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Optimization of the Properties of Low-Frequency Composite Magnetic Soft Material Based on Iron Powders

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In recent years, many centers have been intensively researching soft magnetic composites (SMC) based on the use of soft magnetic particles, usually based on iron, with an electrically insulating coating on each particle. The main purpose of the low-frequency composite soft magnetic material is the construction of high-efficiency inverter electric motors with inverters, transformers, inductors and other devices for which the working remagnetization frequency significantly exceeds the industrial frequency. In this regard, the basic properties of a composite material such as magnetic permeability, magnetic induction, remagnetization losses and mechanical properties should be better than traditional laminated metal magnetic materials.

Currently, Somaloy powders (Hoganas company) obtained using special iron powders and phosphorus oxide based insulation are offered as commercial composite soft magnetic materials. However, individual parameters, first of all, losses on remagnetization, as well as their high cost, do not quite satisfied consumers.

The properties of composite magnetic materials depend and are determined by a number of factors. First of all, this is an insulating coating of iron particles - its type, thickness, resistivity, adhesion to iron powder and a number of other properties. Also important is the very basis of the composite magnetic material — highly pure iron powder — its chemical composition, fractional composition, surface adhesion of particles, and some other factors.

The aim of the work is studying the properties of low-frequency soft magnetic composite material with the optimal choice of insulation coating and directly the type of highly pure iron powder. Magnetic properties were measured both on an express magnetometer, where losses and other magnetic parameters were determined from the remagnetization curves of the samples, and additionally by a direct method by measuring the core heating rate during operation in the adiabatic mode. Both of these methods showed good agreement between the measurement results. The high resistivity of the composite SMC material of the order of $\rho = 10^{-2} - 10^{-1}$ Ohm · m determines the practically absence of eddy current loss. As a result of the study of the properties of SMC materials based on highly pure iron powders, it was shown that materials with the lowest carbon content, for example, iron powder ABC100.30, have increased magnetic parameters and minimal losses. A study was made of the effect on the properties of SMC materials of various types of insulating coatings, as a result of which it was shown that SMC materials with a titanium oxide coating have better characteristics. The effect of the thickness of the oxide coating on the decrease in the magnetic permeability of SMC materials is estimated. It is shown that the SMC material with titanium oxide oxide coating of iron powder (σ=510 MPa) has the maximum strength properties. Small values of the losses developed by SMC materials determine their scope in the frequency range up to 10 kHz.

Based on the theory of direct exchange interaction, the electron density on the Fermi surface for both the metallic state and composite materials should be close. In this case, the magnetic properties of the metallic ferromagnet and the composite material should be identical. This condition can be fulfilled in the case of composite magnetic materials if the insulation of the grains is local and has the smallest possible thickness. As the present studies have shown, the calculated thickness of the insulating layer should be equal to or less than one nanometer.

As for the mechanical properties and strength of the composite material, in this case, the decisive role is played by the adhesion of the insulating layer to the metal. As studies have shown, the maximum strength is achieved when using an insulating layer based on titanium oxide, the minimum strength is typical for insulation based on hexagonal boron nitride.

Studies have shown that further progress in improving the magnetic properties of composite materials and, above all, achieving minimum loss values, is associated with an improvement in the properties of iron powder itself. The defectiveness of the grains of iron powder, determined by the content of carbon forming iron carbides, is one of the factors for the growth of coercive force and losses on remagnetization.