SOME REMARKS TO CONSTRUCTION OF ECR ION SOURCE HEXAPOLES[1]

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This paper gives performance data for construction of suitable hexapoles for Electron Cyclotron Resonance Ion Sources (ECR IS). Permanent magnets are made from NdFeB magnetic material. The main attention is given to hexapoles with inner diameters of ϕ 3.6 cm at different hexapole thicknesses of 1.3 - 6 cm. Some remarks on construction of type hexapoles are presented.

1 INTRODUCTION

About 30-year history of Electron Cyclotron Resonance Ion Sources (ECR IS) [1-2], which are based on the ECR has already shown that the ECR IS is an ideal tool for the production of multicharged ion states. The highly charged heavy ions are very useful not only for the ion source accelerators, but also for the investigations of the ion collision process as well as for various applications to material science.

Recently a compact ECR IS, so called "Compact 10 GHz ECR IS" [3], composed of permanent magnet structure has been developed at University in Giessen, Germany, for atomic physics experiments. This type of ECR IS is very simple and easy for operation and maintenance without powerful electric supplies and cooling systems for getting strong magnetic field without using of coils.

By considering this, we construct ion irradiation system using ECR IS so called "NANOGUN-10B" at Bratislava.

2 MAGNETIC FIELD CALCULATIONS OF HEXAPOLES

The plasma in the ECR IS is kept together by a magnetic field inside magnetic bottle. The field consists of a longitudinal one, made by coils or permanent magnets and a transversal one, made by hexapole compound of permanent magnets. The magnetic bottle is the region surrounded by a closed surface of constant magnetic field B so that $|B|$ e = $m_e \omega_{rf}$, where B is the average value of the magnetic field in the region where the plasma is, e the charge of the electron, m_e the mass of the electron and ω_{rf} the microwave frequency matching the electron cyclotron frequency ω_c. For ω_c = 10 GHz we need $|B|$ = 0.36 T and $|B|$ = 0.50 T for ω_c = 14 GHz. The magnetic field inside the plasma region is lower than that on the surface of the magnetic bottle. The stronger is the magnetic field inside the magnetic bottle the higher is the rf frequency of the resonance electrons. We thus can obtain larger plasma density that results in larger ionization possibility.

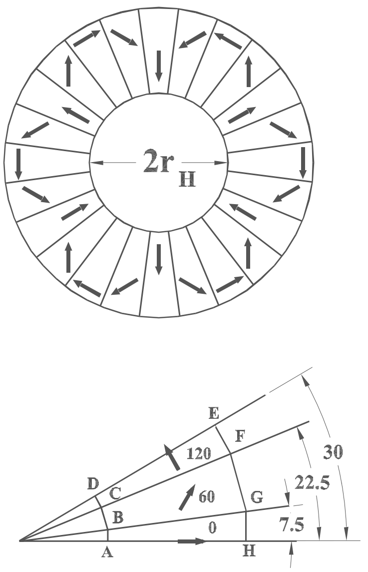

Figure 1: Cross section view of the hexapolar structures. Here, r_H is radius and ABCDEFGH characteristic segment of hexapole.

The computer program PANDIRA [4] was used at the calculations. The program calculates magnetic field on a grid in a 2-dimensional space. Permanent magnets, iron, currents and other anisotropic and isotropic materials can be defined by the user in several regions.

We have investigated 22 hexapoles with the thicknesses of H = 1.4 cm and the inner radii of hexapoles $r_H \in \langle 1.3, 6\rangle$ cm. Hexapole magnets are made of NdFeB 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.

A detailed description of this hexapole geometry is

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given elsewhere [5]. With this hexapole geometry a magnetic field of 1 T is obtained at the inner radius of hexapole r_H = 5.2 cm (the thickness of hexapole H = 1.4 cm). This value corresponds to a ratio of B_{max}/B_{ECR} = 2.77 at the resonance magnetic field of B_{ECR} = 0.36 T corresponding to a cyclotron frequency of 10 GHz.

The calculations were done in the segment that is 1/12 of the total hexapole in which both the mirror and the rotational symmetries are assumed. The boundary conditions were also fixed. The results of the calculations are summarized in Figs. 2 to 7. Figs. 2 to 4 show magnetic field B inside a hexapole as a function of a cylindrical coordinate r. These values correspond to the different cylindrical coordinates r_{min} at which is the magnetic field B_{min} = 0, mainly $r_{min} \in \langle 0.9, 2.1\rangle$ cm. Figs. 5 to 7 show a magnetic field of B inside a hexapole as a function of a cylindrical coordinate r. These values correspond to the different average quantities $\Delta r_a = \sum_i \Delta r_i/n$ for $\Delta r_a \in \langle 0.133, 1.26\rangle$ cm, where $\Delta r_i = (r_H - r)_i$, n is the number of Δr_i , r_H the inner radius of hexapole and r the cylindrical coordinate. Only one value of Δr_i is considered for the given calculation of the magnetic field of hexapole.

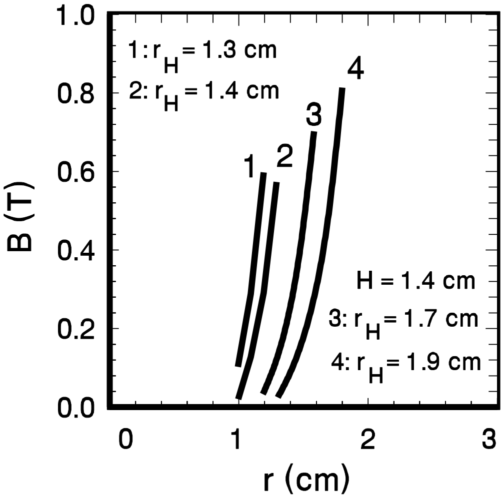

Figure 2: Magnetic field B inside hexapole where B_{min} = 0 for 0.9 cm $< r_{min} <$ 1.3 cm. Here, r_H,H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

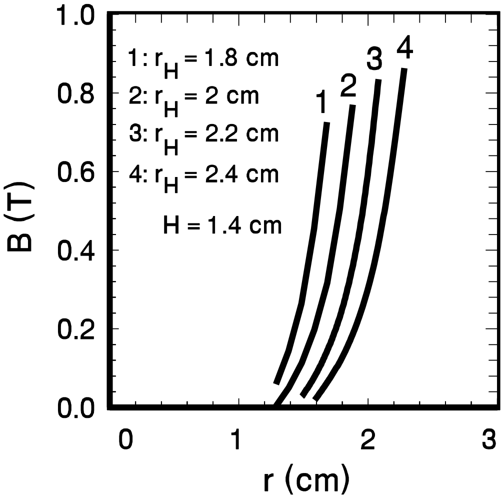

Figure 3: Magnetic field B inside hexapole where B_{min} = 0 for 1.1 cm $< r_{min} <$ 1.6 cm. Here, r_H,H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

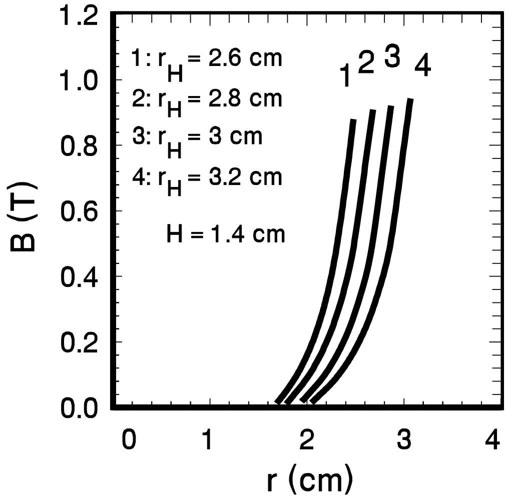

Figure 4: Magnetic field B inside hexapole where B_{min} = 0 for 1.6 cm $< r_{min} <$ 2.1 cm. Here, r_H, H and r are inner radius, thickness and cylindrical coordinate of hexapole, respectively.

3 RESULTS

We have chosen the thickness of hexapole H = 1.4 cm for NANOGUN-10B to find the maximum of the magnetic field B_{max} in the region of $r_H \in \langle 1.3, 6\rangle$ cm. Suitable radius of hexapole can be taken from the region $r_H \in \langle 1.7, 3.2\rangle$ cm for the ECR IS NANOGUN-10B. An increasing of magnetic field at the surface of hexapole has also been found of ΔB = 0.24, 0.14, and 0.06 T in the regions of $r_H \in \langle 1.3, 1.9\rangle$ cm, $r_H \in \langle 1.8, 2.4\rangle$ cm, and $r_H \in \langle 2.6, 3.2\rangle$ cm, respectively.

To understand the influence of parameter Δr_a on B(r) distributions, we have shown Figs. 5 to 7. The higher is the parameter Δr_a the lower is the magnetic field B for the given coordinate r. A saturation of the magnetic field B_s (B_s = 1.09; 0.8; 0.65, and 0.55 T) at the parameters $\Delta r_a \in \langle 0.133, 0.44\rangle$ cm can be seen. Therefore the magnetic field at the ECR IS plasma chamber surface is 0.45 T for hexapole of r_H = 1.8 cm and for the plasma chamber thickness of 1.77 mm.

A well-known rule of plasma physics says that the higher is the mirror ratio of a magnetic trap, the smaller is the number of the particles lost from the confined plasma. The confining trap in the ECR IS is formed by the superposition of a mirror field and a hexapolar field. The higher is the hexapolar field, the higher is the confining trap and the ratios $B_{max}/|B|$ and B_{max}/B_{min} that are also important for ECR heating.

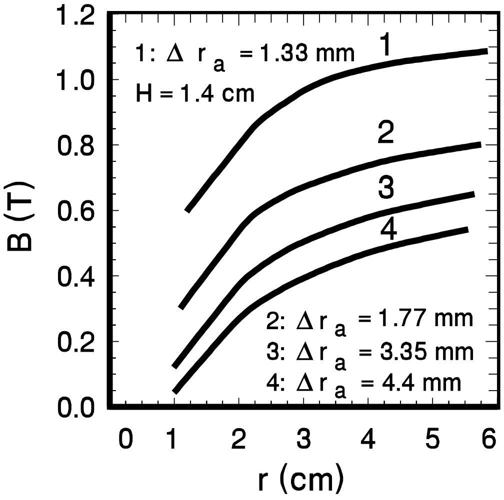

Figure 5: Magnetic field B inside hexapole where Δr_a, H and r are parameter, thickness and cylindrical coordinate of hexapole, respectively.

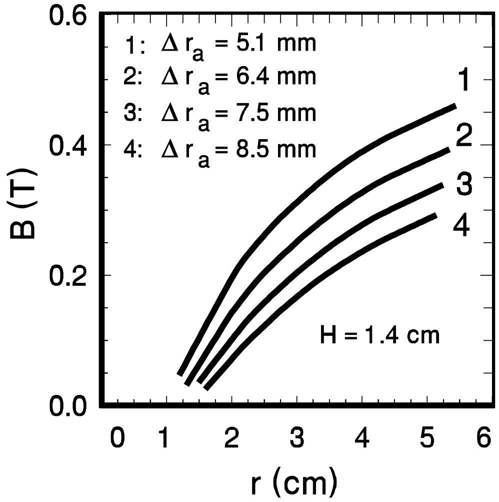

Figure 6: Magnetic field B inside hexapole where Δr_a, H and r are parameter, thickness and cylindrical coordinate of hexapole, respectively.

4 CONCLUSIONS

The magnetic field inside hexapole with thickness of H = 1.4 cm have been calculated, as well as influence of parameters Δr_a on B(r). It has been shown that the higher is the parameter Δr_a the lower is the magnetic field B for the given coordinate r. The thickness of hexapole H = 1.4 cm for NANOGUN-10B has been chosen to find a maximum of the magnetic field B_{max} in the region of $r_H \in \langle 1.3, 6\rangle$ cm. We have shown that the best results are obtained with hexapole shape where $r_H \in \langle 1.4, 2.4\rangle$ cm.

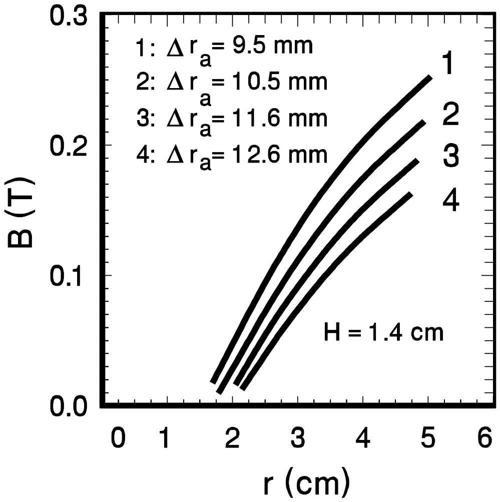

Figure 7: Magnetic field B inside hexapole where Δr_a, H and r are parameter, thickness and cylindrical coordinate of hexapole, respectively.

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