

Romanian 14 GHz ECR Ion Source RECRIS: main features and first operation

S. Dobrescu, L. Schächter and Al.I. Badescu-Singureanu

National Institute for Physics and Nuclear Engineering, Bucharest, Romania

RECRIS, the romanian 14 GHz ECR ion source, designed as a facility for atomic physics and material studies with highly charged ion beams, have been recently completed. The general design, the main characteristics and the detailed measurements of the radial and axial magnetic fields are presented. A maximum axial magnetic field of 1.4 T and a mirror ratio of up to 4 were obtained. The dependence of the mirror ratio and of the ECR plasma zone volume on the configuration of the axial magnetic system configuration was studied. The first operation of this source is described.

I. INTRODUCTION

The Romanian ECR Ion Source (RECRIS) was conceived as an independent source of highly charged heavy ion beams to be used for atomic and solid state physics research. The source will be also used to study the physical processes in the ECR plasma in order to improve the performances. The general layout and some details of the project have been previously described [1 – 3]. The need of high intensities of maximally charged heavy ion beams determined us to choose the microwave frequency of 14.5 GHz despite the greater complexity and costs as compared to lower frequency sources.

This project was developed on the basis of the experience of other laboratories, mainly the Institutes of Nuclear Physics of Johann Wolfgang Goethe University of Frankfurt am Main, Germany, the J.Liebig University of Giessen, Germany and the Flerov Nuclear Reactions Laboratory of the Joint Institute for Nuclear Research, Dubna, Russia. This offered to us large opportunities to chose, to develop and to experience the most adequate solutions corresponding to our conception and possibilities. RECRIS was designed and constructed in our institute.

II. SOURCE DESCRIPTION

A schematic view of RECRIS is represented in figure 1. The construction, though respecting the general features of any ECRIS [4], has some distinct characteristics: (1) the construction is modular, allowing a simple dismounting, intervention and modification of inner parts; (2) it was designed for a rather high extraction voltage, up to 50 kV, in order to obtain high energy ion beams, directly usable in atomic and solid state physics research and applications; (3) the distance d between the two main magnetic yokes may be easily modified in the range $50 \div 80$ mm in order to influence the plasma zone length.

The plasma chamber, made of stainless steel and cooled by distilled water, has an inner diameter of 59 mm and a length of 250 mm.

The radial magnetic field for the plasma confinement is given by a NdFeB permanent hexapolar magnet, 200 mm long, 165 mm outer diameter and 65 mm inner diameter. The axial B_{min} magnetic mirror field is produced by two identical coils surrounded by soft iron yokes. Each coil is made of seven pancakes having an outer diameter of 408 mm, manufactured from 8 mm square copper tubing for water cooling. The maximum current in each coil is 640 A at 54 V. The axial magnetic system is completed by two identical iron plugs mounted on both sides of the hexapole, outside the plasma chamber and one smaller iron plug, 58 mm diameter and 60 mm long, mounted inside the plasma chamber (fig. 1). These iron plugs allowed to increase the mirror ratio B_{max}/B_{min} of the axial magnetic field and to enhance the mirror effect toward the side opposite to the extraction. The axial position of the small inner iron plug may be easily changed in order to optimize the mirror ratio. The magnetic system was computed using the POISSON code.

The microwave system consists of a VARIAN GEN III Klystron High Power Amplifier (KHPA Model VZU-2701M) delivering a maximum r.f. power of 2.2 kW in the KU band (14 - 14.5 GHz). The microwaves are axially injected in the plasma chamber through a stainless steel rectangular waveguide. The KHPA is equipped with an outer circulator and a 2.5 kW dummy load for the klystron protection. The reflected power is minimized by a tuner and permanently monitored.

A special care was given to insulation problems in order to obtain relative high energy ions at the extraction, so that the ion beam may be directly used in atomic and solid state physics research. The plasma chamber, the hexapole and the iron plugs are inside a rigid long insulating tube with a wall thickness of 10 mm. This insulator which rests on the outer magnetic yoke

supports the weight of the hexapole and of the iron plugs. The plasma chamber is free and may be independently dismantled. The axial insulation is realized by two special designed HV insulators. The source insulation has been successfully tested up to 40 kV.

RECRIS is equipped with two Diffstack diffusion pumps of 150 l/s at the injection side and 700 l/s at the extraction side. The pumps use SANTOVAC 5 diffusion oil. The ultimate vacuum measured in the source with no gas feed was 4×10^{-8} mbar.

A disk that may be biased and axially moved is installed in front of the inner iron plug in order to enhance the ion production of the source. All the elements protruding inside the plasma chamber, that is the inner iron plug, the disk, the microwave guide and the gas feed are linked to an entrance flange that allows a simple dismantling and easy access to the inside of the plasma chamber.

The extraction system consists of a puller followed by an Einzel lens for beam focusing. All the extraction system may be axially moved so that the distance from the 7 mm bore diaphragm may be optimized.

The whole source, mounted on wheel carriages for ease of installation and maintenance, is installed on a non magnetic support. Bucharest is in a strong seismic zone, consequently a careful calculation of stability in case of an earthquake with a magnitude of up to 7.8 degrees on the Richter scale was performed and corresponding mechanical solutions were adopted.

III. MAGNETIC MEASUREMENTS

A. Radial field

The quality of a hexapolar permanent magnet for an ECR ion source is represented by its capability to efficiently confine the plasma. The main parameter of quality and performance of a hexapolar magnet is the maximum value of the magnetic field on its inner surface. The uniformity of the radial magnetic field values along the axis of the magnet is also an important parameter.

The Halbach structure of our hexapole was obtained by gluing together 24 radial segments with different directions of the magnetic polarization. Axially this magnet is made of four identical parts, each of 50 mm length, also glued between them.

Detailed and accurate measurements of the radial magnetic field given by the hexapolar permanent magnet were performed using a Hall probe [5]. The variation of the radial magnetic field with the radius and along directions parallel to the axis at different radii was measured for all

six poles. A supplementary purpose of these measurements was to have an indication about the long term stability of the magnet performances.

The radial magnetic field was measured in 7 points for each pole at $R = 31.8$ mm; 29.8 mm; 27.8 mm; 25.8 mm; 23.8 mm; 21.8 mm and 19.8 mm. The inner face of the magnet is at $R_0 = 32.5$ mm. The Hall probe had a thickness of 1.4 mm, so that the minimum distance from the inner surface of the magnet bore at which the field could be directly measured was of 0.7 mm. Along the z axis minimum 40 points were measured for each pole at each of the seven radii mentioned above. The total error associated to the radial magnetic field measured was estimated at approximately ± 0.017 T, corresponding to a relative error of $\pm(1.5 \div 4)\%$ for the range of the field values measured in this study.

In figure 2 is given the curve $B_r = f(R)$, measured for one pole at $z = 7$ cm (the origin of the z axis is on a side face of the magnet). In order to allow an accurate extrapolation of this curve, we approximated it by the empirical equation: $B = aR^2$, where a is a constant (in our case $a = (1.07 \pm 0.005) 10^3$ for R expressed in mm and B in T). The maximum radial field B_{max} at $R = 32.5$ mm results: $B_{max} = (1.13 \pm 0.05)$ T.

For the other five poles of the magnet the maximum value of the radial field differs from the value given above by up to $\pm 5\%$. In figure 3 are plotted the maximum radial field values for the six poles, at two different z values. The field values are plotted with the associated error bars. It can be seen that the poles show different maximum field values, due to different magnetization. There are also differences along the magnet axis. The maximum gradient of the radial magnetic field is 0,07 T/mm.

The axial distribution of the radial magnetic field for one pole along directions parallel to the z axis of the magnet are presented in figure 4. These curves are plotted for points located along directions parallel to the z axis at four different radii: 31.8 mm; 27.8 mm; 23.8 mm and 19.8 mm. Similar curves were measured for the other 5 poles of the magnet.

The analysis of these curves leads to the observation that the different parts of the magnet are not equally magnetized. At $R > 27.5$ mm, the radial magnetic field strongly depends on the quality of the magnetization. For instance, at $z = 50$ mm and $z = 150$ mm, where the parts are glued together, local nonuniformities of up to 10 % of the magnetic field were observed. These nonuniformities are probably due to a wicker magnetization at the axial ends of the magnet parts.

The field decreases as expected at the two ends of the magnet ($z = 0$ and $z = 200$ mm). At $R < 27.5$ mm the influence of local nonuniformities of the magnetization is much lower. In the ECR zone, that is located in the middle of the magnet and estimated to have a maximum radius of 22 mm and a length of approximately 100 mm, the radial magnetic field is uniform inside an acceptable range of $\pm 5\%$.

B. Axial field

The axial magnetic mirror field B_z was measured with a Hall probe in different configurations of the magnetic iron yokes and plugs. The magnetization curves $B_z = f(I)$ of the two axial magnetic yokes, showing a good relative linearity, are given in figure 5.

The axial distribution of B_z measured in the case of the iron plugs positioned as shown in figure 1 and for two distance d of 50 mm and 70 mm between the two iron yokes is shown in figure 6. Maximum field values of 1.24 T, respectively 1 T were measured for a current of 600 A in both coils. The mirror ratio B_{max}/B_{min} of this B-min configuration has the same value for both d distances: $B_{max}/B_{min} = 3.5$ for the yoke #1 and $B_{max}/B_{min} = 2.8$ for the yoke #2. It may be seen that the larger is the distance d , the longer is the ECR zone delimited by the two points corresponding to the resonance value B_{ecr} of the axial magnetic field (for RECRIS, at 14 GHz corresponds $B_{ecr} = 0.518$ T). For $d = 50$ mm, L_{ecr} is 82 mm, whereas for $d = 70$ mm, L_{ecr} is 102 mm. A longer ECR zone should have, in some limits, a beneficial effect on the ECRIS performances, so we set d at 70 mm. The computed ECR zone diameter is 37 mm, which is good when compared to the 59 mm diameter of the plasma chamber. In figure 6 is also represented the field configuration measured when the inner iron plug was inserted in an advanced position, 20 mm closer to the ECR zone. It may be seen that the maximum field increased from 1.2 T to 1.4 T and the mirror ratio increased to $B_{max}/B_{min} = 4$ while the length of the ECR zone remained practically unchanged. So it seems that this advanced position has advantages from the point of view of ECRIS performances, but this fact has to be checked.

IV. FIRST OPERATION OF RECRIS

The source was operated at a rf power in the range $100 \div 400$ W and an extraction voltage of $10 \div 20$ kV. Before gas admission the vacuum

was 1.8×10^{-7} mbar. The integral beam current was measured on a Faraday cup installed after the Einzel lens. A total current of a few emA was obtained. The reflected rf power was of 2 – 3% of the input power. The source was stable and the ion current collected by the Faraday cup responded normally to variations of the electrical parameters of the source or of the pressure. The beam could not be analyzed, the 90° analyzing magnet being not yet available.

ACKNOWLEDGEMENTS

The realization of RECRIS was possible due to the financial support obtained from the romanian Ministry of Research and Technology and from the European Commission of Brussels, through a PECO project.

We salute the memory of our late and most regretted colleague Dr. Valeriu Zoran who made many competent efforts to start this project and who should have been the first user of the beam delivered by RECRIS.

We acknowledge the constant advise and help of Prof. H. Schmidt-Böcking and Dr. K. Stiebing from the Institute fuer Kernphysik der Johann Wolfgang Universität Frankfurt am Main, Germany that were unvaluable for completing this project.

We wish also to acknowledge and thank our colleagues Andrei Radu and Petre Dima, whose competence and technical ability may be found in many parts of the source.

References

1. S.Dobrescu, V.Zoran, L.Schächter and Al.I.Badescu-Singureanu, Proc. of the 5th European Workshop on the Production and Application of Light Negative Ions, edited by M.B.Hopkins (Dublin City Univ., 1994) p.353.
2. V.Zoran, S.Dobrescu, L.Schächter and Al.I.Badescu-Singureanu, Rom. Journ. Phys. **39**, 423 (1994).
3. S.Dobrescu, L.Schächter, Al.I.Bădescu-Singureanu and V.Zoran, Rev. Sci. Instrum. **67**, 974 (1996).
4. R.Geller, *Electron Cyclotron Resonance Ion Sources and ECR Plasmas* (London: Institute of Physics Publishing, 1996)
5. S. Dobrescu, A.I. Badescu-Singureanu and L. Schächter, Rom. Journ. Phys. **44**, Nos. 1-2 (1999).

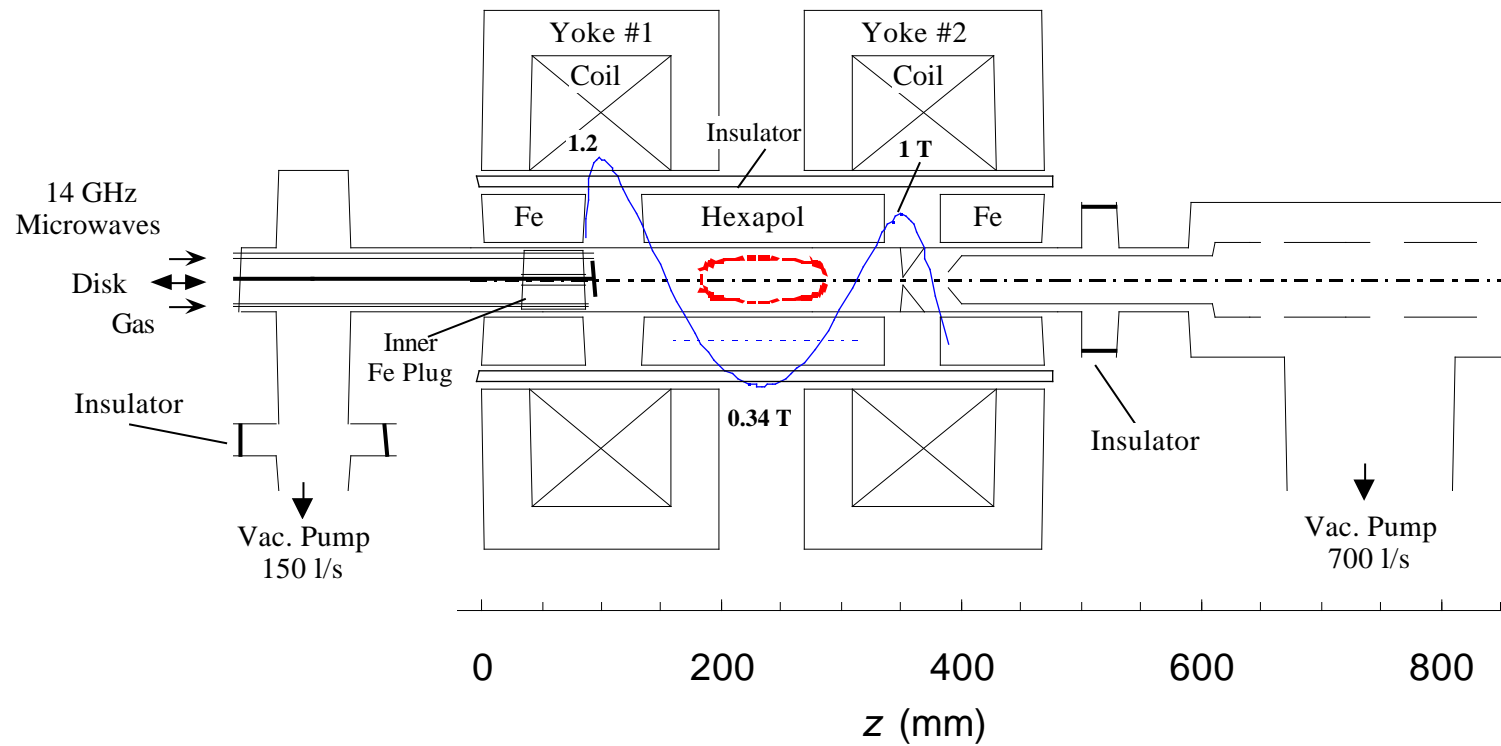


Fig. 1. Schematic view of RECRIS
 Superimposed: the mirror field configuration and
 the ECR zone (102 mm long and 37 mm diameter)

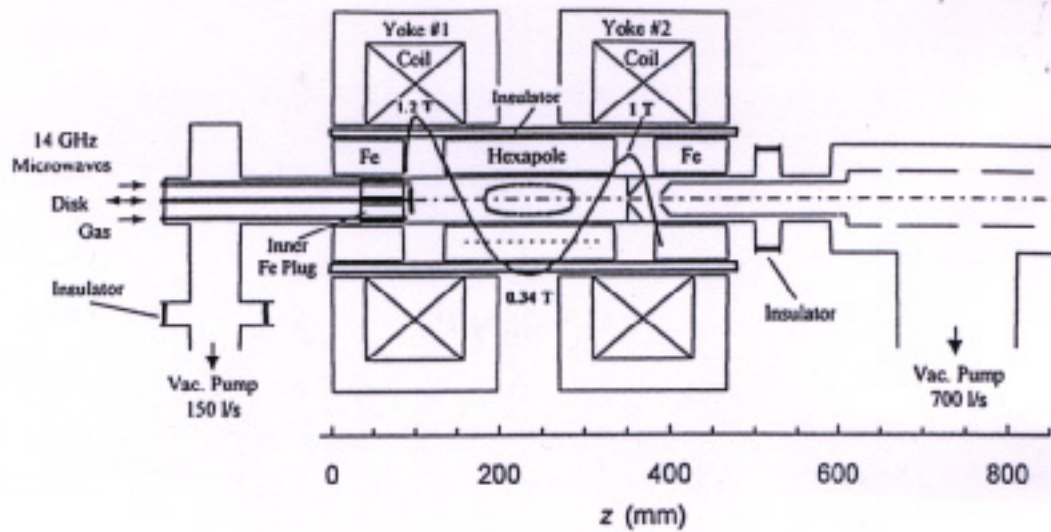


Fig. 1. Schematic view of RECRIS
 Superimposed: the mirror field configuration
 and the ECR zone (102 mm long and 37 mm diameter)

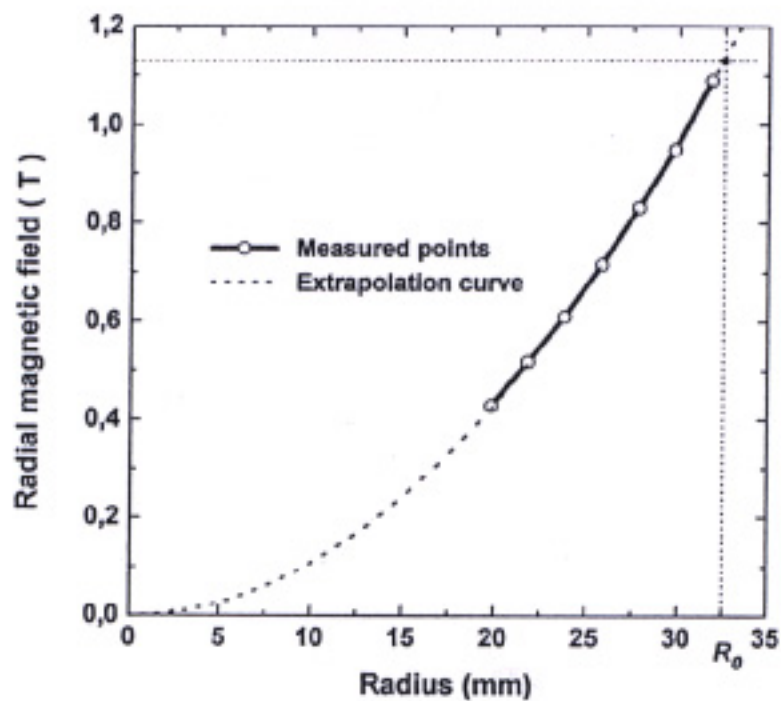


Fig. 2. Determination of the maximum
 radial magnetic field of the hexapole

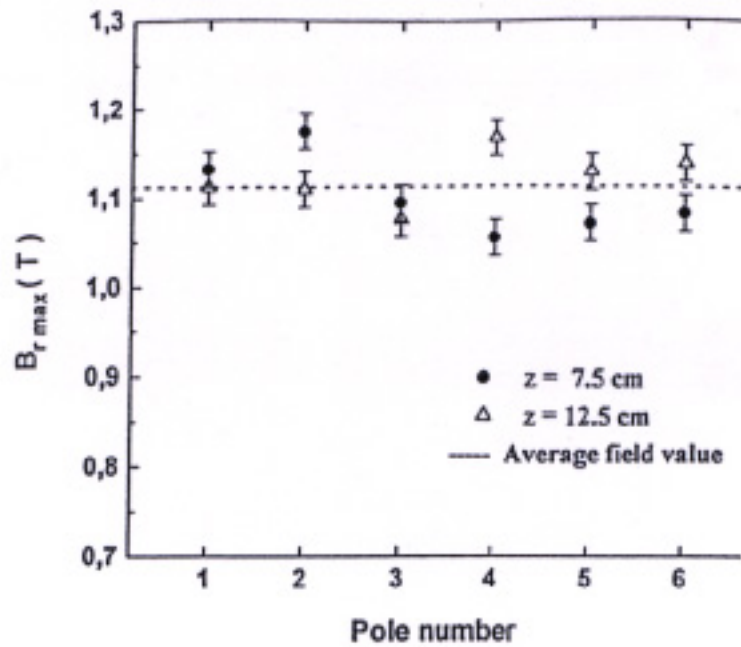


Fig. 3. Maximum radial magnetic field of hexapole, measured at the six pole location

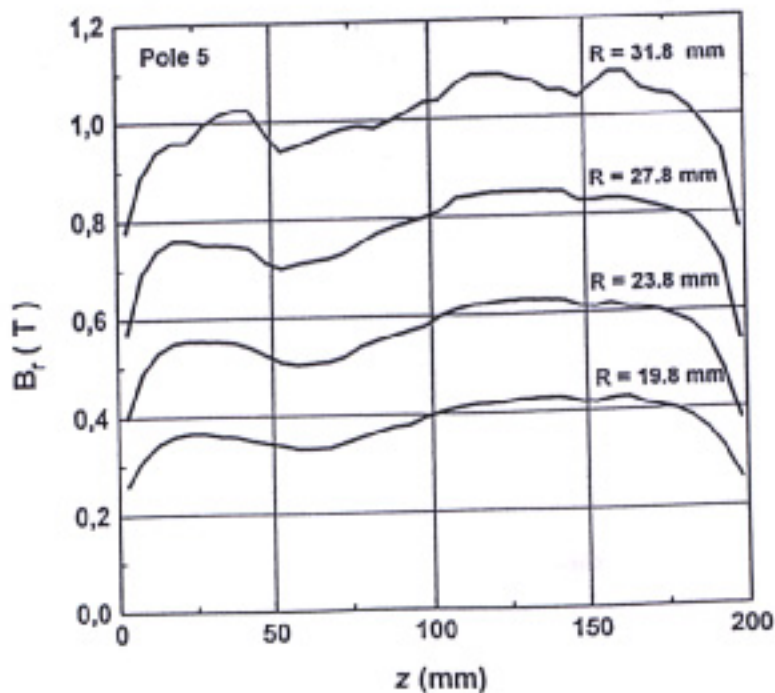


Fig. 4. Variation of the radial magnetic field along the z axis of the hexapole

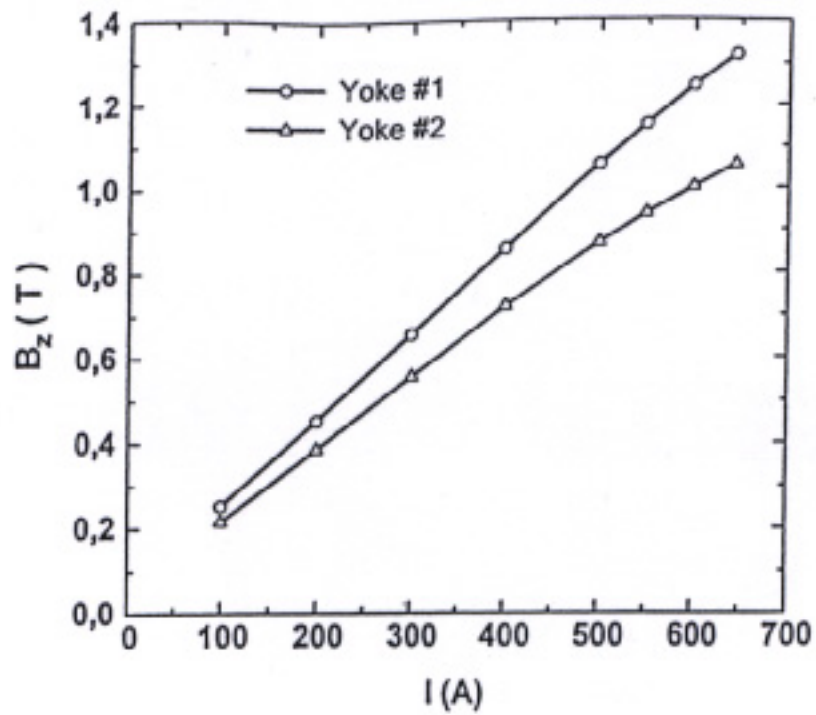


Fig. 5. Magnetization curve of the axial magnetic system

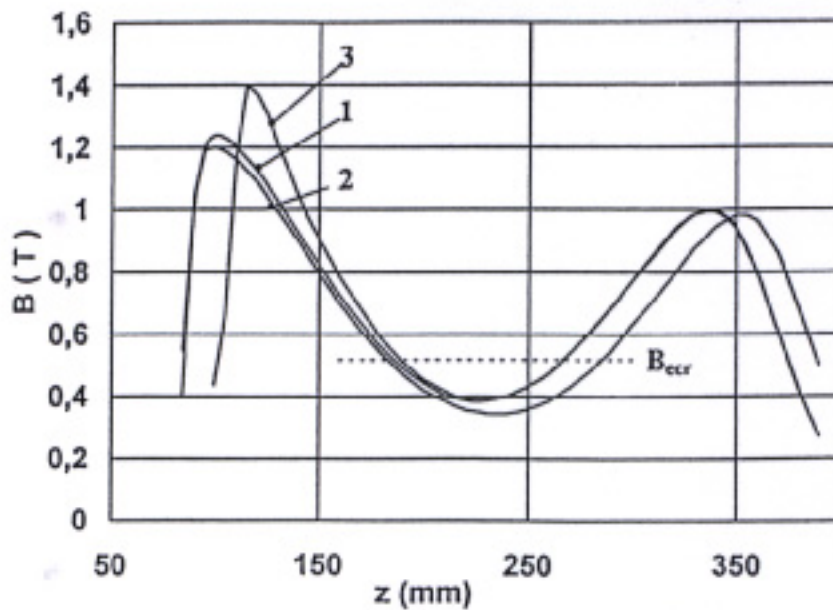


Fig. 6. The axial magnetic field configuration at $I = 600$ A, for two distances d between the iron yokes and for two positions of the inner iron plug
 Curve 1: $d=50$ mm, normal plug position;
 Curve 2: $d=70$ mm, normal plug position;
 Curve 3: $d=50$ mm, advanced plug position with 20 mm