DEVELOPMENT OF THE MAGNETIC SYSTEM FOR NEW DECRIS-PM ION SOURCE

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Abstract

Super-heavy-element factory is under development at the Flerov Laboratory for Nuclear Reactions, JINR, Dubna. The factory will include DC-280 cyclotron, which will be equipped with two 100 kV high voltage platforms. All-permanent magnet ECRIS will be installed on one of the platforms. The request for the source is a production of medium mass ions with A/q=4÷7.5 such as $^{48}Ca^{8+}$. Results of the detailed design of a magnetic structure for DECRIS-PM will be presented.

INTRODUCTION

One of the basic scientific programs which are carried out at the FLNR is a synthesis of new elements requiring intensive beams of heavy ions. To enhance the efficiency of experiments for next few years it is necessary to obtain accelerated ion beams with the following parameters:

Ion energy	4÷8 MeV/n
Ion masses	10÷238
Beam intensity (up to A=50)	10 pμA
Beam emittance	≤ 30 π mm×mrad
Efficiency of beam transfer	> 50%

These parameters have formed the base for the new cyclotron DC-280 [1]. The basic design features of the DC-280 cyclotron project are shown in Table 1.

Table 1: DC-280 Cyclotron - Basic Technical Parameters

Parameter DC280	Goals
High energy of the injected beam (up to 100 kV)	Shift of the space charge limits by a factor of 30
Large gap in a centre	Space for a long spiral inflector
Low magnetic field	Large starting radius. Good orbit separation. Low deflector voltage
High acceleration rate	Good orbit separation.
Flat-top system	Effective capture. Single orbit extraction. Beam quality.

The axial injection system of the DC-280 cyclotron will include two high voltage platforms which will allow for efficient injection of ions from helium to uranium with an atomic mass to charge ratio in the range of 4÷7. Each HV-platform will be equipped with the low power consuming ECR ion source. For production of ions with the medium masses (from He to Kr) the all permanent magnet (PM) ECR ion source will be used. In this paper we report the design of the magnetic system of the new DECRIS-PM ion source.

MAGNETIC STRUCTURE DESIGN

Many good performance all-permanent magnet ECRISs have been built around the world: NANOGAN series [2], BIE series [3], LAPECR2 [4] and others. The main advantages of all permanent magnet ECRISs are low power consumption, low pressure in the cooling water system, simplified operation, etc. However there are few significant drawbacks of all permanent magnet ECRISs. First of them is the fixed distribution of the magnetic field and comparatively low field strength. Thus, the designed magnetic configuration should be optimized for the desired operation mode from the very beginning. Another drawback is strong mechanical force acting on the individual parts of the system. As a result the correction of the magnetic field after the assembly of the magnetic system is practically impossible without the degaussing of it.

Some deviations from the required field distribution can occur for many reasons. The magnetic material itself has scatter in parameters of up to 5%. Furthermore, the magnetic rings that form the axial magnetic field consist of several blocks. In calculations of the magnetic field it is almost impossible to take into account the influence of gaps between individual blocks. Fig. 1 illustrates this problem. The figure shows the distribution of the magnetic field in front of one of the hexapole poles which is made of five blocks of identical magnetic material. With the gaps of about 0.1 mm the oscillations in the magnetic field measured at a distance of 3 mm from the pole are around 10%.

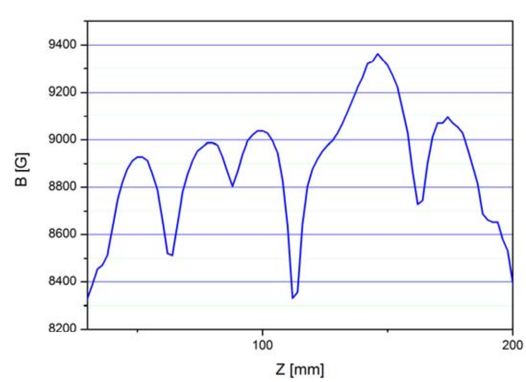

Figure 1: Measured magnetic field distribution along the hexapole pole.

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For this reason it is desirable to provide a possibility for correction of the field distribution in the case of finding an inconsistency between the measured and desired magnetic fields.

The operating frequency selected to be 14 GHz for the source. The corresponding values of B_{inj}, B_{min} and B_r were chosen according to scaling laws for the axial magnetic field configuration [5]. The injection magnetic field maximum was chosen to be around 1.3 T to have a reasonable weight of the system and basing on the earlier experience of conventional ion sources. The desired parameters of the magnetic system of DECRIS-PM are listed in Table 2.

Table 2: Design parameters of DECRIS-PM

Frequency	**14 GHz**
B_{inj}	≥ 1.3 T
B_{min}	0.4 T
B_{extr}	1.0 ÷1.1 T
B_r	1.05÷1.15 T
Plasma chamber internal diameter	70 m

Preliminary calculations were made using the program of synthesis of axially symmetric magnetic systems [6]. It allows optimizing the following parameters of the magnetic system: number of sections, sizes of the sections, orientation and value of the magnetization. The result of this synthesis is shown in Fig. 2.

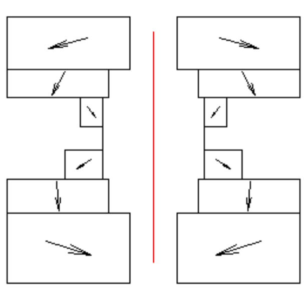

Figure 2: First version of the axial magnetic structure.

The synthesized system provides the desired distribution of the axial magnetic field. However, all magnets have different angular directions of magnetization which leads to a considerable increase in the cost of the magnets. In addition it is practically impossible to correct the field when the system is assembled. Nevertheless this magnetic structure is optimal in terms of weight (477 kg) and size (axial length of 460 mm, outer diameter of 500 mm) and can be used as a reference design.

By further consideration of the different magnetic structures we came to the version which fully satisfies the stated objectives. The structure is shown in Fig. 3. The magnetic structure consists of five large 36-segmented axial magnetic rings with corresponding axial or radial magnetization.

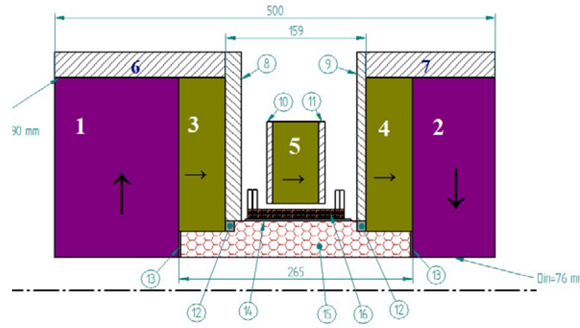

Figure 3: Magnetic structure of DERIS-PM. 1÷5 – PM rings; 6, 7 – soft iron rings; 8÷11 – soft iron plates, 12÷14, 16 - auxiliary elements, 15 – hexapole.

Two magnetic rings at the source injection side provide the injection magnetic field maximum up to 1.3 T, and other two magnetic rings at the extraction side provide the extraction field up to 1.1 T. Single central axial magnetic ring increases the B_{min} field up to 0.42 T. Permanent magnet (PM) rings at the extraction and at the injection sides are inserted into the soft iron rings which slightly increase the magnetic field peaks and strongly suppress the stray field around the source. The soft iron plates around the PM rings with the axial magnetization play an important role in the final magnetic field distribution. The effect of thickness of one of the plate on the B_{min} is shown on Fig. 4. By changing the thickness, it is possible to tune the minimum field when necessary.

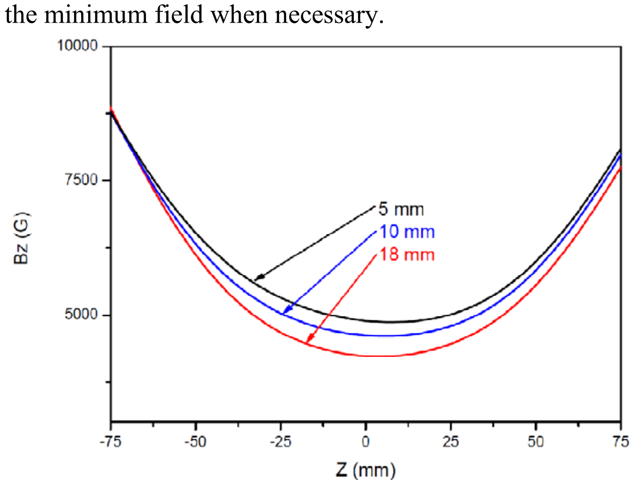

Figure 4: The effect of the soft iron plate thickness.

Figure 5 shows the axial magnetic field distribution of DECRIS-PM. A distance between the injection and extraction maxima is 24.5 cm. The field is changing its sign and reaching 0.8 T at extraction gap, which influences the ion beam extraction and transport.

The magnetic field of DECRIS-PM is the superposition of axial and hexapole fields similar to conventional ECRIS. The hexapole is a 24-segmented Halbach structure magnet which provides a radial field of 1.05 T at the inner wall of the Ø70 mm ID plasma chamber. The

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result of 3D magnetic field calculation is shown in Fig. 6. The ECR zone length is around 7 cm, the $2B_{res}$ zone is closed according to the commonly accepted requirements.

The total weight of the permanent magnets is around 525 kg and total weight of the system is about 1000 kg.

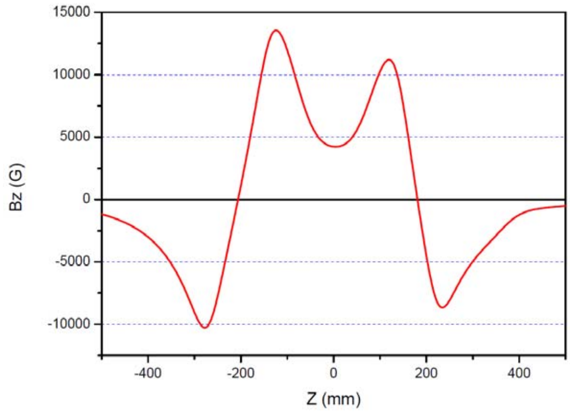

Figure 5: Axial magnetic field distribution of DECRIS-PM.

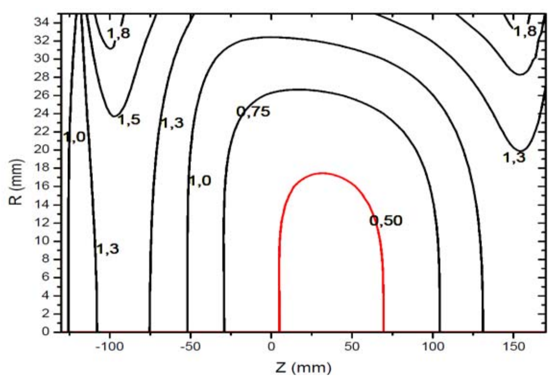

Figure 6: Total field contours.

Other specific feature of the source is an additional coil placed at the centre of the structure between the hexapole and central PM ring. The coil will be used to tune the Bmin value during the source operation. According to [7], the optimal value of Bmin depends on the level of the injected microwave power and it should be changed on-line. Use of such the tuning can assist in improving the source performance.

The coil consumes less than 1.5 kW of electric power and shares the cooling system with the plasma chamber. The influence of the coil on the Bmin value is shown in Fig.7. When the coil is excited to maximum current, the Bmin value is shifted by ±0.05 T depending on the current polarity.

The assembling procedure is planned to be the following: first, the extraction and injection groups of magnets are assembled, and then the axial magnetic field in each group is measured separately. The total magnetic field is calculated basing on the real magnet properties. When necessary, dimensions of soft iron component are defined as the final step.

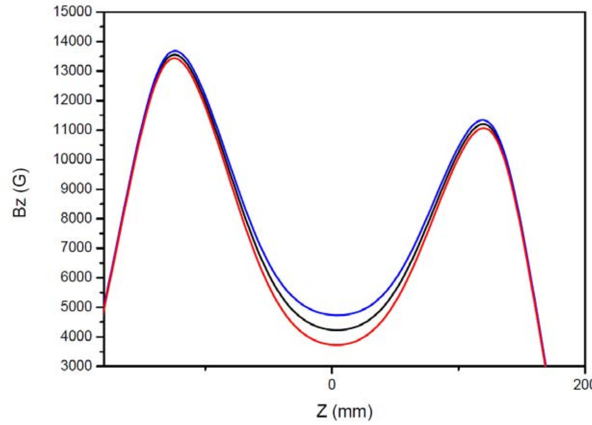

Figure 7: Coil effect.

CONCLUSIONS

A new all-permanent magnet ECR Ion source DECRIS-PM had been designed to be used at the high voltage platform of DC-280 cyclotron. Combination of the permanent magnet rings and soft iron plates makes the magnetic structure flexible. The additional electric coil in the structure centre makes the on-line tuning possible. Manufacturing of the system is planned to be finished in the end of 2014.

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