EMITTANCE MEASUREMENTS OF THE ACCEL K250 SUPERCONDUCTING MEDICAL CYCLOTRON AT PAUL SCHERRER INSTITUTE

by

Dragan TOPREK

Received on March 20, 2006; accepted in revised form on April 3, 2006

The results of beam profile measurements of the proton beam of the ACCEL K250 superconducting cyclotron at the Paul Scherrer Institute are presented in this paper. Beam emittances in both horizontal and vertical planes are estimated by the varying quadrupole method.

Key words: emittance, cyclotron, proton beam

INTRODUCTION

ACCEL Instruments GmbH has delivered a superconducting cyclotron designed for treating cancer with protons. The ACCEL K250 superconducting cyclotron [1, 2] is based on a conceptual design of the National Superconducting Cyclotron Laboratory. As an essential part of Paul Scherrer Institute's project (PROSCAN), it is meant to substitute an existing machine and facilitate further developments in the field of cancer treatment.

Efficient operation of complex accelerators depends on the measurements of relevant beam parameters such as: beam profile (the intensity of the distribution over both transverse coordinates), beam current, beam position, beam energy, energy spread and beam emittances (in transversal and longitudinal phase space).

As the above mentioned list suggests, beam profile and beam emittance are the principal parameters which have to be measured.

Since beam emittance is a measure of both the beam size and of beam divergence, its value cannot be measured directly. But, if beam size is measured at different locations or under different focusing conditions, so that different parts of the phase space ellipse are probed by the beam size monitor, it is possible to determine its value. There are different methods available when emittance measurements are concerned. In this case, we will be focusing our attention on the varying quadrupole setting method, *i. e.* emittance measurements that can be performed by determining profile variations in the considered plane, *vs.* settings of a preceding optical element [3].

There are several possible methods of measuring beam profile. The most frequently used ones involve profile grids (harps) and the ionization of residual gas.

A harp intercepts barely 5% of the beam's particles, yet many experiments are extremely sensitive to these small distortions. A non-interceptive beam profile monitor has also been developed. Its characteristics have been studied previously [4, 5].

In our experiment, we have used a residual beam profile monitor (RG-BPM) for the measurement of beam profile.

The RG-BPM uses ions that are created by beam particles traversing the residual gas in beam tubes. The said ions are extracted from the beam tube with a homogeneous electric field and drifted towards a pair of micro channel plates (MCP's) acting as a charge multiplier. The electrons generated in the MCP's are collected on strips parallel to the beam, so that a position sensitive readout is obtained in a direction perpendicular to the beam. By varying the amplification of the MCP's, signal magnitude can be changed, so that a large dynamic range is achieved.

Technical paper
UDC: 539.125.4:621.384.6
BIBLID: 1451-3994, *21* (2006), 1, pp. 58-60

Author's address:
VINČA Institute of Nuclear Sciences,
Laboratory for Nuclear and Plasma Physics
P. O. Box 522, 11001 Belgrade
Serbia

Author's e-mail:
toprek@eunet.yu

It can be shown that MCP's should operate with an amplification larger than 4 10^4 for a 200 MeV proton beam of 1 nA traversing a residual gas of 10^{-7}-10^{-6} mbar (1 bar = 10^5 Pa) [4]. The produced ions (about 135 s^{-1} cm^{-1}) will then give a final signal current of at least 1 pA. Since the amplification factor of MCP's can be set from 1 to 10^6, this current can be measured quite easily.

The beam profile monitor using the ionization of the residual gas is suitable for all beams, especially those of low intensities. The advantage of such a non-interceptive beam profile measurement is that the amount of neutron and gamma radiation created during the measurements is minimized. This may be very important for some nuclear experiments.

The accuracy of beam positioning with the RG-BPM is approximately 0.3 mm [4].

RESULTS

The proton beam current extracted by the K250 cyclotron is around 200 nA, but the design value amounts to 500 nA. To improve the transmission of the beam during its acceleration (through the cyclotron), beam emittance should be known. The beam profile is measured in both horizontal and vertical planes by using the RG-BPM, one for each plane. For each of them, the beam profile is measured as a function of the strength of an upstream magnetic quadrupole. The RG-BPM for horizontal/vertical beam profile measurements are located 20/30 cm downstream from the magnetic quadrupole.

The kinetic energy (T_k) of the proton beam totals 250 MeV, the length of the magnetic quadrupole 20 cm, and its half aperture 5 cm.

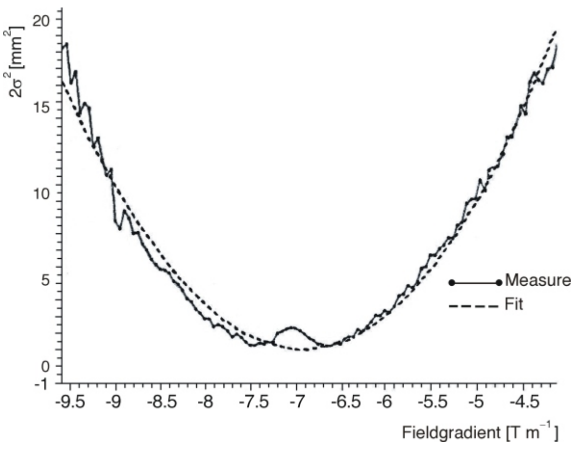

Figure 1. Square of the horizontal beam size *vs*. strength of the quadrupole 20 cm upstream from the measurement point. The points are experimental data and the dashed line is the best fit curvature

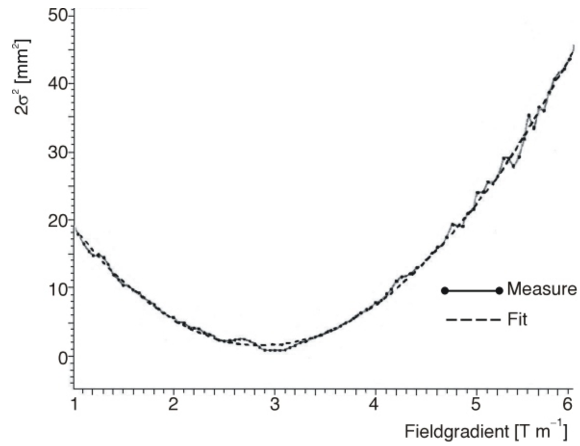

Figure 2. Square of the vertical beam size *vs*. strength of the quadrupole 30 cm upstream from the measurement point. The points are experimental data and the dashed line is the best fit curvature

Data from the RG-BPM are acquired, digitized and processed by the Control System. The beam profile for each of the settings of the corresponding quadrupole is measured either in the horizontal or vertical plane. Then each beam profile is fitted as the Gauss distribution [3]. The estimated values for the emittances and their corresponding errors are: $\varepsilon_x = 7$ 1 π mm mrad, and $\varepsilon_y = 9$ π mm mrad.

We have considered the case when the half beam profile equals 2.35 σ_{ST}, where σ_{ST} is the standard deviation of the Gauss distribution.

In fig. 1 and 2, the dependence of the proton beam profile in horizontal (fig. 1) and vertical (fig. 2) planes on quadropole strength is shown.

CONCLUSION

The design values for beam emittances in both horizontal and vertical planes are 3 π mm mrad. Thus, further studies focused on the optimization of the machine's parameters (position and size of the first slit, the balance of dee voltages [2], position of extracted elements) should be aimed at the improvement of the transmission of the beam through the machine.

REFERENCES

[1] Geisler, A., Baumgarten, C., Hobl, A., Klein, U., Krischel, D., Schillo, M., Timmer, J., Status Report of the ACCEL K250 MeV Medical Cyclotron, *Proceedings*, 17th International Cyclotron Conference and Their Applications, Tokyo, October 18-22, 2004, pp. 178-182

[2] Toprek, D., Measurements of Radio Frequent Cavity Voltages by X-Ray Spectrum Measurements, *Nuclear Technology & Radiation Protection*, *20* (2005), 2, pp. 35-39
[3] Toprek, D., Emittance Measurements by Variable Quadrupole Method, *Proceedings*, 5th International Yugoslav Nuclear Society Conference (YUNSC-2004), Belgrade, September 27-30, 2004, pp. 333-336
[4] Schippers, J. M., Boon, S., Dermois, O., Kiewiet, H., Beam Instrumentation in a Multidisciplinary Accelerator Facility, *Nucl. Instr. Meth., B139* (1998), pp. 389-393
[5] Schippers, J. M., Kiewiet, H., Zijlstra, J., A Beam Profile Monitor Using the Ionization of Residual Gas in the Beam Pipe, *Nucl. Instr. Meth., A310* (1991), pp. 540-543

Драган ТОПРЕК

МЕРЕЊЕ ЕМИТАНСЕ ПРОТОНСКОГ СНОПА ИЗ ACCEL K250 СУПЕРПРОВОДНОГ МЕДИЦИНСКОГ ЦИКЛОТРОНА У ПАУЛ ШЕРЕР ИНСТИТУТУ У ШВАЈЦАРСКОЈ

У овом раду приказани су резултати мерења профила протонског снопа из ACCEL-овог K250 суперпроводног циклотрона у Паул Шерер институту. Емитансе снопа у обе равни, хоризонталној и вертикалној процењене су методом промене струје квадрупола.

Кључне речи: емитанса, циклотрон, протонски сноп