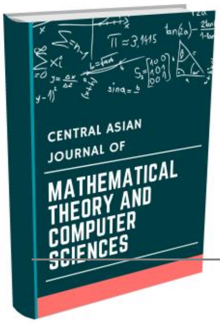

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FERROMAGNET MATERIALS USED IN MAGNETIC CIRCUITS AND THEIR DESCRIPTIONS

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Abstract

In the article, the factors affecting the magnetic properties of electrical steel used in magnetic chains are studied, and the use of cold-worked anisotropic ferromagnetic materials is recommended for the development of devices with high sensitivity and measurement accuracy, and specific recommendations for the use of ferromagnetic materials are developed.

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I. INTRODUCTION

Various ferromagnetic materials which are used in the magnetic systems of electrical devices used in various industries as well. According to the characteristics of the magnetic materials in these electrical appliances, they are divided into soft magnetic and hard magnetic materials.

Examples of soft magnetic materials include carbon and alloyed mild steel, electrical steel, some grades of cast iron with high magnetic absorption and high saturation induction, and thermomagnetic alloys. The theoretical foundations of these ferromagnetic materials have been studied by several foreign and national scientists. However, there are no specific guidelines for the exact application of magnetically soft and magnetically hard electrotechnical materials. In order to facilitate the user and the manufacturer, we analyze the technical specifications of currently used electrotechnical materials and develop instructions for their use. In the table below, we present the main brands of electrotechnical steels used in magnetic systems of electrical devices.

Alloyed electrical steel grades							Non-alloyed electrical steel grades			
1211	1212	1213	1311	1312	1313	1411	108**32**	108**50**	108**64**	108**95**
1412	1413	1511	1512	1513	1514	1521	118**48**	118**60**	118**80**	208**32**
1561	1562	1571	1572	2011	2012	2013	208**50**	208**64**	208**95**	218**48**
2111	2112	2211	2212	2213	2214	2215	218**60**	218**80**	108**48**	108**60**
2216	2311	2312	2411	2412	2413	2414	108**80**	118**32**	118**50**	118**64**
2421	3311	3404	3405	3406	3407	3408	118**95**	208**48**	208**60**	208**80**

3409	3411	3412	3413	3414	3415	3416	218**32**	218**50**	218**64**	218**95**
3421	3422	3423	3424	3425	**--**	**--**	**--**	**--**	--	--

The first number in the grades of electrical steel means the structure and processing method of the metal: 1- hot-worked, 2- cold-worked isotropic electrical steel, 3- cold-worked anisotropic electrical steel.

The second number represents the percentage of silicon in the metal, or the norm of the wear coefficient in unalloyed steel: 0 - silicon content is less than 0.4% (the wear coefficient is not normalized), 1- silicon share 0.8% (standard wear coefficient), 2- silicon share 1.8%, 3- silicon share 2.8%, 4- silicon share 3.8%, 5- silicon share 4.8%.

The third number represents the group of the main electromagnetic characteristics of the metal: coercive force, magnetic induction, etc.

The fourth and fifth numbers represent the value of coercive force (A/m) of the metal.

II. USE OF FERROMAGNETIC MATERIALS

When making magnetic systems of electrical devices using electrotechnical materials, it is necessary to pay special attention to their saturation induction. The value of saturation induction in hot-treated alloyed electrical engineering materials is 1.2÷1.53 Tl, and in non-alloyed electrotechnical materials, the saturation induction value is in the range of 1.54-1.62 Tl, in cold-worked alloyed electrotechnical steel, it is 1.49-1.64 Tl for isotropic materials, 1.7-1.9 Tl for anisotropic materials, in non-alloyed electrotechnical materials, it is in the range of 1.54-1.62 Tl (induction values were obtained for the case where the magnetic field strength is equal to 2500 A/m).

Before using ferromagnetic materials, parameters of the hysteresis surface of these materials (coercive force H_k, residual magnetic induction B_q, saturation magnetic induction B_t, the maximum value of the magnetic field strength H_m) is required to know. In most cases, these parameters are not fully known. It is required to use several available methods (formulas) for modeling the hysteresis surface or to determine them experimentally. In this case, it is necessary to know which formula should be used for which material.

In the development of measuring devices and transducers (sensors), soft magnetic materials are used as their magnetic systems. Among them, cold-worked anisotropic electrical steel grades are widely used in the development of devices with high sensitivity and measurement accuracy due to their high saturation induction.

III. FACTORS AFFECTING THE PROPERTIES OF FERROMAGNETIC MATERIALS

In the development of electrical appliances, along with the technical parameters of steel, it is necessary to take into account its price, that is, the relative price increases as the thickness of the material decreases. Also, when electrotechnical steel is subjected to mechanical and thermal processing (cutting, joining, bending, surface and edge cleaning, etc.), changes in the internal structure of the magnetic material and, in most cases, deterioration of its properties (decrease in magnetic absorption, increase in coercive force) are observed. As a result of mechanical and thermal treatment of the finished magnetic conductor, the properties of the insulation between the plates deteriorate or become completely conductive. This, in turn, leads to increased residual currents in the magnetic system and losses in steel. As a result of cutting electrotechnical steel, material waste increases 2÷2.5 times and magnetic absorption decreases up to 2.5÷3.5 times. In the formation of magnetic cores, steel plates are hardened with a certain pressure through a bolt. In this case, as a result of the increase in the hardening force, the waste in the ferromagnetic material increases by approximately 2 times. In order to eliminate the mechanical stress in the magnetic material, it is necessary to anneal all the details of the magnetic conductor. Depending on the brand, structure and size of the material, the temperature for annealing is selected. For example, a magnetic conductor made of electrical steel plates is annealed at a temperature of 720-780^{0}C for 1-1.5 hours and cooled to a temperature of 200-250^{0}C in a furnace with a cooling rate of 40-60^{0}C per hour.

During the use of magnetic materials at a certain temperature, a change in their properties is observed. It is known that electrical devices with a magnetic system are used in different temperature conditions. During operation, individual parts of the magnetic conductor sometimes heat up to a temperature of 1000C and higher. Temperature has a negative effect on the magnetization curve, residual induction, initial magnetic absorption and other parameters of the magnetic material.

When a ferromagnetic material is heated under the influence of a magnetic field, the magnetism of the material decreases relatively slowly at first, and after a certain temperature it decreases rapidly, and the material completely loses its magnetic properties and becomes paramagnetic. This temperature is the critical temperature for the material concerned. Also, an increase in temperature leads to a decrease in the values of coercive force, saturation induction of ferromagnetic materials and an increase in residual induction, magnetic absorption (around the critical temperature), specific electrical resistance. Therefore, in the process of using ferromagnetic materials, it is necessary to develop measures to ensure that they are not used at a temperature higher than the permissible working temperature.

IV. CONCLUSION

By analyzing the technical specifications of ferromagnetic materials used in the magnetic circuits of electrical devices used in various industries, the following recommendations were developed:

- when the magnetic material of the manufactured electrical device is required to have high magnetic absorption, low coercive force (not more than 4kA/m), low energy consumption due to cumulative currents, high saturation induction, wear resistance, and having a clearly shaped hysteresis surface, soft magnetic materials are used. it was determined that it should be used;
- the manufactured electrical device is made of hot-worked alloyed when the working inductance is up to 1.5 Tl, hot-worked unalloyed or cold-worked alloyed electrotechnical materials when the working induction is up to 1.6 Tl, cold-worked alloyed anisotropic materials when the working induction is up to 2 Tl recommended to use;
- in the development of devices with high sensitivity and measurement accuracy, it is recommended to use cold-processed anisotropic electrotechnical materials;
- mechanical and thermal treatment of finished electrotechnical steel plate is not recommended;
- it is recommended not to use magnetic cores made of electrotechnical steel at temperatures exceeding the specified temperature.

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