EMITTANCE MEASUREMENTS AT THE STRASBOURG TR24 CYCLOTRON FOR THE ADDITION OF A 65 MeV LINAC BOOSTER

A. Degiovanni#, TERA, Novara, Italy and EPFL, Lausanne, Switzerland
U. Amaldi, S. Benedetti, D. Bergesio, A. Garonna, G. Molinari, TERA, Novara, Italy
E. van Lier, R.L. Watt, ACSI, Richmond, B.C., Canada
D. Brasse, M. Pellicioli, M. Rousseau, J. Schuler, IPHC, Strasbourg, France
S. Braccini, E.V. Kirillova, LHEP-AEC, University of Bern, Bern, Switzerland

Abstract

The long term plans of IPHC foresee the installation of a linac that will boost the energy of the protons of the Strasbourg TR24 cyclotron from 24 MeV to 65 MeV. A Cell Coupled Linac, designed by the TERA Foundation, could be used for this purpose. To compute the transverse acceptances of the linac, the horizontal and vertical emittances of the extracted proton beam need to be measured. The secondary emission detector BISE (Beam Imaging with Secondary Electrons) built by TERA and under development at the Bern 18 MeV IBA cyclotron will be used in Strasbourg for the final measurements. The results of the preliminary measurements of the transverse beam profiles are reported together with the development of BISE, the description of the linac structure and the calculation of the expected output current based on the dynamics of the accelerated proton beam.

INTRODUCTION

The Cyrcé cyclotron (CYclotron pour la ReCherche et l'Enseignement) has recently been installed at IPHC (Institut Pluridisciplinaire Hubert Curien) for the development of new radiolabelled molecules based on the research and production of radio-isotopes for diagnostics and medical treatments. The TR24 cyclotron produced and commercialized by ACSI (Canada) delivers a 16-25 MeV proton beam on two extraction ports with intensity from few nA up to 500 μA. The facility will start soon to produce ^{18}F (half-life period 110 min) and ^{64}Cu (half-life period 12,7h). Using standard targets, 15 possible isotopes can be produced with this accelerator.

The long term plans of IPHC foresee the installation of a linac for boosting the energy of the protons from 24 MeV to 65 MeV. The TERA Foundation has developed in the last decades high RF frequency Cell Coupled Linacs (CCL) designed to be coupled with cyclotrons to boost their energy for applications in proton therapy [1]. A 3 GHz CCL, designed by the TERA Foundation, could be used for this purpose.

To compute the transverse acceptances of the linac, the horizontal and vertical emittances of the extracted proton beam need to be measured. Preliminary measurements were conducted at IPHC, in collaboration with ACSI. Further measurements are planned with the secondary emission detector BISE (Beam Imaging with Secondary Electrons) built by TERA and under development at the Bern 18 MeV IBA cyclotron [2].

CYCLOTRON BEAM MEASUREMENTS

The TR24 installed at IPHC in Strasbourg is shown in Fig. 1. The cyclotron has two exit ports. One is equipped with targets for cell irradiation, while the second one is not used at the moment. The second extraction beam port has been commissioned for performing the beam measurements and is shown in Fig. 1.

Figure 1: Picture of the TR24 cyclotron installed at IPHC in Strasbourg. The water cooled beam dump provided by ACSI is visible at the end of the beam pipe.

Preliminary beam profile measurements have been performed at the beginning of July 2013 using Gafchromic™ EBT3 films and adding two pieces of beam pipe in order to obtain profiles at different distances from the extraction point. Meanwhile, the BISE detector is under development and test at the Bern cyclotron.

Preliminary Measurements at IPHC

The absence of a dedicated extraction beam line limited the first measurements to an analysis of beam profiles at different positions from the extraction port (0 m, 0.4 m and 0.7 m), obtained by connecting two pieces of beam pipe (100 mm diameter) to the exit port 2 of the cyclotron. The alignment of the beam pipe was based on results of simulations of beam trajectories in the cyclotron. The pieces of beam pipes were electrically isolated by placing polymeric gaskets, so that it was possible to monitor the beam current on the wall of the beam pipe and on the beam dump, during the irradiation.

#alberto.degiovanni@cern.ch

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Gafchromic™ EBT3 films have been used to obtain an image of the beam profile. Two methods of irradiation have been used: (i) indirect irradiation and (ii) direct irradiation. In the first case the image was obtained by exposing the dosimetric film to the radiation induced onto a water cooled beam dump made of aluminium and provided by ACSI (see Fig. 1). The time of exposure was calculated from the measured activity at the start of the exposure in order to obtain the same integrated dose. In the case of direct irradiation, the dosimetric film was placed into the beam line between a thin aluminium plate of 2.5 mm and the beam dump.

The images collected with indirect method, with the corresponding reconstructed images (obtained from the scan of the dosimetric films with MATLAB), are presented in Fig. 2. The FWHM have been evaluated from the reconstructed images, after noise subtraction and normalization, and are plotted with respect to the distance from the extraction port in Fig. 3.

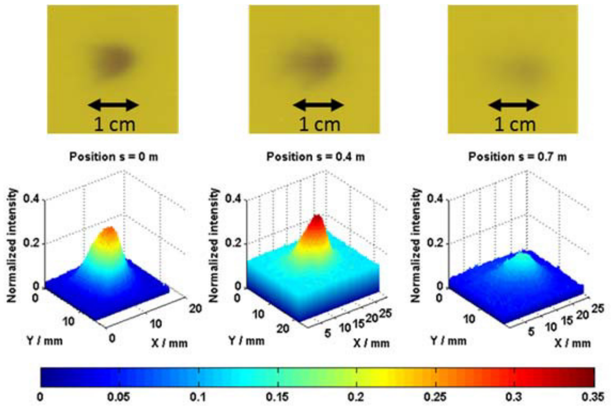

Figure 2: Summary of indirect measurements.

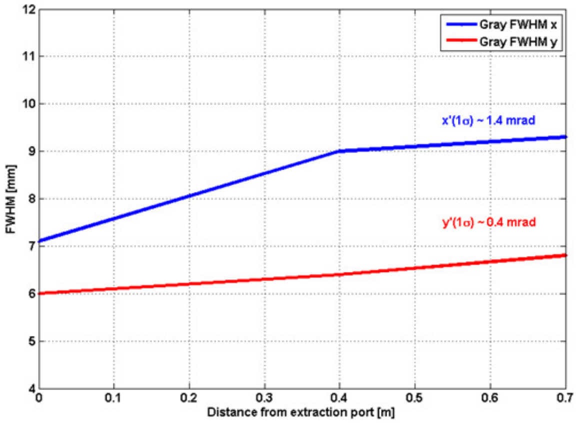

Figure 3: Measured FWHMs of the two transverse beam profiles with respect to the distance from the extraction port.

The preliminary measurements show an increase in the transverse beam profile which corresponds to a divergence of about 1.4 mrad in the horizontal plane and of 0.4 mrad in the vertical plane (1 rms). While the further data is required to calculate emittances, the preliminary results indicate an upper limit of 17 and 5 π mm mrad for the geometrical emittance (4rms). A second measurement campaign will be performed with the use of the BISE detector to obtain a more precise estimate.

Development and Beam Tests of the BISE Detector at the Bern Cyclotron

The BISE detector was designed and built by TERA for the on-line control of the intensity and shape of ion beams along the beam lines. A similar apparatus was previously developed [3]. BISE is based on the detection of low energy (< 50 eV) secondary electrons emitted by a thin aluminium foil (of about 0.8 μm) traversed by the ions, allowing for a minimal perturbation of the beam. The detector operates under vacuum and consists of an electrostatic lens used to focus and accelerate the secondary electrons at the energy of 20 keV. The electric field produced by the lens is such that the electrons reach a plane where a de-magnified image of the primary ion beam is formed with minimal distortion. Here, a sensor is located to detect the 20 keV electrons that form the image. The choice of the sensor was driven by simplicity, reliability and cost-effectiveness criteria. Furthermore, in case of currents of the order of a few μA, the produced neutron fluxes do not allow the use of radiation-sensitive devices. The sensor of BISE is composed by a phosphor screen (P47) read out by a CCD camera. To amplify the signal, in case of beam currents in the nA range or less, a micro channel plate can be used in front of the phosphor. BISE is now under development and test in collaboration with LHEP at the new Bern 18 MeV cyclotron laboratory, where a specific beam transfer line ending in a separate bunker has been constructed to perform research activities [2]. The experimental set-up is shown in Fig. 4.

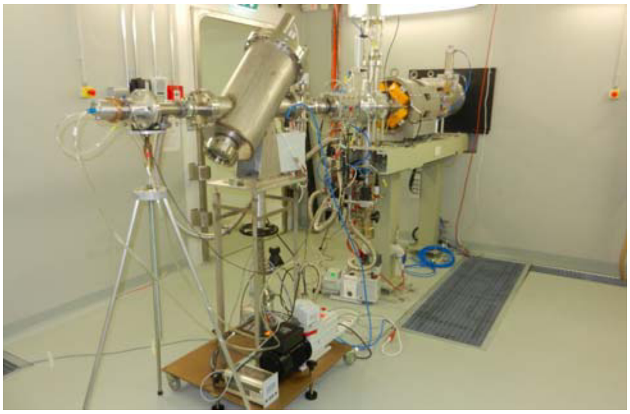

Figure 4: The BISE detector installed in the beam transfer line of the Bern cyclotron. The foil and the electrostatic lens are contained in the cylinder located at 45 degrees with respect to the beam direction.

These developments aim at the optimization of the electrostatic lens and, in particular, at the use of BISE for currents in the μA range, typical of radioisotopes production. Simulations have been performed using SIMION and COMSOL to study the optimal configuration of the electrostatic lens, the magnification

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and the resolution of the images. A beam test campaign is presently on-going and the first preliminary results are reported in Fig. 5.

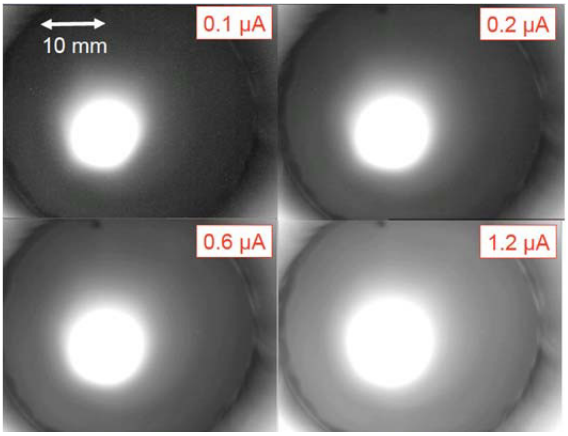

Figure 5: Images of an 18 MeV proton beam at several intensities obtained with the BISE detector. The intensity is measured by means of a Faraday cup located at the end of the beam line.

These first results show that the detector equipped only with a phosphor screen is able to operate in wide range of beam intensities. The measurement of the magnification will be performed by interposing a multi-hole collimator in front of the thin foil. This method will also allow assessing possible distortions. For the measurement of the beam intensity through the analysis of the detected images, the detector will be calibrated by means of a specific high-sensitivity Faraday cup.

CYCLINAC DESIGN

A cyclinac is an accelerator complex formed by a cyclotron and a linac used as a booster [1]. The main parameters of the design for the linac boosting the proton beam from 24 to 65 MeV are summarized in Table 1.

Table 1: Main Parameters of the Linac

Parameter	Value
Frequency [MHz]	2998.5
Number of RF units	2
Number of tanks per RF unit	4
Number of cells per tank	14-15
Bore hole diameter [mm]	7
Units length [m]	2.19-2.84
Effective shunt impedance ZT^2 [MΩ/m]	22.3-51.8
Average electric field on axis E_0 [MV/m]	14.6
Maximum surface electric field [MV/m]	75.0
Peak power per RF unit [MW]	10
RF pulse length [µs]	4
Repetition rate [Hz]	100
Duty cycle [%]	0.04

The 5 meter long linac is made of two independent RF units. With the addition of other RF units, higher energies could also be reached. Moreover, the accelerating performance increases at higher energies due to higher shunt impedance values [4]. ACSI will modify the cyclotron source, so that the extracted beam will be chopped in 4 µs long pulses at the same repetition rate of the linac.

Beam Current at the End of the Linac

In Fig. 6, the linac transmission has been computed considering different values of the transverse emittances of the input beam. A continuous beam with 0.24 MeV energy spread has been considered for the simulations. The plotted results represent the transmitted particles with energy within ± 3% of the peak value (65 MeV).

Figure 6: Linac transmission considering a ratio between ε_x and ε_y of 0.5 (blue curve) and 0.25 (red curve).

For a current of 300 µA from the cyclotron, the expected current is in the range of 14 to 57 µA, considering emittances of 30-15 or 5-2.5 π mm mrad.

SUMMARY

Preliminary beam profile measurements have been performed by ACSI, TERA and IPHC at the TR24 cyclotron installed at IPHC in Strasbourg. The measurements will be completed by using the non-destructive beam detector BISE, which is now under test and development at the Bern cyclotron. A linac design to boost the beam energy from 24 to 65 MeV is proposed and will be optimized based on the information obtained during the final beam measurements.

ACKNOWLEDGMENT

Financial support from ADAM SA is gratefully acknowledged.

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