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Optics design of the extraction lines for the MedAustron hadron therapy centre

Michael Benedikt*

AB-Department, CERN, CH-1211 Geneva 23, Switzerland

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Abstract

The MedAustron hadron therapy centre will provide proton and carbon ion beams for tumour treatment. The accelerator complex is based on a synchrotron that will employ slow resonant extraction to provide beams with the time structure required for active scanning. Four medical treatment rooms and two research rooms are foreseen for the centre. The present paper describes the optics design of the extraction lines that link the synchrotron to the different beam application rooms. A modular approach has been adopted to facilitate running-in and operation and to minimise the number of different magnets and power converters to reduce the overall cost. Specific attention was given to the rather special transverse properties of the slow-extracted beam and to the correct matching of the strongly asymmetric beam to the rotational optics of the gantries. Another important aspect for the design was the overall compactness of the centre.

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1. Introduction

In Europe in the early 1990s, a strong interest sprung up in hadron therapy, especially with light ions, for treating deep-seated tumours with an active scanning system that delivered a precise radiation dose into a volume closely conforming with the tumour [1,2]. Towards the end of the 1990s studies such as PIMMS at CERN [3] elaborated the concepts for the accelerator complex design and indicated how the performance goals could be achieved. At present, several groups are either building or moving towards building dedicated centres [4–6], which brings up the need to produce practical and economic designs that preserve the theoretical recommendations [7]. The present paper treats the approach that has been

*Tel.: +41 22 767 3380; fax: +41 22 767 9145.
E-mail address: michael.benedikt@cern.ch (M. Benedikt).

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adopted by MedAustron for the extraction lines and the beam delivery complex.

2. Brief description of MedAustron

The MedAustron hadron therapy centre will use a synchrotron as its main accelerator [6]. The proton or light ion beams (C, O) for patient treatment will be extracted from the synchrotron using ''resonant slow extraction'', over a few million turns. This technique increases the extraction time to a few seconds, providing sufficient time for active scanning and the online dosimetry in front of the patient.

The resonant slow extraction scheme has a strong impact on the design of the extraction beam lines. Firstly, the transverse phase space of the extracted beam in the extraction plane, the horizontal plane, is not of the characteristic elliptical shape (in contrast to the beam circulating in the synchrotron). This makes it difficult, if not impossible, to describe the extracted beam with the standard Twiss formalism. Secondly, the dispersion function at the beginning of the extraction line (in the extraction plane) is not the continuation of the synchrotron's dispersion (as is the case for a fast extraction). The ''splitting'' action in phase space of the electrostatic extraction septum, together with the parameters of the beam ''waiting'' in the synchrotron and the extraction set-up create a discontinuity, requiring a redefinition of the dispersion function for the downstream extraction lines.

The two above-mentioned aspects are fundamental to resonant slow extraction and have to be taken into account when adjusting beam size for patient treatment and when matching to a gantry, in order that the beam at the gantry isocentre is independent of the gantry angle. The theoretical principles involved have been treated in some detail in Refs. [3,7] and the present paper will look into their inclusion in the practical layout, which foresees four medical treatment rooms comprising two horizontal fixed beams, one proton gantry and one carbon ion gantry. All rooms will be equipped with active scanning magnets to enable patient treatment with the highest possible precision. There will also be two research rooms, equipped with fixed horizontal beam lines and scanning systems.

3. Medical requirements

For MedAustron, the extraction energy of the beams is varies from 120 to 400 MeV/u for carbon ions (active scanning) and from 60 to 220 MeV for protons[1] (active scanning), corresponding to a maximum penetration depth of ~30 cm in human tissue at the top energies. The beam size at the isocentre is to be adjustable from 4 to 10 mm at full-width half-height (FWHH). The extraction line design has to handle beam size changes that are significantly larger than the medical requirements in order to compensate for the adiabatic damping introduced by the extraction energy range in the vertical plane.

4. Design philosophy

The design of the MedAustron extraction lines is based on the philosophy developed within the PIMMS study [3]. The extraction lines are organised in a modular way where each module fulfils a certain task (e.g. horizontal beam size control) while leaving all other parameters unchanged. It is expected that such an ''orthogonal'' approach will facilitate running-in as well as standard operation, which is especially important for a medical accelerator centre. The use of identical modules for the deflection to the different treatment rooms implies identical controls, power supplies and magnets so that operation of the deflection modules will be similar for all rooms. The modular layout also provides flexibility for future extensions of the accelerator complex. A detailed theoretical description of the design philosophy is given in Ref. [7].

[1]Frequently a maximum extraction energy of 250 MeV for protons is quoted in the literature. The higher energy is needed to compensate for energy loss in scatterers, etc. when using passive beam delivery techniques which is not foreseen for MedAustron.