# SETTING UP THE ISIS INJECTION SYSTEM AT JULIC

W. Bräutigam, V.S. Pandit*), J. Reich, P. Wucherer, H. Beuscher, W. Krauss-Vogt
Institut für Kernphysik, Kernforschungsanlage Jülich, D-5170 Jülich, W. Germany
*) permanent address: VEC, BARC, Calcutta, India

## Summary

The commissioning of the external injection system in the frame of the project ISIS[1] starts in November 86. The complete injection beam line is already tested with beam. Test results as well as examinations and refinements by additional calculations are presented. All cyclotron components are reinstalled and under test. The cyclotron vacuum now matches the requirements for the acceleration of heavier ions.

## Introduction

All components of the injection system of ISIS (see figure 1) have been tested on or off line except the small 5 GHz-ECR source LIS[2] which was added in a late stage of the project. Since preference has been given to the development of the large 14 GHz-ECR source[3] the assembly of LIS started recently. The ions from this source will be separated by a Wien filter and focused by two solenoid lenses LH01 and LH02 into the diagnosis box downstream of quadrupole QS8 to match the beam line requirements. The introduction of a second Glaser type solenoid lens LH02 has been deduced from an emittance study of the LIS-prototype Pre ISIS 2. The set up taken for the emittance study used the solenoid LH01 and a diagnosis box in the same geometric configuration as in figure 1. Since the designed beam configuration at this diagnosis box is very near to the one at the start of the axial line underneath the cyclotron the same set up was used for the off line test of the axial yoke insert. Computer simulations have been made for the evaluation of the different test results as well as for a refinement of the double gap buncher. They are prepared for further investigations of the hyperboloid inflector[4] and the cyclotron center region[5].

## On line tests

In a first on line test so far of the injection system up to a Faraday cup on top of the 90°-bending system underneath the cyclotron with 7 keV deuterons from the 14 GHz-ECR source[3] a transmission of 55 % has been encountered with respect to the beam intensity after mass analysis by the first 90° bend of the 180° achromatic bending system. The according transmissions at the exit of the 180°-bending system and after the horizontal transport system consisting of 6 solenoids were 79 and 73 %, respectively. 5 diaphragms in the 180° bending system, 9 diaphragms in the horizontal transport system of solenoids and 2 diaphragms after the 90°-bending system underneath the cyclotron restricted the beam 5 times to an acceptance of 600 mm mrad which is somewhat larger than the acceptance of the cyclotron. This set of diaphragms and the only 12 set parameters for 21 focusing elements shall force the subsystems into the desired optical mode and shall lead to a continuous centering of the beam. The agreement between actual and design values encountered so far indicates that this idea will probably work.

The first 90° of the 180°-bending system have been heavily used for the recording of charge state spectra developping the 14 GHz-source[3]. Typically the charge

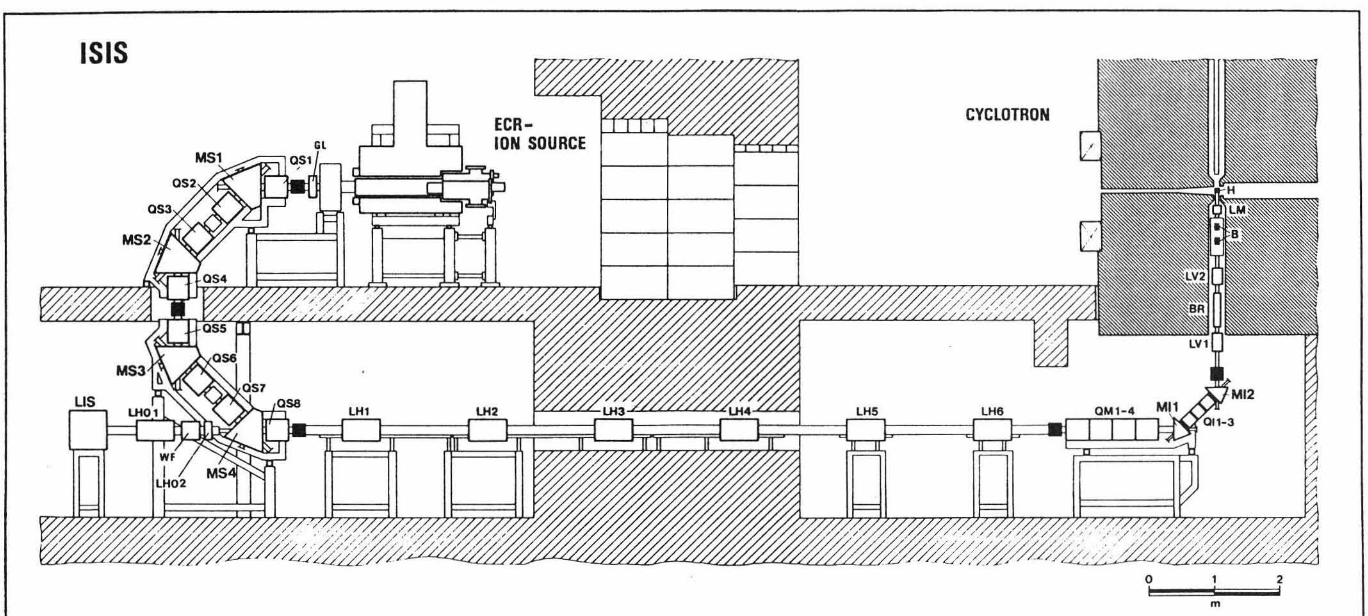


Figure 1:
Layout of the project ISIS at JULIC: LIS-light ion source; WF-Wien filter; QS, QM, QI-quadrupole magnets; MS, MI-dipole magnets; LH, LV-solenoid lenses; BR-beam rotation solenoid; B-bunching system; LM-magnetic lens; H-hyperboloid inflector; ■ beam diagnosis boxes; Gl-Glaser type lens.

resolving power $Q/\Delta Q$ ranged between 25 and 29 which is in good agreement with the reported design value of 26 for a set of two 22 mm diameter diaphragms at the entrance and exit of the first $90^0$ bend.

The behaviour of the system comprising the 14 GHz-ECR-source, its fringe field with the matching lens GL (see figure 1) and the first $90^0$ bend have been studied in more detail. The intensity through the system with diaphragms of 22 mm diameter for a 7 keV deuteron beam has been empirically optimized by variing the lens GL and the quadrupole parameters QS1+3 and QS2+4. After this 10 mm diaphragms have been inserted. The parameters QS1+3 and QS2+4 have then be varied around the empirically found optimum values and the 7 keV deuteron line has been recorded. This same experiment including the fringe field and the Glaser lens has been computer simulated using the code TURTLE[6]. Figure 2 gives the results for the variation of qua-

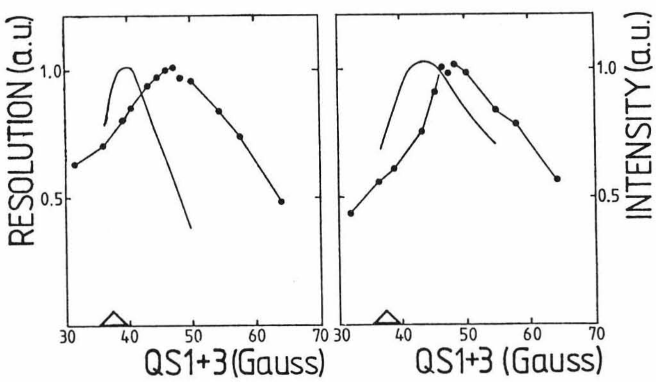


Figure 2:
Intensity and charge resolution $Q/\Delta Q$ versus the variation of the pole tip field strength of quadrupoles QS1+3. Curves to the left give the results of the computer simulation of the experiment, sign Δ marking the design value.

drupoles QS1+3. In general (also for the variation of quadrupoles QS2+4) the comparison shows agreement in the curve structures and the trend towards a higher quadrupole field setting with respect to the design value. The latter trend results from an emittance mismatch probably enhanced by an off centered beam which cannot be corrected before the $180^0$-bending system so far.

## Off line tests

Prior to installation at the cyclotron the last part of the injection beam line, the cyclotron yoke insert, has been tested off line. The device has been inserted into a test magnet (see figure 3). The magnet simulates the cyclotron center region field. As already pointed out the beam line connecting the Pre ISIS 2 source to the yoke insert corresponds to the design of the beam line coupling the 5 GHz-source LIS to the ISIS system. It has been shown that the set up provides sufficient mass selection for light ions when recording the beam intensity behind the diaphragm D2 and variing the current through the lens LH01.

The set up was first used for an emittance study[7] of the LIS-prototype Pre ISIS. For an ion beam extracted from a plasma in an axial field $B_0$ through a hole of radius $r_0$ analytical considerations lead to a formula for the emittance value ε of the beam after passage through the magnetic fringing field as

$$\varepsilon = C_1 B_0 r_0^2 \sqrt{Q/A*U} = C_2 B_0 r_0^2/B\rho \quad (1)$$

Q/A is the charge to mass ratio and U the voltage level of the source. After the choice of the size of the exit hole and the magnetic field level the emittance is therefore only dependent on the beam rigidity $B\rho$. For the emittance measurements diaphragms D1, D2 and the cup FC2 has been removed and an emittance measuring device has been inserted in the box. The emittance has been evaluated for more than 95 % beam intensity and is displayed versus the rigidity in

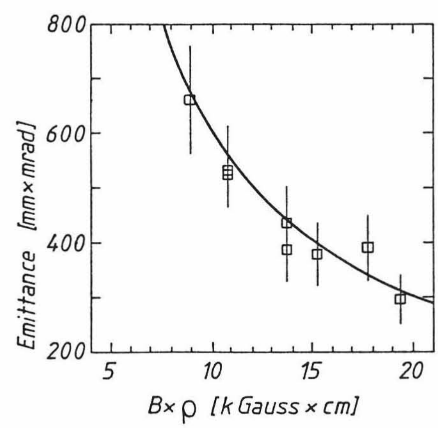


Figure 4:
Emittance vs. beam rigidity. The experimental results are compared with the theoretical formula (Eq. 1).

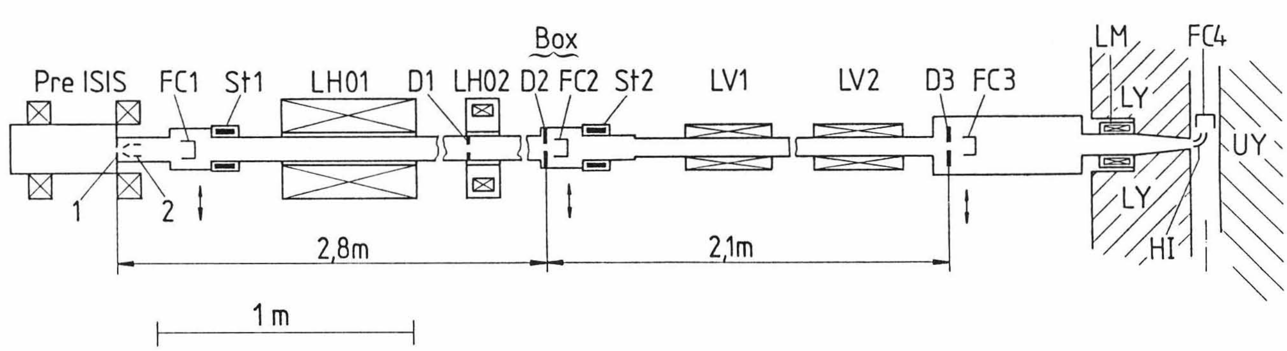


Figure 3:
ECR-source-beamline test set up (schematic): 1 source exit hole; 2 accel decel extraction electrodes; FC Faraday cups; St steerer magnets; LH01, LV solenoid lenses; LH02 Glaser type lens (planned); D diaphragms; LM Glaser type lens; HI Hyperboloid inflector; UY,LY "upper and lower" yoke.

figure 4 demonstrating the validity of the above equation for different Q/A-values from 1/4 to 1.

The emittance measurements enabled us to evaluate the size of the virtual source delivered by the Pre ISIS as it is displayed in figure 5. The strong increase

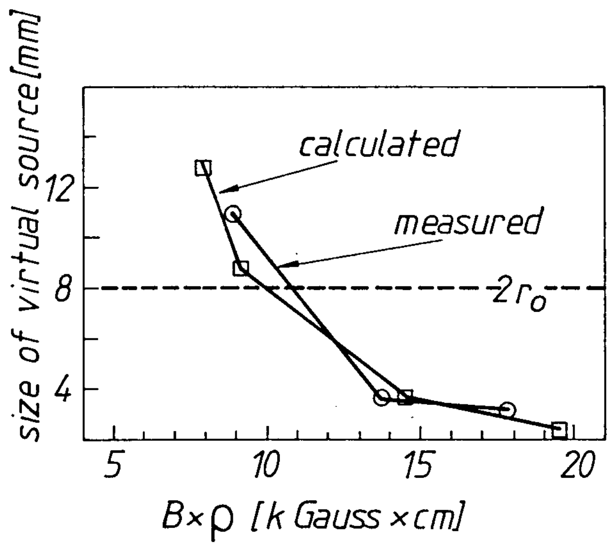


Figure 5:
Size of the virtual source vs. the rigidty. Calculations are performed with the Hermannsfeldt code.

of the virtual source size and emittance had already been recognized by a corresponding decrease of the transmission between the cups FC1 and FC2 (figure 3) through the diaphragm D2 for low rigidity. Calculations using the SLAC-Hermannsfeld code[8] explained and confirmed this behaviour. It turnes out that for this 5 GHz ECR-source the configuration of the emittance is the output of the electric and the magnetic forces. For very low rigidity the size of the virtual source exceeds the geometrical size of the source exit hole $2r_0$ by a factor of two or more. For proper matching of a wide rigidity range one therefore has to add a second lens LH02 as indicated in figure 3.

After the emittance study the axial yoke insert was examined. All ion optical and technical tests were successfull after a few minor modifications. Only the transmission from cup FC3 to FC4 revealed a strange behaviour presumably due to the hyperboloid inflector (figure 6). This transmission was measured versus the magnetic field ( ∿ excitation current) of the dipole substituting the cyclotron center field. The slight loss of 10 % is partly due to bad vacuum conditions in the test set up. But the broad maximum of the transmission around 275 Amps does not coincide with the theoretical value of 308 Amps derived from the designed injection energy. The beam spot size (inlays in figure 6) around the theoretical field level fits rather well with the ion optical properties of the hyperboloid inflector[9] investigated so far but there is a strong axial steering effect of about 100 mrad. To investigate this behaviour in more detail an analytical treatment and according computer codes have been worked out by the EUT Eindhoven cyclotron laboratory[4].

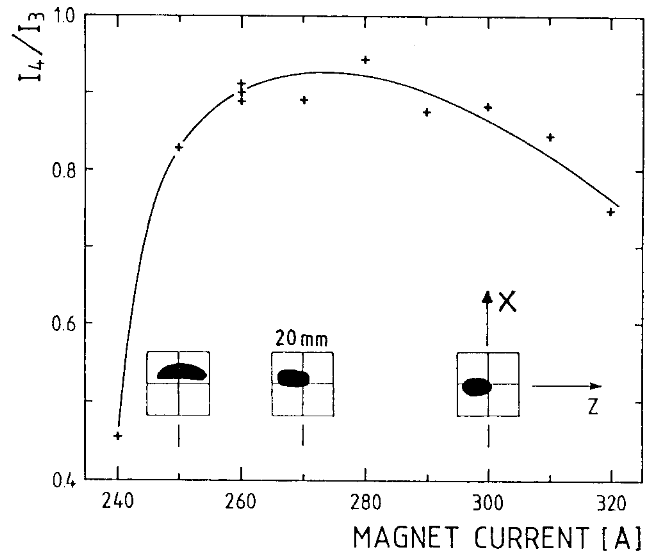


Figure 6:
Transmission between FC3 and FC4 for deuterons of 4.5 keV vs. the magnet current. Inlays: Observed beam spots after $180^0$ bend; Z, X - axial, radial direction.

Buncher calculations

Two double gap bunchers are available (B in fig. 1) fed by sinosoidal voltage of the cyclotron frequency f or 2f, respectively. The acceptance of the cyclotron center region $\Delta\phi_c = 40^0$ RF is large but the bunch distance $\lambda = v/f = 3.2$ cm is short compared to the necessary aperture of ~ 2.5 cm of the buncher electrodes. A poor bunching efficiency for bunchers without any grid can thus be expected (case A in fig. 7). Therefore,

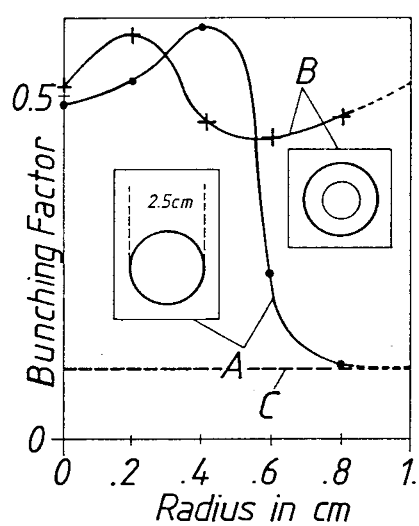


Figure 7:
Calculated bunching factor vs. radius for optimum phase and amplitude. Geometry B with and geometry A without ring "grid". Level C without buncher. The buncher is fed by the cyclotron RF with frequency f.

numerical calculations using realistic fields have been performed. The "bunching factors" versus the radius in fig. 7 are the ratios of the number of particles focused into $\Delta\phi_c = 40^0$ RF to the ones starting from $\Delta\phi = 360^0$ RF. The real gain in beam current depends strongly on the radial beam profile. For a homogenous beam a gain of intensity by a factor of 2 can be expected when switching the buncher on. By providing a "grid" calculated as a ring electrode (case B) the theoretical gain is a factor of 5 and nearly independent from the beam distribution.

## Cyclotron vacuum improvement

After more than 15 years of almost continuous operation - except the annual 6-weeks shut downs - many subsystems of the cyclotron needed extensive inspection, repair or modification. As an example the modification of the vacuum system is reported, which was necessary to meet the requirements defined by the future acceleration of heavier particles.

As there is no reasonable way to eliminate O-ring sealings in a machine like ours, two measures were taken to achieve a pressure of $1\cdot10^{-6}$ mbar reliably in the tank

- improvement of pumping capacity
- minimizing the leaks .

The pumping systems was completely exchanged and is now mainly based on 3 cryopumps with speeds of 10.000 ℓ/s each and two additional turbomolecular pumps of 2.200 ℓ/s. - Simultaneously the complete vacuum control and measuring equipment was exchanged. Operation is now controlled by a commercial automation system.

The vacuum sealing problem was solved by applying differential pumping in especial critical sections, as for example between pole tips and vacuum chamber. Here an intermediate ring is used as appears from fig. 8.

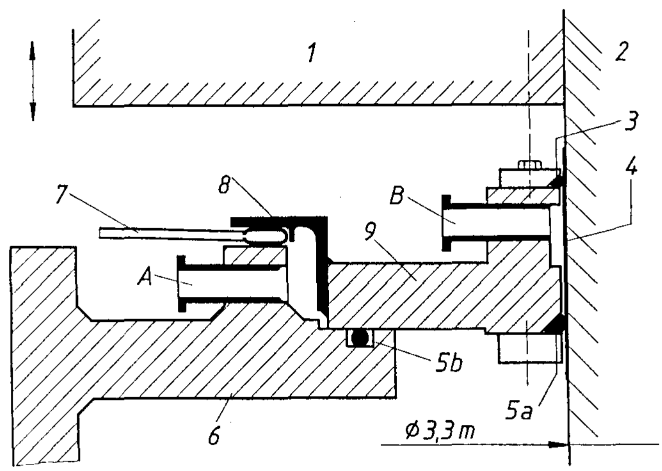


Figure 8:
Vacuum sealing between pole tip and vacuum chamber: 1 main coil, 2 upper pole tip, 3 additional O-ring for differential pumping zone B, 4 Ni coating, 5a,b original O-rings, 6 vacuum chamber, 7 "pneumatic sealing" for differential pumping zone A, 8 L-shaped profil, 9 intermediate ring.

In order to provide chambers for prevacuum this ring had to be modified to accept two additional sealings. A nickel-coating was applied to the pole tip iron in the sealing area as a precondition for a durable solution. For the acceptance of an additional sealing element between ring and chamber, L-shaped profiles had to be welded in the indicated position. It could not be expected to attach the L-profile with a precision adequate for a normal O-ring. So it was decided to use a toroid of ordinary PVC tube, blown up by pressed air as a "pneumatic sealing".

During first tests, when the vacuum chamber of the cyclotron was pumped without accelerating system installed, the final pressure was $2...3\cdot10^{-7}$ mbar. So it should be possible to reach the attempted value of $1\cdot10^{-6}$ mbar during normal operation.

References:


1 L. Aldea, H. Beuscher, R.K. Bhandari, H.G. Mathews, C. Mayer-Böricke, J. Reich, P. Wucherer, Proc. 9th Int. Conf. on Cyclotrons and their Applications (Caen 1981) p. 261, 285, 461

2 H. Beuscher, W. Krauss-Vogt, R. Fiedler, J. Reich, U. Rindfleisch, P. Wucherer, IKP Annual Report 1984, Jül-Spez-305 (1985) p. 328

3 H. Beuscher, W. Krauss-Vogt, W. Bräutigam, J. Reich, P. Wucherer, these proceedings

4 J. Botman, J. Reich, P. Wucherer, H. Hagedoorn, these proceedings

5 P. Wucherer, H.L. Hagedoorn, U. Rindfleisch, IKP Annual Report 1983, Jül-Spez-255 (1984) p. 129

6 K.L. Brown, Ch. Iselin, CERN 74-2 February 1974

7 W. Krauss-Vogt, Thesis, Jül-2043, 1986

8 W.B. Hermannsfeldt, SLAC-226 UC28 1979

9 R.W. Müller, Nucl. Instr. & Meth. 54 (1967) 29