Resource-Saving Technologies Based on Powder Metallurgy Research and Development

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**Abstract.** Addressing one of the priority areas of scientific research and technological development, which is the implementation of technical and organizational measures associated with energy saving and reasonable consumption of energy, this article is devoted to an issue that is an aspect of strategic learning. It also touches upon the proliferation of the use of high specific consumption magnetic materials as they have entered the manufacturing of the micromachines. One especially promising line of work in the subject would be the generation of a zero-waste technology towards making the magnetic cores and conductors involved in electrical engineering through the employment of the powder metallurgy techniques in manufacturing processes. Electrical steel losses can be minimized, many labor-intensive processes can be removed due to the use of soft magnetic materials prepared with the help of the process of powder metallurgy, the technological process can be automated, and the necessary parts dimensional accuracy cannot be achieved without a series of fine machining operations. The use of soft magnetic materials in the construction of electrical machines allows to achieve much higher efficiency coefficient η and to distinguish the losses known as hysteresis.

**Keywords:** Energy-efficient electric motors, soft magnetic materials, power reserves, peak values, magnetic anisotropy, soft magnetic alloys, efficiency coefficient, induction, hysteresis losses.

**INTRODUCTION**

Conservation of energy and resources is in the list of priorities of scientific research and technology development. Society has vast resources put in the production of energy and one of them is electricity. Meanwhile, the energy resources utilized per a unit of production are three times greater compared to the locally developed industrialized nations. The growing challenges associated with limited fuel reserves are being addressed at the cost of significant material, labor, and intellectual resources [1, 3]. In the meantime, the technical and organizational steps connected with the issue of energy conservation and rational use of energy demand much less expenditures. The analysis of the situation and the state of the significant national economic problem, i.e. the enhancement of the resource efficiency of alternating current drives, illustrates the necessity to formulate the new concept. This involves creating energy-saving soft magnetic materials by utilizing encapsulated powders for electric motor components, as well as developing modern starting devices for asynchronous electric drives and refining methods to assess the energy and resource efficiency of their implementation [2, 5].

The production of soft magnetic materials is another new direction others are using, encapsulated powders form here with a layer of alloying elements coated on the base component. These alloying components can be organic or inorganic materials [1, 2, 4]. The encapsulation process for each individual particle enables the formation of a thin and uniformly distributed electrical insulation layer on the surface of iron powder or its alloys while maintaining a high concentration of ferromagnetic material per unit volume [3, 4]. The method has a large effect in raising the specific electrical resistance thereby restricting eddy currents and magnetic losses. Materials composed of these powders are isotropic in that all directions are magnetically identical and thus they do not resemble electrical steels. Some of the most significant characteristics of modern soft magnetic materials that are developed in top countries of the world are seen in Table 1. When the organic insulating materials are placed in the first powder, the pressed product will then have to be polymerized or annealed upon the surface layer produced on the powder particles at temperature of maximum 500 0C. Such samples exhibit high specific electrical resistance, which prevents the formation of eddy currents, allowing these materials to be used in alternating electromagnetic fields [2, 4, 7]. This research work will explore the influence of the conditions of composite material synthesis which is of metallic iron powders with insulating coating on the magnetic characteristics.

**SYNTHESIS OF SAMPLES AND RESEARCH METHODS**

Resin, rubber, and these kind of materials are usually used as an insulating layer in most of the studies. However, this approach leads to a slight decrease in magnetic induction and magnetic permeability [5, 6]. According to the major soft magnetic powders developer and maker, the powder manufacturers, called it as the leading manufacturer of soft magnetic powders- Ho-gans, that to eliminate the eddy current, every individual particle in a powder should comprise an insulation layer. These blocking materials could be either organic or inorganic additives.

**EXPERIMENTAL RESULTS AND DISCUSSION**

The production process is based on traditional powder metallurgy methods. Various resins are used for insulation, and to improve the pressing of such powder, a lubricant such as Kenolube is recommended in the range of 0.3–0.5% by mass. The lubricant must be compatible with the insulation under the given heat treatment conditions of the material. For instance, the developed material Somaloy TM 500 combined with the Kenolube lubricant (0.5%) [3, 5, 6] is recommended for products operating in alternating electromagnetic fields.

**TABLE 1.** Comparative Data on the Magnetic Properties of Modern Soft Magnetic Powder Materials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Material | Country of Manufacturer | Density ρ, g/cm³ | Alternating Field | | |
| В, T | μmax | Losses  Р1,0/50 |
| Pure Iron ЕU-10 | Japan | 7,4 | B2000 = 1,4 | 4500 | 30 |
| Iron Powder + Resin ЕU-62Х | 7,0 | B2000= 0,15 | 200 | 7 |
| Fe, Coating Ni-P | USA | 7,35 | B =1,7 | – | - |
| Somaloy 500 + Kenolube | 7,37 | B2500 = 1,15 | 581 | 29 (Р1,5/50) |
| Fe 0,8% P, Т, Sintering 1500°, 24 часа | Poland | 7,8 | B2500 = 1,62 | 14400 | 20,6 |
| Atomet EM-1(2) (Fe + resin) | Canada | 7,2 | B2500 = 1,4 | – | 10-12 |
| PJRV+ 0,5% Epoxy Resin | Ukraine | 6,9 | B2500 = 1,1 | 393 | 9,1 |
| PJRV with Electroplated Coating | 7,29 | B2500 = 1,38 | 3200 | 15,0 |

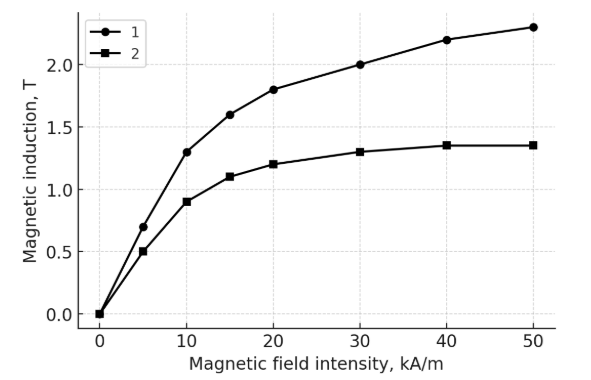
Currently, Höganas has also begun industrial production of new materials made from encapsulated LCM powders, designed for operation at frequencies of 60 Hz [4, 6]. Just like the earlier IP powder, which applies in the bandwidth of 200 to 400 Hz, LCM powders are also aimed at making alternating electric current electronic devices, not only on components but also on whole assemblies. Therefore the introduction of LCM powders in the production of micromotors gives a chance of its adoption in automotive world. In LCM powders, the particles are painted with a non-conductive material. Nevertheless, unlike IP powder, LCM powders are insulated with a coating of a mixture, and this factor contributes to reduction in losses. Both types of powders are manufactured by Höganas using the hot pressing method [1, 7, 8].

Simultaneously, low mechanical strength is one of the downsides of such materials when compared to the powder material or materials that are sintered at a high temperature. Thus, a study that will create and choose a suitable insulating element will assist in disposing of this limitation and enhancing both physical and mechanical characteristics of the material. Such ferromagnetic materials used to make the insulating layers are the most promising since these materials simultaneously substantially increase the electrical resistivity. The purity state of the initial iron powders should also be taken into account and the right methods of manufacturing chosen. In recent years, amorphous materials have been widely used in radio and electrical engineering devices as alternatives to permalloy, ferrites, electrical steels, and magnetodielectrics [6, 8, 11]. At present, the most common are soft magnetic amorphous alloys that combine the best magnetic and mechanical characteristics. A key feature of soft magnetic amorphous alloys compared to crystalline ones is their high content (about 20%) of non-magnetic elements, such as boron, carbon, phosphorus, and others, which are necessary to maintain the amorphous structure. These components reduce the highest values of saturation induction in the amorphous alloys compared to the crystalline materials and heighten the temperature coefficient of the magnetic powers. At the same time, these elements enhance the electrical resistance, hardness, strength, and corrosion resistance of amorphous alloys [4, 6, 10].

Figure 1, presents the dependence of induction magnitude on the magnetic field for composites based on iron metal powders ASC100.29 (1) and LiaoNing (2), where the particles are coated with oxide layers and have grain sizes greater than 100 µm and less than 100 µm. The B=f(H) dependencies show that the magnetic induction of the composite material based on the Chinese LiaoNing powder is lower than that of the ASC100.29-based composite by 8% in the field range H = 1–9 kA/m for low-frequency applications and H = 4–9 kA/m for high-frequency applications. This is likely due to the fact that the LiaoNing powder contains more impurities (1.31% compared to 0.5% in ASC100.29) in addition to pure iron.

|  |  |
| --- | --- |
| *а)* | *b)* |
| **FIGURE 1.** a – with grain size greater than 100 µm, b – with grain size less than 100 µm | |

Figure 2, Dependence of B = f(H) for the soft magnetic composite based on ASC100.29 (1) and LiaoNing (2)



**FIGURE 2.** Dependence of Magnetic Induction on Magnetic Field Strength for Composite Soft Magnetic Materials  
1 – Composite based on ASC100.29 iron powders with oxide insulation; 2 – Composite based on Micrometals powders with dielectric insulation

Figure 2, illustrates the magnetic induction dependence of samples of ASC100.29 powders made on the iron basis with a layer of oxide and Micrometals powders with a layer of dielectric. In case of Micrometals powders, throughout a magnetic field strength of 20 kA/m, the saturation induction is got to the value of 1.25 T. The situation is different with the sample based on ASC100.29, which at the same field strength will already have an induction of 1.8 T that will further increase as the field strength increases, to a maximum value of 2.1 T at a field strength that is more than 40 kA/m. Analysis of the above research findings shows that the ASC100.29 powder with its oxide-coated particles and the composite thereof has a number of advantages. The overall electromagnetic losses in a range 250-2000 Hz are two-fold less in comparison with Atomet 1001HP powder. It has increased the maximum induction in fields of Micrometals-based composite with dielectric insulation (60 percent lower than that using ASC100.29-based composites) in fields up to 50 kA/m. LiaoNing powders are not that good either, as they have been shown to be inferior to ASC100.29 powders in all aspects. Therefore, for further research, iron micropowders of the ASC100.29 grade (Sweden) were selected as the primary material. Among the key factors, there is the enhancement of the efficiency of the product manufacturing and the drop of the technological costs. In order to attain it, the dependence of electromagnetic parameters on the thickness of the used oxide layer has been studied [9, 12, 13, 14].

**CONCLUSION**

As demonstrated through the conducted research, there are immense technical difficulties when it comes to the production of amorphous alloys that display high magnetic permeability. It uses cold-roll sheet in the range of   
1,5-20 , hot-roll sheet and cold draw wire. Consequently, such materials only find application in niche applications where they need to be used where high magnetic permeability is needed. The informational analysis of technological methods of obtaining soft magnetic powder materials, the study of magnetic and physico-mechanical characteristics of investigational samples indicates that, perhaps, the creation of materials based on nanocrystalline powders is currently one of the most prospective directions in the further development of this area.

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