Axial Flux Motor Using Nanocrystalline Soft Magnetic Material

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Abstract. This paper presents the magnetic characterization of the nanocrystalline soft material for use in the stator core of the axial flux motor considering the effects of heat treatment and magnetic core potting. In addition, finite element analysis results of axial flux motor are presents comparing with laboratory tests results which despite the manipulation challenges arising from physical properties of the nanocrystalline soft material, the motor had a significant reduction in the iron losses at high frequency increasing its efficiency level in comparison to the same project based on silicon steel, which is the material traditionally used in the manufacture of electric motors.

Keywords: Nanocrystalline Soft Material, Magnetic characterizations, Axial Flux Motor.

1 Introduction

The nanocrystalline soft material is made into a thin strip by rapid quenching solidification of molten alloy and then heat-treating to obtain the low iron loss characteristics and high permeability [1]. Moreover, it is difficult to die-cut since it is hard and brittle [2].

Due to the magnetic characteristics of the nanocrystalline material, an axial flux motor was developed and manufactured, which has the characteristic of being a compact motor with a high-power density, meeting the search for more sustainable motors by requiring less raw material for its manufacture.

The main objective of an axial flux motor development having nanocrystalline soft material core is to reduce stator iron losses to increase the electrical efficiency. Therefore, it was necessary to find a processing method to build a stator core.

In Figure 1 the properties of magnetic losses and maximum relative magnetic permeability of the nanocrystalline soft material are compared with the electrical steel and the Soft Magnetic Composite (SMC). It is possible to conclude that nanocrystalline magnetic losses are minimal and relative magnetic permeability is much higher than other two raw material.

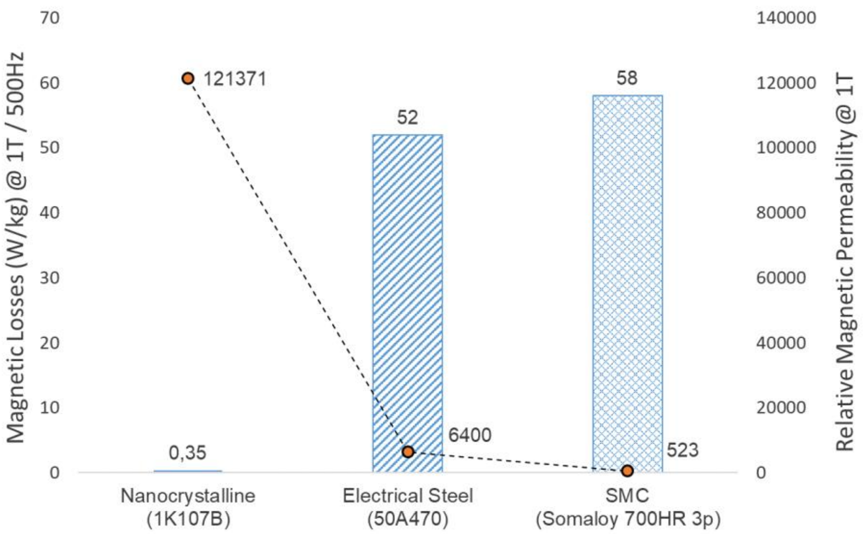

Fig. 1. Magnetic properties of Nanocrystalline, Electrical Steel and SMC in magnetic induction 1T and 500 Hz.

2 Nanocrystalline Magnetic Characterization

The nanocrystalline soft material is widely used in magnetic components for electronic devices such as common mode chokes, high frequency power transformer, switch power supplies, inductors and current sensors, where the materials are characterized at high frequencies in the order of megahertz. In electric motors application is necessary to characterize the nanocrystalline soft material at low and medium frequency in the order of 50 to 1000Hz, considering the magnetic induction range up to magnetic saturation.

A nanocrystalline ribbon, see Fig. 2a, of FeSiBCuNb alloy having a thickness of 20 μm and width of 40 mm was used to manufacture an axial flux motor.

a) b)

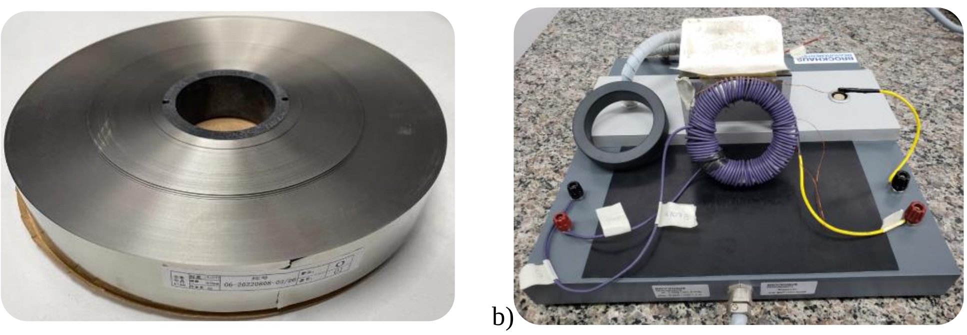

Fig. 2. Nanocrystalline, a) Ribbon used to manufacture the magnetic characterization samples and AFM, b) Nanocrystalline core test to measure magnetic properties.

The nanocrystalline material ribbon is supplied in an amorphous state requiring a heat treatment to create a nanocrystalline structure, in the order of 10 to 20 nm, to get the nanocrystalline material. The saturation induction of this alloy is 1.2 T.

Usually, during the heat treatment cycle a magnetic field is applied in the same direction that the magnetic flux will pass in the component, creating magnetic anisotropy in the core of the nanocrystalline, improving the magnetic properties in magnetic flux direction.

For electric motor it is not interesting an anisotropic material because the magnetic flux will change the direction in the area from teeth to the stator yoke. Therefore, it was necessary to evaluate the impact on the magnetic properties of not applying the magnetic field during the heat treatment of stator core.

To enable the manufacture of the stator of AFM the magnetic core was potting using epoxy resin, providing mechanical rigidity and thermal conductivity for the magnetic core. Therefore, the impact of potting on the magnetic properties of nanocrystalline material was evaluated.

To evaluate the magnetic properties were realized Core Test using the bench test Brockhaus MPG 200D, see Fig. 2b, where the following samples were tested:

- Sample 1: Treatment with Magnetic Field and without Epoxy resin
- Sample 2: Treatment without Magnetic Field and without Epoxy resin
- Sample 3: Treatment without Magnetic Field and with Epoxy resin

Carrying out the heat treatment without the magnetic field the magnetic losses increased approximately 113% in 1 T at 500 Hz, see Fig. 3, and the maximum relative magnetic permeability reduced 76%, see Fig. 4, in relation to the treated sample with magnetic field both without epoxy resin.

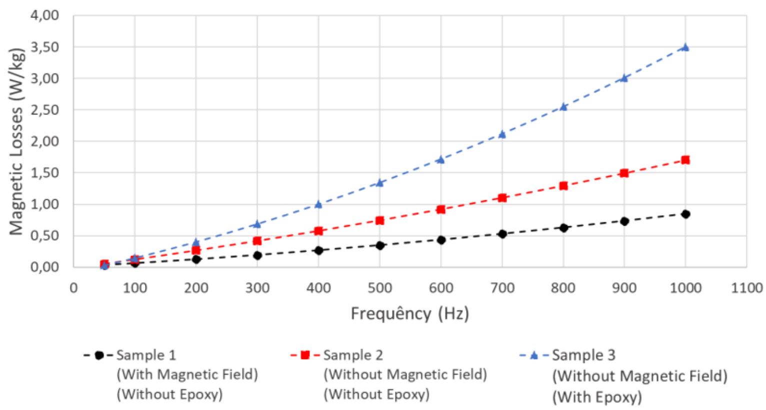

Fig. 3. Magnetic losses of nanocrystalline samples in different frequency at 1T.

Comparing the results of samples without and with epoxy resin potting, both with heat treatment without magnetic field, the potting sample had an increase in magnetic losses of approximately 80% and the maximum magnetic permeability reduced 28%.

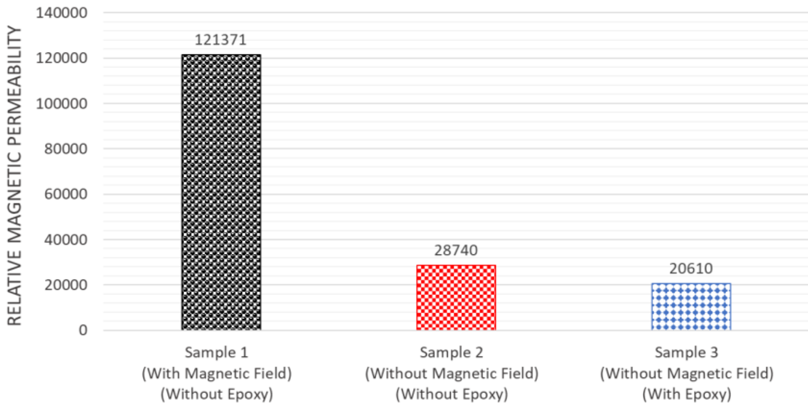

Fig. 4. Maximum relative magnetic permeability of nanocrystalline samples.

3 Axial Flux Motor Design

To use the nanocrystalline soft magnetic material in electrical motor was designed an Axial Flux Motor (AFM) of 8kW, 3000 rpm, 25.5 Nm and 225V. This motor has the air gap flux oriented in the axial direction and it is tied to high power density and low volume density designs.

There are three different axial flux motor configurations, as: one stator and one rotor (1), double stator (2) and double rotor (3). According [3] from a magnetic point of view, the three configurations present similar performance. The AFM with nanocrystalline soft material was designed with one stator and one rotor, see Fig. 5, due to the stator manufacturing process and to the ease of dissipating the heat generated.

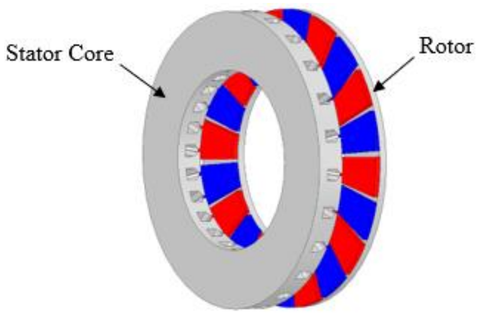

Fig. 5. AFM with one stator and one rotor configuration [3].

The low magnetic losses at high frequency of nanocrystalline soft magnetic material reduce the iron losses of AFM consequently increase the efficiency. To take advantage of the magnetic properties of the material at high frequency the AFM was designed with high polarity (20 poles) and is fed with high frequency (500 Hz).

The electromagnetic project was analyzed by finite elements 3D and the following Table 1 gives a summary of the results of three projects considering the curves of samples 1, 2 and 3 characterized in the Core Test. The axial flux motor was mechanical and thermal designed using the magnetic results considering the heat treatment without magnetic field and with epoxy resin to potty the stator.

Table 1. Results of the AFM designs with different magnetic properties.

Project	Sample 1 With Magnetic Field Without Epoxy	Sample 2 Without Magnetic Field Without Epoxy	Sample 3 Without Magnetic Field With Epoxy
Generated Voltage (V/krpm)	136.8	125.6	125.3
Current (A)	22.5	24.5	24.7
Total Losses (W)	563	645	654
Efficiency (%)	93.42	92.53	92.44
Power Factor	0.94	0.93	0.93
Temperature Rise (K)	54	64	65

4 Axial Flux Motor Manufacturing and Testing

The axial flux motor, see Fig. 6a, was manufactured with the stator using potting nanocrystalline magnetic core, providing mechanical rigidity and thermal conductivity. NdFeB rare earth magnets were used in the rotor.

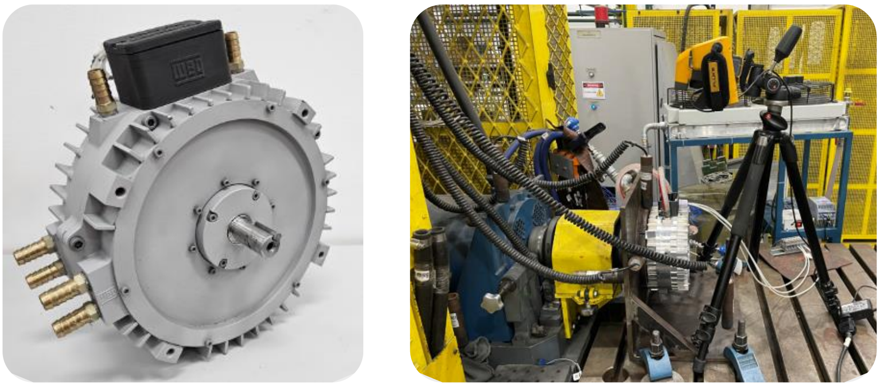

Fig. 6. AFM a) one stator and one rotor, b) Magnetic flux of AFM with nanocrystalline.

To analyze the performance of AFM the motor was tested on laboratory bench, see Fig. 6b, to measure the efficiency at full load. The laboratory test was performed with a switching frequency of 10 kHz and a water flow was applied in shields to cool the motor. Tests results can be seen in Table 2.

Table 2. Results of the AFM test comparing with design data and baseline motors.

Sample	Baseline RFM[1]	Baseline AFM[2]	Nanocrystalline AFM	
			Manufactured Design	Test Results
Efficiency (%)	91.10	88.65	92.44	92.50
Power density (kW/kg)	0.107	0.500	0.571	0.588
Total Losses (W)	781	1024	654	648
Frequency (Hz)	50	250	500	500
Mass (kg)	75	16	14	13.6
Temperature Rise (K)	80	60	65	59

[1] RFM = Radial Flux Motor (Super Premium)

[2] AFM = Axial Flux Motor with Electrical Steel (2S1R)

Analyzing the main results of the test, it is possible to verify that the values met the design data, presenting a difference of 0.92% in total losses and 9% in temperature rise. Comparing the baselines RFM and AFM, both using electrical steel, it is possible to verify the gain with the increase in power density, practically 4.7 times higher in AFM. The AFM with nanocrystalline soft magnetic material increased the efficiency 3.85 percentage points, reducing total losses 36.71%, comparing with AFM using electrical steel. Furthermore, the power density increased 17% due to use of less active raw material and epoxy resin.

5 Conclusions

The magnetic properties of the nanocrystalline soft material are excellent for application in electric motors, due the high magnetic permeability and low losses at high frequencies. However, there is the challenge in increasing magnetic saturation induction without compromising the losses and magnetic permeability values. An axial flux motor was designed and manufactured using nanocrystalline material despite the various challenges of manufacturing process of the stator magnetic core. The tests results validated the axial flux motor project that used nanocrystalline, obtaining a significant gain in motor efficiency when compared with an AFM that uses electrical steel.

References

1. Nishikawa, Y., Kojima, T., Segawa, T., ‘Highly efficient motor using soft magnetic material with super-low iron loss’, Panasonic Technical Journal, Vol. 62 (2) 2016, p. 43.
2. Nonaka, T., Zeze, S., Makino, S., Ohto, M., ‘Research on motor with nanocrystalline soft magnetic alloy stator cores’, IET Journal The Institution of Engineering and Technology.
3. Nau, S. L., Martins, C. E.G., Schmitz, C., ‘Technologies for High Efficiency Motors’. 12th International Conference on Energy Efficiency in Motor Driven Systems (EEMODS), Stuttgart, Germany, 2022.