EXTRACTION OF D¯BEAMS FROM THE CYCLOTRON JULIC FOR INJECTION INTO THE COOLER SYNCHROTRON COSY

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Abstract

The cooler synchrotron COSY was intended from its inception to provide also deuteron beams which, in addition to protons, could considerably expand the range of experiments accessible at this accelerator facility. A major obstacle to deliver the required D¯beams with the injector cyclotron JULIC has been its electrostatic septum deflector at extraction. After the conversion of JULIC into a negative ion machine, operation of the original deflector at the voltage levels necessary for D¯extraction proved to be impossible with reversed polarity due to severe electrical strength problems like sparking and dark currents. The design and development of a suitable septum deflector turned out to be a challenging and tedious process lasting several years. The new device is in operation since January 2000 and the cyclotron was successfully tested in October for delivering D¯beams at 75 MeV with an extracted current in the order of 10 µA. Development, test procedures and characteristics of the new electrostatic septum deflector are reported together with its operational performance to date. Results achieved during the first test run with D¯ ions are presented, including injection and acceleration of the deuteron beam in COSY.

1 INTRODUCTION

For nearly a decade already, the cyclotron JULIC is being operated almost exclusively as the injector for the cooler synchrotron COSY, which requires particles suitable for stripping injection. At first an H_2^+ beam at 76 MeV has been used for this purpose, but since January 1996 either non-polarized or polarized H¯ beams at 45 MeV are routinely provided [1]. In recent years there is also a growing demand from experiments for deuteron beams at COSY. All our external ion sources are designed to produce both H¯ as well as D¯ beams, and the extraction of D¯ions from JULIC at comparable energies to H_2^+ should also be possible, but operating the original electrostatic septum deflector with reversed polarity at high voltage levels encountered significant problems due to excessive field emission and discharges. Hence a new septum deflector had to be designed and constructed which is also suitable for D¯ operation. This process turned out to be more intricate and time consuming than expected. Many iterative steps were necessary to develop a septum deflector that meets our requirements.

2 ELECTROSTATIC SEPTUM DEFLECTOR

2.1 Design Considerations

The new septum deflector has to replace the original one as part of an otherwise unchanged extraction system. The essential design requirements and specifications can be summed up as follows.

Our operational experience has shown that the original septum deflector had an unexpected poor transmission for H¯ beams compared to H_2^+ extraction. The beam losses typically doubled from about 30% to 60%, becoming a rather serious limitation for the extracted beam intensity. In addition we found that the reliable operation of the septum deflector with reversed polarity at high voltage is extremely sensitive to the vacuum pressure in the chamber. Only materials with excellent outgassing properties and low vapour pressure should therefore be used for constructing the new device, and any potential source of contaminating the surfaces has to be eliminated. This applies in particular to the use of transformer oil as cooling fluid for the deflector electrode.

Part of the higher beam losses can be attributed to a slightly different orbit geometry due to reduced saturation effects in the magnet, combined with the fact that JULIC makes use of multi-turn extraction. Providing a septum deflector with an adapted curvature could solve the problem but would necessitate the use of different devices for H¯and D¯operation. This is not acceptable in practice as it would require breaking the vacuum for each exchange, followed by several days of pumping down to a vacuum pressure in the order of 5×10^{-7} mbar to avoid excessive beam losses due to residual gas stripping.

The new septum deflector has to fit into the given vertical space of only 50 mm and should be equally suitable for H¯and D¯ extraction, but with improved transmission. This can only be achieved with a thinner septum and an increased radial aperture of the deflector channel, which allows one to compensate for small deviations of the orbit shape from the septum curvature. The heat load of the septum is greatly reduced for pulsed beams. To avoid damages, however, the septum foil has to be capable of dissipating the total internal c.w. beam power. A maximum field-strength of approximately 120 kV/cm would be needed for the extraction of D¯ions at 90 MeV.

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2.2 Deflector Characteristics

The new septum deflector is shown in Fig. 1 and in its present version has the following characteristics:

- Septum foil of 0.2 mm thick tungsten wires.
- Titanium as electrode material.
- Almost 25% wider radial and vertical apertures.
- Special high voltage insulators.
- Fluorinert® FC-77 as cooling fluid.

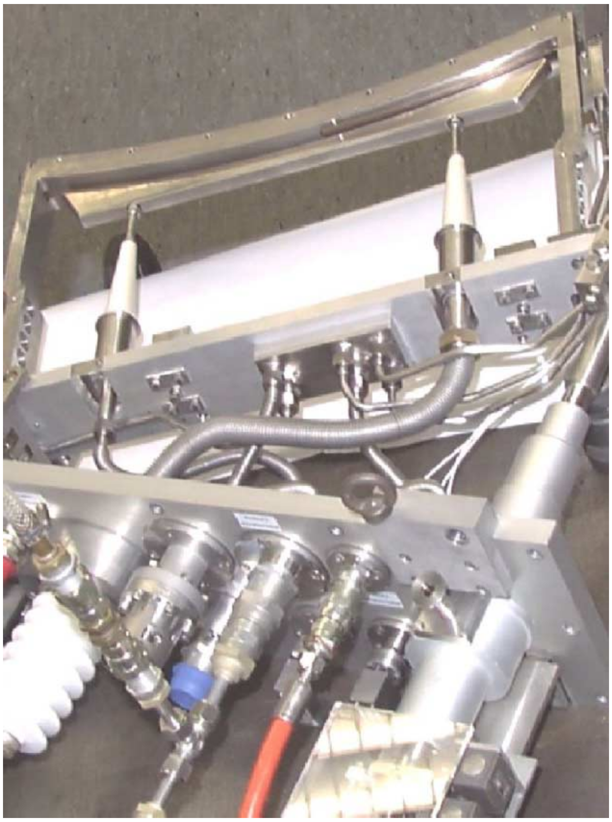

Figure 1: The new septum deflector before installation. The high voltage electrode is supported by two ceramic insulators which are also used as ducts for the cooling fluid. The high voltage cable is fed through the right tube.

Many tests had to be carried out during development under realistic conditions, i.e. with magnetic field and a vacuum in the low 10^{-7} mbar range. For this purpose we made use of a separate magnet equipped with a vacuum chamber. Tests of different electrode materials at high voltage revealed that titanium was the best choice. Furthermore, the geometries of the electrode and septum support had to be optimized carefully for maximum electrical strength. The vertical aperture of the collimator and septum support was increased from 9 to 11.2 mm.

The ceramic insulators were specially made to our specifications by an external company. These components turned out to be a source of trouble when operated with reverse voltage. The alloy used for the metal/ ceramic joints produced severe sparking which resulted in a partly conductive coating of the insulator surface. Other techniques to achieve a properly working joint also failed. Finally we developed a method to make vacuum tight joints between the ceramic and titanium end-caps using only a pressfit and knife-edge Al seals at the hidden faces of the insulator tubes.

2.3 Septum Development

Our first attempt at an improved septum made use of a foil of sixteen 0.02 mm thick tantalum strips positioned along the entrance section of the deflector channel. The subsequent part of the septum (where the extracted beam already is separated from the internal beam) was formed by a wedge of solid titanium. The radial aperture of the channel had a width of 3.1 mm at the entrance increasing to 4.5 mm at the exit like in the original septum deflector. In this configuration a field-strength of up to 120 kV/cm could be achieved with the required polarity, thus allowing us to increase the radial aperture to 3.8 mm at the entrance and 5.6 mm at the exit. After installation in the cyclotron, first tests with H^{-} beam indicated an improvement of the deflector transmission to about 65%. Unfortunately, however, some of the tantalum strips were already destroyed after a few days with beam. Probably excessive mechanical tension was the reason that the strips ruptured when they were heated up by the beam.

After this set-back we replaced the tantalum strips with a septum foil formed by a tungsten wire fence (0.2 mm wire diameter and 0.2 mm distance) as is shown in Fig. 2. This is a significantly improved version of the original septum foil.

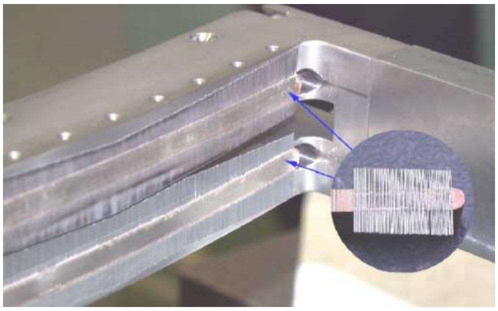

Figure 2: The new septum foil for improved beam transmission. An upper and lower fence of 0.2 mm thick tungsten wires (see insert) is brazed into Cu profiles and mounted on the water-cooled titanium supports providing precise alignement and efficient heat transfer.

The wires are manually inserted into slots in the Cu profiles, precisely cut by electro-erosion, and then kept in place by a slight deformation of the separating lips. With all wires inserted the profile surface is rolled to achieve a still better fixation together with a good surface quality. Finally the profiles are brazed under vacuum for best possible heat conduction. The upper and lower parts of the wire fence are separated by a zig-zag running gap of 0.5 mm to avoid any strain in the wires due to misalignement or heat expansion. The gap gradually opens up towards the entrance to distribute the heat load of the beam.

2.4 Operational Performance

The new septum deflector is in operation since January 2000 and performs well. The deflector voltage required for best H^- extraction has increased from about 23 kV to 28 kV and can be attained with relative ease. Extremely good vacuum conditions in the low 10^{-7} mbar range and careful conditioning are still required to reach and reliably hold the voltage levels (44 to 50 kV) needed for D^- extraction at 75 to 90 MeV.

The leakage current of the deflector electrode now varies considerably during operation forcing us to use a power supply with a higher current limit. Careful monitoring of the deflector voltage and current as well as vacuum pressure indicates that this must be related to variations in resistance of the cooling fluid due to some recurring contamination not yet fully understood.

At present a transmission ratio of up to 60% can be achieved for the septum deflector with both non-polarized and polarized H^- beams, but some of the gained beam current is now lost in other parts of the extraction system. The transmission ratio for D^- beams could neither be optimized nor measured exactly in the short time available for beam development.

3 FIRST D^- BEAM FROM JULIC

3.1 Ion Source Development

The D^- beam for axial injection into JULIC was produced with our commercial multi-cusp ion source from the company IBA in Belgium. For H^- ions this source delivers typically 250 to 350 µA of beam at the first cup downstream. By modifying its extraction electrode system, the maximum D^- beam current could be increased from about 150 µA to 280 µA at the same cup. Also the ion-optical elements used to match this beam to the source beamline have been optimized for minimum aberrational effects to improve its transmission. Hence comparable beam intensities can now be injected into the cyclotron for D^- and H^- operation.

3.2 Beam Properties

After some initial injection tests, the first D^- beam was successfully extracted from the cyclotron at 75 MeV in October 2000 and then immidiately used for injection into COSY. The chosen ion energy allowed us to start with machine settings equivalent to H_2^+ operation. At the same time a relatively low deflector voltage of only 44 kV was sufficient for extraction. The beam characteristics are summed up in Fig. 3 and very similar to those usually obtained with H^- operation. A beam current of over 9 µA could be extracted at some stages, but there was not enough time available for careful optimization.

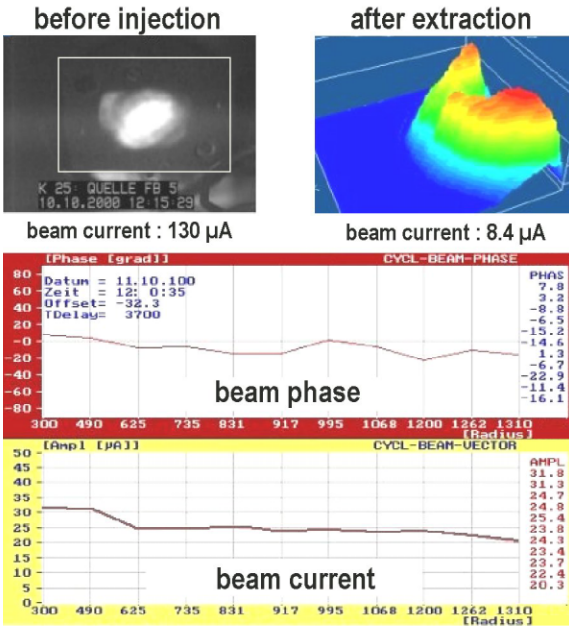

Figure 3: The characteristics of the first D^- beam before axial injection and after extraction from JULIC together with the beam phase and current measured in the cyclotron as a function of radius. The viewer boundaries are indicated by frames and, as seen by the beam, have an actual size of 7×5 and 3×3 cm^2 respectively.

The results are satisfactory, but also indicate the usual vertical split of the extracted beam into two parts represented by the double-peak in Fig. 3 after extraction. This is caused by a persistent coherent vertical oscillation of the beam generated in the central region of the cyclotron. Earlier tests with H^- beam have shown that only one of the two beam parts is accepted by the injection system of COSY. It is therefore highly probable that the same problem exists with D^- beams.

4 CONCLUSIONS

To demonstrate acceleration of deuterons in the cooler synchrotron COSY, an approximately 9 µA intense D^- beam was successfully extracted from the injector cyclotron JULIC at 75 MeV and transported without losses through the transfer beamline to the ring. COSY was tuned to the new corresponding injection momentum of 539 MeV/c. A total of 1.4×10^{11} deuterons could be stored in the ring of which 4.5×10^{10} deuterons were accelerated up to a maximum momentum of 3.0 GeV/c, close to 10% off the COSY limit. In preparation for future experiments with deuteron beams, a spare electro-static septum deflector is now under construction for JULIC.

REFERENCES

[1] W. Bräutigam et al, “H^- Operation of the Cyclotron JULIC as Injector for the Cooler Synchrotron COSY-Jülich”, CYCLOTRONS’98, Caen, June 1998.