3D Design and Visualisation of Complex Magnetic Traps

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Abstract

To design the magnetic system of the ATOMKI electron cyclotron resonance (ECR) ion source and to study the behaviour of complex charged particle traps an interactive, graphical computer code (TrapCAD) and method was developed. This paper describes the implementation and functionalities of the code. Using TrapCAD the multipolarity number of radial magnetic traps and the effect of the edges of those multipoles were studied and are shown. A short status report of the Debrecen ECR program is also given.

1. INTRODUCTION - THE DEBRECEN ECRIS PROGRAM

In the ATOMKI a 14.5 GHz electron cyclotron resonance ion source (ECRIS) of heavy ions is being designed and will be soon built. The source is planned to be applied for low energy basic atomic, solid state and plasma physics research and foreseen to also serve as a research tool for future developments and improvements of ECRIS[1]. Details of the whole project have been described elsewhere [1].

For the successful performing of the program a new group (called the Ion Source Developing Group) was established in the ATOMKI in 1993 and this is the effective starting date of the project. The ECR source is designed and constructed entirely in the institute basing on the experiences made at other laboratories.

2. STATUS OF THE ECRIS DEVELOPMENT

2.1 General layout

An important and useful co-operation evolved with the Institut für Kernphysik of the University of Frankfurt where a 14.5 GHz ECRIS and an RFQ post-accelerator are being developed. Some parts of the Debrecen-ECRIS are directly derived from the Frankfurt-ECRIS while others have been significantly re-designed - accordingly to our requirements and limited financial resources.

The working principle of the ECR ion sources can be found in many papers. The Debrecen-ECRIS will be a room-temperature, one-stage, as compact as possible, 14.5 GHz ion source. The dimensions of the plasma chamber are: 20 cm long and 5.8 cm in diameter that are typical values for 14.5 GHz ECR sources.

The mechanical assembly has the feature that the two big solenoid coils that ensure the axial confinement, are axially movable together with their iron yokes. This way the assembly and disassembly of the source can be very quick and easy and one also can change the positions of the minimum and maximum of the axial magnetic field.

2.2 Magnetic system

The designing of the magnetic system of the Debrecen ECRIS has been recently finished. The POISSON/PANDIRA codes were used for basic calculations and the TrapCAD/AutoCAD softwares to study the magnetic trap and the expectable behaviour of charged particles in the chamber (see in sections 3 and 4). As newcomers we were strongly forced to use solutions of some other existing or being under development 14.5 GHz ion sources and the helpful suggestions of numerous ECR builders who have much more practice in this field.

In Fig.1. the cross section sketch of the magnetic system of the ATOMKI ECRIS can be seen. We used the traditional Halbach-type 24-pieces hexapole for radial confinement. For the axial confinement four coils will be applied in two groups. The highest closed magnetic surface in the plasma chamber is expected above 1 Tesla.

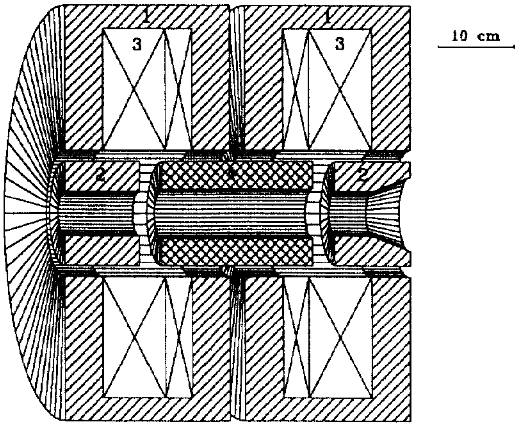

Figure 1. Sketch of the magnetic system of the Debrecen ECR ion source. 1-2 : iron, 3: coil, 4: hexapole magnet

All the elements of the magnetic system have been ordered and will be delivered soon to our institute.

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[1] The Debrecen ECRIS program is supported by the National Scientific Research Foundation (OTKA) under the contracts No. A077 and F013961.

The calculated main parameters of the magnetic elements:

	Hexapole	Coils (2 grp.)
inner diameter (mm)	65	165
outer diameter (mm)	135	480
length (mm)	200	120..130
calculated mag. field (T)	1.0-1.05 (wall)	1.1-1.15 (peak)
total expected power consumption (kW)		80

3. THE TRAPCAD CODE

In a recently submitted paper [2] we described the implementation and the features of the code in details. Here we give only a short summary.

3.1 Features and functionalities

Input of TrapCAD. TrapCAD requires one or two files as input data files. These files presently are the output files of the POISSON and PANDIRA magnetic field calculating codes. The reason of this choice is that the ECR community mostly uses this group of codes for magnetic system calculations (other inputs are also possible).

Functions and commands. TrapCAD is a graphical application. Having loaded the contents of the input files the program switches to the graphics screen and the schematic front and side views of the cylindrical ECR chamber is displayed (Figure 2.). Using a mouse any point of the chamber can be easily reached. The actual coordinates and the value of the magnetic induction are continuously displayed. The following actions can be performed presently in TrapCAD:

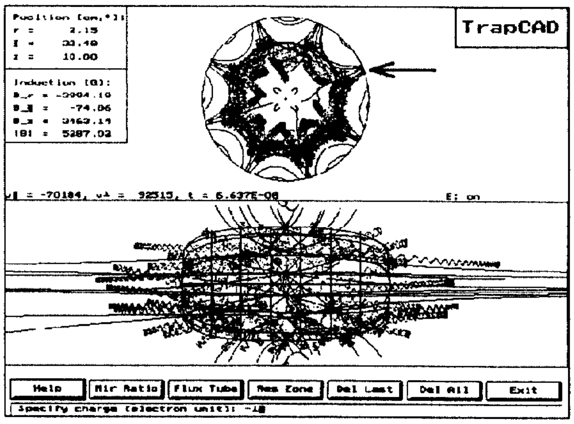
- drawing field lines (one line or a set of lines -see Fig. 2.);
- calculation several kind of mirror ratios of the field lines;
- drawing flux tubes;
- drawing resonant zones and calculating its parameters;
- simulating the moving of a charged particle;
- switching on/off the edge effects of the multipole;
- preparing magnetic map files;
- preparing 3D DXF type files for AutoCAD.

In Figure 2. the resonant zone for 14.5 GHz and the motion of an electron is shown. The initial energy was enlarged (E_{par}=1 keV, E_{perp}=100 keV) for a better visualisation.

3.2 Implementation

Structure of the code. TrapCAD is a real mode MS-DOS application coded in C/C++ language and having an event handling structure. Because of the portability of C language the code can be translated into different operating systems such as OS/2 (Presentation Manager) and UNIX (XWindows).

End-region effects. If the hexapole is long and the examined region is far from the ends PANDIRA gives good results, but if the length of the chamber approximates the length of the hexapole one has to take into consideration the effects of the edges of the magnet on the magnetic field. Based on some unpublished measured data and approximating the permanent magnet multipoles by wire conductors some semi-empirical formulas were found [2]. The functions are built in the code optionally.



Position [cm,°]:
r = 2.15
φ = 33.40
z = 10.00

Induction [G]:
B_r = -3904.10
B_φ = -74.06
B_z = 3463.14
|B| = 5287.02

v∥ = -70184, v⊥ = 92515, t = 6.637E-08
E: on

Specify charge (electron unit): -1

Figure 2. Inverted hardcopy of the VGA screen when running TrapCAD. Arrow shows the place where the particle hit the wall and lost. The radial field is created by an octupole.

4. MAGNETIC TRAP STUDIES

4.1 The multipolarity number

In ECRIS usually hexapoles are used for radial confinement. Very rarely higher multipoles (octupoles and decapoles) were also applied and it is not completely clear why these attempts proved finally unsuccesful. We calculated the magnetic fields inside different multipoles so that the field strengths at the inner surface of the poles were equal (1 Tesla). The inner diameter of the examined region (chamber) was 6 cm. A symmetrical axial field was added (calculating by POISSON). The distance between the peeks was 20 cm and the peek values were 1 Tesla.

Then we examined the behaviour of these traps by TrapCAD (Figure 3.). The resonant zones (for 14.5 GHz) and the largest 'passing-through' flux tubes are shown. As it follows from the known power function for such multipoles the flat field region of the $B_r(r)$ function is increasing with the polarity number so does the diameter of the resonant zone. The length of the zone has not been changed because it depends only on the applied axial profile which was not varied. The modification of the shape of the zone is also observable. In Figure 4.a) the diameters of the resonant zones and of the flux tubes are shown. Both curves reach a well observable saturation in the N=10..12 region. This result is similar to other calculations [3] (although in [3] the saturation is in the N=14..16 region and not so remarkable) and can show a possible way for future ECRIS developments: the optimal polarity number seems to be 10 or 12.

In Figure 4.b) the surface area and volume of the resonant zones are shown. Because the length of the zone has not been changed the area and the volume produce similar curves and the saturation effect is observable at the same place.

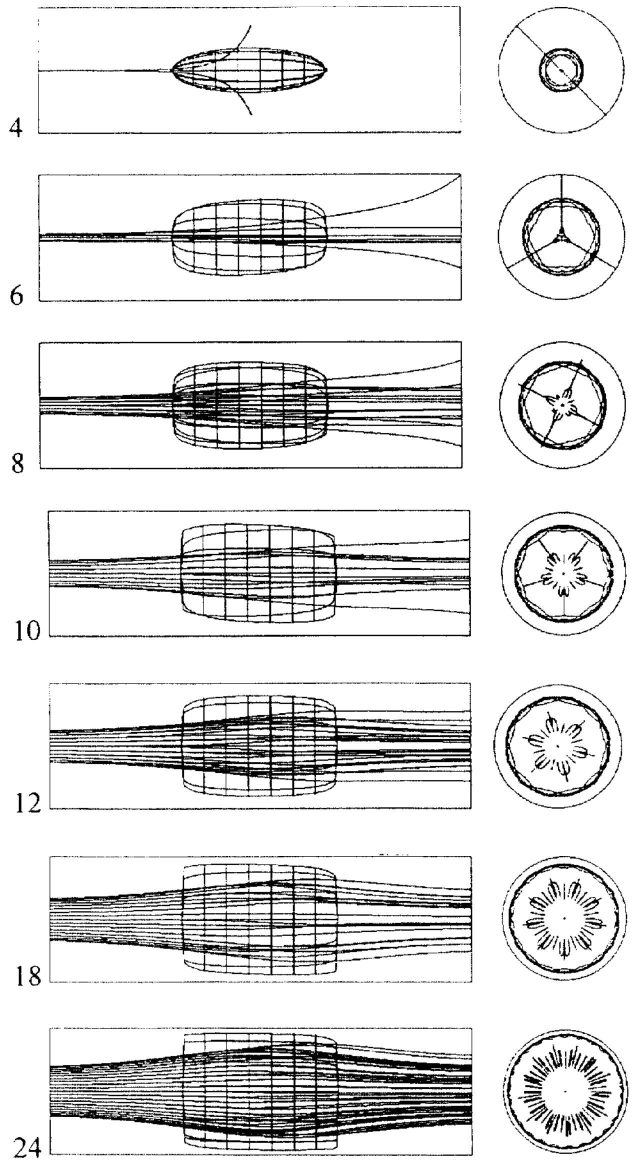
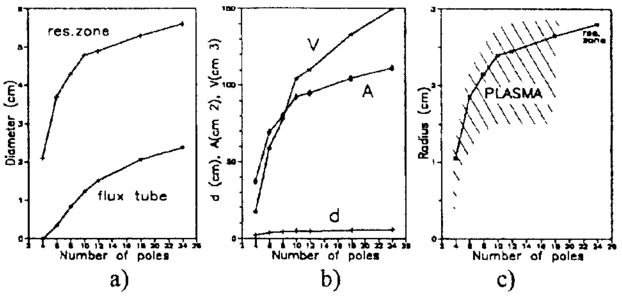


Figure 3. Resonant zones and tubes of flux lines for different multipoles in two views. The multipole numbers are shown at left. The flux tubes start at the left side of the chambers.

In ECR ion sources usually the whole volume of the resonant zone is considered as 'plasma'. Simulating the motion of electrons with wide range of initial energy components in ECR traps with different multipoles one can roughly estimate the space these particles fill that is the volume of the plasma. The result can be seen in Figure 4.c) and is also observable in Figure 2. The particles usually do not reach the center of the trap so the plasma is near 'hollow'. This means that the plasma density is far to be homogenious and much less inside than on the zone. This way the surface of the resonant zone seems to be more important than its volume. We note that all this is true in the presence of the classical quadratic shape axial field distribution created by 2 big coils.



a) b) c)

Figure 4. Effect of the multipolarity number on the resonant zone and on the flux lines. a) Diameter of the zone and the flux tube. b) Diameter (d), area (A) and volume (V) of the resonant zone. c) Position of the plasma in the chamber.

4.2 Effect of the edges of multipole

Switching off and on the end region effects in TrapCAD it was concluded that this makes only a slight changes for the resonant zones and for the flux tubes. This is probably due to the fact that in these calculations we applied relatively strong magnetic fields. TrapCAD can generate magnetic maps at the required angle. It is clear from the maps that there is a remarkable difference between the structure of the magnetic field near the end-walls with and without of this effect. The B minimum geometry is injured near the end of the plasma chamber and the B_{max}/B_{res} parameter that is usually used to describe the goodness of the magnetic trap can not be defined. Dangerous 'corners' appear where particles can be trapped and finally hit the wall and will be lost. This phenomena is well known from experiments and reduces the efficiency of extraction of the ions. Several solutions are known: the hexapole frequently longer than the chamber; specially designed iron plugs compensate those effects etc.

5. CONCLUSION

The present status of the Debrecen ECRIS program was summarised. It was shown that the TrapCAD code is suitable - with some restrictions - for simulation of complex magnetic traps. From these simulations follows that the ideal multipolarity number is higher than the traditional six - it is around ten-twelve. It was also showed that the ECR plasma is near 'empty' inside that is the surface of the resonant zone is more important parameter than its volume. The effects of the end regions of the multipoles have also been shown.

6. REFERENCES

[1] S.Biri and J.Vámosi, "The Debrecen ECR Project", in Proc. XI. Int. Workshop on ECR Ion Sources, Groningen, The Netherlands, May 1993, ed. A.G. Drentje, KVI-Report 996, pp. 128-132.

[2] J.Vámosi and S.Biri, "TrapCAD - a tool to design and study magnetic traps of ECR ion sources", submitted to the Nuclear Instruments and Methods B.

[3] G.D.Alton, D.N.Smithe, "Design studies for an advanced ECR ion source", Rev.Sci.Instr. vol.65(4), pp 775-787 April, 1994.