A comparison of chosen permanent magnets arrangements for high gradient magnetic fields generation

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Abstract: - In the paper, there are several permanent magnet configurations for high gradient static magnetic field generation and magnetic field distribution in a workplace. There are mentioned their comparisons and finally, there are presented some results of model measurement.

Key-Words: - Permanent magnets, high gradient magnetic fields

1 Introduction

To generate a stationary high gradient magnetic field, it is possible to use either suitable DC current-carrying coils arrangement or corresponding permanent magnet system. The disadvantage of coils is generating of a weaker magnetic field compared with permanent magnets. The coils must be supplied with electrical current and then they warm up, but it is possible to annul magnetic field by power supply cut-off. While using permanent magnets, they must be dismantled for magnetic field nullification.

There are series of permanent magnet arrangements for high gradient magnetic field generation. In this short paper I can mention only a few selected systems.

There are four families of permanent magnets. They are Alnico, ferrite, SmCo and NdFeB. Permanent magnets $Nd_2Fe_{17}B$ and SmCo ($SmCo_5$ and Sm_2Co_{17}) are characterized by high coercivity, remanence and energy product $(BH)_{max}$.

For this purpose, the most suitable are permanent magnets made of high coercivity materials to be able to resist to demagnetising fields generated by other magnets in the arrangement. The optimal materials are NdFeB alloys. They are relatively cheap and have excellent magnetic properties, see e.g. [1].

NdFeB magnets are manufactured in four distinct varieties: hot pressed, die upset, sintered and bonded. Bonded magnets offer greater manufacturing flexibility over others, but the magnetic performance of them is limited by amount of used polymer (maximum 45%).

While using these permanent magnets, it must be ensured that working temperature does not exceed 150°C because Curie temperature is only 310°C. If it exceeds the temperature of 150°C, it is necessary to use SmCo permanent magnets, but they are essentially more expensive. It is possible to find some available permanent magnets on internet pages, too, see e.g . [2], [3]. As a reference, there are stated demagnetising characteristics of most important permanent magnets in Fig. 1.

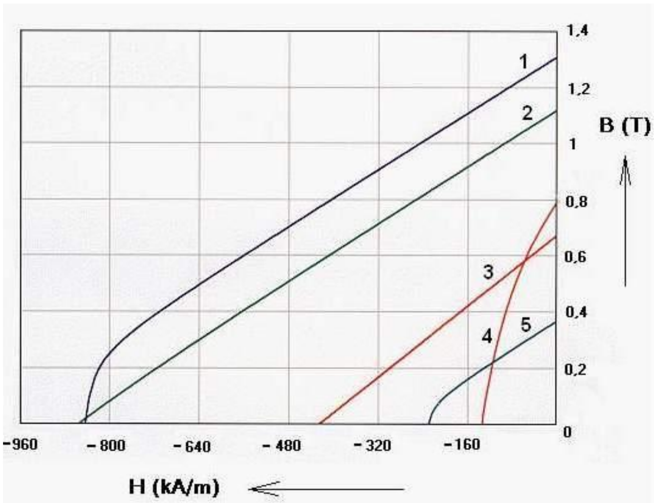


Fig. 1 Reference demagnetisation characteristics of main permanent magnet types
1 – NdFeB, 2 – SmCo, 3 - bonded NdFeB, 4 – Alnico, 5 – ferrite

Demagnetisation curve NdFeB material used by us has been very similar, but a little worse than 2.

We can see in the Tab.1 that the highest Curie temperature is in alloys Sm_2Co_{17} that are comparable to Curie temperatures in Alnico alloys. However, Alnico alloys are not applicable in this application for the reason of minimal coercivity.

Tab. 1 Main magnetic properties comparison of some SmCo and NdFeB alloys

Magnetic properties	**Coercivity H_{CB} [kA/m]**	**Remanence Br [mT]**	**Energy product $(BH)_{max}$ [kJ/m^3]**	**Curie temperature T_c [°C]**
$SmCo_5$ 140/175	640-690	800-850	140-155	720
$SmCo_5$ 160/175	680-710	900-925	160-170	720
Sm_2Co_{17} 175/160	700-730	960-1010	175-200	825
Sm_2Co_{17} 190/160	720-790	1030-1060	190-215	825
Fe-Nd-B 195/175	760-830	1020-1090	195-220	310
Fe-Nd-B 210/160	780-850	1050-1120	210-240	310
Fe-Nd-B 255/125	800-870	1090-1170	225-255	310
Fe-Nd-B 240/95	830-870	1130-1200	240-265	310

2 Applied analysis method

In order to find the magnetic field distribution in the area of permanent magnets arrangement, it is used the Finite Element Method. The applied programme is FEMM, available on web pages [4]. The programme solution is 2D and programme itself is very user-friendly. As usually, FEMM contains preprocessor, processor and postprocessor like other similar programmes. Preprocessor enables an easy input of the variables (geometry, material characteristics, boundary conditions - Dirichlet's conditions used here) and a choice of accuracy solution, which influences the computing time. There is also an opportunity of mesh density choice. In the part called the processor, there is a solution of equation for vector potential $\vec{A}$. For magnetostatic tasks we can write

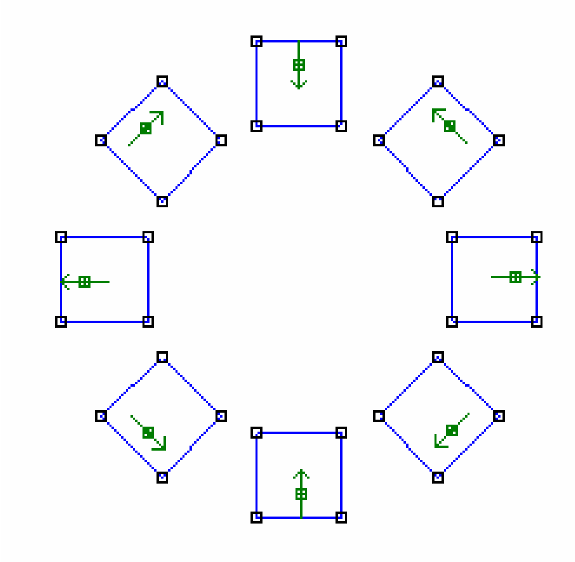
$$-\frac{1}{\mu}\nabla^2\vec{A} = \vec{J} \qquad (1)$$

From the calculated vector potential, which has only one component, it is possible to determine magnetic field quantities B and H. Postprocessor is a graphic programme, which enables to display final field. Finally, it also enables to give you an output in form of data with a possibility of following processing in Excel, for example.

3 Some important magnet arrangements

There is a set of different permanent magnet configurations for a high gradient magnetic field formation. At this paper, I deal with the octopole, which has been designed on the base of a quadrupole and an opposite quadrupole [5] complemented by transverse oriented permanent magnets. The octopole which arose from the extension of a basic quadrupole analysis is performed firstly, see Fig. 2.

a)



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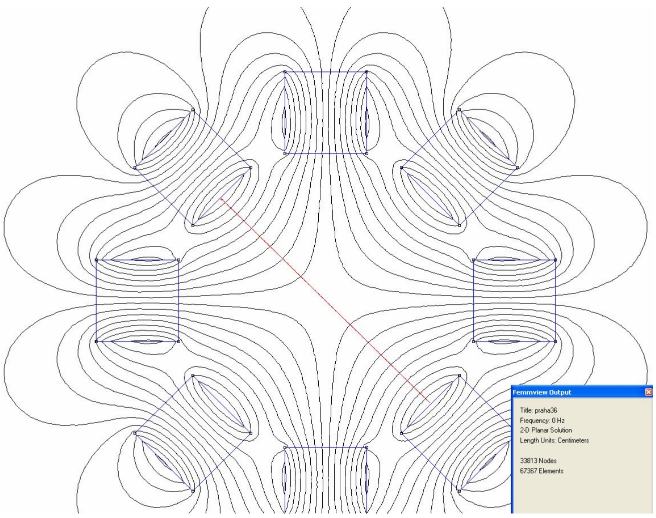
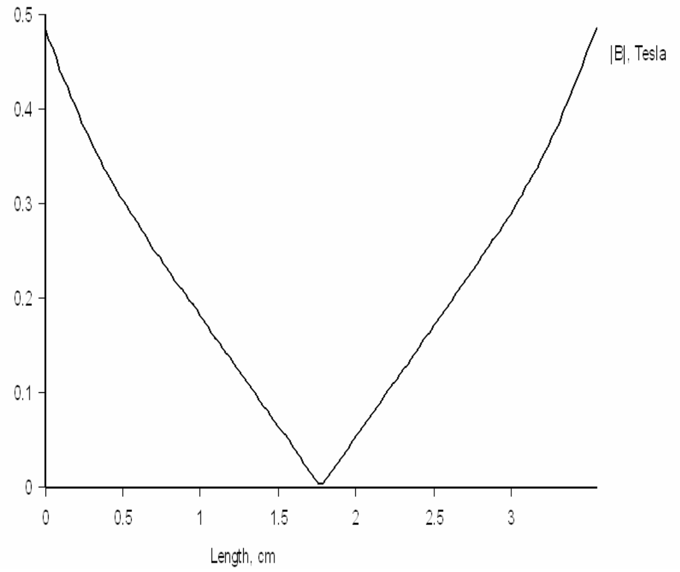


Fig. 2: The octopole based on basic quadrupole

Explanatory text to Fig. 2
a) permanent magnet of basic octopole arrangement
b) flux lines with abscissa connecting the transverse permanent magnets

c)



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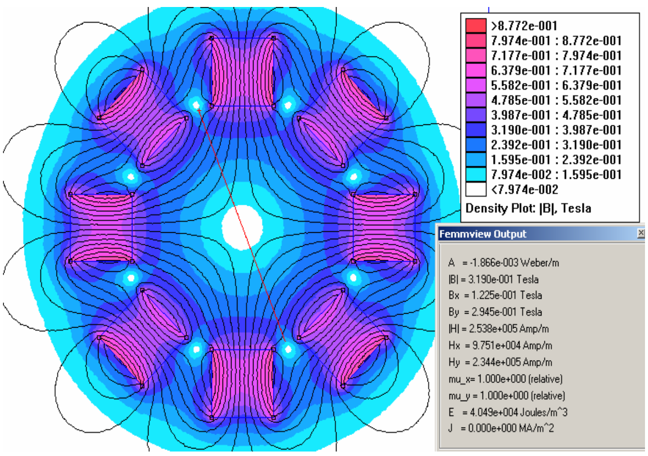

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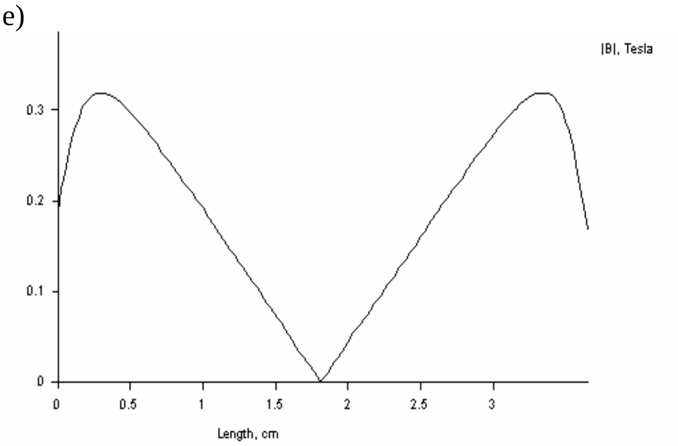
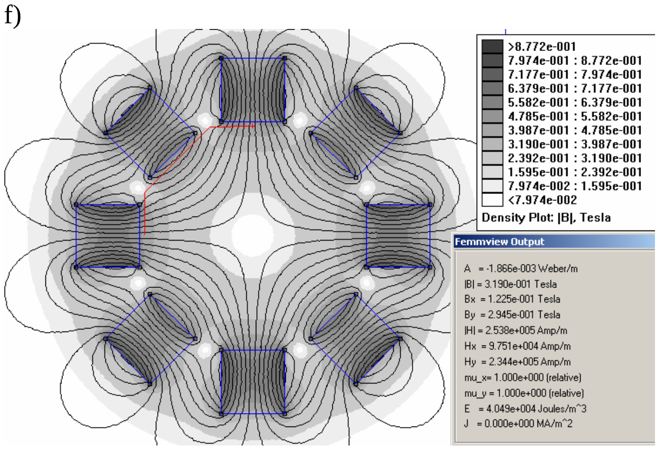


Explanatory text to Fig. 2

c) magnetic flux density along the abscissa from the point b)
d) magnetic flux density distribution colour map with abscissa connecting the interspaces
e) magnetic flux density along the abscissa from point d)
f) magnetic flux density distribution map with broken line connecting centres of Basic quadrupole
g) magnets magnetic flux density curve along the broken line from point f)

f)



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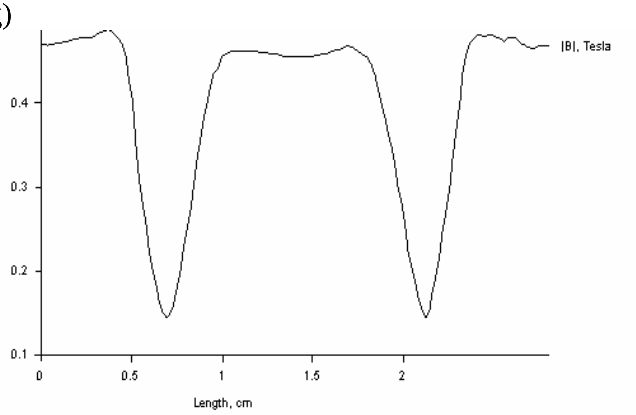
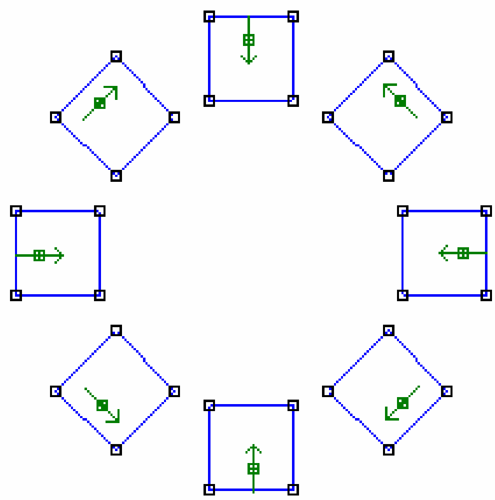


Fig. 2 The octopole based on basic quadrupole -cont.

The octopole based on opposite quadrupole is presented in Fig. 3.

a)



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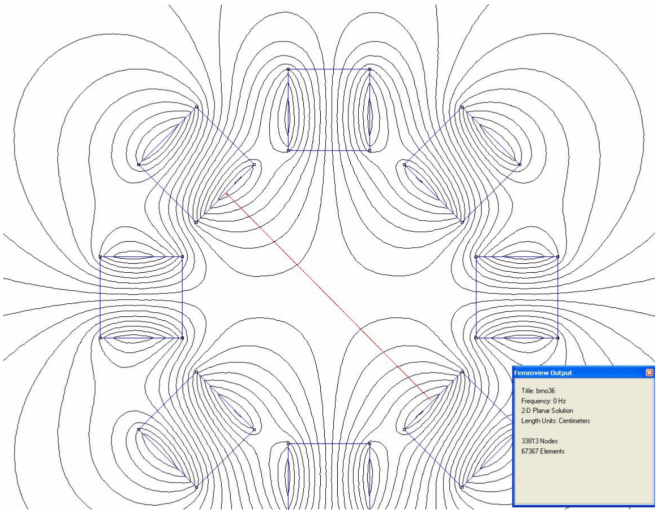

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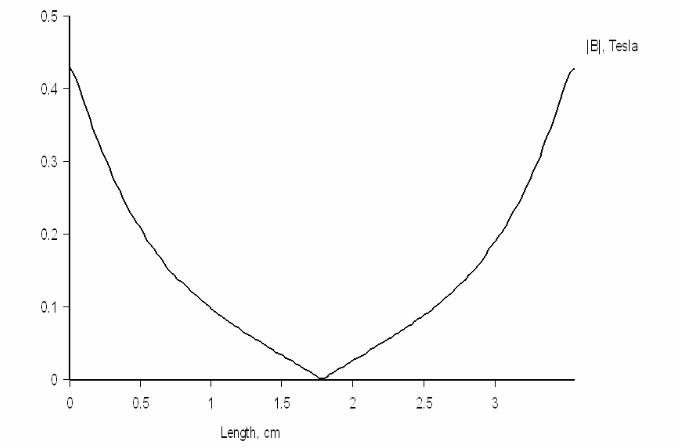

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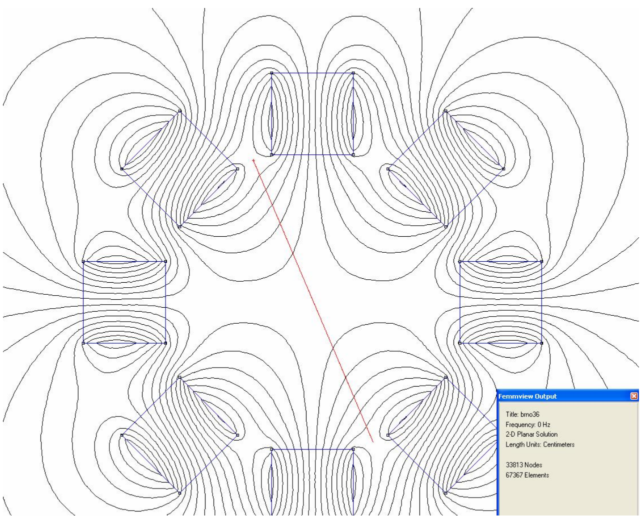

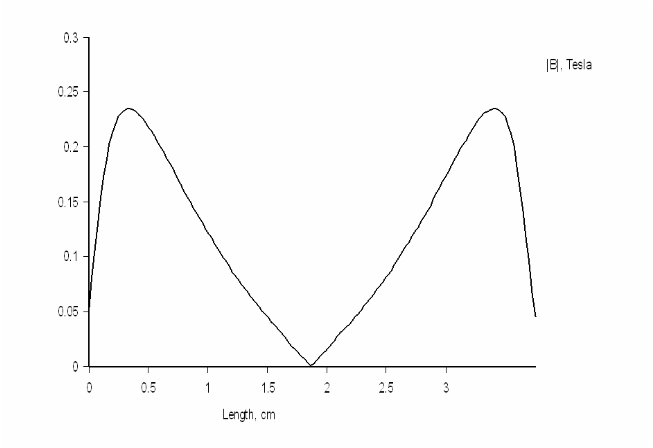

e)

e) Fig. 3 The octopole based on opposite quadrupole

Explanatory text to Fig. 3

a) permanent magnets of opposite octopole arrangement

b) flux lines with abscissa connecting the transverse permanent magnets

c) magnetic flux density along the abscissa from point b)

d) flux lines with abscissa connecting the interspace between transverse and basic permanent magnets

e) magnetic flux density curve along the abscissa from point d)

4 Measuring arrangement and some results of measurements

In order to carry out the measurements, permanent magnets were placed in the holder. The holder is presented in Fig. 4.

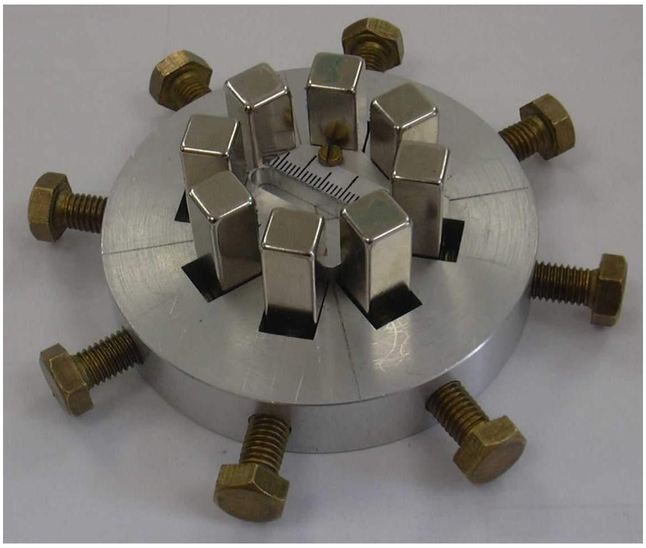

Fig 4: Permanent magnets holder

In spite of used permanent magnets (10 x 10 x 39 mm, magnetisation direction is upright to plane 10 x 39 mm) that are characterised by high coercivity (c. 800 kA/m), it is suitable to assembly them to prevent them from touching each other. Finally, the danger of mechanical damage is eliminated (force effects are very strong). The results of two measurements are stated in Fig. 5.

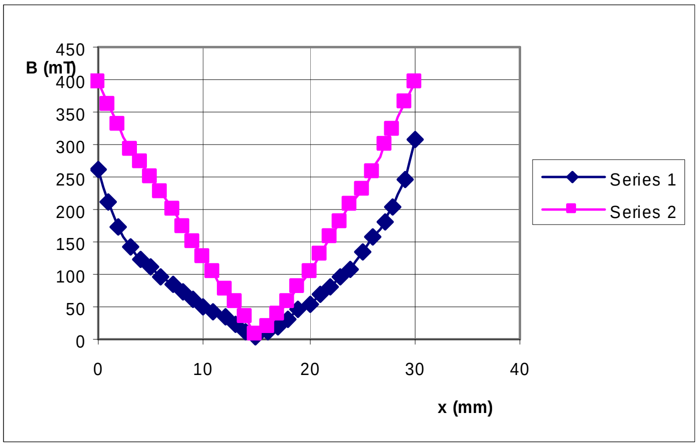

Fig 5: Measured magnetic flux density distribution curve of opposite octopole (series 1) and basic octopole (series 2 – upper)

The centre of the system is in 18 mm on the axis “x”. It is not possible to measure up to extreme system limits. The conclusion of this figure shows that a gradient of the generated magnetic field is high (c. 0,22 T /cm).
In Fig. 2 and Fig. 3, there are presented two opposite configurations with inner diameter of 36 mm. When these permanent magnets configurations are used for particles separation (e.g. iron dust), it is necessary to monitor two important parameters – magnetic flux density gradient and magnetic flux density value. These values can be compare when the basic octopole diameter changes from 36 to 26 mm (the comparison of Fig. 2b and Fig. 6).

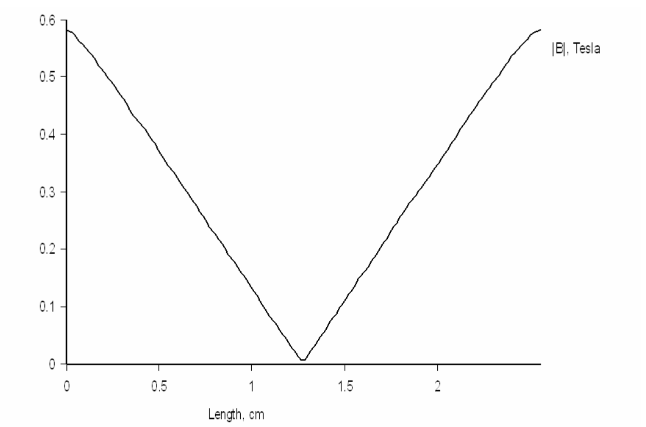

Fig. 6. Calculated magnetic flux density for basic octopole inner diameter 26 mm

5 Conclusion

There are series of permanent magnets arrangements useful for high gradient magnetic field generation. In this paper, there have been discussed only the arrangements, whose quadrupole and opposite quadrupole are completed by across oriented permanent magnets. As one of the results of the measurements on the model, it is mentioned only the magnetic flux density arrangement in octopoles working gaps on the join among transverse permanent magnets. When we compare the results of measurements with theoretical values, we can state relatively good correspondence. The measurement was carried out only at indoor temperatures. The temperature dependence of permanent magnets characteristics is presented in [6], in this text, this issue was mentioned only a little. More extensive analysis of thermal properties can be found in e.g. [1] , [2].

References:

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