EARLY PERFORMANCE OF THE SUPERCONDUCTING ISIS ECR SOURCE AT JÜLICH

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Summary

A superconducting ECR ion source for the production of ions up to Ne, which shall be accelerated by the Jülich isochronous cyclotron up to energies between 22,5 and 45 MeV, has been installed. The early performance of the source is described and results are presented.

Introduction

The project ISIS [1] has been initiated some years ago to extent the particle beams of the Jülich Isochronous Cyclotron from He^{2+} to heavy ions up to Ne. Since the Jülich Cyclotron can only accelerate particles with a charge to mass ratio larger than 1/3 in the normal 3ω mode, the ions can only be produced by a powerful external source. A high frequency ECR source seemed to be the best choice for this purpose. It was decided to mount the source outside the cyclotron cave and have a second smaller source for light particles which can at least replace the old internal ion source. There will than be some time available for source development or atomic physics experiments on the big source while the cyclotron is running on light particles with the small source. Additionally the breakdown time of the cyclotron caused by ion source failure can be reduced with two sources available.

Figure 1 displays a schematic view of the two sources. The light ion source (LIS) is a 5 GHz-ECR-source which is similar to the former test source PreISIS 2 (ref. 2). The charge separation for LIS is provided by a Wienfilter (WF) and the charge distributions are measured at point 32 where the ion beam enters the beamline to the cyclotron. The LIS shall be assembled and in operation until the end of this year.

The charge separation for the big source (ECR) is provided by a 90^0 double focussing magnetic bending system, which contains two identical unit cells. Each unit cell consists of 1 dipole (MS) and 2 quadrupole (QS) magnets. The particle beam extracted from the source is focussed by a Glaser type magnetic lens through a collimator at point 4 (Fig. 1) which is the entrance to the 90^0 bending system and the charge distributions are measured at point 18. The resolution of the system is about 1/25 for diaphrams of 22 mm diameter at point 4 and 18.

More information about the beamline, the injection system and the new center region of the cyclotron is presented in a second contribution to this conference [3].

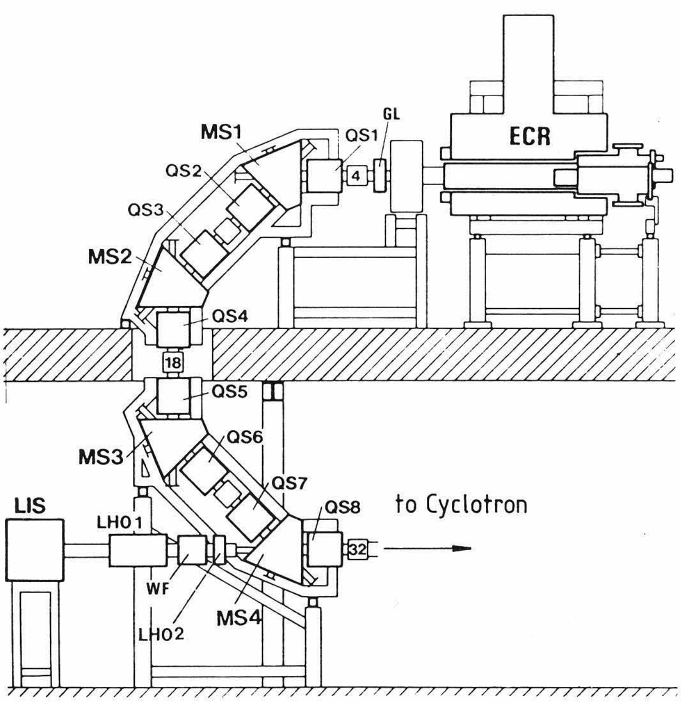


Fig. 1:The new ion sources for the Jülich Cyclotron

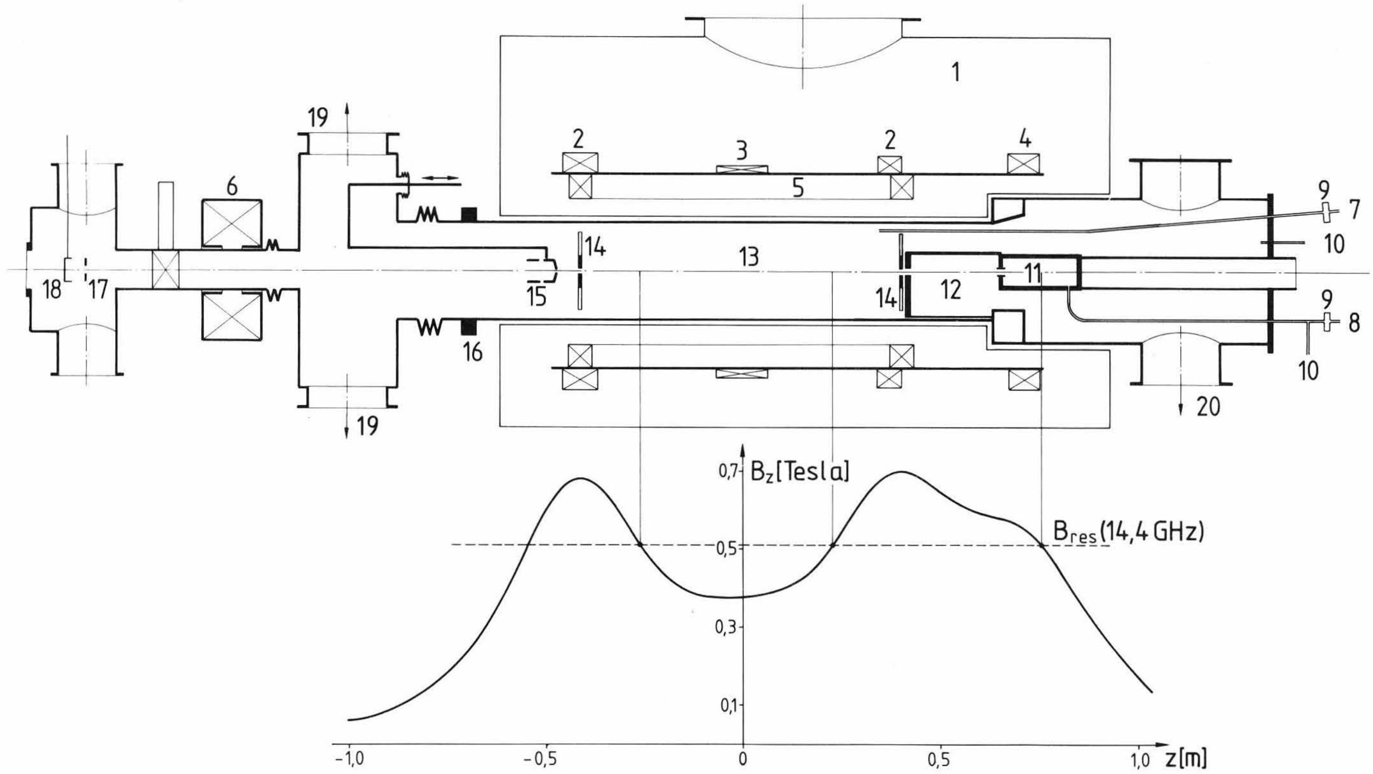
Description of the Source

The source is shown in some more detail in Fig. 2 together with the axial magnetic field distribution which is used at present.

The superconducting magnet system consists of two mirror coils (2 in Fig. 2), one weak solenoid to adjust the mirrow ratio (3), a hexapole magnet (5) and a solenoid for the first stage field (4) all mounted in one common cryostat (1). Each coil has its own power supply and the current leads are demountable to reduce the liquid He comsumption. The system has been built by the BBC company (Mannheim). After a long delay in the delivery caused by a cold leak and the break down of a superconducting switch the system has been trained to 80% of the designed maximum field. The presently available field would allow to use a microwave frequency up to 18 GHz. For higher frequencies further training of the hexapole would be necessary. The system is now on liquid He-temperature for more than one year. The He comsumption is about one liter per hour.

The microwave system of the source consists of two 14.4 GHz generators with a maximum output power of 2 kW each. A block diagram of one generator is shown in Fig. 3. The output power from the Klystron (TH 2426A from Thomson CSF) is divided into two parts by a 6 dB coupler. 3/4 of the power are injected into the main plasma stage, 1/4 into the injection stage. The power for the injector stage can be varied from 0 to 500 watt at full output power from the Klystron with a motor driven variable power divider. By using the coupler in addition to the variable power divider an almost complete decoupling of the two branches is achieved. The second generator is only feeding the main plasma stage. There are then 3.5 kW microwave power available for the main stage and 0.5 kW for the first stage. The microwave system has been set up in collaboration with the "Laboratorium für Mikrowellenanwendungen, Dr. Beerwald" (Bochum).

The source has three vacuum sections: The first plasma stage (11 in Fig. 2), a differential pumping stage (12) and the main plasma stage (13). The pumping system is a combination of cryopumps and turbopumps. Turbopumps have been added for gases like He and Ne. The pumping speeds are 1.800 l/s for the differential pumping stage and 5.000 l/s for the main stage. The main plasma stage is only pumped axially from the extraction regions. It has a length of 84 cm (mirror length) and a radius of 12 cm. This is about 40% fo the volume of Supermafios B [4] or ECREVIS [5]. The background vacuum pressure comes down to about $5 \cdot 10^{-8}$ mbar in the intermediate pumping region and below $1 \cdot 10^{-8}$ mbar in the extraction region.



(1)	He-cryostat
(2,3,4,5)	superconducting coils
(6)	Glaser lens
(7)	microwave injection to main plasma stage
(8)	microwave injection to 1st stage
(9)	microwave vacuum window
(10)	gas inlet
(11)	1st plasma stage
(12)	differential pumping stage
(13)	main plasma stage
(14)	plasma electrodes
(15)	extraction electrodes
(16)	HV insulation
(17)	beam collimator
(18)	Faraday cup
(19,20)	pumping

Fig. 2: Schematic view of the superconducting ISIS-ECR-source

In the beginning mainly the following two problems were responsible for bad vacuum conditions during source operation:

First: It took sometime to determine the right dimensions of the axial plasma electrode (14) at the extraction end of the main plasma stage. It has to provide good plasma and microwave shielding, but on the other hand has to allow sufficient pumping of the main plasma stage.

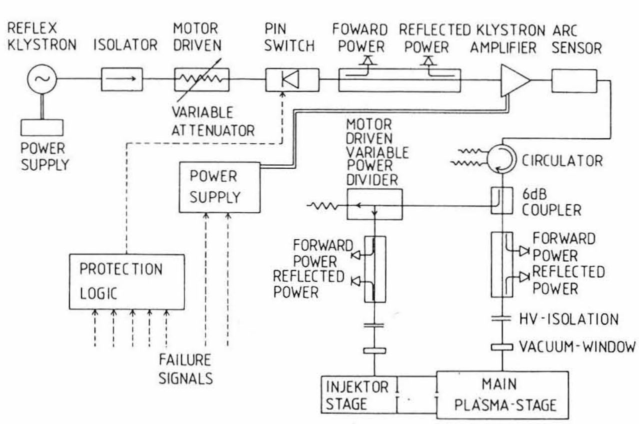


Fig. 3: Block diagram of a 14 GHz-2kW microwave generator

Second: It turned out to be quite essential to have seperate microwave shielding of the cryopumps in addition to the shielding of the plasma stages.

The microwave injection into the first stage is done radially while to the main stage only axial injection is possible. Despite of having an ECR resonance field at least in the waveguide to the second stage no measurable absorption of microwave power in the waveguide was found. Probably because of the small dimensions of the waveguide electrons cannot be accelerated to high velocities before hitting the walls of the waveguide. Consequently the vacuum windows could be mounted outside the vacuum chamber (9). Thus many problems arising from mounting them inside the chamber are avoided. Commercially available Al_2O_3 as well as home made water-cooled Teflon windows are used. Gas can be injected into the first plasma stage as well as into the second stage (10).

The two collimators between the first stage and the intermediate pumping stage and from here to the main plasma stage have a diameter of 16 mm. This size has been chosen as large as possible to have a large amount of plasma from the first stage injected into the main stage. For the same reason the distance between the first and second stage should be as short as possible, here it is 25 cm. On the other hand, the size of the collimators is limited by the request that a pressure gradient of about 3 to 4 orders of magnitude from the first to the main stage has to be achieved for the given pumping system.

The properties of the extraction system and the Glaser lens have been determined by trajectory calculations with the Hermannsfeld-code [6]. It turned out that in this case of a strong magnetic fringing field calculations with the TRANSPORT-code [7] give the same results.
The extraction electrodes are set up in an accel-decel system with the possibility to vary the distance between the plasma electrode and the puller in the axial direction on line. The diameter of the extraction hole is 8 mm.

Performance and Results

Deviating from the original plans where a higher frequency should be used for the first stage (11 in Fig.2) the source is now running with the same frequency of 14.4 GHz in both stages. Because of the fixed positions of the superconducting coils it is under these conditions not possible to have a mirror shape field in the first stage.
The first plasma stage has shown reasonable performance when running on its own. Several hundred µAs of beam could be extracted behind the main stage with an input power of about 200 Watts. Running both stages the first stage really acts as an injector in the sense that the main plasma does not start without the first stage. In full operation of the source the power injected into the first stage is very low mostly below 100 Watts. It seems that the combined plasma of the first and second stage is not a well adjusted load for the microwaves going to the first stage. Probably the first stage also receives microwave power from the main stage. But still the whole plasma breaks down if the power to the first stage is turned off.
Concerning the microwave power for the main stage it was so far not possible to inject more than 2.7 kW into the main stage in a "useful way". Useful way means that injecting more power results in an increase of high charge states. The 2.7 kW were needed for the production of highly charged Kr ions.
The operation of the source is not very sensitive to small changes in the magnetic field distribution except for the position of the ECR resonance in the first stage.
The best distance between the extraction electrode and the puller turned out to be rather large. It is now mostly around 6 cm but in many cases it could still be larger. The trend is: Larger distance for higher q/A and lower plasma density. Because of the large distance the puller hole had to be increased from 10 to 16 mm diameter.
The collimators in the analysing system have been chosen to pass a beam with an emittance of 600 mm mrad which can be almost fully accepted by the Jülich Cyclotron. In some cases smaller collimators which provide better resolved spectra have been used to determine the components of unresolved peaks in the charge spectra.
Gas mixing has been used for almost any ion species. Different modes like injecting both gases into the first stage or one into the first stage and the other into the main stage have been applied. Fig. 4 shows a Ne charge distribution. For this spectrum the Glaser lens was set to achieve optimum transmission for the 8^+ state. That means that the states further away from this peak are suppressed in the displayed spectrum. O_2 has been used as mixing gas. The suppression of the ^{16}O charge states as a result of the gas mixing is surprisingly complete. But the suppression of the charge states of the mixing gas is not a necessary condition for good gas mixing, especially not in cases where the two gases are not injected into the same plasma stage. As an example Fig. 5 shows a charge distribution for ^{84}Kr with Ar as a mixing gas. In this case Ar was injected into the first stage and Kr into the second stage. Despite of having the Ar charge states strongly visible in the spectrum the highest observed Kr charge states (20^+; 22^+) are more strongly populated than in the case of Kr + O_2 mixing where the Kr-spectrum is very clean (Fig. 6).

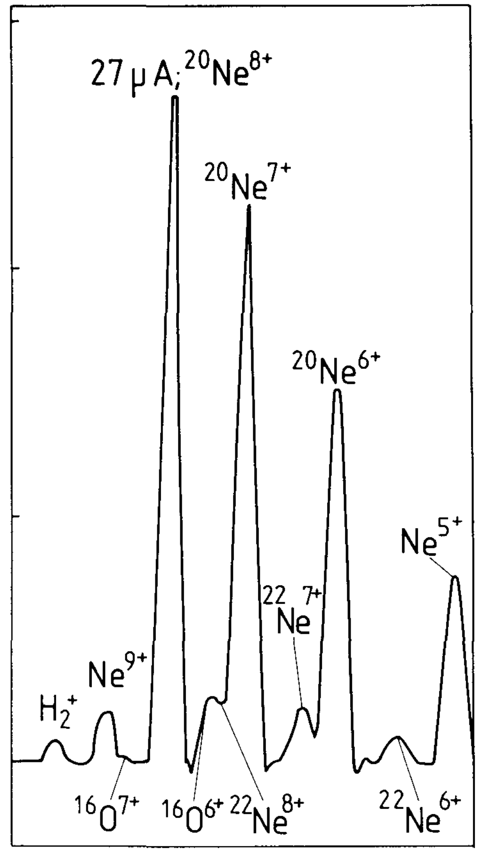


Fig. 4: ^{20}Ne charge distribution using O_2 as mixing gas

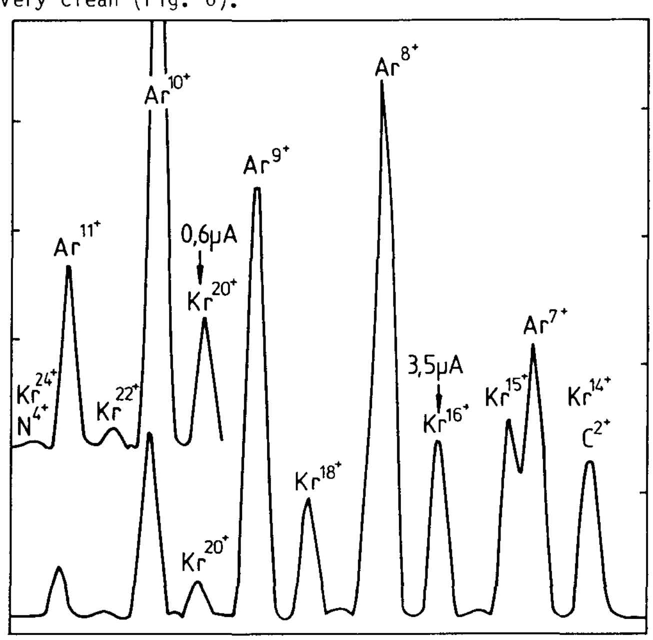


Fig. 5: High charge states of ^{84}Kr enhanced by adding Ar as mixing gas. Taken with increased resolution but reduced transmission of the analysing system.

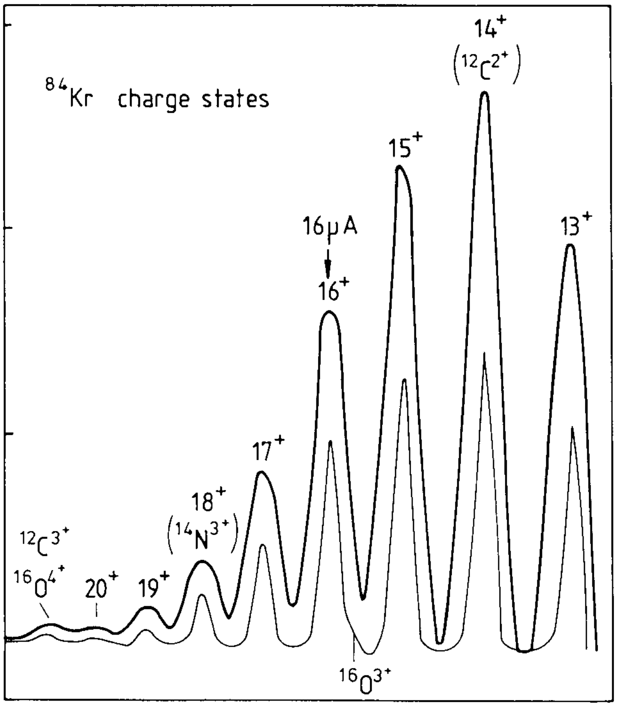


Fig. 6: High charge states of ^{84}Kr using O_2 as mixing gas. The charge distribution is also plotted with better resolution to show the small amount of ^{16}O charge states.

Concerning gas mixing one statement can be made from the comparison of the behaviour of the big ISIS ECR source and the PreISIS test device: There is no unique answer to the question, which gas is the best mixing gas for a certain ion species. Helium was for example the best mixing gas for Ne in the small PreISIS source whereas O_2 works much better for Ne in the big ISIS source. There seems to be a trend that heavier gases are better mixing components in the bigger source.
The achieved extracted ion beams from the source are given in Table 1. For charge states with $q/A \ll 1/3$ like in the case of ^{84}Kr the extraction voltage could not be raised above 7 kV since the Glaser lens, which was mainly designed for $q/A > 1/3$ is not able to provide efficient coupling between the source and the beam line for higher voltages. For ^{84}Kr ion currents are given for plasmas with O_2 and Ar as mixing gas. It seems that Ar gives some improvement for the highest observed states.
The production of fully stripped ions has been demonstrated for ^{15}N. The probability to remove both electrons from the K-shell is about a factor of eight smaller than to remove one electron under the best conditions achieved so far. The microwave power injected into the main plasma stage was 2 kW.
The dashed lines give the limits above which the charged states can be accelerated in the Jülich cyclotron. So far these particles can been transported to a point just underneath the cyclotron. Injection into the cyclotron [3] will be tried soon.

Table 1
Ions from the ISIS-ECR-Source
(Sept. 1986)

	$^{14,15}N$	^{16}O	^{20}Ne	^{40}Ar	$^{84}Kr(+O_2)$	$^{84}Kr(+Ar)$
4^+	66					
5^+	71	62				
6^+	36	72	60			
7^+	4.5	20	35			
8^+			27	70		
9^+			2.8	50		
10^+				$\lesssim$ 36		
11^+				22		
12^+				12		
13^+				4	34	
14^+				1	$\lesssim$ 30	$\lesssim$ 17
15^+					25	*
16^+					16	12
17^+					8.5	*
18^+					$\lesssim$ 5	$\lesssim$ 5.5
19^+					2	*
20^+					1	1.6
21^+					*	*
22^+					0.15	0.3
23^+					~ 0.05	*
24^+						~ 0.05

Currents in eμA

Extraktion Voltages: (7-9) kV

Microwave Power 2.7 kW

* superimposed peaks

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