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ScienceDirect

Ciência & Tecnologia dos Materiais 29 (2017) 80–90

Ciência & Tecnologia dos MATERIAIS

http://ees.elsevier.com/ctmat

Development of electrical machine with magnets and cores obtained by powder metallurgy

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Abstract

The aim of this work was the development (design, construction and tests) of a Three-phase Synchronous Machine with permanent magnets and four poles to be used in small wind turbines, where the rotor and stator cores, usually constructed from laminated steel sheets, were replaced for massive blocks obtained from the Powder Metallurgy (PM) process. The other parts of the machine, such as housing, shaft, bearings and covers, were obtained from conventional three-phase induction motor of 10 HP. Initially, it was studied sintered alloys from pure iron, Fe-Si, Fe-P and Fe-Ni; eventually these alloys were analyzed in terms of magnetic and mechanical properties as well as electrical resistivity. From this study, it was chosen the use of sintered pure iron for the construction of the rotor and Fe1%P for the construction of the stator. The permanent magnets used were Nd-Fe-B, and the windings calculation was based on the coiling of the three-phase induction motor. According to the tests performed, it was observed the generation of a three-phase sinusoidal wave voltage of 242 VRMS, and the yield of 40.8%.

Keywords: three-phase synchronous machine; magnetic materials; powder metallurgy.

1. Introduction

Rotating electrical machines can function as a motor or generator, and have two basic parts that are the stator and rotor cores. These cores, with rare exceptions, are currently built from thin metal blades (low carbon steel sheets) with thickness less than 1 mm that are stacked together. Some higher-yielding machines such as generators are built with silicon-steel sheet, with percentage of approximately 3% silicon [1,2].

Magnetic cores surrounded by coils, where alternate currents circulate, also generate an alternating magnetic flux. For this reason, these cores are subjected to the action of eddy currents, also known as Foucault currents, which are responsible for significant power loss in these cores [1-4]. According to design engineers of motors manufacturers, with respect the construction, changes in shape and drive of the electric machines are on the limit of technological improvement and only drastic changes in the materials used to build the cores of the electric machines will result in improved performance of that. The same occurs with respect to the drive, where devices from semiconductors such as inverters are also within the limits of technological improvement.

However, using the processes of Powder Metallurgy (PM), it is possible to build the referred cores in massive single blocks with high magnetic permeability and a higher electrical resistivity as compared to conventional steel, which reduces eddy currents [5,6]. In this case, the machines will be constructed with fewer steps, leading to a decrease in the consumption of energy. It should be noted also that using magnetic alloys with higher resistivity in the construction of stator and rotor cores, there will be

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http://dx.doi.org/10.1016/j.ctmat.2017.09.001

a reduction in eddy current loss, higher yield, thereby resulting in electricity savings [7,8].

Currently the application of PM in cores of electric machines is restricted to special motors where the yield is not the most important criterion, as in the case of mini motors with complex geometry, in some servomotors where the armature windings are supplied with current electrical of high frequency, and parts of machines where there is no change in magnetic flux, as rotor core of synchronous machines. However, some studies are being conducted in other types of machines obtained from the PM in order to prove or dismiss the application of this technology [7].

2. Electrical machines by powder metallurgy

2.1. Synchronous machines with permanent magnets

Rotating electrical machines with three-phase power, usually, can function as a motor or generator and are classified as synchronous or asynchronous. In synchronous motors, the angular velocity of the shaft is constant and independent of the load coupled to the shaft, i.e. up to certain values of power, with the limit the nominal power of the machine. In asynchronous motors, there is a decrease in the angular velocity when load is coupled to the shaft [1,2,8].

With regard to the constructive aspect, the three-phase machines consist mainly of two parts which are the rotor and stator. These ones are, in most cases, made of laminated steel sheets, insulators and juxtaposed in the longitudinal direction of the machine. Thus, there is a considerably reduce in losses by eddy current, leading to an increase of the efficiency of the machine [1,2,8].

Synchronous machines with permanent magnets are rotating three-phase machines in which the rotor windings, usually supplied with direct current, are replaced by permanent magnets of high energy product such as NdFeB. In general, these machines have high yield (greater than 90 %) and, in some applications, such as in servomotors, they are used operating at high speeds and high frequency of armature currents [1,2].

2.2. Physical properties of interest

The physical properties of interest for use of a particular material and process in cores of rotating electrical machines or electric motors are the following:

- Magnetic properties (coercivity, permeability and saturation induction).
- Electrical resistivity.
- Mechanical properties (hardness and compression curves / yield stress).

Regarding the magnetic properties, the materials to be used in cores of electrical machines must have: high magnetic permeability, which reduces the reluctance of the magnetic circuit of iron cores, thus concentrating the entire magnetic field in the air gap; high saturation induction, which enables to work with higher magnetic flux, resulting in greater torque on the shaft; and low coercivity, which reduces the hysteresis cycle losses [1,2,7,8].

Related to electrical resistivity, this parameter must have the highest possible value in order to minimize the effect of eddy currents. Whenever there is the incidence of an alternating flux on a magnetic core, there will be induced currents (eddy currents or Foucault currents) on the core. The stator and rotor are constructed with laminated and insulated sheets, since this isolation between sheets restricts the induced currents to a smaller area of circulation. The eddy current losses in a solid core are significantly larger than the losses in cores made from electrically isolated sheets. The smaller the sheet thickness, the smaller the eddy currents and power losses in these cores. The reduction of induced currents may also be obtained from an increase in the electrical resistance of the piece or from the increasing of electrical resistivity of the material, since resistance (or resistivity) and electrical current are physical quantities inversely proportional. For this reason, high-performance electric machines are built with a silicon steel sheet, which has higher electrical resistivity than the low carbon steel [1,2].

With respect to mechanical properties, materials that could be used in cores of electrical machines must bear the stresses caused by the resistive load torque and vibration, among others. Thus, it should be performed hardness or ductility tests, as well as compression curve *versus* deformation [1,2,8].

2.3. PM and sintered ferromagnetic alloys

Powder Metallurgy (PM) is a relatively recent process of metallurgy processing, where the parts are obtained from the powder constituents. The basic processes of PM are: getting the powders, mixing, compression and sintering. Sometimes a fifth process known as rectification is required. In the PM, the powders, after being mixed, are compressed into dies where they