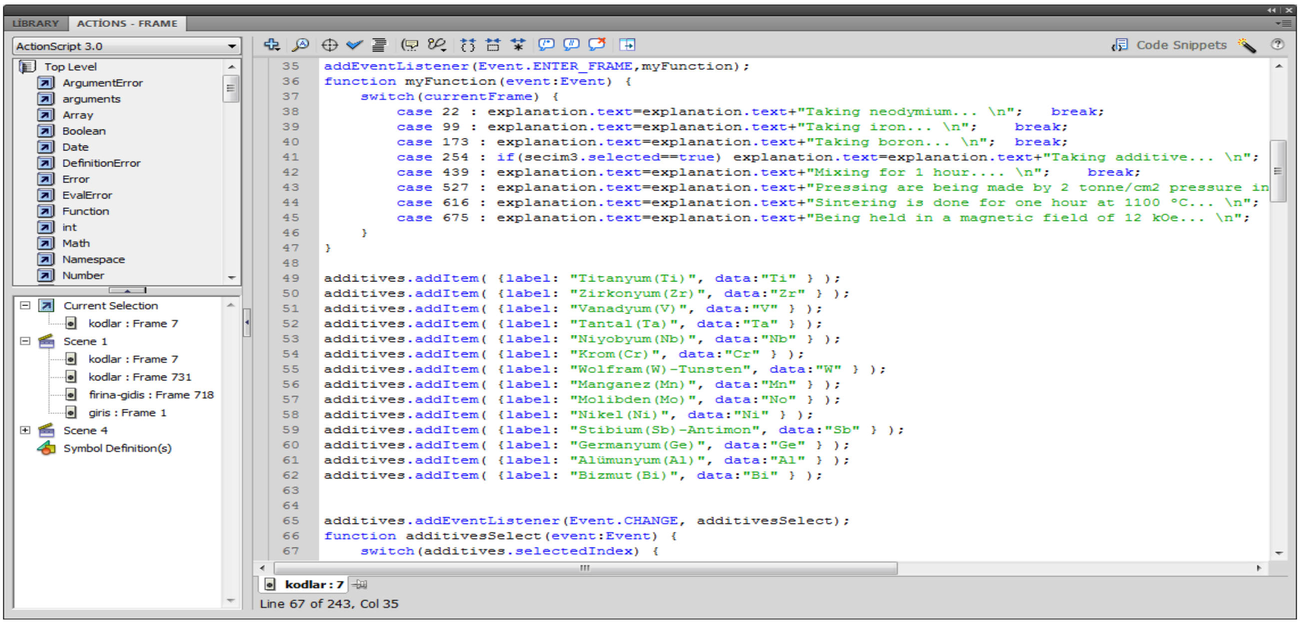

Figure 1. Creating virtual laboratory codes.

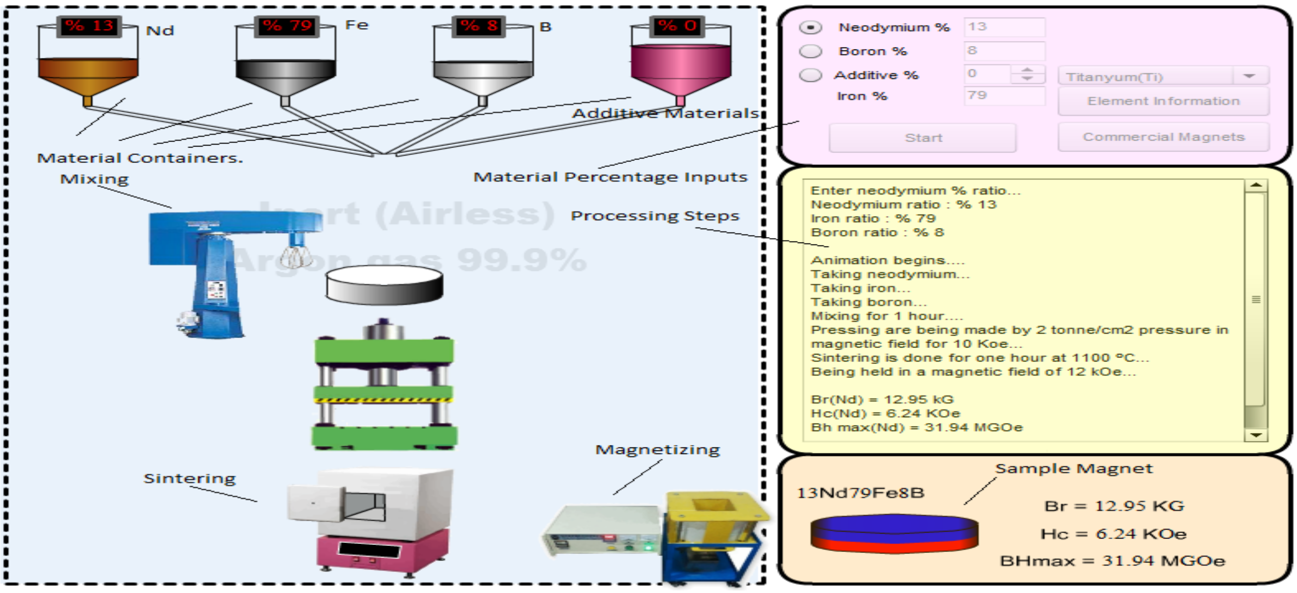

Figure 2. Screen shot of the developed virtual laboratory software.

Whenever it is wanted to produce a sample magnet in the virtual laboratory by taking the Nd element, the Nd value as % in the 9th part must be entered and then clicked to OK button. The system starts to run and the alloy formulae and BH_{max} value of the sample can be obtained. The same task can be done for the B element and the desired NdFeB alloys can be produced. After the data into the 9th part as % for addition materials are entered, the effects of B_r can be investigated on 15Nd-Fe-8B-xM alloy (M=addition materials).

4. Conclusion

The below values were obtained when the results are compared by using the same working values (i.e mixed time, pressed pressure, applied magnetic field, sintering temperature and time) which have the same environment values during their preparation in order to test the virtual laboratory. As result, Tables 3, 4, and 5 are obtained by using the developed software. In these tables there seem comparisons and the values which are seen in the other studies' columns belong to Sagawa et.all [11, 12].

Table 3 – Comparison of the results of other studies with the results of the virtual laboratory.

Alloy name	Atomic % of elements	Virtual Laboratory Results			Other studies		
		B_r (kG)	H_c (KOe)	BH_{max} (KGOe)	B_r (kG)	H_c (KOe)	BH_{max} (KGOe)
15Nd-Fe-xB	%B = 5	12.25	4.98	26.08	12	7.8	-
	%B= 15	12.91	9.48	22.58	9.8	7.7	-
	%Nd=10	12.23	3.68	25.31	10.8	7	-
xNd-Fe-8B	%Nd=15	12.46	7.77	33.37	12.3	8.1	-
	%Nd=25	5.57	13.19	9.22	6.8	10.8	-

Table 3 shows that virtual laboratory results have been come to close to the other results at other studies on comparing B_r, H_c and BH_{max} values according to Nd and % B change.

Table 4 – Comparison of the results of other studies with the results of the virtual laboratory.

Alloy name	Sintering Temp(◦C)	Virtual Laboratory Results			Other studies		
		B_r (kG)	H_c (KOe)	BH_{max} (KGOe)	B_r (kG)	H_c (KOe)	BH_{max} (KGOe)
15Nd-77Fe-8B	1040	11	8.4	28.6	11.6	9	30.5
	1100	11.8	8.4	33	12.4	9	34.1
15Nd-57Fe-8B-20Co	1000	11.2	6.2	26.8	11.5	7	29.,8
	1080	12	8.2	29.2	11.,8	9	31.8

Table 4 shows that effect of sintering temperature to magnetic specifications has been investigated. As result of this, it has been seen that virtual laboratory results have been come to close to real laboratory results.

Table 5 – Comparison of the results of other studies with the results of the virtual laboratory.

Alloy name	Additionmaterials	Vir. Lab. Results B_r (KG)	Other studies B_r(KG)
15Nd-Fe-8B-xM	M= Zr =%4	7,49	7,9
	M= Ni =%6	10,24	10,8
	M= Mo=%6	8,1	8,3
	M= Cr =%6	8,39	7,8

Table 5 shows that additive elements have created effects of residual magnetism (B_r) at NdFeB magnet. As result of this, it has been stated that there is a difference such as 5 – 10 % between virtual laboratory results and real laboratory results.

5. Results and Discussion

In the study, a new virtual laboratory software has been developed for investigating the production conditions for new NdFeB permanent magnets. For virtual laboratory environment, real laboratory conditions and also same algorithm have been used as parameters of the developed software. Experimental studies have validated by using virtual laboratory results. It has been seen that the experimental results and virtual laboratory results are very close to each other. The error is 10% percent. Software can simulate the breaking values of permanent magnets. The software is open for development for different experimental studies and may be shaped again for this purpose.

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Corresponding author: İlhan Tarımer
Institution: Muğla Sıtkı Koçman University
E-mail: itarimer@mu.edu.tr