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RESEARCH ARTICLE **OPEN ACCESS**

DEVELOPMENT OF A THREE-PHASE SYNCHRONOUS ELECTRIC MACHINE VIA POWDER METALLURGY

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ABSTRACT

The developments achieved by electric machines in recent decades were more significant in terms of their resizing and in the ways in which they are activated than in the field of materials used for their manufacture. The electric machine project proposes the improvement of the technology of a three-phase synchronous machine through changes in the material and in the manufacturing process of the rotor and stator cores. Cores were constructed from four different materials: laminated sheets, Fe2%P alloy, commercial soft magnetic composite material and soft magnetic composite material developed using iron and phosphoric acid (H_3PO_4). The machines were tested as generators on a test bench. The use of the powder metallurgy manufacturing process to obtain cores of electrical machines proved to be a viable alternative to the traditional method of making the cores of electrical machines. However, the results of operating tests at different frequencies pointed to yields below 86% for the laminated core machine against 42% for the Fe2%P alloy, 38% for Somaloy and 41% for the developed material.

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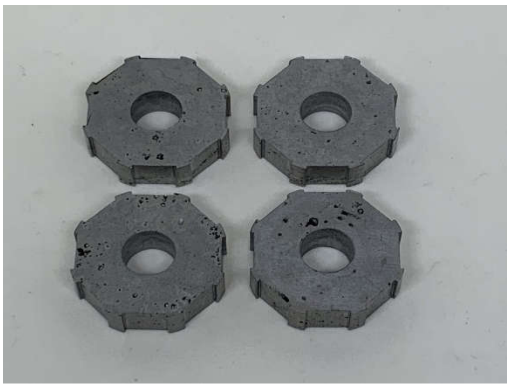
INTRODUCTION

Electrical machines are machines and equipment developed over the years with the aim of transforming electrical energy into mechanical energy or mechanical energy into electrical energy. Electric machines are indispensable equipment nowadays because they are present in several applications that can be from small mechanical drives to large electric power generators such as those used in hydroelectric plants. The universe of electric machines is very broad, allowing these equipment to be divided into categories such as the principle of energy conversion, type of electric current used in the power supply, shaft rotation speed, constructive characteristics of the rotor and stator, among others. The evolution of electric machines is very close to the limit of improvement. This has motivated research related to changes in the manufacturing process and in the materials used in the construction of rotor and/or stator cores. Powder metallurgy is a manufacturing process that has gained increasing space in this area. This process makes it possible to manufacture the rotor and stator cores in single solid blocks. Depending on the chemical composition of the alloy of materials used, it is possible to obtain an electrical machine with characteristics superior to those built in a traditional way with laminated silicon steel sheets. In addition, powder metallurgy meets the ideals of the concept of "cleaner production" and "sustainability" as it has low environmental impact characteristics when compared to competing technologies, requires lower consumption of transformation energy and enables high use of raw material (above 95%). The studies carried out at the Mechanical Transformation Laboratory of the Federal University of Rio Grande do Sul have produced, over the years, a solid base of knowledge regarding the use of powder metallurgy in the production of electrical machine cores. In this research, the development of electrical machines with cores obtained from the powder metallurgy process for use at high operating frequencies was proposed. The cores will be made from different materials and the machines will have their performance evaluated on a test bench.

MATERIALS AND METHODS

The electrical machine used as a reference was the SWA 402-1.6-30 model from Weg's SWA line of servomotors. This machine has as main features 400 W of power, operating voltage of 230 V, rated current of 2 A, torque of 1.6 Nm, rotation of 3,000 rpm and 8 permanent magnet poles. The stator core produced with 0.5 mm thick silicon steel laminated sheets and has 24 slots, 73 mm outer diameter, 42 mm inner diameter and 40 mm length. The rotor has an external diameter of 39.2 mm, eight poles where the pairs of NdFeB magnets are located, a center hole of 13 mm in diameter for the shaft and a core of laminated silicon steel sheets with a thickness of 0.5 mm. and length of 40 mm. The electrical machine design maintained the main characteristics of the reference model, where the main changes will be in the rotor and stator cores. These cores will be produced according to powder metallurgy processes, using as raw material an alloy of Fe2%P, a commercially available soft magnetic composite material (Somaloy) and another soft magnetic composite material developed from iron and phosphoric acid (H_3PO_4). A set of laminated steel sheet cores will also be produced. Seeking to maximize the performance of the machines, the rotor core will use NdFeB permanent magnets. The compaction of the cores was carried out in specific metallic dies for each part format. They were designed and made in tool steel, seeking to reproduce the parts of the cores with their geometry as close to the final one as possible. This eliminates the need for further machining, which is one of the advantages of the powder metallurgy process over the traditional way in which laminated sheets are produced. The core production process followed the steps of traditional powder metallurgy: mixing, compaction and heat treatment. The mixture was carried out between the metallic powder and zinc stearate in a mixing equipment. Zinc stearate is a very important component as it acts as a lubricant to reduce friction between powder particles and between matrix components and powder during compaction. A value of 1% by weight of lubricant with respect to the powder was added. The mixture of powder and lubricant was left in the mixer for 20 minutes to homogenize the components. The compression pressure used was 600 MPa, in order to guarantee the same physical properties in all parts. Based on the measurements performed, the rotor core has an area of approximately 878 mm² and the stator has an area of approximately 1,760 mm². The force required to compress the parts at 600 MPa was calculated, resulting in 53.70 tonf for the rotor core and 107.65 tonf for the stator core. Each core will be formed by four pieces that will be joined through the axis. The heat treatment of the parts ended the manufacturing cycle of the cores. The oven without a controlled atmosphere was programmed with a heating rate of 10 °C/min to 530 °C and after that, a 60minute plateau at 530 °C, after which the pieces remained inside the oven for cooling to room temperature. The sintered parts obtained using the Fe2%P alloy that form the cores are shown in Figure .

(a)



(b)

Figure 1. Cores of (a) stator and (b) rotor

The final machine assembly process completes the design and construction stages, allowing you to move on to bench testing. The assembly was performed based on the availability of all the necessary parts, such as rotor and stator cores, shaft, housing, NdFeB magnets, side covers, winding, bearings and fixing screws. Figure 2 refers to all the parts that make up the electrical machine developed before final assembly.

Figure 1. Parts that make up the Fe2%P core servomotor

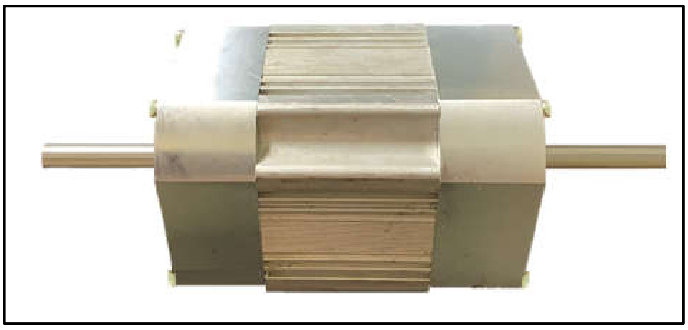


Figure 3. Final assembly of the servomotor

RESULTS

The making of the rotor and stator cores of an electric machine from the powder metallurgy process as well as the theoretical and practical performance of this machine were evaluated in the course of this work. The information collected during the research allowed the analysis and interpretation of the results based on the theoretical framework elaborated, in addition to its implications. The lubricant mixed with the iron powder proved to be effective, reducing friction during compaction and facilitating the extraction of the parts at the end of each cycle. After extraction, all parts underwent a quality control. This inspection was carried out to evaluate characteristics of the compact, such as the presence or absence of cracks and the quality of the surface finish. The result of the evaluations indicated that there were no superficial cracks, all the pieces presented a uniform color and a green density suitable for handling. The sintering process provided the parts with the necessary mechanical strength so that the complementary machining operation could be carried out later. The tests of electrical machines were carried out with the objective of analyzing their performance acting as generators, through the relationship between the energy released and the energy introduced. It was defined that the performance would be analyzed for a frequency range from 10 to 80 Hz, with an increment of 10 Hz. This frequency variation is carried out through an inverter, which operates the drive of the induction motor, allowing the rotation variation on the motor shaft. As the developed machine is coupled to the motor, the induced voltage in the generator stator windings can be analyzed.

Table 1. Performance test as a generator at 60 Hz

cores	η 10 Hz (%)	η 20 Hz (%)	η 30 Hz (%)	η 40 Hz (%)	η 50 Hz (%)	η 60 Hz (%)	η 70 Hz (%)	η 80 Hz (%)	η 90 Hz (%)	η 100 Hz (%)
Laminated sheets	29	46	57	64	68	70	71	72	73	73
Fe2%P	7	20	29	41	43	38	36	30	25	23
Somaloy	3	10	12	19	30	33	35	36	33	28
Material developed	10	15	20	27	38	43	43	44	45	42

All tests were performed with both servomotor cores made of the same materials. Table 1 shows the performance of the four machines for the frequencies tested. In Figure 2, it is possible to see the operation of the bench during the test and the graph in Figure 3shows the relationship between the variation in the operating frequency of the machines and the performance in each one of them.

Figure 2. Performance test

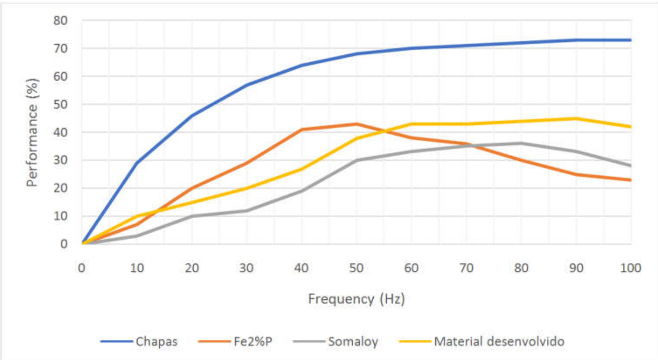


Figure 3. Yield x frequency variation

CONCLUSION

The search for technologies that allow sustainable development with low environmental impact has driven the advancement of powder metallurgy in the manufacture of electrical machines. Requiring a lower consumption of electrical energy and providing a high use of raw material, powder metallurgy seeks to produce electrical machines with characteristics superior to those built in a traditional way. Obtaining the stator and rotor core from the powder metallurgy process is a perfectly viable alternative. Powder metallurgy eliminates a number of costly steps that are required in the traditional laminated sheet core production process. The developed material presented some properties inferior to the others, it can be applied in specific cases, demonstrating the capacity of M/P, being an alternative to the current manufacturing processes. The tests to evaluate the performance of electrical machines had to be performed only up to the frequency of 80 Hz because there was detachment of the rotor magnets. The type of fixation glue was changed, since this was the most viable alternative found. A change in the constructive form of the rotor core that would allow the magnets to be fixed without the need for glue is one of the modifications suggested for future works. The output values recorded in the stator coils and the voltage induced by the movement of the rotor, which through the movement of its permanent magnets and magnetic field generate an alternating magnetic flux which flows through the stator generating an induced voltage in the three windings of the machine, which means that the higher the value of the induced voltage, the smaller the losses in the material. During the development, design, assembly and testing, it is concluded that the development of this type of machine needs significant changes due to the complexity of its operation. As the materials of the rotor and stator cores were changed, quantities such as induced voltages underwent changes in the developed prototypes, as shown in the graph that relates induced voltage as a function of the frequency of the primary drive machine. The core materials being of different magnetic properties resulted in different induced voltages. The results presented in this work provided information about the feasibility of using massive cores in electrical machines. This argument is justified, since the electrical and magnetic data of the alloys were unsatisfactory and that, after the construction of the machine, it was tested and obtained an efficiency for the frequency of 60Hz of 70% of the laminated core machine against 38% for the Fe2%P alloy, 33% for Somaloy and 43% for the material developed.

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