RECENT PROGRESS AT THE JYVÄSKYLÄ CYCLOTRON LABORATORY

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Abstract

The Jyväskylä K130 cyclotron has been in use since 1992. It has been used mainly for nuclear physics research but also for applications, such as radioisotope production, space electronics testing and membrane production.

The MCC30/15 cyclotron delivers proton and deuteron beams for nuclear physics research and for isotope production. The experimental set-up has been mainly under construction and so far we have had only a couple of beam tests. Isotope production with the MCC30/15 cyclotron has suffered from severe administrative delays. Finally in December 2012 a preliminary budget study for a GMP laboratory for FDG production (18F) was done. Decisions on the radiopharmaceuticals production at JYFL will be done during 2013. The beam quality dependence on the stripper angle has been studied. The preliminary results will be given.

THE K130 CYCLOTRON

Statistics

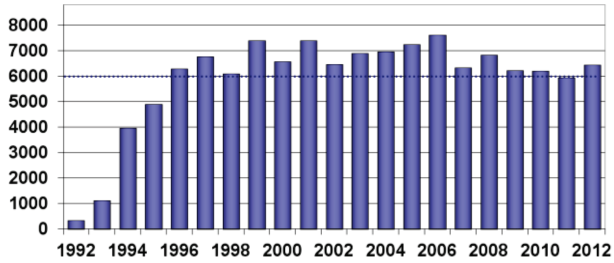

Figure 1: Use of the K130 Cyclotron. The total run time is 124’138 hours at the end of 2012.

The use of the K130 cyclotron during the past few years has been normal. The total use of the cyclotron in 2012 was 6441 hours out of which 4610 hours on target. Three quarters of the beam time was devoted to basic nuclear physics research and one quarter for industrial applications, the main industrial application being space electronics testing. Altogether over 20 different isotopes were accelerated in 2012. Beam cocktails for space electronics testing were the most commonly used beams (26 %). Since the first beam in 1992 the total run time for the K130 cyclotron at the end of 2012 was 124’138 hours, and altogether 32 elements (73 isotopes) from p to Au have been accelerated.

THE MCC30/15 CYCLOTRON

The MCC30/15 Cyclotron, manufactured and installed by the Efremov Institute, St. Petersburg, Russia, was accepted for use in May 2010. However, the re-installation and upgrade of the experimental setup (IGISOL) was still going on, and so far only a few beams have been accelerated by the MCC30/15 cyclotron for experiments and tests.

The emittance of the extracted beam has been measured by a gradient method, i.e. measuring the beam size as a function of quadrupole magnet focusing strengths and finding the emittance and the Twiss parameters by an rms-fit.

The Emittance Measurement Method

The transfer matrix of a beam line gives the position and direction of a particle at the end of the beam line when the initial position and direction is known according to matrix equation

$$\begin{pmatrix} x \\ x' \end{pmatrix}_1 = \begin{pmatrix} C & S \\ C' & S' \end{pmatrix} \begin{pmatrix} x \\ x' \end{pmatrix}_0 . \tag{1}$$

The matrix elements above can be used to write a 3x3 transfer matrix for the Twiss parameters as

$$\begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix}_1 = \begin{pmatrix} C^2 & -2CS & S^2 \\ -CC' & CS' + SC' & -SS' \\ C'^2 & -2C'S' & S'^2 \end{pmatrix} \begin{pmatrix} \beta \\ \alpha \\ \gamma \end{pmatrix}_0 , \tag{2}$$

and then the square of the beam half-width at the end of the beam line can be written as

$$\hat{x}^2 = \epsilon\beta_1 = \varepsilon(C^2\beta_0 - 2CS\alpha_0 + S^2\gamma_0), \tag{3}$$

where

$$\gamma = \frac{1+\alpha^2}{\beta}. \tag{4}$$

The transfer matrix elements (C, S, C', S') as functions of the quadrupole magnet strengths (or currents) can be calculated by a linear ion optics program. Measuring the beam sizes (horizontal and vertical) with several different quadrupole settings we get the Twiss parameters and the emittance by an rms-fit.

Measuring Results

The beam transverse emittances were determined in the beam line at the entrance of the first quardrupole magnet. The beam line consists of a quadrupole doublet and a drift. At the end of the beam line the beam size was determined from a scintillation plate with a ccd-camera. First the smallest beam spot was found experimentally and then the quadrupole strengths were varied around these values, and the horizontal and vertical beam diameters were recorded. From the series of quadrupole settings and beam half-widths we get vectors *x(i)*, *C(i)* and *S(i)*. Inserting these into equation (3) and using the constraint (4) we get the emittance ε and Twiss parameters β, α and γ from an rms-fit.

The stripper angle with respect to the beam direction was varied (-30°, 0°, +30°).

Figure 2: The stripper mechanism. The stripper foils from left to right correspond to angles -30°, 0° and +30° with respect to the original direction. The left foil is at the nominal position for 30 MeV H^- beam. The beam comes from the left.

Table 1: Emittances and the Twiss parameters for an extracted 30 MeV p beam at the entrance of the first qadrupole. The *x* direction is axial in the cyclotron and *y* radial (the cyclotron median plane is vertical).

Foil angle	**-30°**	**+30°**
ε_x (mm mrad)	20.1	17.6
β_x (m)	19.2	15.8
α_x	-5.65	-4.61
ε_y (mm mrad)	20.3	15.1
β_y (m)	3.12	3.07
α_y	-0.58	-0.54

The results for the tilted foils are given in Table 1 and the beam ellipses for the foil angle +30° is shown in Figure 3. A tilted stripper foil can be considered as edge focusing in the bending/radial plane but not in the axial one (the charge state changes from -1 to +1, which is equivalent to the magnetic field change from +B to –B with an unaltered charge). As we see from Table 1, the vertical Twiss parameters practically don't change. This is due to a very small beam radial width at the stripper foil edge. However, the tilt angle seems to have on effect on the beam emittance in both planes. For linear focusing there shouldn't be any change in emittance. The explanation is the nonlinear focusing in the cyclotron fringing field together with the different radial beam envelopes due to different edge focusing at the stripper. The emittance in the bending plane changes more.

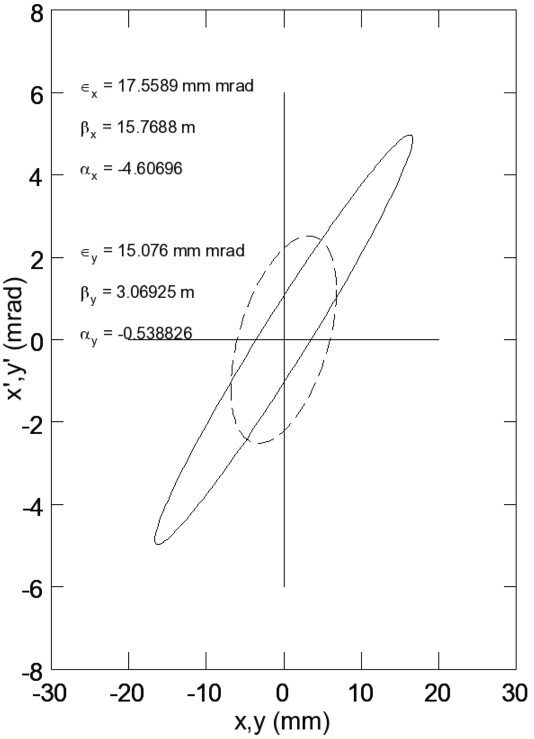

Figure 3: The fitted horizontal (solid) and vertical (dashed) beam ellipses of the extracted 30 MeV proton beam at the entrance of the first quadrupole magnet with the foil angle +30°. The vertical direction corresponds to the cyclotron bending plane.

Numerical simulations [1] give the same effect as measured. In addition to the stripper angle, the magnetic field quality (the first harmonic component B_1) has a clear effect. The emittances with an optimized field (minimum B_1) are smaller than with the measured field. The simulated vertical emittance (for the stripper angle +30°) decreases from 14 mm mrad to 7 mm mrad when the magnetic field has been corrected with three anti harmonic bumps. Subtracting artificially the first harmonic component reduces the vertical emittance even more.

Isotope Production

One of the main motivations to get the MCC30/15 cyclotron was to use it for radioisotope production. However, there have been long delays in the University administration concerning this project. Our primary concept is that the Accelerator Laboratory produces the radioisotope and an external company takes care of the final product, such as FDG. In December 2012 a preliminary budget study for a GMP laboratory for FDG production (18F) was done. The final decision of the radiopharmaceuticals at JYFL should be done by the end of 2013.

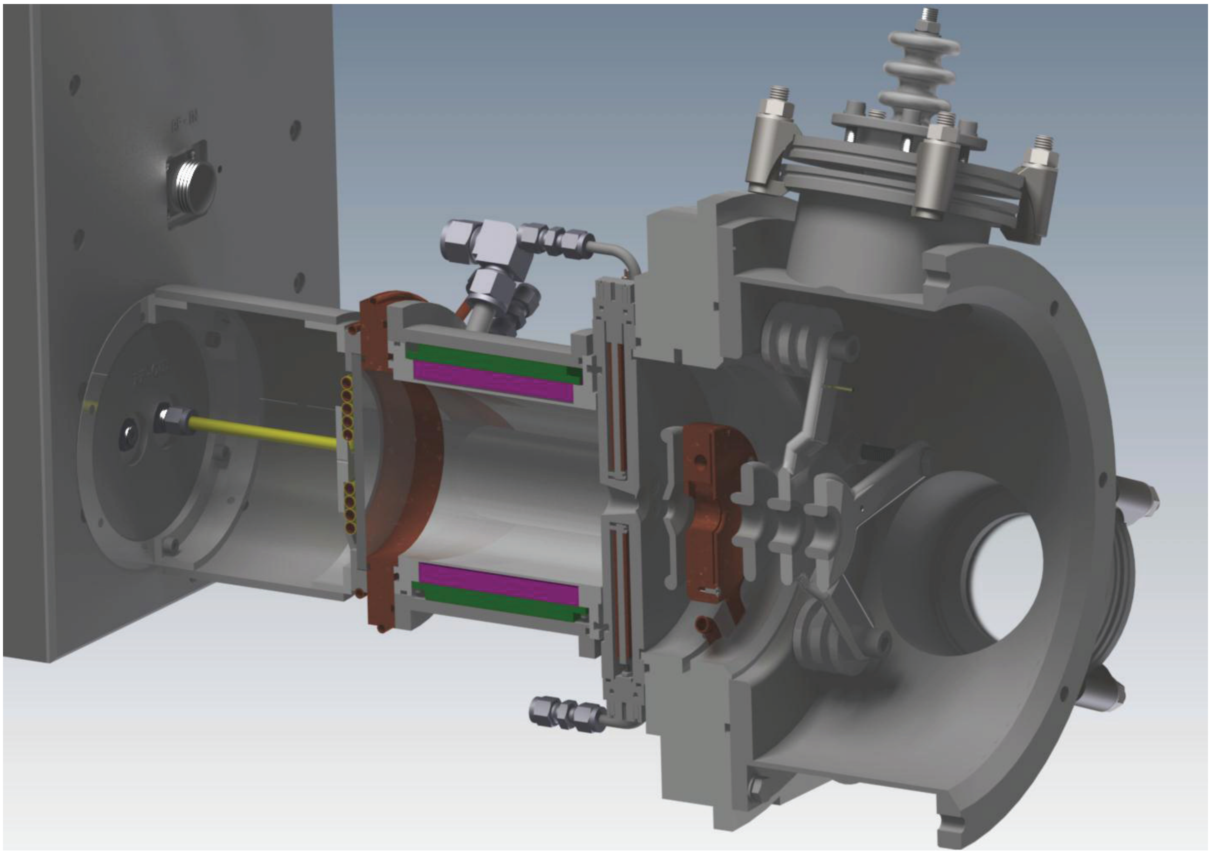

Figure 4: Cross-section of the RADIS ion source.

ION SOURCE DEVELOPMENT

The MCC30/15 cyclotron ion source is a conventional filament-driven multicusp source for production of H− and D−. It is capable of continuous operation at 1 mA H^- output for about 130 hours before filament failure. The ion source is located in the cyclotron vault. When the cyclotron is in regular use (beams for nuclear physics experiments and radio isotope production) the radiation levels in the vault are expected to be high and therefore hours of cooldown time is required before the filament change can be done. This kind of operation is not acceptable as 350 h and longer continuous experiments are expected. Therefore a project for developing a CW 13.56 MHZ *Radiofrequency Ion Source*, RADIS, for the cyclotron was initiated in March 2011 [2]. The goal of the RADIS project is to develop a new ion source to produce at least 1 mA of CW H− beam or 500 µA of CW D^- beam at the cyclotron injection energy of 19 keV, with a maintenance interval of at least one month.

Preliminary Results

The RF antenna was first tested with an existing multicusp ion source by replacing the original back plate with a plate which has the antenna in it. Later, a new chamber with a Modified MultiPole Structure (MMPS) [3] was built together with a new extraction. In the last test an RF power of 3200 W (75 W reflected) produced 1 mA of H^- beam at the energy of 7.5 keV. The extracted electron current was 27 mA.

REFERENCES

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[2] T. Kalvas, O. Tarvainen, J. Komppula, M. Laitinen, T. Sajavaara, H. Koivisto, A. Jokinen and M. P. Dehnel, "Recent Negative Ion Source Activity at JYFL", AIP Conf. Proc. 1515 p. 349 (2012).

[3] H. Koivisto, P. Suominen, O. Tarvainen and D. Hitz, *Rev. Sci. Instrum.* **75**, 1479 (2004).