Development of new composite electrotechnical materials with advanced characteristics for application in novel equipments

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Abstract: *An urgent task for the electrical industry is to develop new soft magnetic materials, in particular composites. The greatest interest present composites in which filling components have metal-dielectric-metal (MDM) interaction. Recent few years many research centres are carry out intensive developments of soft magnetic composites (SMC) based on use of soft magnetic particles, usually based on iron, with an electrically insulating coating on each particle. The carried out preliminary researches of a composite magnetic material based on iron ASC 100.29 and Atomet 1001HP powders, surface of which is capsulated by ferrite, have shown perspectives of their application in engineering. Unique specific parameters of a softmagnetic composite material - a magnetic induction of saturation 2.1 Tesla, work in a frequency range up to 100 kHz at Curie temperature from above 800°C allow to use it in high speed valve and valve-jet electromachines and as chokes and high-frequency transformers.*

Keywords*: SOFT-MAGNETIC COMPOSITE MATERIAL, IRON POWDERS, INSULATING COVER, HIGH-FREQUENCY TRANSFORMERS, STATORS AND ROTORS OF ELECTROMACHINES*

1. Introduction

Currently, known soft magnetic alloys are mainly used in the production of electrical machines. 90% of them are various types of electrical steel. Also Fe-Si and Mn-Zn-ferrites alloys are used [1-3]. Such materials have practically reached the limit of their physical, mechanical and operational properties. To create a new generation of products it is necessary to develop a completely new class of soft magnetic materials with improved characteristics. The advantages of a composite magnetic material over electrical steel and other soft magnetic alloys make it possible to ensure their wider application in electrical machines in order to increase the specific power at a high rotation speed with lower losses. Manufacturability and ease of cores production by the compacting method is much superior to the method of sheet assembly from electrical steel. There is not practically waste in the manufacture of magnetic cores [4-6].

One of the new directions in the soft magnetic material fabrication is using of encapsulated powders, the initial grain of which is covered with a layer of alloying components, which can be organic and inorganic materials [7-8]. The process of encapsulation of each particle makes it possible to create a thin and uniformly distributed electrical insulating shell on the surface of an iron powder or its alloys at a high concentration of ferromagnet per unit volume. This allows a significant increase in electrical resistivity, which limits eddy currents and reduces magnetic losses. The magnetic properties of materials made from such powders are the same in all directions, that is, they are isotropic, which distinguishes them from electrical steels.

Similar materials have already been developed and released by various companies. For example, composite materials based on metal powders with encapsulated particles developed by Micrometals (USA), Atomet (Canada), etc. have one of the highest saturation inductions, and in this parameter they surpass all other traditional alloys. But the cost of such materials reaches 100 USD per 1 kg, which complicates the mass using of such materials. Therefore, an important task is to find cheaper materials that allow to achieve high efficiency of magnetic components for using in the electronics industry.

2. Results of development

In Scientific–Practical Materials Research Centre NASB are actively developed composite magnetic materials (SMC) based on various types of pure iron powder, for example, ASC 100.29 (Sweden), Atomet 1001HP (Canada), etc. Fig. 1 shows the relationship between permeability and saturation induction for a number of known soft magnetic alloys. It can be seen that composites based on iron powders with encapsulated particles (ferritized Fe powders) have one of the highest saturation inductions, and in this parameter they are superior to all other alloys.

For comparison, Table 1 shows the main parameters of Fe-Si alloys, Mn-Zn ferrites and the investigated magnetic composite material based on ASC100.29. Developed material is superior to iron-silicon alloys and ferrites by almost all characteristics. In addition, the cost of the composite is much less than the cost of ferrite materials.

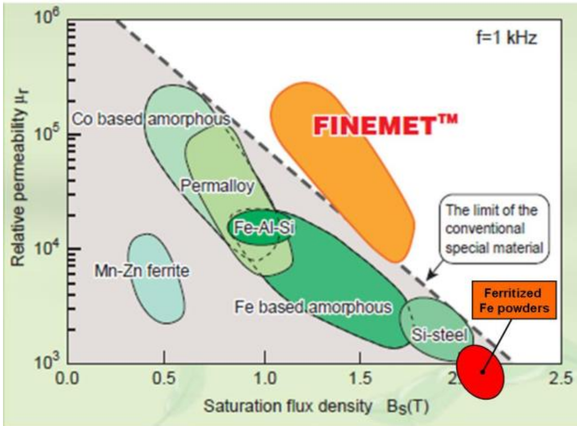

Fig. 1 *Relationship between permeability and saturation flux density in several soft magnetic alloys*

Table 1: *Properties of Fe-Si alloys, Mn-Zn-ferrites and magnetic composite material*

Parameters	Fe-Si alloy	Mn-Zn-ferrite	Composite based on ASC100.29
Saturation induction, T	1,8	0,45	2,1
Working induction, T	above 1,5	above 0,2 - 0,3	above 1,8
Maximum magnetic permeability	4000 – 7000	500 – 4000	500 – 1000
Field dependence of inductance	Non-linear	Non-linear	Close to linear
Environmental factor	Potential harmful effects	Environmentally friendly	Environmentally friendly
Core manufacturing	Complex	Simply	Simply
Electrical resistance	10^{-6} Ohm m	10^{6}-10^{9} Ohm m	10^{4}-10^{6} Ohm m
Price, USD/kg	2	~20	2

In order to successfully compete in the electric vehicle segment, it is currently necessary to develop an electric vehicle that will not only be innovative in its technical and driving characteristics, but also have an accessible price within the price of a classic car. The cost of a car consists of two main factors: the price of the energy storage unit and the price of the electric drive. It is very difficult to influence on the cost of batteries due to the monopoly on the materials contained in them. And in order to reduce the cost of an electric drive, it is necessary to propose new scientific and technical solutions, which are primarily based on the using of new materials. One of such solutions is the creation of an axial flow electric motor-generator with magnetocomposite cores.

It is quite difficult for car manufacturers to regulate the cost of batteries, and hence the final cost of an electric vehicle. Accordingly, in order to remain competitive in the electric vehicle market, it is necessary to reduce their price, which is possible only with the constant development and modernization of existing technologies for the manufacture of an electric drive and an increase in its efficiency.

A synchronous axial flow electric motor-generator based on new composite materials will significantly improve the characteristics of the product itself and significantly reduce its price. Due to the design features and high electromagnetic characteristics of the material, according to calculations, it is possible to create an electric motor with a higher power density, smaller weight and size parameters and low manufacturing costs in comparison with other types of electric motors. Indicators of specific power density range from 11 kW/kg, depending on the tasks and design.

The design of the stator of such a motor assumes a change in the direction of the magnetic flux, which is possible only with the use of a composite soft magnetic material, in contrast to electrical steel (Fig.2). The high efficiency of the proposed electric motor is due to the presence of two stators or two rotors. Stators or rotors can be made from separate parts of the magnetic cores, as shown in Fig. 3. Such parts are manufactured by pressing in special molds under a pressure of 10 t/cm^2, followed by annealing in air at a temperature of 400°C. The main advantages of the developed electric motor are compact size and light weight combined with a high degree of protection, high operating temperature and long service life, energy saving by 15% compared to existing ones, no "sliding" current collectors and elements, low maintenance costs and long service life. The multi-pole design will allow for the most smooth running and stable operation over a wide power range. A stator made of soft magnetic composite materials with high electrical properties will allow:

• refuse to use electrical steel,

• to reduce the requirements for additional cooling of the coil windings due to the material's insensitivity to induction heating,

• achieve high efficiency - 98% and specific power 12-18 kW/kg.

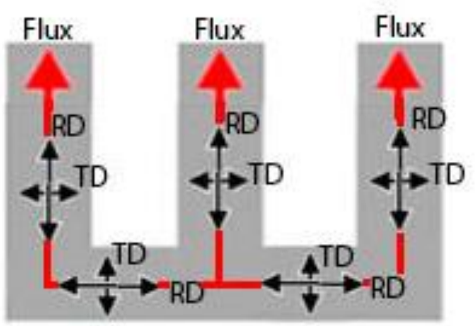

Fig. 2 *Magnetic field distribution in a composite core*

Fig. 3 *The stator of a prototype two-stator electric motor using a composite soft magnetic material based on ASC100.29*

The described technologies are also suitable for another following applications, which are used in microelectronics:

- manufacture of microforms using micro-pressing technology;

- manufacture of mechanical parts for micro-positioning - gears, stands, etc .;

- manufacture of magnetic cores;

- stators and rotors for brushless and stepper motors (including linear ones);

- production of arrays of microlenses, filters.

3. Summary

An experimental technology for producing composite materials has been developed. For production, commercially available pure iron powders (ASC100.29 Hoganas AG, Sweden) are used. The surface of individual iron particles is covered with a special oxide layer. The results obtained can find further application in the development of new soft magnetic materials with specified characteristics and in the creation of new types of highly efficient technological electrical devices.

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