# THE ECR-SOURCE FOR THE PROJECT ISIS AT JULIC

H. Beuscher, H.-G. Mathews, C. Mayer-Böricke and J. Reich

Institut für Kernphysik, Kernforschungsanlage Jülich, D-5170 Jülich, W. Germany

Abstract.- An ECR-ion source for the Jülich isochronous cyclotron JULIC has been designed. It consists of a compact fully superconducting magnet system for two plasma stages in one common cryostat. Some improvement of the performance compared to existing sources is expected since high frequency microwave generators of 28 and 18 GHz can be used for the first and second plasma stage, respectively.

1. Introduction.- To provide the acceleration of heavy ions up to neon between 22.5 and 45 MeV/nucleon at JULIC the project ISIS (Injektion schwerer Ionen nach EZR-Stripping: Injection of heavy ions after ECR-stripping) has been started. This project comprises the design and construction of an Electron-Cyclotron-Resonance (ECR)-ion source, a beam preparation, -guiding and injection system[1] as well as a new RF-center region for JULIC[2]. A sophisticated and expensive source like the ECR-source is needed since JULIC only accelerates highly charged ions ($Q/A \geq 0.33$).

2. Description of the design.- The first ECR-source which was able to produce highly charged heavy ions was the Super-Mafios B (SMB) built by Geller in Grenoble[3]. The proposed ECR-source for Jülich (in Fig. 1) is designed for higher beam intensities and higher charge states.

The source consists of two plasma stages: The injector- and the stripper-stage. In the injector stage with a small aperture and a gas pressure of $10^{-3}$ Torr a cold plasma is produced by ECR. The ECR is caused by microwave injection into a suitable axial magnetic field. The cold plasma consisting mainly of ions in the lowest charge state diffuses into the second plasma stage with a larger aperture and a very low pressure ($<10^{-7}$ Torr). This stripper stage is a magnetic bottle with a rising magnetic field in the axial and radial direction, a so-called $B_{min}$-structure. The $B_{min}$-structure is realized by super-position of a magnetic mirror field and a hexapole field. The $B_{min}$-structure of the magnetic field and the low gas pressure lead to a long confinement time of the electrons in the plasma. By injecting microwaves from a second powerful generator into this stage a plasma with a high density of fast electrons is produced (hot plasma), which is able to generate in a step by step process highly charged heavy ions.

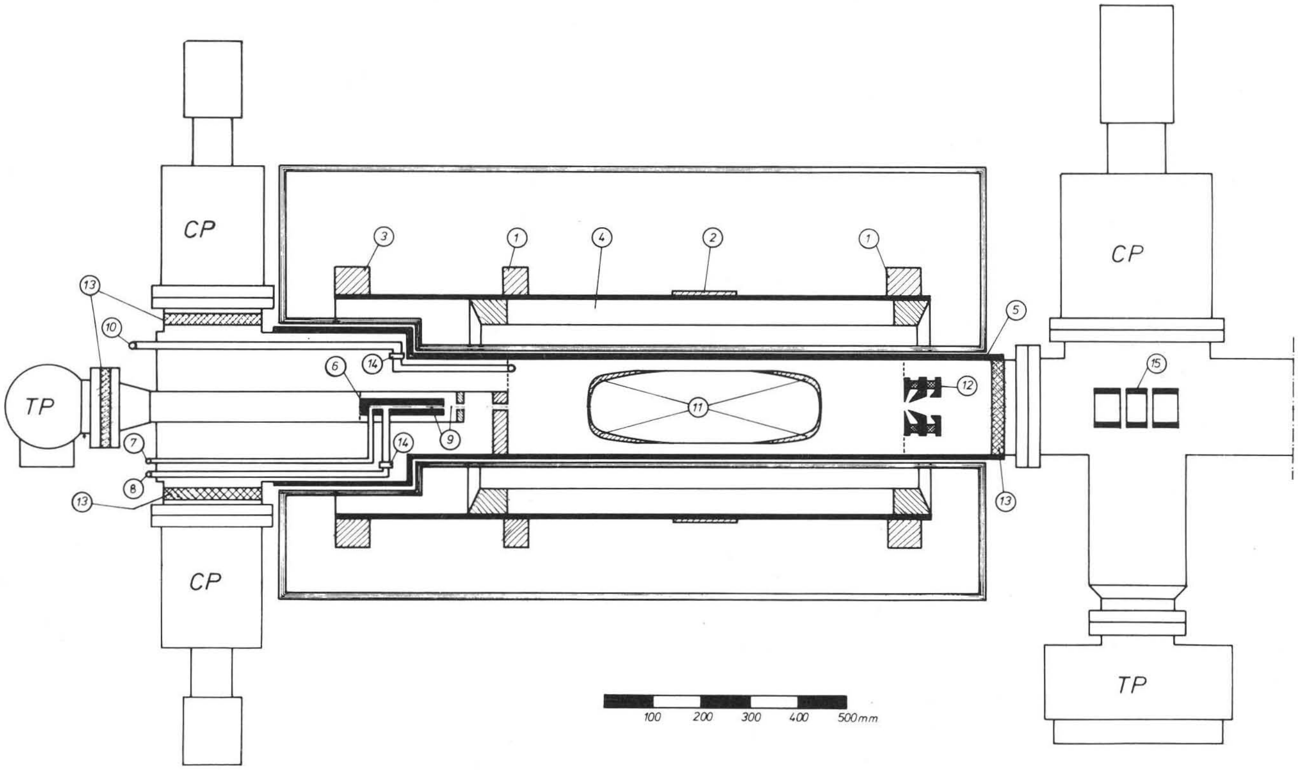
The magnet system of the proposed Jülich source is designed to be completely superconducting. This choice was made because of the low power consumption at considerably high fields. The device consists of one short solenoid for the first plasma stage, two mirror coils, one additional weak solenoid to adjust the mirror ratio and a hexapole magnet for the second stage (see fig. 1). For the vacuum system of the source it is planned to use only refrigerator cryopumps (CP) and turbomolecular pumps (TP). The required high pressure gradient between the cold and hot plasma stage is achieved by differential pumping.

Since the extracted heavy ions will be injected into the Jülich cyclotron with an energy up to 10 keV per charge the whole plasma chamber of the source has to be on a positive potential up to 10 kV relative to the extraction electrodes.

Fig. 2 shows the magnetic field along the source axis (z-axis) for about the maximum current in the coils. The maximum mirror field is about 1 Tesla (z=42 cm). The mirror ratio in this case is $B(z=42)/B(z=0)=2.1$, but can be adjusted within a wide range. The radial dependence of the magnetic field in the middle of the source (z=0) can be seen in fig. 3. The lower curve represents the field of the hexapole alone ($|B| \sim r^2$). The other one is the superposition of the hexapole and mirror field. At the inner diameter of the vacuum chamber (r=10 cm) the total field has about the same value as the maximum mirror field ($\approx$1 Tesla). In this superimposed field of the hot plasma stage the points where ECR can occur form a closed surface. The projection into the drawing plane of this resonance surface for 18 GHz belonging to a magnetic field of 0.64 Tesla is included in fig. 1. The mirror and hexapole fields have to be strong enough to keep this resonance zone fully within the vacuum chamber. In order to achieve a sufficient confinement time for the accelerated electrons the magnetic field has to increase strongly from the resonance zone towards the walls of the hot plasma stage. The chosen magnet configuration provides an increase in $|B|$ of at least 1.5, i.e. $|B| \geq 0.96$ Tesla at any point on the walls of the second stage.

The field shape shown in fig. 2 allows to use microwave frequencies of 28 and 18 GHz in the first and second stage, respectively. These frequencies are considerably higher than those used in existing ECR-sources (Grenoble[3]) or sources under development (Karlsruhe[4]), Louvain-la-Neuve[5])). Since the attainable electron density $n_e$ increases with the square of the microwave frequency an improvement in the production of highly stripped ions can be expected. Since the required microwave power is proportional to the electron density, powerful and expensive microwave generators of about 1.5 kW at 28 GHz for the first stage and of the order of 10 kW at 18 GHz for the second stage may be necessary for the Jülich ECR-source.

3. Estimated performance.- A rough estimate about the ion production of the Jülich ECR source is possible under the assumption that the average charge state in the second plasma stage depends on $n_e \cdot \tau_i$ and Z as shown in fig. 4 (ref. 6). The two $n_e \cdot \tau_i$-lines in fig. 4 re-



(1) mirror coils
(2) thin additional solenoid
(3) first stage solenoid
(4) hexapole magnet
(5) watercooled vacuum chamber
(6) watercooled 1. plasma stage
(7) gas inlet
(8) microwave injection to 1. stage
(9) resonance point and cold plasma of 1. stage
(10) microwave injection for 2. stage
(11) resonance zone of 2. stage for 18 GHz
(12) extraction electrodes
(13) high voltage insulation
(14) microwave window
(15) einzellens

Fig. 1: Schematic view of the proposed ECR-source for the Jülich Cyclotron

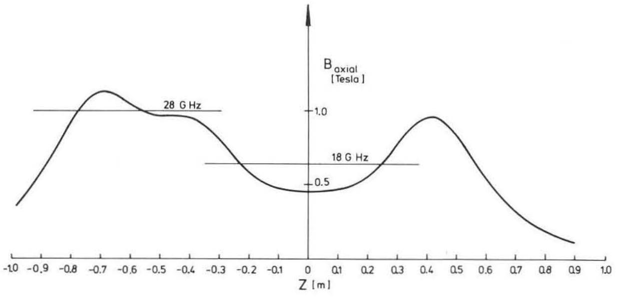


Fig. 2: Magnetic field along the axis of the source

present experimental values for the SMB$^{3)}$ and extrapolated values for the Jülich ECR-source. For the extrapolation it has been assumed that $n_e$ increases with the square of the microwave frequency while the confinement time $\tau_i$ remains constant.

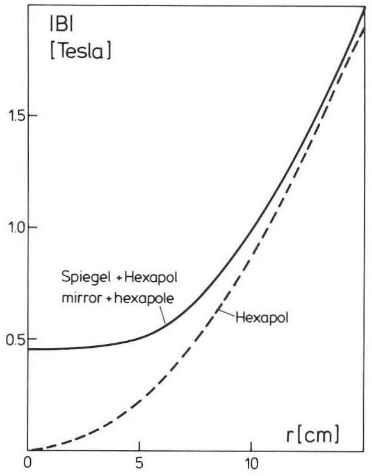


Fig. 3: Radial dependence of the magnetic field at the mirror center (z=0)

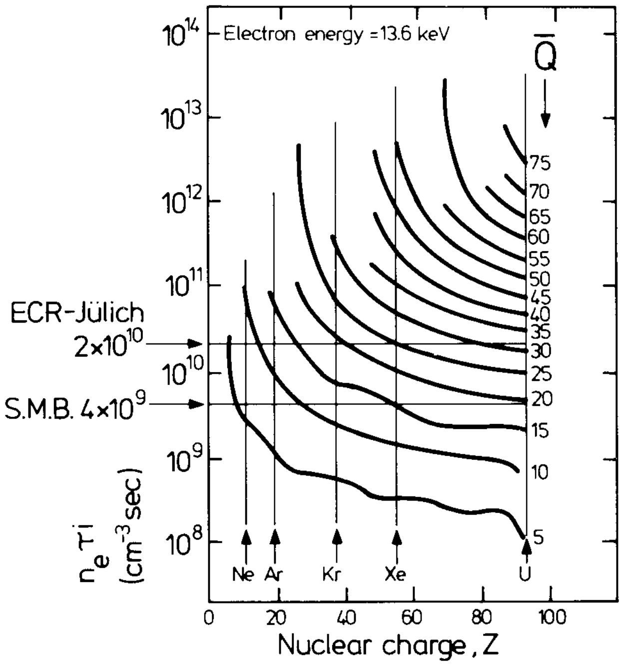


Fig. 4: Average charge states, $\bar{Q}$, produced in a plasma for various $n_e\tau_i$ and ion species Z (ref. 6)

According to the different microwave frequencies for the two sources of 8 GHz (SMB) and 18 GHz for the Jülich source the $n_e \cdot \tau_i$-value is expected to increase by a factor of 5.

Applying this extrapolation one can expect the ion species given in table 1 to be accelerated in the Jülich cyclotron and to be available with currents larger than 10 particle-nA for experiments at the exit of the cyclotron.

| Ion | q/A | max. energy per nucleon (MeV) | max. particle energy (MeV) |
|---|---|---|---|
| $^{12}C^{4+}$ | 0.333 | 22.5 | 270 |
| $^{12}C^{5+}$ | 0.417 | 31.3 | 375 |
| $^{12}C^{6+}$ | 0.500 | 45.0 | 540 |
| $^{14}N^{5+}$ | 0.357 | 22.9 | 321 |
| $^{14}N^{6+}$ | 0.429 | 33.1 | 463 |
| $^{14}N^{7+}$ | 0.500 | 45.0 | 630 |
| $^{16}O^{6+}$ | 0.375 | 25.3 | 405 |
| $^{16}O^{7+}$ | 0.438 | 34.5 | 552 |
| $^{16}O^{8+}$ | 0.500 | 45.0 | 720 |
| $^{20}Ne^{7+}$ | 0.350 | 22.5 | 450 |
| $^{20}Ne^{8+}$ | 0.400 | 28.8 | 576 |
| $^{20}Ne^{9+}$ | 0.450 | 36.5 | 730 |

Table 1: Ion species and their maximum energy which can be expected with a current >10 particle-nA at the exit of the cyclotron.

References:

1) R.K. Bhandari, J. Reich, contribution to this conf.

2) L. Aldea, J. Reich, P. Wucherer, contrib. to this conf.

3) R. Geller, IEEE Trans-NS 26, No. 2 (1979) 2120

4) V. Bechthold, H.P. Ehret, L. Friedrich, J. Möllenbeck, and H. Schweickert, IEEE Trans-NS 26, No. 3 (1979) 3680

5) Y. Jongen, C. Pirart, G. Ryckewaert, and J. Steyaert, IEEE Trans-NS 26, No. 2 (1979) 2160

6) J.D. Daugherty, L. Grodzins, G.S. Janes, and R.H. Levy, Phys. Rev. Lett. 20, No. 8 (1968) 369