PERFORMANCE OF ISIS AT JULIC

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Abstract: For the acceleration of medium mass ions up to Ar between 22.5 and 45 MeV/A the project ISIS has been realized. ISIS comprizes a 5GHz-ECR-source for the light and a superconducting 14GHz-ECR-source for the heavier ions, a fully magnetic beam handling and axial injection system and a new RF-center region. The cyclotron was recommissioned for experiments in March 1987. Up to now beams of 0.61 eµA of 344 MeV $^{12}C^{5+}$, 1.4 eµA of 403 MeV $^{14}N^{6+}$, 0.14 eµA of 530 MeV $^{15}N^{7+}$, 0.1 eµA of 535 MeV $^{16}O^{7+}$, 2.6 eµA of 505 MeV $^{20}Ne^{8+}$ and 0.07 eµA of 1020 MeV $^{32}S^{13+}$ at the exit of the cyclotron have been used for experiments. Between the sources and the cyclotron exit a transmission of typically more than 10 % can be achieved.

Introduction

The Jülich Isochronons Cyclotron JULIC [1] was originally designed for the acceleration of light ions up to 45 MeV/A from an internal source. Since 1969 it has delivered these beams for more than 75 000 hours for experiments mainly in nuclear physics but also materials and life sciences. The acceleration of heavier ions was not possible for a long time because JULIC can only accelerate ions with charge to mass ratios larger than 1/3. The development of electron cyclotron resonance (ECR) sources opened new possibilities. Therefore, the ISIS (Injektion schwerer Ionen nach EZR-Stripping: injection of heavy ions after ECR-stripping) project could be started in 1982 (see figure 1).

ECR-Sources

The superconducting 14GHz-ECR-source developed in Jülich is schematically shown in figure 2 and has been described already in detail [2,3,4]. Ion currents for masses up to 40 extracted from this source and measured after analysis behind the first 90° of the 180°-bending system (see figure 1) are listed in table 1.

Table 1

Ions from the 14GHz-ECR-source

numbers give the currents in eµA
* superimposed peaks

	$^{12,13}C$	$^{14,15}N$	^{16}O	$^{20,22}Ne$	^{32}S	^{35}Cl	^{40}Ar
3+	*	100					
4+	80	85	*				
5+	23	85	70	110			
6+	1.1	64	125	80			
7+		4.5	20	58			
8+			*	30	*	30	85
9+				4.2	40	*	80
10+				0.25	*	27	*
11+					16	*	30
12+					*	7	17
13+					1.5	*	6.6
14+					*	0.7	1.5
15+							*
16+							0.06

A small 5GHz-ECR-source (LIS, see figure 1) with normal coils [5] based on the Pre-ISIS test-sources [6] delivers the light ions for the cyclotron. Most recently it has been used to produce H_2^+ and H^- beams to test the stripping injection for the cooler synchrotron COSY-Jülich [7].

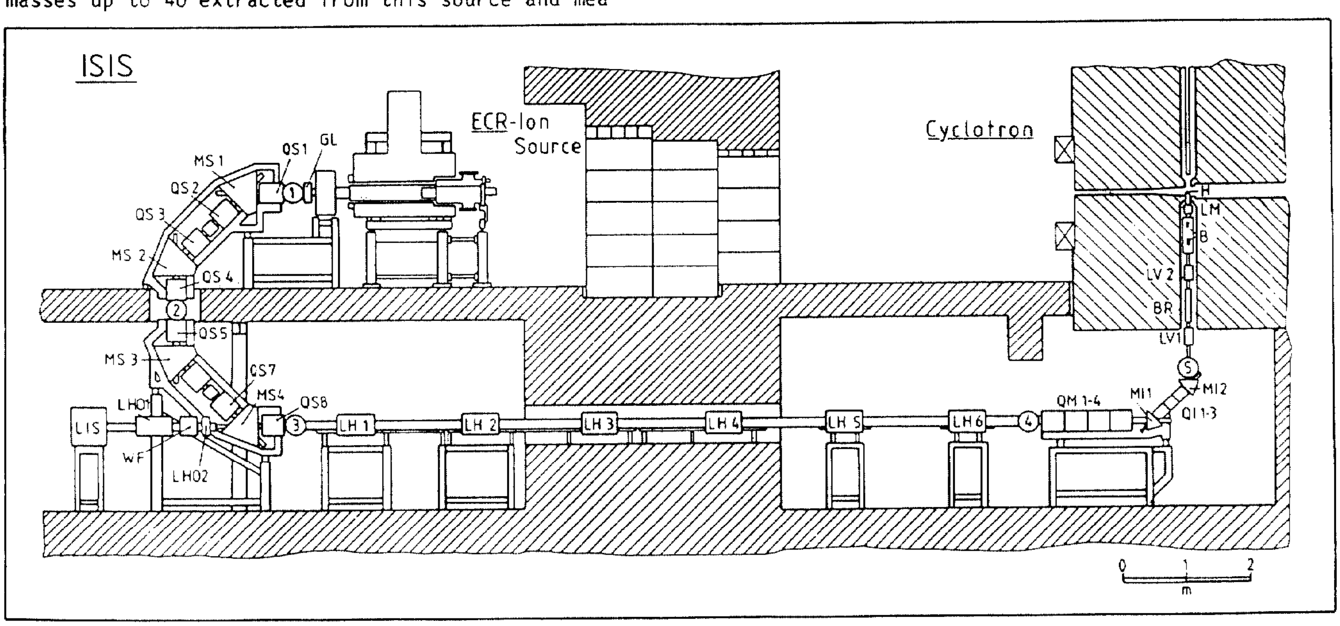

Figure 1: Layout of the project ISIS at JULIC: LIS-light ion source; WF-Wienfilter; QS, QM, QI-quadrupole magnets; MS, MI-dipole magnets; LH, LV-solenoid lenses; GL, LHO2, LM-magnetic glaser type lenses; B-bunching system; H-hyperboloid inflector; 1 ... 5 -beam diagnosis boxes

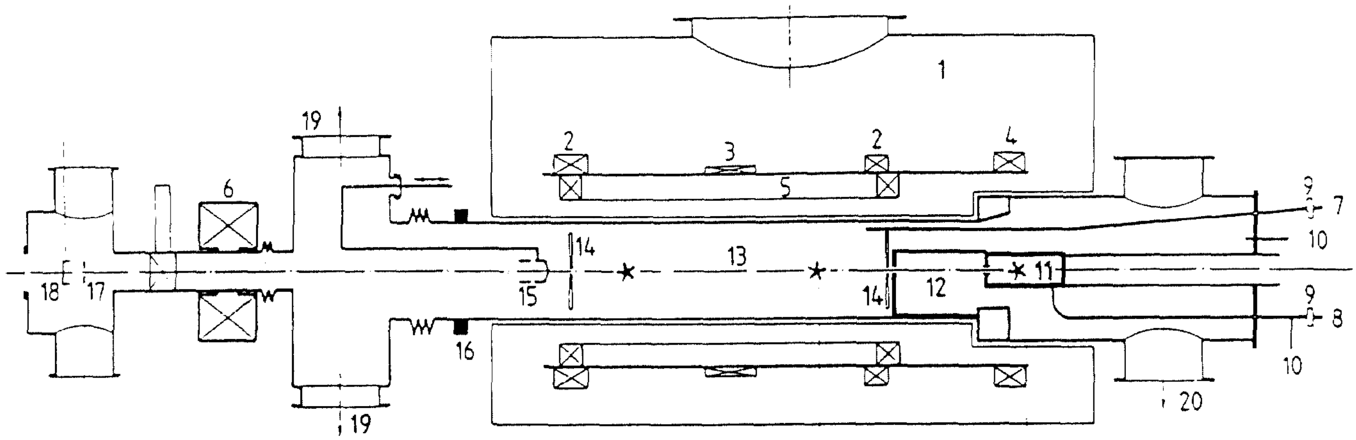

Figure 2: Schematic view of the 14GHz-ECR-source: 1-He-cryostat 2 ... 5-superconducting coils, 6-glaser lens, 7-microwave injection to main stage, 8-microwave injection to first stage, 9-microwave vacuum window, 10-gas inlet, 11-first stage, 12-differential pumping, 13-main stage, 14-plasma electrodes, 15-extraction electrodes, 16-HV insulation, 17-beam collimator, 18-Fataday cup, 19-20-pumping, *points of ECR on axis.

Source Matching

The emittance as well as sizes and location of the upright phase ellipse of the ECR-ion sources vary due to the plasma condition, the extraction voltage and the space charge effects in the extraction region [8]. During the on and off line tests of the beam handling system and the sources [9] it became evident that it would be advantageous to have two solenoid lenses and sufficient beam steering between source and the succeeding beam handling system to cope with the variation in beam emittance and direction.

Beam Handling, Bunching and Injection

Different from the original design [10] the last lens squeezing the beam into the hyperboloid inflector [11,12] has been changed from an Einzellens to a glaser type solenoid lens. During a number of off and online tests prior to final commissioning the system has proven to function satisfactorily with respect to transmission and charge state analysis [9]. At this stage also the first harmonic double gap buncher was equipped with a rough grid according to a calculated optimization [9]. The bunching efficiency ranges typically above a factor of three. The last magnetic steerer before the lens LM in front of the hyperboloid inflector turns out to be most valuable to optimize the beam transmission into the cyclotron.

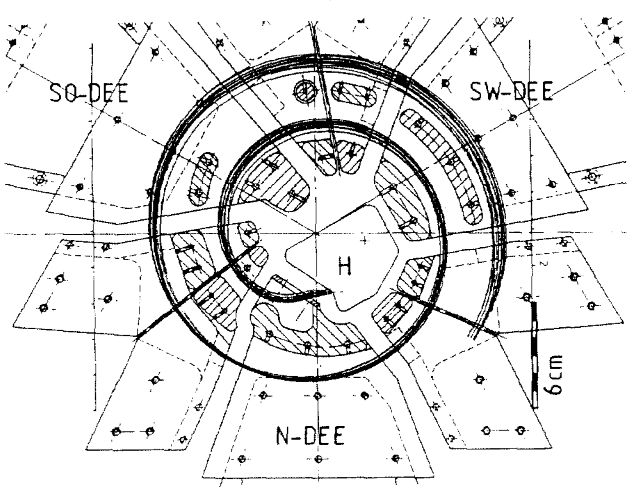

Figure 3: Sketch of the new RF center with the beam traced for 2 revolutions; H-hyperboloid inflector.

Center Region

To accomodate the axial injection a new RF-center region has been designed [13] and refined during the construction stage [14]. Also the central iron plugs had to be modified. During the commissioning it turned out that one of the plugs had to be reshimed to center the beam in axial direction [15]. This procedure was possible without removing the plug.

Performance

A typical beam loss pattern with the bunching system in operation is given in figure 4. Position 2 to 5

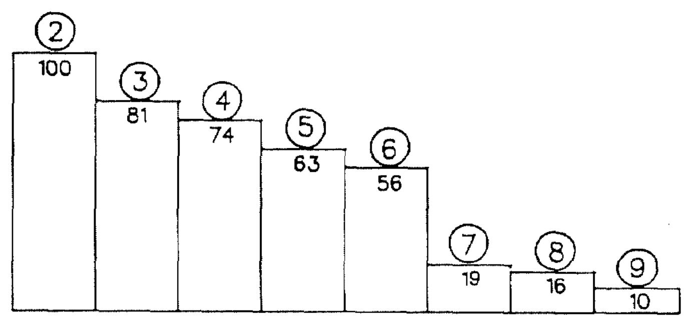

Figure 4: Beam loss pattern after the 14GHz-ECR-source

refer to the beam diagnosis boxes as shown in figure 1. Position 6 is the upper electrode of the inflector, 7 is at a cyclotron radius of 16 cm, 8 is before extraction and 9 at the cyclotron exit. Because of the vacuum improvement to better than 10^{-6} mbar [9] losses due to residual cyclotron tank gas are negligible. The extraction efficiency ranges above 60 %. This and other measured values (coherent radial amplitude $\leq$ 1mm, energy width $\leq$ 2/1000 and phase width $\leq$ 14° RF) prove that the cyclotron beam quality has improved. Table 2 lists the available beams and those so far developed for experiments.

Experiments

With the now available beams interactions between nuclei at the Fermi velocity can be studied. The experiments now under way cover the following topics: Giant resonances in highly excited nuclei, hard photons up to 100 MeV from Bremsstrahlung-mechanisms, fast nucleon and pion production, fragmentation of light and heavy nuclei, X-ray microstructure of heavy elements and multi-nucleon transfer [16].

Table 2

Available and developed ISIS-beams

AVAILABLE BEAMS		DEVELOPED BEAMS			
ISOTOPE	ENERGY RANGE [MeV]	ION	ENERGY [MeV]	INTENSITY [enA]	TRANSM. [%]
^1H	22 - 45	H^+	29	630	9
^2H	45 - 90	$^2H^+$	59	4600	11
H_2	45 - 90	H_2^+	80	11000	6
^3He	68 - 135	-	-	-	-
^4He	90 - 180	$^4He^{2+}$	120	4200	-
^{12}C	270 - 540	$^{12}C^{5+}$	344	610	11
^{13}C	295 - 500	-	-	-	
^{14}N	315 - 630	$^{14}N^{6+}$	403	1400	10
^{15}N	337 - 585	$^{15}N^{7+}$	530	140	8
^{16}O	360 - 720	$^{16}O^{7+}$	535	100	8
^{18}O	405 - 639	-	-	-	-
^{20}Ne	450 - 900	$^{20}Ne^{8+}$	505	2600	11
^{22}Ne	495 - 825	-	-	-	-
^{32}S	720 - 1120	$^{32}S^{13+}$	1020	70	5
^{35}Cl	788 - 1015	-	-	-	-
^{40}Ar	900 - 1020	-	-	-	-

Outlook

Further improvements in the performance can be expected from the day by day operation and optimization of the sources, from additional lenses and steering devices being built into the matching sections, from second harmonic bunching and from refinements of the first accelerating gaps in the cyclotron. The beam decorrelation techniques for ECR-sources worked out in collaboration with EUT-Eindhoven [17,18] may be when realized another exciting improvement possibility. ISIS and the tools developed during her realization will also pay off for the coming COSY-Jülich [19] with JULIC as injector [20] which in principle then can accelerate lower weight ions up to 1 GeV/A [7,21].

Acknowledgement

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