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Efficiency Enhancement of a Permanent Magnet Brushless DC motor with an Innovative Methodology

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ABSTRACT

Nowadays, automation plays an essential role in various real-time applications. This scenario leads to the adoption of high-efficiency drives. In this aspect, the usage of Permanent Magnet Brushless DC motor (PM BLDCM) is increasing tremendously day by day. In the conventional design of PM BLDCM, the complete focus is on the electrical and mechanical parameters. The various limitations in electrical parameters are cogging torque and magnetizing components of currents. The various limitations of mechanical parameters like axial length and bore diameters. One cannot proceed beyond this scope. In this aspect, this paper presents a unique design methodology of a PM BLDCM.

In general, the PM BLDCM consists of stator and rotor. Stator generally consists of various parts, and its operation is related to electrical and mechanical parameters, whereas the rotor is a Permanent Magnet.

In this paper, the efficiency of a BLDCM can be enhanced by increasing the magnetic properties of the rotor. In general, the rotor of the PM BLDCM is made with Nd-Fe-B magnets or other alloy materials. One of the elements which are having an excellent magnetic property is Zinc Aluminate ($ZnAl_2O_4$).

This paper presents the synthesis of $ZnAl_2O_4$ Nano material by hydrothermal synthesis procedure. Further, this $ZnAl_2O_4$ material is doped with ferrous material with concentrations of 1%, 3%, and 5%, respectively.

The developed powders are characterized by X-ray powder diffraction (XRD), Scanning electron microscopy (SEM), Energy-dispersive X-ray spectrum (EDS), and Vibrating Sample Magnetometer (VSM).

Key words: PM BLDCM, Efficiency, XRD, SEM, EDS, VSM.

1. INTRODUCTION

In the design of PM BLDCM, the efficiency of the motor can be enhanced by coating the rotor permanent magnet with Nano material. This phenomenon improves the efficiency, mechanical strength, torque, and power density [1]. This will be helpful for high power applications. In the proposed paper, the magnetic property of the rotor can be enhanced by coating its magnetic portion with Zinc Aluminate Nano material ($ZnAl_2O_4$). This paper also presents the further enhancement of the magnetic property of the proposed Nano material by coating with ferrous material with various doping concentrations. Since the ferrous material has better magnetic properties, the proposed Nano powder is prepared with 1%, 3%, and 5% molarities of ferrous material doping concentrations, i.e. (Fe1, Fe3 & Fe5) with Zinc Aluminate. The Nd-Fe-B magnet properties can be enhanced by coating these proposed materials on it.

The layout of a PM BLDCM, is as shown in figure.1

Figure 1: Overview of PMBLDC Motor

Figure 2: Rotor of PMBLDC Motor

Electromagnetic torque Γ_{em} is given as

$$\Gamma_{em} = \frac{\Pi}{2\lambda}(1-K_f)(\sqrt{K_r \beta E_{ch} E} D^2 (D+E) B_e \quad (1)$$

From equation (1), the electromagnetic torque is directly proportional to flux density (B) [2]. If one can increase the magnetic moment of the rotor, which is shown in figure.2, then one can enhance the torque component [11].So this paper presents the enhancement of the magnetic field of the rotor using an innovative way.

2. SYNTHESIS OF NANO MATERIAL

In order to prepare the proposed Zinc Aluminate ($ZnAl_2O_4$) the various composites used are Zinc, Aluminum, and Oxygen. Zinc aluminate Nano powders remained primed by the hydrothermal method in this way [7].

The $Zn(NO_3)_2.6H_2O$ (0.2 mol) was liquefied in 20 ml of deionized aquatic auxiliary to $Al(NO_3)_3.9H_2O$ (0.4 mol), which was dissolved in 20 ml deionized water and stimulated magnetically. At that point, 20 ml of zinc solution was auxiliary drop by drop to the aluminum elucidation with persistent mixing. A homogeneous white precipitation was acquired. At that point, one has check the PH esteem. In the event that the PH esteem is under 9, one needs to add ammonia to the arrangement drop by drop until the PH esteem arrives at 9 and afterward blended for an hour till white precipitate happens. The acquired elucidation was moved into the Teflon crinkled stainless toughen autoclave and fixed firmly; at that point, it was brought into a muffle furnace at 220℃ for 8 hrs. The white precipitate solution was washed and centrifuge threefold with deionized water, ethanol, and water individually then dehydrated at 80℃ for 6 hrs. Subsequent to drying, the resultant powder was annealed at 1000℃ for 5 hrs. The sample obtained through the aqueous strategy was named as base powder, and these samples are squashed genuinely to get fine particles.

The above procedure is repeated for various doping concentrations Fe1, Fe3, and Fe5.

3. CHARACTERIZATION OF PROPOSED NANO MATERIALS

The developed Nano composite material along with various doping concentrations Fe1, Fe3, and Fe5 were finally characterized in order to identify the properties of the developed compound materials [6].

The various characterizations are XRD, SEM, EDS and VSM.

A. XRD

XRD is an important procedure in the field of materials in order to get some data regarding the structure of the prepared Nano material, the crystal size of the material, lattice strain, surface and interface roughness, etc. of the corresponding prepared material.

The particle size 'D' can be assessed by equation

$$D = \frac{0.9\lambda}{\beta Cos\theta} \quad (2)$$

B. SEM Device

A SEM is a device used to identify the crystal morphology and surface morphology of prepared Nano materials at different Magnifications.

C. EDS

EDS is one of the important measurements in the field of Nano materials. This is used to identify the elemental conformation of the organised Nano material. Purity of the prepared Nano material can be assessed by EDS analysis.

D. Magnetic study

The magnetic behavior of the prepared Nano material can be assessed by Vibrating Sample Magnetometer (VSM). This test can estimate the hysteresis loop characteristics and magnetic field parameters.

4. RESULTS

A. XRD

The XRD pattern of $ZnAl_2O_4$ sample obtained by the hydrothermal method is shown in figure 3. Similarly, the XRD arrangements of $ZnAl_2O_4$ with ferrous sedate with different sedate congregation are illustrated in figure 4.

All the obtained pinnacles can be labelled as (111), (220), (311), (400), (331), (422), (511), (440), (620) and (533) spreading lines at different positions of 2Ɵ as shown in figure.3 and figure.4. The obtained peaks related to standard XRD patterns of a zinc aluminate spinel with FCC as per JCPDS: 05-0669 [5]. This reflects that the prepared Nano material is very nearer to standard data. From the figure.3 and figure.4, one can observe that there are no additional peaks other than the position values. It shows the purity of the prepared material.

For every one of the three examples, the FCC constraint was determined from XRD patterns.

The particle sizes of the various models are illustrated in table 1. The typical particle size of the synthesized material is in the order of 21.7 nm. This indicates that the prepared material is Nano compound material [4].

The lattice structure parameters of the synthesized Nano material are illustrated in table 2. According to standard values of lattice structure parameters, the $ZnAl_2O_4$ Nano material is having 'a' as 0.8084 nm and cell volume 'V' as 0.528 nm^3 [3]. The synthesized Nano materials are having the values less than the standard values, which indicate the quality of the prepared Nano materials.

Table 1: Particle Size of Various Samples

S. No	Sample	Pos [°2Th]	FWHM [°2Th]	D (nm)
1	**Fe1**	36.6002	0.48	**17.4**
2	**Fe3**	36.4928	0.3149	**26.6**
3	**Fe5**	36.5863	0.3936	**21.3**

Table 2: Lattice Structure Parameters of Various samples

S. No	Sample	Lattice Structure Parameters	
		a (nm)	Cell Volume (nm^3)
1	**Standard**	**0.8084**	**0.528**
2	$ZnAl_2O_4$	0.7882	0.490
3	Fe1	0.7887	0.491
4	Fe3	0.7894	0.492
5	Fe5	0.7885	0.490

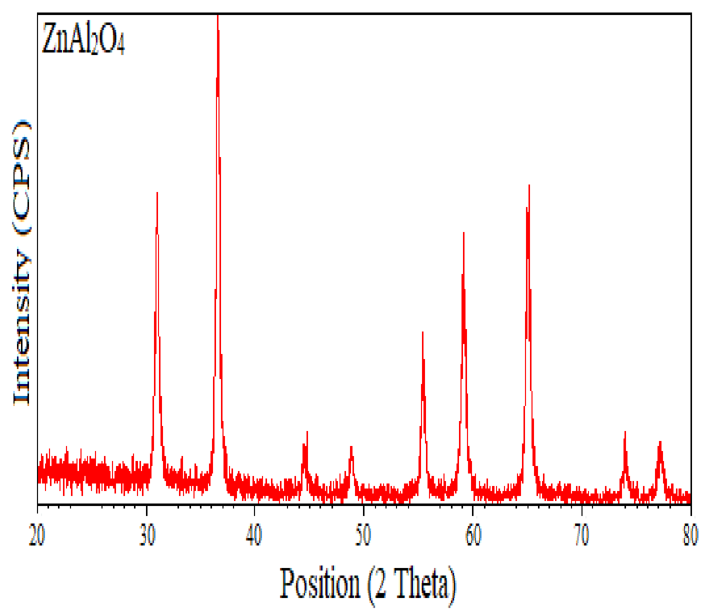

Figure 3: XRD pattern of $ZnAl_2O_4$ sample obtained by hydro thermal method

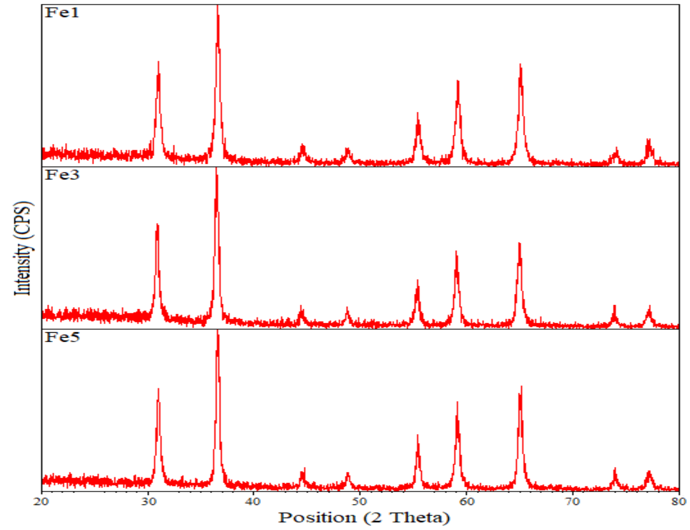

Figure 4: XRD pattern of $ZnAl_2O_4$ sample obtained by hydrothermal method with Fe doping (Fe1, Fe3, Fe5)

B. Scanning electron microscopy (SEM)

The morphology of the obtained zinc aluminate ($ZnAl_2O_4$) was categorized by using SEM [8] is as shown in figure. 5 (a & b).

The zinc aluminate ($ZnAl_2O_4$) Nano materials with ferrous doping with various doping concentrations Fe1, Fe3, and Fe5 are illustrated in figure. 6 figure. 7 and figure. 8.

The low amplification SEM image is shown in figure. 5 (a).The slowly amplified SEM pictures of appeared in figure. 5 (b).

From the figures 5, 6, 7 & 8, one can observe the crystal morphology of prepared Nano materials. In all the cases, the morphology of prepared Nano materials is the same.

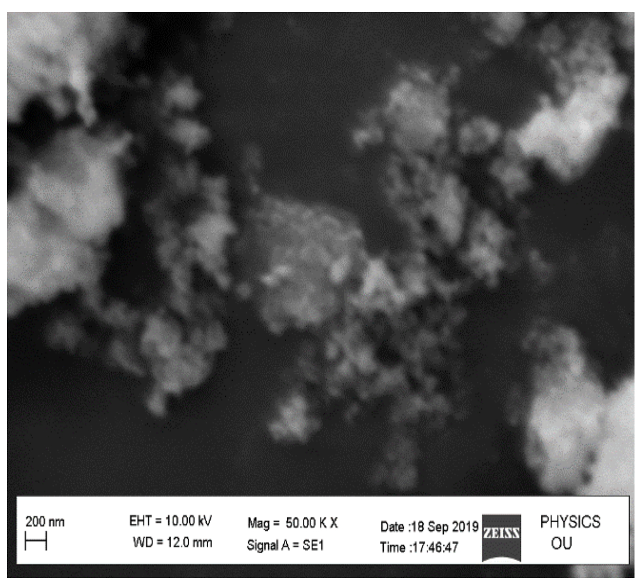

Figure 5 (a)

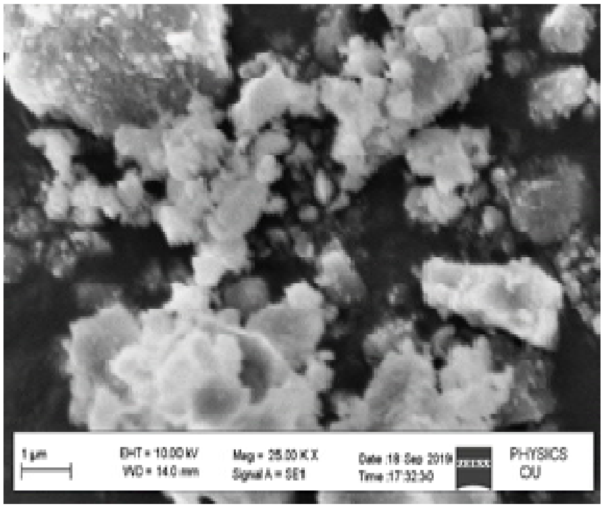

Figure. 5 (b)

Figure 5(a &b): SEM images of $ZnAl_2O_4$ Nano Material at different Magnifications

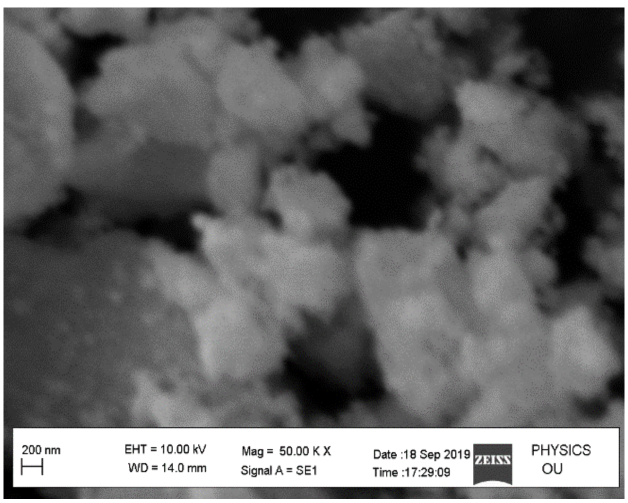

Figure 6: SEM image of $ZnAl_2O_4$ Nano Material with Fe1 Doping

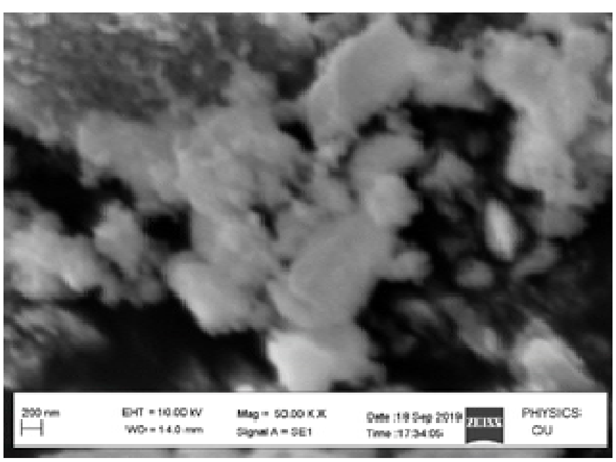

Figure 7: SEM image of $ZnAl_2O_4$ Nano Material with Fe3 Doping

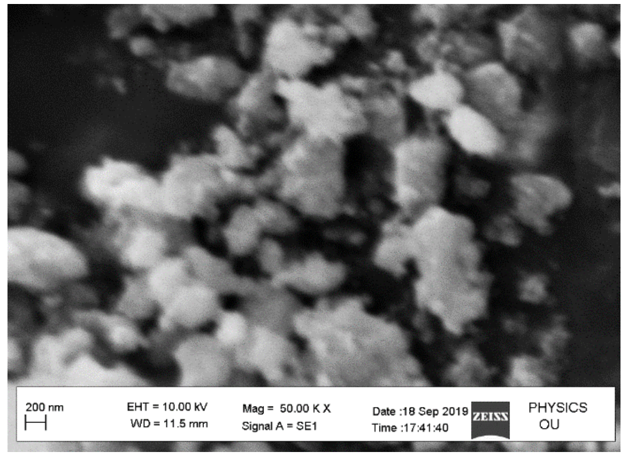

Figure 8: SEM image of $ZnAl_2O_4$ Nano Material with Fe5 Doping

C. EDS Analysis

The EDS Analysis of prepared $ZnAl_2O_4$ Nano material is illustrated in figure.9.

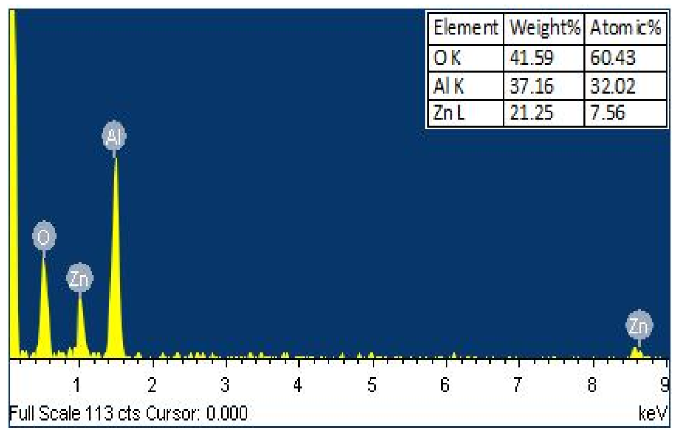

Figure 9: EDS Patterns of $ZnAl_2O_4$ Nano Material

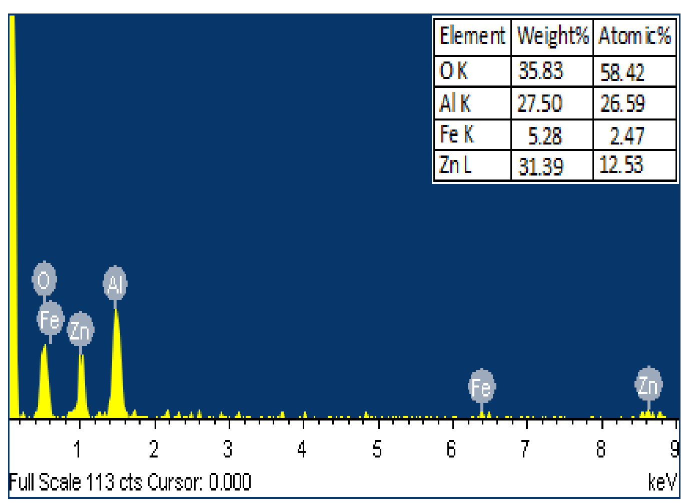

Figure 10: EDS Patterns of $ZnAl_2O_4$ Nano Material with Fe doping

The EDS Investigation of prepared $ZnAl_2O_4$ Nano material with ferrous doping is illustrated in figure.10.

In the case of $ZnAl_2O_4$ Nano material the compound materials are Zinc, Aluminium, and Oxygen. After the final realization of the Nano powder the compounds that are present in the powder are Zinc, Aluminium, and Oxygen only, as shown in figure.9. It indicated the purity of the prepared Nano powder. The synthesized material is free from impurities [9].

In the case of $ZnAl_2O_4$ Nano material with ferrous doping, the compound materials are Zinc, Aluminium, Oxygen, and ferrous. After the final realization of the Nano powder the compounds that are present in the powder are Zinc, Aluminium, Oxygen, and ferrous only as shown in figure.10. It indicated the purity of the prepared Nano powder. The synthesized material is free from impurities.

D.Vibrating Sample Magneto Meter (VSM)

The magnetization behaviors of $ZnAl_2O_4$ Nano material with ferrous doping along with various doping concentrations are illustrated in figure.11. The hysteresis characteristics are shown between magnetization and the applied magnetic field.

These samples are exhibiting Ferromagnetic behavior at room temperature.

Figure.11 indicates the hysteresis loop characteristics for various doping concentrations Fe1, Fe3, and Fe5. From figure. 11, one can observe that the magnetic properties are increasing from Fe1 to Fe3. As doping concentration increases from Fe3 to Fe5, the magnetic properties are decreasing.

The better magnetic properties can be extracted from $ZnAl_2O_4$ Nano material with Fe3 doping.

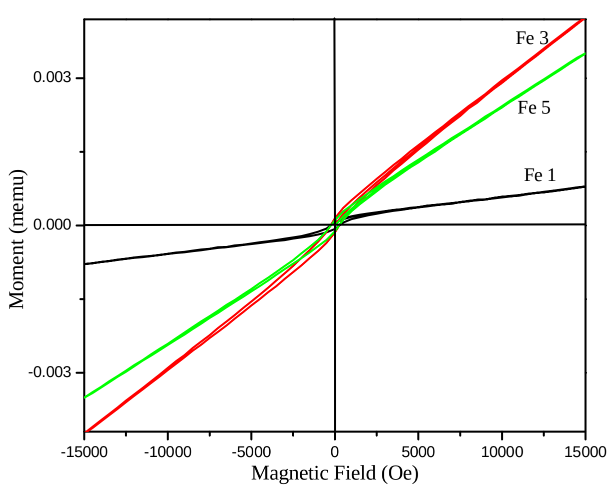

Figure 11: M – H loop of $ZnAl_2O_4$ amalgamated Nano powder along with Fe doping

5. CONCLUSION

The efficiency or the power density of a permanent magnet brushless DC motor can be enhanced by increasing the magnetic property of the rotor. In this paper, a unique procedure is adopted to increase the magnetic property of the rotor.

Zinc Aluminate ($ZnAl_2O_4$) Nano compound material along with ferrous doping with various doping concentrations like Fe1, Fe3, and Fe5 were prepared with the hydrothermal method.

The developed Nano materials are characterized using XRD, SEM, EDS Analysis, and VSM to identify various characteristics like crystal structure, crystal morphology, chemical decomposition, purity, and the magnetic behavior.

The crustal structure can be estimated with the help of XRD are as shown in figure.3 & figure.4. From the above results, the crystalline size of the prepared material is Nano compound material, which can be illustrated from Tables 1 and 2.

The crystal morphology can be estimated with SEM are as presented in figure.5, figure.6, figure.7, and figure.6. The results show the prepared materials are Nano compound materials, and it shows many agglomerates with spherical like morphology.

The chemical compositional details of prepared samples analyzed with the help of EDS Analysis are as presented in figure.9 & figure.10. From the results, one can observe that the prepared Nano compound materials are pure, and there are no impurities.

The magnetic study of the prepared Nano material is analyzed by Vibrating Sample Magneto Meter (VSM) is as shown in figure.11. All the samples are exhibiting well-defined hysteresis loops, which is indicative of room temperature ferromagnetic behavior.

From the hysterics graph, one can observe that as the sedate congregation escalations from Fe1 to Fe3, the magnetic behavior of the proposed material is increased. Further, as the sedate congregation escalations from Fe3 to Fe5, the magnetic behavior is decreased. That means with Fe3 doping; the proposed Nano material is exhibiting good magnetic behavior.

From equation (1), the torque (T) is directly proportional to the magnetic field component (B) [10].

The Output power (P) is given by

$$P_{out} = \frac{2\Pi NT}{60} \quad (3)$$

From the figure.11, one can observe that the magnetic field of the PM can be enhanced by using the proposed Nano compound Material.

From equation (1), the increment in the magnetic field increases the value of the torque. From equation (3), the increment in torque increases the output power. Increment in output power finally increases the efficiency of the motor.

Finally, this increase in magnetic behavior increases the efficiency and torque capability of a PM BLDC motor.

6. FUTURE SCOPE

The present paper proposes an innovative design procedure to increase the adeptness and torque of a PMBLDC motor for a specific application. Further, one can enhance the power density of the motor by choosing the suitable Ferromagnetic behavioral elements as doping materials and perform similar studies to observe the quality and magnetic behavior of the Nano materials.

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