Injection molded dielectromagnets with zero value temperature coefficient of coercivity

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Abstract: Dielectromagnets are permanent magnets prepared by bonding hard magnetic powders by dielectric. Decisive for dielectromagnets characteristics is used hard magnetic powder. Using mixture of hard magnetic powders instead of one kind of it enables us to control magnetic and thermal properties of dielectromagnets and to develop dielectromagnets with properties adequate to application. In research different mixture compositions of powders of strontium ferrite and Nd-Fe-B melt-spun ribbon were used. The advantage of strontium ferrite dielectromagnets is their positive value of temperature coefficient of coercivity, at the same time weakness of Nd-Fe-B dielectromagnets. The aim of research is to develop injection molded dielectromagnets with temperature coefficient of coercivity near zero. Temperature coefficient with zero value was obtained in dielectromagnets with 10 vol. % of MOP-A and 90 vol. % of ferrite powder. Such dielectromagnets have following magnetic properties: \( B_y = 0.16 \) T, \( H_c = 350 \) kA/m, \( H_{ce} = 100 \) kA/m, \( (BH)_{max} = 5.0 \) kJ/m³.

Key words: dielectromagnets, hard magnetic powders, injection molding, magnetic properties, thermal properties.

1. Introduction

Development of electrical machines is closely connected with development of permanent magnets. The industry offer of permanent magnets is very wide: from bonded ferrite magnets to die-upset Nd-Fe-B magnets.

![Magnetic properties of permanent magnets.](image)

Figure 1 shows properties of few kinds of permanent magnets prepared from different materials and by different technologies. Permanent magnets have different magnetic properties depending on materials and technology, they have also different thermal properties and different prices. So many kinds of permanent magnets on the market enable us to choose magnets with properties adequate to application. In last years development of bonded magnets is observed, especially from Nd-Fe-B alloys. This kind of permanent magnets, comparing with sintered magnets made from the same hard magnetic powder, have worse magnetic properties, but they are cheaper. Properties of bonded magnets, known also as dielectromagnets, are suitable for many application. Technology of dielectromagnets permits to control magnetic, thermal and mechanical properties. There are two main ways of preparing dielectromagnets: compression molding and injection molding. These methods enable us to prepare dielectromagnets with complicated shapes with high dimension tolerances. Dielectromagnets can be made also by extrusion and calendering [1]. Dielectromagnets from ferrite powder are known since a long time. Energy products of ferrite dielectromagnets are approximately between 2.4 to 12.8 kJ/m³. They are used mainly in door seals, motor arc segments, permanent magnet motors, magnetic signs and sensors. Energy products of Nd-Fe-B dielectromagnets reach value in range between 24 to 80 kJ/m³. They are used mainly in permanent magnet motors, computer peripheral motors. Dielectromagnets from ferrite and Nd-Fe-B powders differ in magnetic and thermal properties and in price. For ferrite magnets temperature coefficient of coercivity has high positive value of about +0.30 %/°C, for Nd-Fe-B dielectromagnets value of this coefficient is about -0.40%/°C. Negative value of coercivity means, that coercivity decreases in elevated temperature - it is weakness of Nd-Fe-B dielectromagnets. It eliminates many applications of this kind of dielectromagnets. Comparison of characteristics of dielectromagnets from ferrite and Nd-Fe-B powders produced in effect idea to prepare dielectromagnets from mixture of these powders by compression molding. It was done in the past [2, 3, 4].

The purpose of presented investigation is to develop dielectromagnets by injection molding from mixture of hard magnetic powders with zero temperature.
coefficient of coercivity, it means, that coercivity of this dielectromagnets will stay constant in room and elevated temperatures.

2. Experiments

The Nd-Fe-B powders from melt-spun ribbon for compression and injection molding are commercially made by General Motors. Magnetic properties of MQP-A used in experiments are: \( B_r = 0.73-0.77 \) [T], \( H_c = 1040-1360 \) [kA/m], \( \mu H_c = 504 \) [kA/m], \( (BH)_{max} = 96 \) [kJ/m\(^3\)]\[5\]. In experiments MQP-A powder in mixture with ferrite was used. As a binder polystyrene of thermoplastic binder was used. The mixture of hard magnetic powders for different samples was changed from 100 vol. % of MQP-A to 100 vol. % of ferrite. The first step in preparation of samples of magnets was preparing granules for injection. The composition of granules was 50.0 vol.% of hard magnetic powders and 50.0 vol.% of binder. Coupling agent was not used in trials. The samples for investigation were prepared on the laboratory piston machine under constant conditions: injection temperature of 220\(^\circ\)C, injection pressure of 100 MPa. The dimensions of samples were 9.0 mm in diameter and 4.0 mm in height. Magnetic properties were measured by Permagraph - Hysteresisgraph in room temperature.

To define temperature coefficient of coercivity the magnetic properties of samples in the range of temperatures 24\(^\circ\)C-120\(^\circ\)C were measured. The results of measures were the base for calculation of temperature coefficient of coercivity.

3. Results and discussion

Magnetic properties of prepared samples are shown in figure 2.

Figure 2 shows decrees of magnetic properties of dielectromagnets with increasing ferrite powder content in mixture of powders. Remanence \( B_r \) and coercivity \( H_c \) change proportionally to changes of mixture's composition. Calling attentions are changes of coercivity \( H_c \) and energy product \( (BH)_{max} \). Although samples from pure Nd-Fe-B powder have coercivity about 1200 kA/m, coercivity of samples where in mixture of powders is 50 vol. % of Nd-Fe-B and 50 vol.% of ferrite powder is 1050 kA/m. Drop in coercivity is only 12.5 %, and then coercivity drop rapidly. Energy product for pure MQP-A powder is 40.0 kJ/m\(^3\), for samples with 50 vol. % of ferrite energy product fall to 12 kJ/m\(^3\). The change is about 70 %.

Fig. 2 Magnetic properties of injection molded dielectromagnets with different powder composition.
Figure 3 shows correlation between temperature coefficient of coercivity and powder's composition.

![Graph showing correlation between temperature coefficient of coercivity and MOP-A content.]

**Fig.3.** Temperature coefficient of coercivity for dielectromagnets with different composition.

Changes of value of temperature coefficient of coercivity are very slowly in the range from 100 vol.% to 25 vol.% Nd-Fe-B content in mixture of powders. In this range temperature coefficient of coercivity has negative value. Temperature coefficient with zero value was obtained dielectromagnets with 10 vol.% of MOP-A powder. Such dielectromagnets have following magnetic properties: $B_r = 0.16 \, T$, $H_{c1} = 350 \, kA/m$, $B_H = 100 \, kA/m$, $(BH)_{max} = 5.0 \, kJ/m^3$.

For all dielectromagnets temperature coefficient of remanence has negative value, because it is negative for both dielectromagnets from Nd-Fe-B only and from ferrite only.

### 4. Summary

To summarize, investigation confirmed possibility of preparing by injection molding dielectromagnets from mixture of hard magnetic powders. This technology permits to develop dielectromagnets, which connect good points of dielectromagnets from only one kind of hard magnetic powder. Injection molded dielectromagnets from mixture of Nd-Fe-B and ferrite powders have magnetic properties better than dielectromagnets from ferrite only, temperature coefficient of coercivity better than that of from Nd-Fe-B only. At the same time they are cheaper than dielectromagnets from pure Nd-Fe-B powder only. The zero temperature coefficient of coercivity of dielectromagnets with about 10 vol.% addition of Nd-Fe-B powder may be treated as ferrite bonded magnets with improved magnetic properties and insignificantly increased price. It makes possible for micromachines designers to choose right magnets for each particular application preventing wasting of energy and improving efficiency of constructions.

### References

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