TEST MEASUREMENTS OF THE DEBRECEN ECRIS SUBSYSTEMS

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A room temperature, 14.5 GHz, one-stage electron cyclotron resonance ion source with Halbach-type NdFeB permanent magnet hexapole is being constructed. The ion source was originally intended for the cyclotron of ATOMKI, however, in the near future it will be used as a stand-alone device only for low-energy atomic physics experiments. The main design aspects of the ion source, the results of the magnetic field measurements and that of the tests of the microwave system are reported.

1 Introduction

To facilitate the heavy ion collision research of the ATOMKI in the field of atomic and nuclear physics a decision has been made to establish a heavy ion physics facility [1], based on an electron cyclotron resonance ion source (ECRIS). The project to develop the ion source started in 1993 , the assembling of the main parts are in progress, and the first run with plasma is planned in the beginning of 1996. [a]

Beside the design of the ECR source theoretical and experimental researches were carried out to study and to optimize the operation of the ECR source.

2 Magnetic system and mechanical layout

The goal was to built a high-charge state, heavy ion source delivering Ar^{15+} ions with an intensity of about 100 enA. An important and mutually useful co-operation was developed with the Institute of Nuclear Physics of the University of Frankfurt and our design is a modified, recalculated version of the Frankfurt ECRIS [2].

The dimensions of the plasma chamber (20 cm in length and 5.8 cm in diameter) are typical values for 14.5 GHz ECR sources.

The closed Halbach-type 24-pieces hexapole is used for radial confinement and four coils (consisted of modules of double pancakes) are applied for the axial trapping. The field value for highest closed magnetic surface in the plasma chamber is expected to be about 1 T (twice of the resonant magnetic field).

The mechanical assembly has the feature that the big mirror coils are axially movable together with their iron yokes. This way the assembling and disassembling of the vacuum chamber can be quick and easy and it also makes possible to change the position of the minimum and maximum values of the axial magnetic field.

The arrangement of the magnets is shown in Fig. 1. A relatively thick (5 cm) iron shielding, consisting of iron discs, rings and plugs, is applied around the coils. The inner diameter of the pancakes is 16.5 cm, the outer one is 48 cm. The pancakes are electrically connected into three groups (5, 2+2 and 5 double pancakes per group, see Fig. 1) and supplied by a 3-channel power supply. The power consumption of the coils is about 80 kW. The Halbach segments are glued to each other, their materials are NEOREM400i (B_r=1.30 T, ${}_jH_c$=1000 kA/m) and NEOREM490i (B_r=1.15 T, ${}_jH_c$=1900 kA/m). The inner diameter of the hexapole is 6.5 cm, the outer one is 13.5 cm and the length is 20.0 cm.

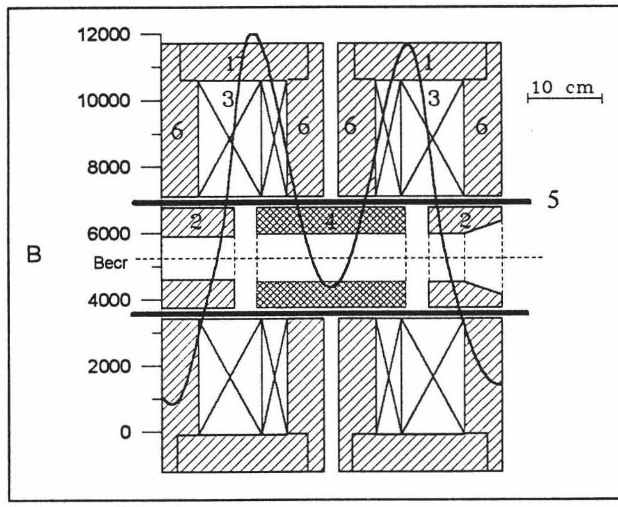

Figure 1: The layout of the magnetic system of the ECRIS and the calculated axial magnetic field (*in gauss*) along the source axis. *1,2,6* - iron components, *3* - coils, *4* - hexapole, *5* - insulator.

3 Design and simulation of the magnetic trap

The POISSON/PANDIRA codes [3] were used for the calculation of the *2D* magnetic field of each element and the TrapCAD code [4] to study the *3D* magnetic trap and the expectable behaviour of charged particles in the source chamber.

The TrapCAD code was and is still being developed to visualize the structure of any combined magnetic field

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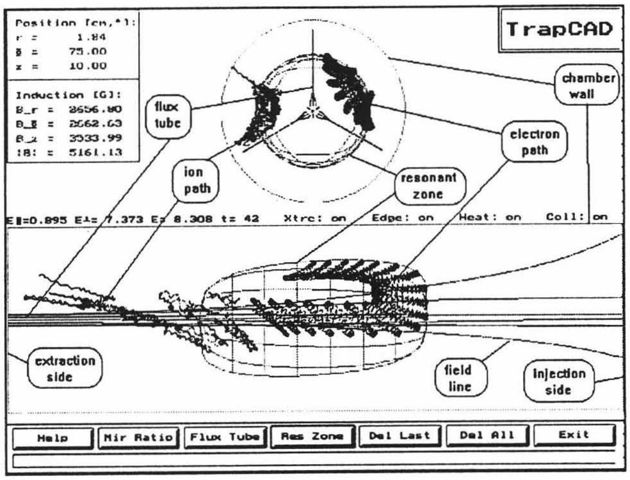

Figure 2: Example output of TrapCAD. 14 GHz, 1 T configuration.

and to simulate certain elementary processes. A DOS version for IBM PC and UNIX version (without graphics) for workstations exist. In Fig. 2 the graphical output of TrapCAD can be seen with some explanation texts.

The following actions can be performed: drawing magnetic field lines, calculation mirror ratios for the field lines, drawing flux tubes, drawing resonant zones and calculating its parameters, simulating the moving of a charged particle in the chamber (incl. ion-ion scattering), simulating the electron heating process, simulating the effect of an optional electrostatic field, optional correction for edge effects of the multipole, preparing magnetic map files, preparing DXF type files for AutoCAD.

4 Test of the magnetic field

The coils with the iron discs have recently been assembled and tested. The magnetic field measured in the centre of the coils was found to be higher than the calculated one. A comparison of the calculated and measured values can be seen in Table 1.

Table 1. Calculated and measured values of the magnetic field (in Tesla)

	Coils			Hexapole	
	Assy1	Assy2	Assy3	29mm	32.5mm
Calculated	0.69	0.92	1.2/1.16	1.0	1.25
Measured	0.80	n.m.	n.m.	0.95*	1.20*

Assy1: assembled with irons "6", Assy2: assembled with irons "6" and "1", Assy3: assembled with irons "6", "1" and "2", n.m.: not measured,
* : extrapolated data.

The magnetic field of the hexapole was checked using a Hall-probe. The axial distributions of the azimuthal and axial magnetic field components were measured at three different radii. Fig. 3. shows the measured values together with the calculated ones (for better visualization only every fifth point is drawn). The radical changing of the field components near the edge of the hexapole are in good agreement with the calculations using the suggested semiempirical formulas [4]. The average total magnetic field at r=29 mm (i.e. at the inner radius of the plasma chamber) and at the inner surface of the hexapole were extrapolated from these values (see Table 1).

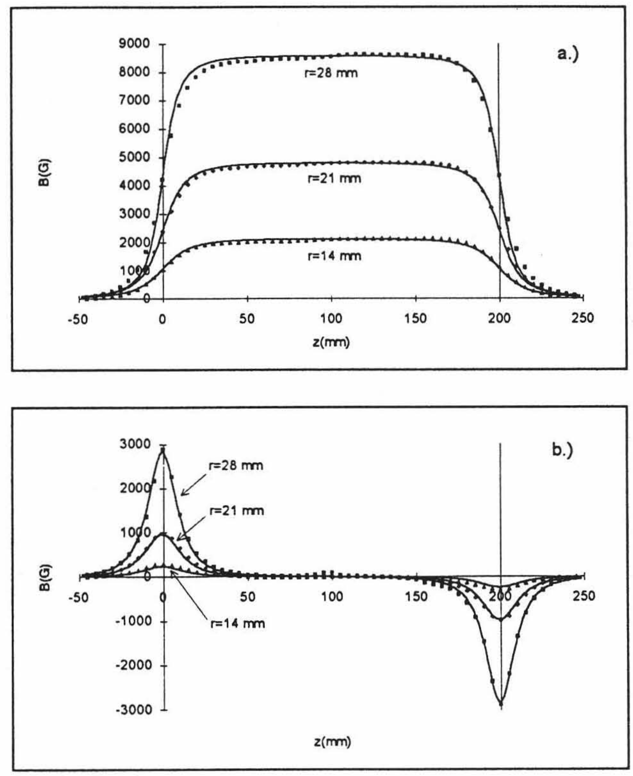

Figure 3: Axial distribution of the azimuthal (a) and axial (b) magnetic field components of the hexapole. *Symbols* - measured values, *continuous lines* - calculated curves.

5 Test of the microwave system

The design concept of the microwave system was to separate the supply of the RF power from the operation condition of the ion source as much as possible, e.g. the system should be operational at high level of the reflected power from the plasma chamber. The structure of the microwave system is shown on the Fig. 4. A HP435A power meter can be connected to measure the indicated power levels. A commercial VARIAN GEN-III transmitter (KHPA) is used to produce the high microwave power. In the input line of the transmitter the RF level is attenuated to the required value, and the input power

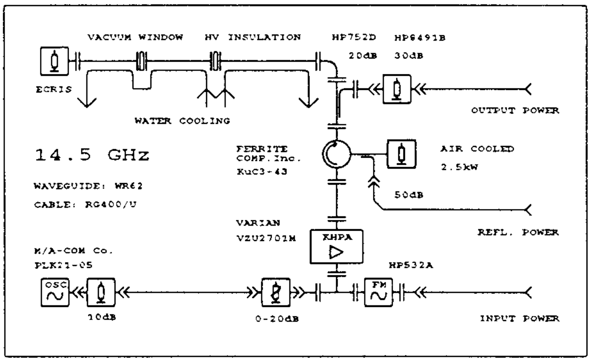

Figure 4: The microwave system of the ion source. *OSC* - oscillator, *FM* - frequency meter, *KHPA* - klystron high power amplifier.

and RF frequency can be measured. Both the oscillator and transmitter can be tuned in the region of 14.0-14.5 GHz.

The microwave power in the output line can be varied by setting the klystron high power amplifier in the range of 50...2200 W. Instead of a direct analogous control here a keyboard is used to adjust the output power, the accuracy of the regulation is about 5 W. The operation of the KHPA is controlled and protected by microcontrollers. The output and reflected powers are measured by the KHPA itself. The maximum allowed level of the reflected power is 200 W.

To prevent the klystron from the dangerous level of the reflected power a high power circulator is built in the output line of the transmitter. The allowed power dissipation and the isolation of minimum 23 dB ensure the tuning of the ion source independently of the operation of "RF source".

The length of the waveguide between the KHPA and the ion source is about 5.5 m, the circulator is placed close to the ion source. The straight sections at the vacuum window and the high voltage insulation are cooled by water. Directional couplers are built to measure the power level supplying the ECRIS and that of reflected by the plasma. The power meter output is connected to a voltage controlled tone generator, so during the tuning/operation of the ECRIS the variation of the level of the reflected power can be observed by acoustic signal, too. To avoid the irregular operation of the ion source and the output line an interlock system will switch off the KHPA: its inputs are the temperature of the circulator, temperature of the cooled waveguide sections, level of the reflected power measured at the circulator, preseted low and high pressure levels in the plasma chamber, level of the X-ray radiation at the ion source.

The straight sections of the waveguide are manufactured in our workshop. Materials of the rectangular waveguide tubes are copper or brass. The measured insertation loss of copper and brass components were about 0.15 and 0.6 dB/m, respectively. A complex waveguide line, consisting of straight sections and E- and H-bends was tested at 800 W power level: the average insertion loss was about 0.3 dB/m, the surface temperature of the copper components was about 66 °C and that of the brass one about 85 °C. Brass material will be used only in short sections, mostly to manufacture the water cooled components.

To design the high voltage insulation experimental data were collected measuring the insertation loss and reflection of a waveguide connection. Teflon sheets of different thicknesses were mounted between standard cover and choke flanges[5] and the transmitted and reflected power were determined at 500 W RF power level. The insertation loss and the reflected power were near zero for the sheets of 0.3 and 0.5 mm. For thicker sheets the power loss and reflected power were about the same regarding the accuracy of the measurement. The teflon material did not absorb the microwave radiation, the losses came mostly from the mismatching of the connections. The insertation loss for the sheets of thicknesses of 1, 2, and 3 mm were about 0.2, 0.4 and 0.3 dB, respectively. Because the lower value the 3 mm teflon sheet is planned to use in the high voltage insulator.

To detect the microwave leaks of the transmitter and the heavily loaded waveguide line a temporally built "leak detector" was used. A waveguide-to-coax adapter connected to the power sensor HP8481A was the RF field detector, and the radiation level was estimated from the reading of the power meter. To find the sites of the microwave emission easier the use of the acoustic output signal was also available. Notable leakages were observed only at the connections where the waveguide was interrupted by a teflon gasket, and the radiation level at about half meter distance from the emitting sources decreased to the standard limit of 0.1 mW/cm^2.

References

1. S. Biri, J. Pálinkás and A. Valek in Proc. 13th Int. Conf. on Cyclotrons and their Applications, Vancouver, Canada, 6-10 July, 1992, eds. G. Dutto and M.K. Craddock (World Scientific, Singapore 1993).
2. K.E. Stiebing et al., in Proc. 12th Int. Workshop on ECRIS, RIKEN, Japan, 1995, INS-J-182, 122 (1995)
3. M.T. Menzel, H.K. Stokes, LA-UR-87-115 (Los Alamos, 1987).
4. J. Vámosi and S. Biri, Nucl. Instr. Meth. B 94, 297 (1994).
5. M. Cavenago and C.T. Iatrou, Rev. Sci. Instr. 65, 1122 (1994).

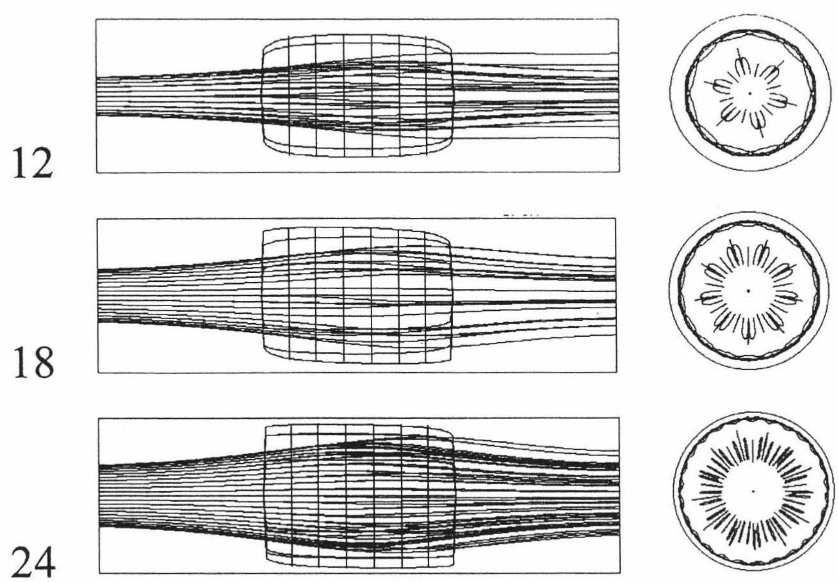

Fig. 5 Resonance zones and tubes of flux lines for different multipoles in two views. The multipole numbers are shown at left. The flux tubes start at the left side of the chambers.