CYCLOTRON DEVELOPMENT PROGRAM AT JYVÄSKYLÄ

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Abstract

The Jyväskylä K130 cyclotron has been modified to allow also negative ion acceleration with stripping extraction. A multi-cusp ion source for negative ions (H$^-$ and d$^-$) was built[1]. The source gives over 5 mA at a voltage of 5.9 kV, which is used for 30 MeV protons. The extracted 30 MeV proton beam of 60 μA from the cyclotron has been reached. Due to very good extraction efficiency the dose rate in the cyclotron vault has decreased by a factor of 10-20 with 30 MeV protons compared to positive ion extraction. Also the inflector change was automated in order to reduce the dose for personnel.

1 INTRODUCTION

The Jyväskylä cyclotron was initially designed for heavy ions. However, quite soon there was a large demand for light ions to be used in isotope production and in light ion induced fission experiments (HI 4500 h/y, light ions 1500 h/y). The use of the cyclotron has reached an annual level of about 6500 h/y (Fig. 1).

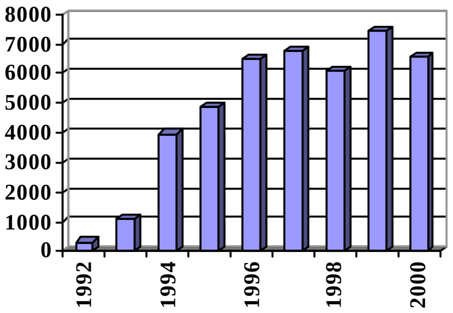

Figure 1. Total time of cyclotron use in 1992 – 2000.

Until the year 2000, only positive ions could be accelerated in the K130 cyclotron. The intensity of proton beams (E > 20 MeV) was limited to about 20 μA due to beam losses at extraction. Recently higher proton beam intensities were required, especially 30 MeV proton beams for the radioactive isotope production. The high intensity proton beams from H$^-$ acceleration will be used once a week for ^{123}I isotope production, and also the proton beam intensities for IGISOL will be increased from the current ones. As a solution a project of negative hydrogen acceleration with stripping extraction was started in 1999 as an international collaboration with PNPI, St. Petersbug, Russia[2]. This was a feasibility study to determine whether losses due to residual gas scattering or electromagnetic dissociation would be a problem in our cyclotron. It was found that the residual gas losses would be 5 % at the most and that 75 MeV protons could be accelerated without major electromagnetic dissociation losses. Another international collaboration was with Dr. T. Kuo, TRIUMF, Canada. The project included construction of a new powerful multi-cusp ion source for negative ions and the stripper foil mechanics.

The cyclotron was closed down in May 2000 for a month to carry out the installations of the new components. This explains partly the decrease in cyclotron use time from 7415 h to 6555 h in year 2000 (Fig. 1).

2 INJECTION AND ION SOURCE

2.1 The multi-cusp H$^-$ source

The negative ion source for the H$^-$ and d$^-$ beams was built at JYFL with the help of T. Kuo from TRIUMF, where the source was developed. It has been installed to the

Figure 2. Sami Hahto (JYFL) and Thomas Kuo (TRIUMF) assembling the multicusp ion source.

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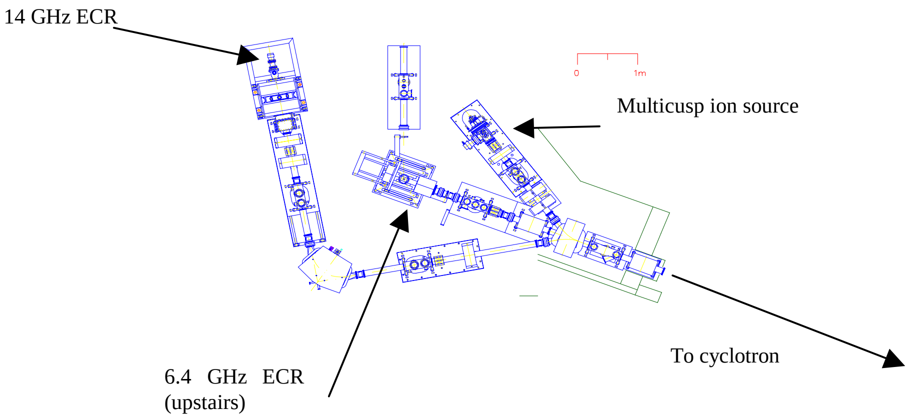

Figure 3. The first part of the K130 cyclotron injection line with three ion sources: 6.4 and 14 GHz ECR sources[3] and a multicusp source for negative ions.

existing injection line (Figs 2-3). The multi-cusp source is capable of producing over 5 mA at 5.9 kV extraction voltage. Due to constant orbit acceleration in the cyclotron the injection energy for 30 MeV protons is fixed to 5.9 kV. This leads to special requirements concerning the beam intensity and emittance as well as space charge effects.

2.2 Injection line

For low energy, high intensity negative ion beam it is very important to have a good vacuum in the injection line, which in our case is about 15 m long. After replacement of several turbomolecular pumps by new ones with oil-free pre-pumps in the injection line the vacuum level went

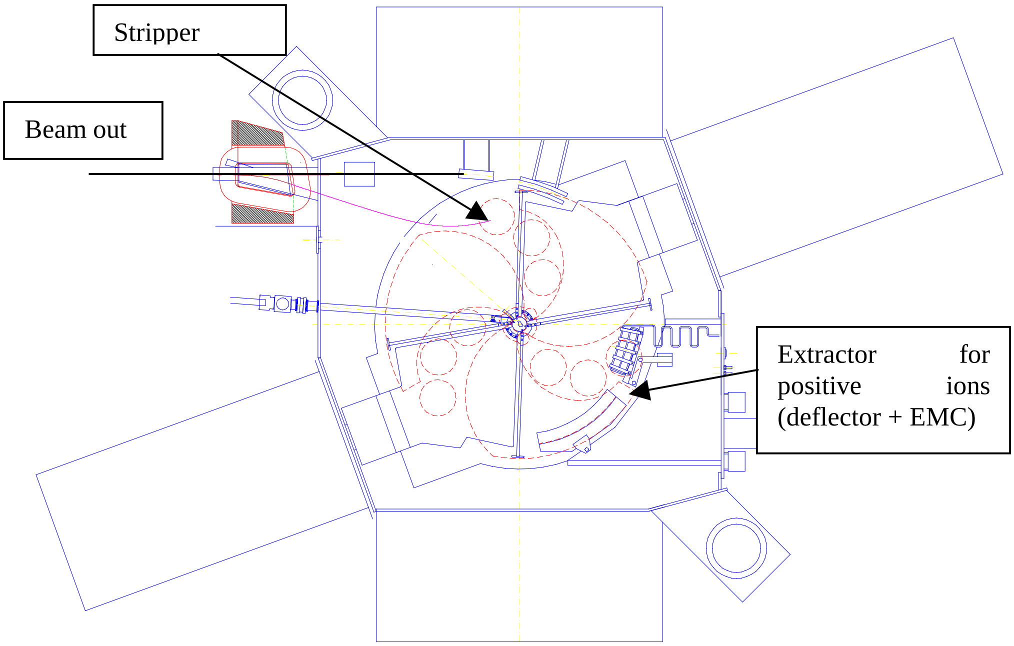

Figure 4. Layout of the K130 cyclotron. The 20 degree dipole steers the stripped beam into the existing beam line.

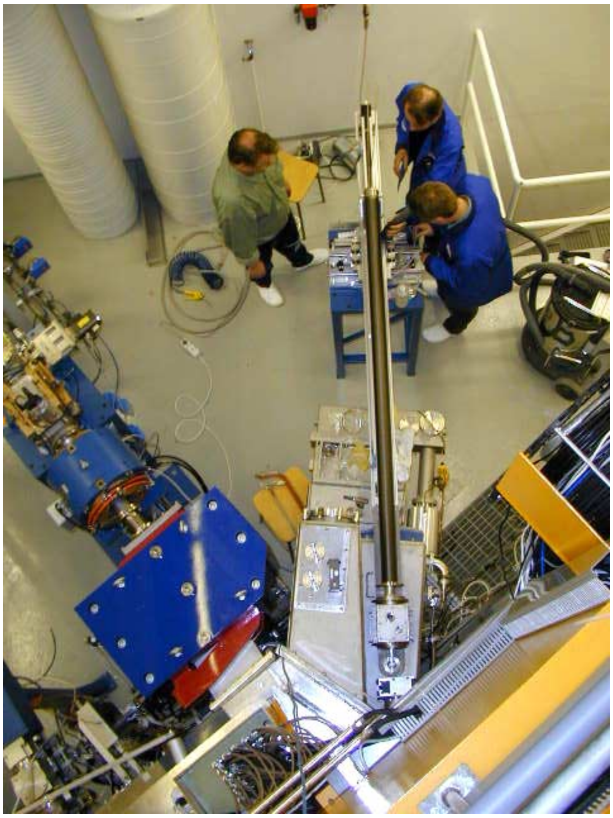

Figure 5. The cyclotron exit. A new 20 degree dipole magnet guides the stripped bean into the existing beam line. The stripper arm moves inside a long bellow allowing the stripper foil change without breaking the cyclotron main vacuum.

down to $2x10^{-8}$ mbar. In this vacuum the beam losses due to residual gas scattering are not significant.

So far, space charge effect is the most limiting factor in our injection efficiency. A typical transmission through the injection line is 20-30 %. More attention has still to be paid on this problem. Possibly additional focusing elements have to be added and space charge neutralization with gas feeding close to ion source exit and in the cyclotron axis close to median plane must be applied. One possible solution in the future will be to move the negative ion source below the cyclotron. Hence, the length of the 15 m beam line can be reduced to about 5 meters.

3 HARDWARE MODIFICATIONS

Since the cyclotron will be used for both positive and negative ions, some changes in magnetic and electric fields had to be done. Also the stripped beam must be guided into the existing beam line. This calls for additional magnet(s).

3.1 Magnets

The negative ion beam is guided into the cyclotron along the existing injection line. Therefore the polarity of the magnetic field in one dipole is changed. The focusing of the beam in the injection line is mainly done by solenoids. The polarity affects only the direction of rotation but not the focal length and hence the solenoid fields no not need to be changed. The four quadrupoles in the injection line have bipolar power supplies and hence also they do not need any changes.

The polarity of the cyclotron main magnetic field is reversed for negative ions, since orbiting direction is kept unchanged. It is done by an automatic pneumatically operated switch. The power supplies for trim coils are bipolar and hence they need no modifications. One 20-degree dipole magnet was added outside the cyclotron vacuum chamber to guide the stripped beam to the old beam line (Figs 4-5). For that, one quadrupole singlet and one triplet were moved forward along the beam line. This meant slightly different focusing conditions for the positive beams compared to the previous focusing. No significant changes in transmission after the cyclotron were seen.

Figure 6. The stripper arm inside the vacuum chamber. The stripper wheel is not in its place.

Figure 7. The stripper wheel with four foils as seen through the window in the vacuum lock box. The size of the foil is 16 mm x 22 mm.

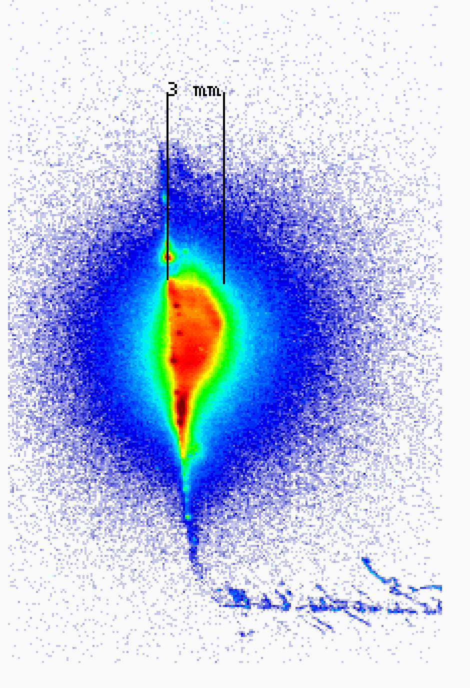

Figure 8. Autoradiograph of the stripper foil after several H^- runs. (The measurement was provided by Olof Solin at Åbo Akademi, Turku, Finland.)

3.2 Stripper

The stripper mechanism with a rotating foil holder was installed in the cyclotron vacuum tank (Figs 6-7). The foil holder has four foils. The beam is stripped at a constant position, slightly inwards from the $\nu_r = 1$ resonance. The stripper can be moved around the nominal position by ±20 mm both radially and azimuthally.

We have used 1 and 2 μm carbon foils. The difference in beam quality has been very small. One stripper foil was analyzed as an autoradiograph, which shows the activated area of the foil. After several H^- runs the radial width of the activated area was about 3 mm and the height 11 mm (Fig. 8).

3.3 Voltages

RF-voltages do not need any modifications. Only the polarity of the spiral inflector needed to be changed for negative ions.

Figure 9. Automatic inflector change system on top of the cyclotron.

4 AUTOMATION

Due to regular weekly isotope production the beams will be changed 1-2 times per week. Often an experiment is interrupted during the isotope production and continued after it. Usually this also means the change of the inflector: each harmonic mode needs a separate inflector. Therefore, in order to minimize the dose for personnel and to minimize the interruption time, the change of the inflector has been automated (Figs. 9-10). The inflector change system operates pneumatically and it is operated through the control system.

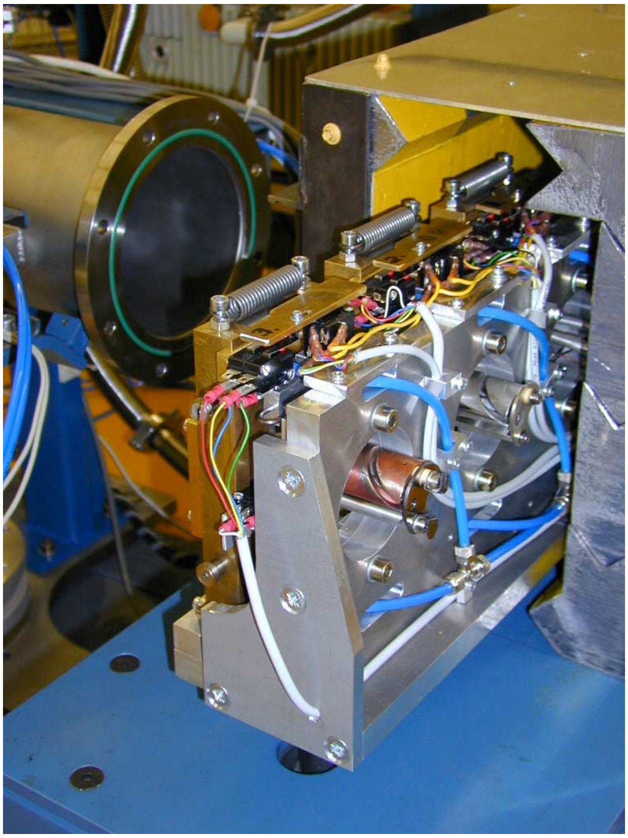

Figure 10. Inflectors for each harmonic mode (1, 2, 3) are stored in a shielded cassette from where the appropriate inflector is picked.

5 RESULTS

The primary goal was to get routinely a 30 MeV proton current of 50 µA. The ultimate goal is to reach 100 µA. In August 2000 we extracted the first 30 MeV H^- beam by stripping and the extraction efficiency was 100 % as expected. During the following weeks the intensity of the 30 MeV H^- beam was gradually increased to 60 µA and at 45 MeV it was 100 µA. The new multi-cusp ion source has exceeded all expectations. It can produce up to 5.8 mA of H^- beam at low 5.9 kV extraction voltage which is needed for 30 MeV protons. The intensity at this moment is limited by injection efficiency.

In addition to higher intensities another goal was to decrease the dose rates at the cyclotron. Due to near 100 % extraction efficiency the dose rate with protons and deuterons has decreased by a factor of 10-20.

The lifetime of the stripper foil has been found to be sufficient. So far we have not encountered any foil failures.

The extractor for positive ions remains inside the cyclotron during H^-/d^- runs. It is just pulled about 10 mm outwards from its nominal position. The probe between the deflector and the EMC measures the beam current at a radius where the beam will hit if the stripper foil fails. This is used as an interlock to prevent accidents due to a high intensity beam hitting the vacuum chamber or some other structures inside the cyclotron.

REFERENCES

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