INFLUENCE OF DIFFERENT INNER HEXAPOLE RADIUS ON CONSTRUCTION OF ECR ION SOURCE HEXAPOLES: NEW RESULTS *

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Abstract

The paper presents new data concerning dimensions of permanent magnets which are used for construction of suitable hexapoles for Electron Cyclotron Resonance Ion Sources (ECR IS). Permanent magnets are made from FeNdB magnetic materials. The main attention is given to hexapoles with hexapole thickness of 2.8 cm at different inner diameters of $\phi D \in \langle 3.6, 12 \rangle$ cm. An influence of inner radius r_H ($r_H \in \langle 1.8, 6 \rangle$ cm) of hexapole to the maximum value of the magnetic field inside hexapole is investigated.

1 INTRODUCTION

About 33-year history of Electron Cyclotron Resonance Ion Sources (ECR IS) has already shown that ECR IS is an ideal tool for the production of multicharged ions. ECR IS have been used continuously in many fields of science. They are very efficient tools for providing highly charged ions for atomic and nuclear research, material science, and surface physics. There have been various attempts to increase beam intensity and charge state of ions producing by ECR IS. The multi-frequency heating has proved an effective way to increase both the number and widths of the ECR zones. Wall coating in the inner wall of plasma chamber was used in order to supply the plasma chamber more electrons. Despite of these attempts, only a small fraction of the whole plasma of ECR IS is used at the resonance of microwaves and electrons. Of course, electrons can be accelerated only in this plasma zone. In order to produce more highly charged ions, the ECR zone would have be the utmost.

A small ECR IS, so called "Compact 10 GHz ECR IS"[1], composed of permanent magnets, has been developed at GANIL for radioactive ion beams experiments. This type of ECR IS is very simple and easy for operation and maintenance without powerful electric supplies and cooling systems to get strong magnetic field not using of coils.

We should like to construct an irradiation system using ECR IS with permanent magnets, so called "NANOGUN-10B". In order to understand suitable hexapole configuration for such compact ECR IS we studied hexapoles with inner diameters of $\phi D \in \langle 3.6, 12 \rangle$ cm at hexapole thickness of H = 2.8 cm.

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2 MAGNETIC FIELD CALCULATIONS OF HEXAPOLES

The calculations were performed using the computer program PANDIRA [2]. The program calculates magnetic field on a grid in a 2-dimensional space.

Permanent magnets, iron, currents and other anisotropic

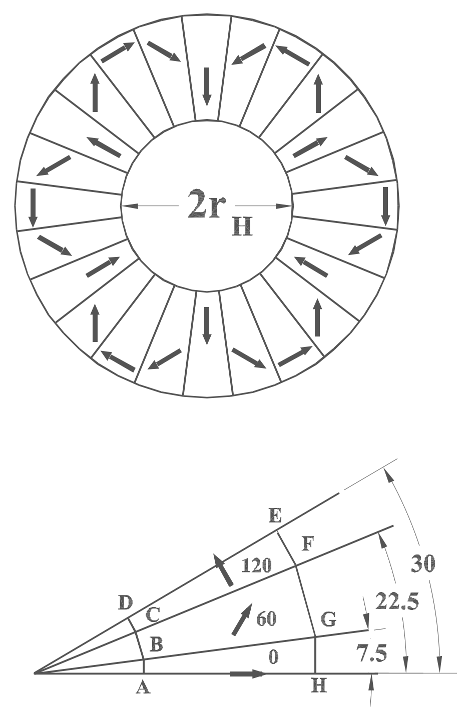

Figure 1: Cross section view of the hexapolar structures. Here, r_H is radius and ABCDEFGH the characteristic segment of hexapole.

and isotropic materials can be defined by the user in several regions.

We have investigated 20 hexapoles with thickness H = 2.8 cm and the inner radii $r_H \in \langle 1.8, 6 \rangle$ cm. Hexapole magnets are made of FeNdB with a remanence of 1.1 T and a coercivity of 800 kA/m. Each calculated hexapole consists of 24 trapezoidal segments where the angle of magnetization varies by 60° from one segment to the next one. Fig. 1 shows cross section view of hexapolar structures.

Magnetic field of 0.9 T is generated by hexapole at the inner radius of hexapole r_H = 3.5 cm (H = 2.8 cm). This corresponds to a ratio of B_{max}/B_{ECR} = 2.5 at resonance magnetic field of B_{ECR} = 0.36 T corresponding to a cyclotron frequency of 10 GHz.

The calculations were done in one segment that is 1/12 of the total hexapole in which both the mirror and the rotational symmetries are assumed. The boundary conditions were fixed. The results of the calculations are summarized in Figs. 2 to 9, which show magnetic field B inside a hexapole as a function of a cylindrical coordinate r.

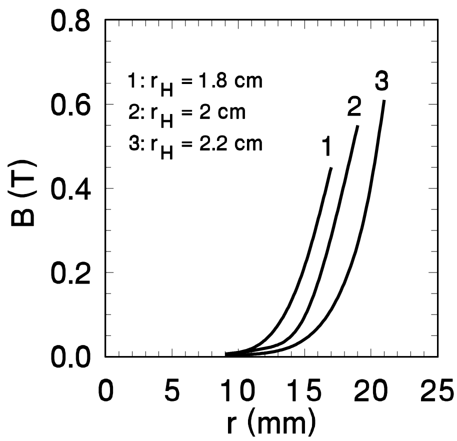

Figure 2: Magnetic field B inside hexapole of B_{max} = 0.61 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

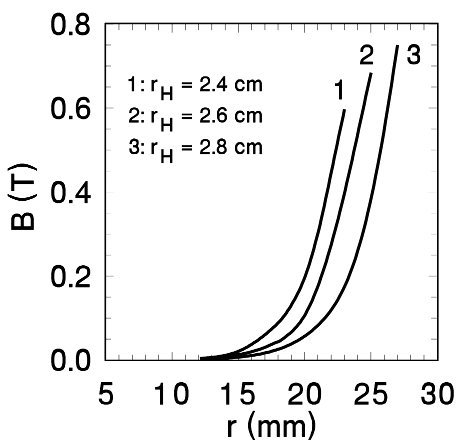

Figure 3: Magnetic field B inside hexapole of B_{max} = 0.76 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

3 RESULTS

We have chosen the thickness of hexapoles H = 2.8 cm for our investigations. The calculations showed that differences ΔB between neighbouring magnetic fields at the surfaces of hexapoles are practically constant. An increase of ΔB was found to be ΔB = 0.09, and 0.16 T in the regions of $r_H \in \langle 2.4, 2.6 \rangle$ cm, and $r_H \in \langle 5.2, 5.5 \rangle$ cm, respectively. It was also shown that the magnetic fields at the surfaces of hexapoles are found to be B = 0.45, and 0.6 T in the regions of $r_H \in \langle 1.8, 2.4 \rangle$ cm. This region is interesting for us because of the construction of suitable hexapole for our ECR IS NANOGUN-10B.

We have also shown that the higher is the radius of hexapole r_H the lower is the magnetic field B for the given coordinate r at the hexapole thickness H = 2.8 cm. The magnetic field at the ECR IS plasma chamber surface is 0.35 T (see Fig. 9) for hexapole of r_H = 1.8 cm and for the plasma chamber thickness of 2 mm. It is also seen (see Fig. 9) that the highest magnetic fields B are for the highest radius hexapoles r_H. By extrapolation of calculated values it is also possible to show that the magnetic field B = 0 for the different cylindrical coordinates $r_o^{min} \in \langle 0.9, 4.3 \rangle$ cm.

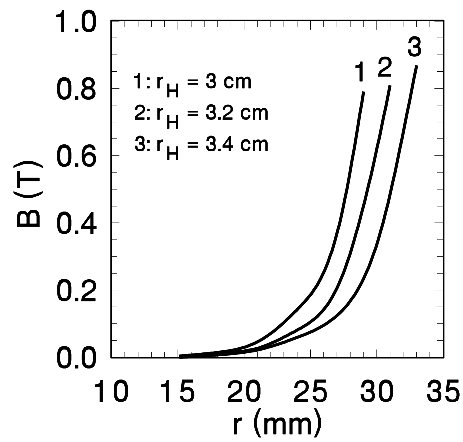

Figure 4: Magnetic field B inside hexapole of B_{max} = 0.87 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

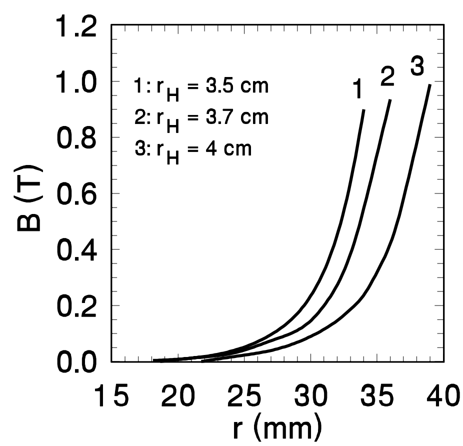

Figure 5: Magnetic field B inside hexapole of B_{max} = 0.99 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

4 CONCLUSIONS

The results obtained here show that the magnetic fields B(r) inside hexapole with thickness of H = 2.8 cm have the highest value for the highest radii r_H. On the other hand, the larger the radius of hexapole is the larger is the distance from the centre of hexapole to the point with the magnetic field B = 0.

According to the results, the thickness of hexapole H =

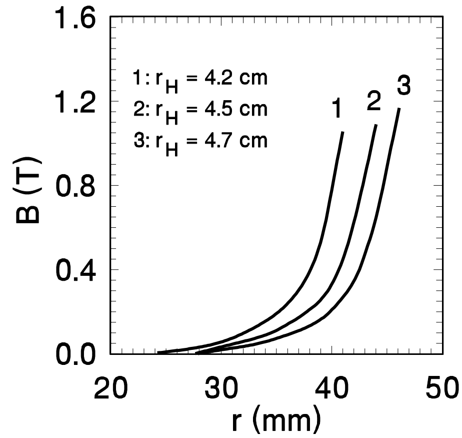

Figure 6: Magnetic field B inside hexapole of B_{max} = 1.17 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

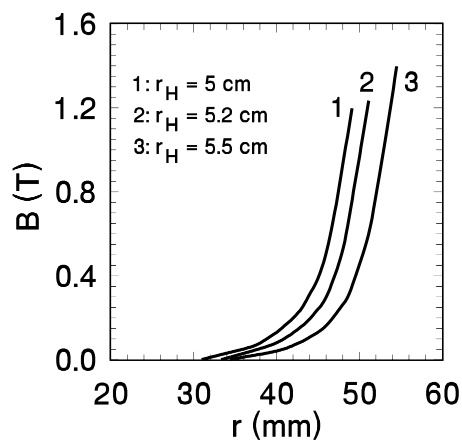

Figure 7: Magnetic field B inside hexapole of B_{max} = 1.4 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

1.4 cm [3] for NANOGUN-10B is confirmed as sufficient. It was shown that the magnetic field B_{max} = 0.72 T for radius r_H = 1.8 cm and thickness H = 1.4 cm and B_{max} = 0.45 T for the same radius and thickness H = 2.8 cm. Then ΔB_{max} = 0.27 T.

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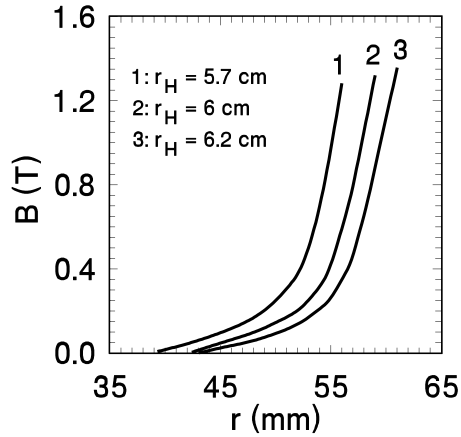

Figure 8: Magnetic field B inside hexapole of B_{max} = 1.365 T for H = 2.8 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

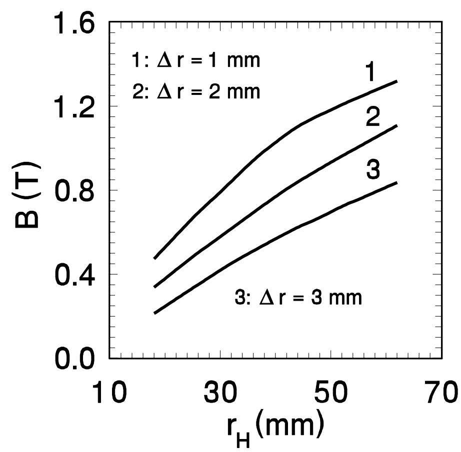

Figure 9: Magnetic field B inside hexapole as a function of the radius r_H for different distances Δr from the surface of hexapole $\Delta r \in \langle 1, 3 \rangle$ mm.

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6 REFERENCES

[1] P. Sortais, M. Bisch, P. Bricault, P. Lehérissier, M. Lewitowicz, R. Leroy, C.F. Liang, J.Y. Pacquet, P. Paris, J.C. Putaux, J. Obert, J.P. Rataud, M.G. Saint-Laurent, NANOGAN: An Ultra Compact ECR IS for on Line and High Voltage Applications, KVI Report 996, Proc. of the 11th ECR IS Workshop, Groningen, May 6-7, 1993. Ed. A.G. Drentje, University of Groningen, The Netherlands, p. 97.

[2] POISSON/SUPERFISH Reference Manual: Report LA-UR-87126, Los Alamos, New Mexico, USA, 1987.

[3] J. Pivarč, J. Pivarč (Jr.), M.N. El-Shazly, IEEE Transaction on Nuclear Science 46(No.3) (1999) 1896.