Use of composite alloys for two stator-valve electric motors

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Abstract. The article discusses the methods of using composite soft magnetic alloys for two stator-valve motors of electric transports in railways. The main groups of alloys are studied, which sharply differ in the shape of the hysteresis curve and the values of the main magnetic characteristics. Variable magnetization applied as cores of electric transports. It has been established that structural changes causing the rise of mechanical and magnetic hardness of alloys.

1 Introduction

The technique for applying insulating coatings based on phosphorus oxide was developed in relation to the tasks of this work based on the method of manufacturing a composite soft magnetic material [5, 8, 12], which actually proposed a technique for adding metal powder to the original in a rotating evacuated drum at a pressure of 0.15 - 1.5 Pa, heated to a lubricant melting temperature of 150-200ºC and the treatment is carried out until a uniform distribution of the lubricant is obtained in the material for 15 - 30 minutes, while the lubricant content in the composite material ranges from 0.01 to 0.1%.

From calculated, according to formula (1), and experimental data, it was established that, depending on the thickness of the insulating coating and the particle size of the initial metallic iron powder, the resulting composite materials can be divided into two classes: low-frequency ($f < 1$ kHz) and high-frequency ($f > 1$ kHz). For subsequent high-frequency applications, powders with a size of less than 100 microns are screened out using a separator; for low-frequency applications, powders with a size of more than 100 microns are screened out. After separation, an insulating layer was applied to the surface of the iron particles.

In the first stage, the lubricant is introduced by mixing it with isolated metal powder in ball mills or other mixers. The composite material prepared with lubricant is placed inside the drum. After this, the vacuum pump is turned on, reducing the air pressure inside the drum with the material to 0.15 - 1.5 Pa. When the required vacuum is achieved, the drum is heated to a temperature of 150 – 200ºC. The powder processing process continues for 15 – 30 minutes. Cooling of the soft magnetic material occurs after turning off the heating while maintaining a vacuum.

The advantage of this method compared to the known ones is the reduction of the lubricant content to 0.01 -0.1%, which makes it possible to subsequently obtain a high-quality pressed product from a soft magnetic composite material with a density of 7.5 - 7.65 g/cm^3 and, as a result, has high magnetic characteristics [7, 8, 10].

Most railway electric vehicles use valve motors, which are used to rotate the main equipment. Some elements of these electric motors are made of composite soft magnetic alloys [1, 4].

As it is known, only three metals have ferromagnetism, i.e. the ability to significantly thicken magnetic field lines, which is characterized by magnetic permeability: for example, iron, nickel, cobalt. The relative magnetic permeability of ferromagnetic metals reaches tens and hundreds of thousands of units. For the rest it is close to unity. If the relative permeability is slightly greater than unity, it is paramagnetic. If it is less than unity, it is diamagnetic [1, 3, 6].

Recently, cores made of composite powder materials with the necessary magnetic characteristics have been widely used. in various devices operating in alternating magnetic fields, At the same time, they have relatively small eddy current losses and high electrical resistivity. The required characteristics are achieved by doping iron-based materials with phosphorus or silicon with the introduction of special dielectric layers from organic and inorganic additives [2, 3, 6].

This makes them competitive with traditionally used laminated electrical steel cores. The use of powder metallurgy methods when molding products of complex shapes, in addition, makes it possible to obtain isotropic materials that change the nature of magnetization, as well as the direction and distribution of the magnetic flux. Composite materials with the required set of performance characteristics are widely used in components of various mechanisms [2, 5].

Certain properties of solids are used in any technical applications. Such as electrical, magnetic, optical, thermal, mechanical, corrosion-resistant, etc. One of the pressing problems of industry today is the production of magnetic materials with low energy losses during magnetization reversal. Despite the fact that research and development of such materials have been carried out

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since the beginning of the last century, studying the mechanism of magnetization reversal and improving the quality of these materials is still relevant today.This is due to the fact that magnetic materials are widely used in various electrical devices (generators, electric motors, measuring installations, inductors, etc.) [4, 6, 7].

2 Experimental research

The purpose of this work is to develop the main elements of two stator-valve motors using composite alloys.

Figure1 shows magnetization curves and magnetic properties of alloys. As indicated in the diagram that curve 2 is the initial magnetization curve [5, 8, 9], curve 1 shows the change in magnetic induction depending on the field strength during subsequent magnetization and demagnetization.

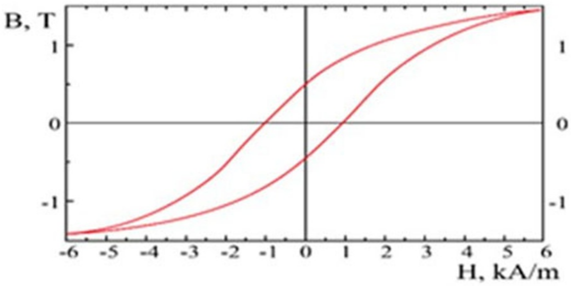


Fig.1. The main magnetization curves of magnetic alloys: 1-hysteresis; 2-primary; + B and –B - magnetic induction; –H and + H - field strength.

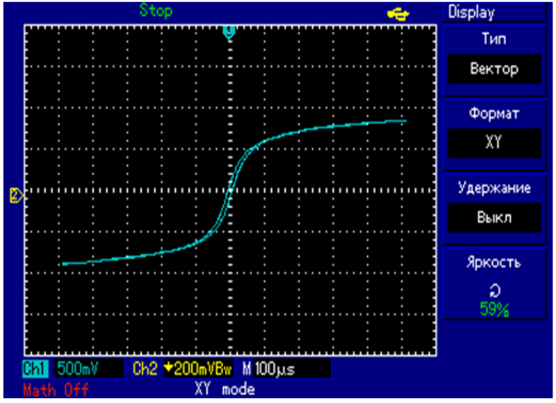
The main area bounded by this curve, which is called the hysteresis loop, represents the so-called hysteresis losses, i.e. energy expended on magnetization. The most important are the following magnetic characteristics, determined from the magnetization curves. It is these characteristics that are shown in Fig. 1 with magnetization curves [5, 6, 8].

The diagram shows that the residual induction Br is the magnetic induction remaining in the experimental sample after it is magnetized and the magnetic field is removed (this is measured in gauss G). Next comes the coercive force Hc, the field strength that must be applied to the test sample in order to demagnetize it (this is measured in oersteds E) [6, 7].

As can be seen from the main course of the initial magnetization curve, the magnetization intensity changes with the change in field strength. The magnetization intensity is proportional to the tangent of the tangent to the initial magnetization curve and is numerically equal to the B/H ratio. The intensity of magnetization is called magnetic permeability, and magnetic permeability in very weak fields is called initial magnetic permeability, the dimension of magnetic permeability is G/E, which is measured in Gaussians and Oersteds [8, 10, 12].

According to their magnetic characteristics, magnetic alloys are divided into two groups: 1-hard magnetic alloys; 2 - soft magnetic alloys. They differ sharply from the shape of the hysteresis curve and the values of the main magnetic characteristics. Hard magnetic alloys are characterized mainly by a large Hc value and are used for permanent magnets, while soft magnetic alloys are characterized by a low Hc value and small hysteresis losses and are used as alloys subjected to alternating magnetization [8, 11]. Hysteresis curves of lines of soft magnetic alloys are shown in Fig. 2.

There are special groups of alloys with high initial magnetic permeability that must be intensively magnetized in weak fields. Alloying a metal causes an increase in magnetic hardness. If only a solid solution is formed (in iron or in another ferromagnetic metal), then the magnetic hardness, i.e. coercive force increases slightly; the formation of the second phase during doping actively increases the coercive force. The higher the dispersal of the second phase in the alloy, the higher its coercive force [7, 8, 10].



Тип
Вектор
Формат
XY
Удержание
Выкл
Яркость
59%

Fig.2. Hysteresis curves for soft magnetic alloy.

The main stresses in the lattice caused by cold hardening or phase transformations, grain refinement and other deviations from the equilibrium state cause an increase in the coercive force [4, 7]. This means that changes in the structure that cause an increase in mechanical hardness, namely, increase magnetic hardness. This justifies the use of terms such as magnetic hardness and magnetic softness of materials.

In contrast to hard magnetic materials - alloys for permanent magnets, where a high coercive force is required, a large group of magnetic alloys are represented by the so-called soft magnetic alloys, which must first of all have a low coercive force [8, 10]. For example, if high magnetic hardness was achieved by obtaining non-equilibrium and highly dispersed structure but, for obtaining magnetic softness it is necessary to get as close as possible to the equilibrium state, and it is also necessary to obtain large grains and eliminate sources causing lattice distortions and fragmentation of blocks.

In addition to low coercive force, magnetic materials must also have high magnetic permeability in weak, medium or strong fields, and low magnetization reversal losses [5, 7, 10].

In our studies, we took the most suitable soft magnetic material as pure metals, primarily pure (technically pure) iron. In some limited cases, alloys not only based on iron, but also other metals, for example, nickel and cobalt, as well as electrical steel were used [6, 9, 12].

Technical iron, in which all impurities, especially carbon, are harmful and therefore their content is strictly limited according to Construction Standards [7, 8, 11].

Industrial production produces three grades of technical iron based on chemical composition, each of which in turn is divided into grades based on magnetic characteristics. The chemical compositions of technical iron are given in Table 1, and the magnetic properties in Table 2. This table presents the grades of iron, the main chemical elements and magnetic properties of these materials [7, 8]. These materials are used in electrical installations and various elements and parts of two stator-valve motors are made from them.

Table 1 The chemical composition of technical iron

Brand gland	Element content, %					
	C	Si	Mn	Cu	P	S
E	≤ 0,04	≤ 0,2	≤ 0,2	0,15	≤ 0,025	≤ 0,3
EA	≤ 0,04	≤ 0,2	≤ 0,2	0,15	≤ 0,025	≤ 0,3
EAA	≤ 0,04	≤ 0,2	≤ 0,2	0,15	≤ 0,025	≤ 0,3

Table 2. Magnetic properties of technical iron

Brand gland	Magnetic properties			
	Coercive strength Ns,uh	Maximum magnetic permeability, G/E	Magnetic induction, gf	
			B10	B25
E	1,2	3500	15000	16200
EA	1,0	4000	15000	16200
EAA	0,8	4500	15000	16200

The magnetic properties of iron (except for its purity) also depend on its structural state. Hardening sharply worsens the magnetic properties, while grain coarsening improves them [10, 12]. In common industrial grades of iron, coercivity is obtained on the order of 1E or slightly lower, while a minimum coercivity value of 0.01· E is obtained on very coarse-grained pure iron. To obtain large grains and eliminate work hardening, the metal is annealed at high temperatures. Technically pure iron was used for the manufacture of cores, relays and direct current electromagnets, magnetic screens, poles of electrical machines and other transport parts [11, 13].

3 Research results

Research has shown that slow cooling is necessary to obtain acicular ferrite. With slow cooling, polyhedral ferrite is obtained (Fig. 3, a). With rapid cooling, a needle-type structure is obtained - needle-shaped ferrite (Fig. 3, b). The hardness of acicular ferrite is 100-150 HB higher than the hardness of polyhedral ferrite.

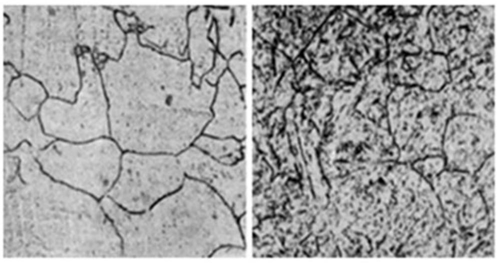

a b

Fig.3. Ferrite microstructure: a-polyhedral ferrite, slow cooling; b-needle ferrite, very fast cooling. X400

Electrical steel is a ferrite alloy of iron with silicon and other alloying elements (Fig. 4). This graph shows almost all alloying elements of the alloys [12].

The iron-silicon solid solution, due to distortions in the lattice caused by the presence of foreign silicon atoms in it, has a higher coercive force than pure iron.

However, in this alloy, when heated, it is possible to obtain large grains, which do not become crushed when cooled, since there is no γ-α transformation, and this in practice leads to the fact that the value of the coercive force in such a material is no greater than in ordinary iron. The higher electrical resistance of silicon-doped ferrite reduces losses due to Foucault currents [8, 11]. Naturally, a change in the dimensions of especially the α-lattice also causes a change in the properties of ferrite - the strength increases, and the ductility decreases. Changes in the properties of ferrite, for example, hardness or toughness when various elements are dissolved in it (see Fig. 4). As can be seen from the diagrams, chromium, tungsten, and molybdenum strengthen ferrite less than nickel, silicon, and manganese. Molybdenum, tungsten, as well as silicon and manganese (if present in more than 1%) reduce the viscosity of ferrite. Chromium reduces the viscosity much more weakly than the listed elements, and nickel does not reduce the viscosity of ferrite, but on the contrary slightly increases it [12, 13].

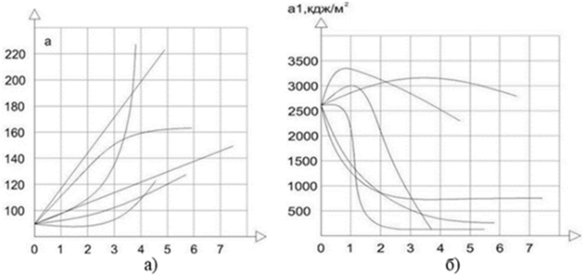


Fig.4. Actual influence of alloying elements on ferrite properties: a-hardness; b-toughness.

Electrical steel is made in the form of thin sheets, which are used for the manufacture of transformer cores, magnetic cores of electrical machines and alternating and direct current devices. This sheet electrical steel (Construction Standards 21473-75) is divided by product range - mainly by thickness, production method - cold-rolled and hot-rolled sheet, degree of anisotropy, as well as basic magnetic characteristics - magnetic induction and specific losses and degree of silicon alloying [11, 14].

It should be added that the specific losses due to magnetization reversal are lower, the thinner the sheet, therefore electrical steel is manufactured only in the form of thin sheets with a thickness of 0.35 to 0.50 mm. If during the manufacturing process of transformer parts, the steel was subjected to even slight plastic deformation, for example, cutting sheets, bending, etc., then the magnetic properties deteriorate. To restore magnetic properties, it is recommended to carry out annealing to relieve stress (eliminate distortions in the lattice) at a temperature of 750-800°C with slow (<50°C/h) cooling.

This means that to restore deformable magnetic properties, the optimal heat treatment mode is used - annealing, which is carried out at the above temperature [11, 14]. It must be remembered that all manufactured elements or parts of transformers, magnetic circuits of electrical machines and alternating and direct current devices are subjected to heat treatment, namely annealing together with a furnace. To do this, you can choose an electric furnace of the SNOL type with a heating temperature of up to 1000°C [9, 12, 13].

In connection with the above, it can be said that currently at the Tashkent State Transport University, scientific research is being carried out to develop the use of composite soft magnetic alloys for two stator-valve motors of electric vehicles.

4 Conclusion

The results of testing magnetic cores made of composite soft magnetic material using the developed method showed the following characteristics:

1. Magnetization reversal losses for magnetic cores P = 90 W/kg at a frequency of 1 kHz.
2. Hysteresis losses per cycle for components based on the new composite material do not depend on frequency and amount to p = 0.08 J/cycle.
3. A decrease in the thickness of insulating coatings leads to an increase in the induction value at 20 kA/m from Bm = 1.7 Tesla to Vm = 1.85 Tesla and to a corresponding increase in hysteresis losses from P = 80 W/kg to P = 90 W/kg at a frequency of 1 kHz.

References

1. Rahman, K.M.; Patel, N.R.; Ward, T.G.; Nagashima, J.M.; Caricchi, F.; Crescimbini, F. Application of direct-drive wheel motor for fuel cell electric and hybrid electric vehicle propulsion system. IEEE Trans. Ind. Appl. 2006. - P.42, 1185-1192.
2. Chau, K.T.; Chan, C.C.; Liu, C. Overview of Permanent-Magnet Brushless Drives for Electric and Hybrid Electric Vehicles. IEEE Trans. Ind. Electron. 2008. - P.55, 2246-2257.
3. Berdiev, UT , Kolesnikov, IK , Tuychieva, MN , Khasanov, FF , Sulaymonov, UB Methods of new technological developments of electric motors based on soft magnetic materials . E3S Web of Conf. Volume 401, 2023. 03038. https://doi.org/10.1051/e3sconf/202340103038
4. Usan Berdiev, Abitkhodja Burkhankhodzhaev, Malika Tuychieva. Investigation of energy indicators with asymmetry of the voltage of the power source of mainline electric locomotives of alternating current. Cite as: AIP Conference Proceedings 2552, 030018 (2023); https://doi.org/10.1063/5.0131839 Published Online: 05 January 2023
5. Optimization of the method of oxide coating of metallic iron powder particles. Usan Berdiyev, Olga Demedenko, Mirjalol Ashurov, FF Hasanov and UB Sulaymonov. E3S Web Conf., 383 (2023) 04039. DOI: https://doi.org/10.1051/e3sconf/202338304039
6. Wang, J.; Patel, V.I.; Wang, W. Fractional-Slot Permanent Magnet Brushless Machines with Low Space Harmonic Contents. IEEE Trans. Magn. 2013-P.50,1-9.
7. Y.M.Dovgalevsky. Alloying and heat treatment of hard and soft magnetic alloys. – M.: Metallurgizdat, 2000. - 178.
8. Govor G.A., Vecher A.K., Berdiev U.T., Pirmatov N.B., Karabaev A., Khasanov F.F. Magnetically soft iron-based materials used in electrical engineering, Bulletin of TashIIT, 2019. No. 3. - 212-218 p..
9. Govor G.A., Mikhnevich V.V., Mityuk V.I., Berdiev U.T., Pirmatov N.B., Berdiyorov U. Magnetically soft materials based on iron. Problems and prospects of innovative equipment and technologies in the agricultural and food sector // Collection of scientific papers of the International scientific and scientific-technical conference. - Tashkent. Tashkent State Technical University, 2020. 76-77 p.
10. Govor G.A., Berdiev U.T., Pirmatov N.B., Urakov S. Magnetic soft materials based on iron. Problems and prospects of innovative equipment and technologies in the agricultural and food sector // Collection of scientific papers of the International Scientific and Scientific-Technical Conference. -Tashkent. Tashkent State Technical University, 2020. 85-86 p.
11. Rahman, K.M.; Patel, N.R.; Ward, T.G.; Nagashima, J.M.; Caricchi, F.; Crescimbini, F. Application of direct-drive wheel motor for fuel cell electric and hybrid electric vehicle propulsion system. IEEE Trans. Ind. Appl. 2006, -P.42,1185-1192.
12. Cao, R.; Mi, C.; Cheng, M. Quantitative Comparison of Flux-Switching Permanent-Magnet Motors with Interior permanent magnet motor for EV, HEV, and PHEV Applications. IEEE Trans. Magn. 2012. - P.48, 2374-2384.
13. Kolesnikov I.K. Criteria for the Efficiency of an Electric Drive based on the mechanical conversion of Energy to be completed. Oriental Renaissance: Innovative, educational, natural and social sciences. 2023-yil, march, 737-743-p
14. .Kolesnikov, I., Yaronova, N., Ametova, A. Building a “Smart” Electric Network Using 5G and Unmanned Aircraft AIP Conference Proceedings, 2022, 2432, 030037
15. Abduraxman Akhmedov, Galina Sauchuk, NatalliaYurkevich, Sardorbek Khudoyberganov, MahammatyakubBazarov, KarimberdiKarshiev; The influence of production conditions on the electrophysical parameters of piezoceramics for different applications. E3S Web Conf. 264 04020 (2021), DOI: 10.1051/e3sconf/202126404020
16. R. Mirsaatov, S. Khudoyberganov, A. Akhmedov; Uncertainty estimation in determination of Cocoons silkiness by thickness of their shell. AIP Conference Proceedings 15 March 2023; 2612(1):050010. https://doi.org/10.1063/5.0114683