

A FAST DEGRADER TO SET THE ENERGIES FOR THE APPLICATION OF THE DEPTH DOSE IN PROTON THERAPY

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Proton therapy with a fixed energy cyclotron needs a degrader to adjust the energy of the proton beam for the application of the depth dose. Within the scope of the PROSCAN project, a degrader system is being realized that meets the requirements as given by the spot-scan technique. This requires infinitely variable energy in the range of ≥ 240 MeV down to 70 MeV. The depth, referred to as the range of the protons into the body, has to be set within an accuracy and a reproducibility of 0.1 mm water equivalent. The time to change the penetration depth of the protons by a typical step of 4.5 mm water equivalent has to be ≤ 50 ms.

INTRODUCTION

The objective of the PROSCAN project is to expand the existing facility and technical infrastructure with an independent cyclotron that meets the high specifications and requirements for the application of advanced and improved irradiation techniques. With the spot-scan technique, many individual beam spots are superimposed in the target volume in such a way as to impose the desired radiation dose distribution uniformly within a tumour. To achieve this, the individual spots have to be positioned precisely in a rapid sequence. This can be realised with a fixed energy cyclotron combined with a fast degrader system that permits a rapid setting of the different beam energies. Furthermore, the beam transport system from the cyclotron to the treatment rooms has to satisfy the requirements for the implementation of energy modulation in addition to lateral scanning. Magnets and power supplies have to enable the desired rapid change of the beam setting in order to transport the beam properly.

The degrader is an important component of the facility, and it has to fulfil the general requirements imposed on the whole facility. These are high reliability (99% availability of scheduled beam time), short service periods (maintenance task < 4 h), fast accessibility and low dose load in case of required servicing. Specifically, the degrader has to be constructed with standard units, with the drive installed outside the vacuum chamber. The degrader should be small and light and be fabricated out of high-density graphite to reduce activation and beam losses due to scattering. Equally important is redundant diagnostics to control and read back the setting and the position of the degrader.

DUAL DEGRADER UNIT

The degrader has to enable an infinitely variable energy setting in the range of ≥ 240 MeV down to 70 MeV. For that the thickness of the absorber has to be increased uniformly. A change of the penetration depth of the beam into the body, typically ~ 4.5 mm water equivalent, has to be accomplished within 50 ms with an accuracy of ± 0.1 mm. The positional change of the degrader itself depends on the beam energy and on the specific design of the degrader. The settings have to be performed according to a measured calibration curve.

To satisfy all the requirements [1], a degrader was chosen that consists of two multi-wedge high-density graphite absorbers. As shown in Fig. 1., they are facing each other

from both sides of the beam, such that they fit into each other when they are moved simultaneously into the beam. The heat load is ≤ 90 W and high temperatures are prevented by sufficient heat conduction ($T_{\max} \leq 165$ °C).

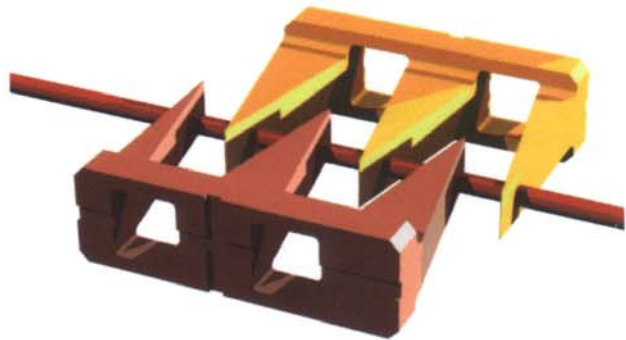


Figure 1: Degrader pair of high-density graphite, partially inserted into the beam.

As illustrated in Fig.3, the degrader units are set up on a girder that is fixed to the bottom of the vacuum chamber. The girder facilitates installation and de-installation of the degrader units. It is equipped with a stopping mechanism to prevent the multi-wedge degraders from colliding when they are moved completely into the beam. The girder has to be stiff and stable in order to withstand the bending moments, that occur due to the accelerating forces, the vacuum force, the pressure forces of the bellows and the moment of inertia, which can add up to as much as 300 N. As a result, there are no dynamic forces acting on the vacuum chamber and therefore it does not deform when the dual absorbers are moved at the high acceleration of 6 m/s^2 . This enables the degrader pair to be set at the desired position with the necessary precision of 0.03 mm, which corresponds to the required accuracy of 0.1 mm water equivalent in the penetration depth of the protons.

Screw thread drives, driven by stepping motors and guided by parallel mechanisms, shift the multi-wedge degraders precisely into the beam. The braces of the parallel mechanisms tilt towards the vacuum chamber and provide the required stability. The movement of the absorbers is along an arc of a circle. However, it is analytic and the relation between the position encoder of the stepping motor and the position of the degrader can be established.

The beam spot size at the exit of a multi-wedge degrader is larger than that of a compact degrader for identical energy degradation. This is due to beam divergence in the drift lengths between the wedges. The differences in the beam spot sizes are particularly distinct at moderate degradation where the drift lengths are larger. However, at lower energies, when the multi-wedge degraders nest more and more into one another to form an almost compact body, the difference of beam spot sizes decreases. At 70 MeV the beam spots have almost the same size. As can be seen in Fig. 2, the dependence of the beam-size on the absorber setting is reduced and the dynamic range is more constant. Together with the selected beam spot size, this decreases possible control and stability uncertainties of the beam intensity.

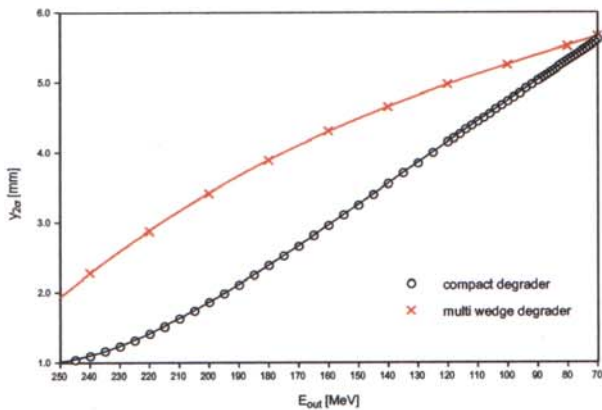


Figure 2: Beam spot size at the exit of the multi-wedge degrader compared to that of a compact degrader

DEGRADER SYSTEM

The degrader system is installed in a small and compact vacuum chamber. This is to enhance safety and to avoid contamination risks. Radiation protection requirements would not allow this length of beam section in an air-filled box, which would have to be evacuated and flushed before opening. This is in contradiction with the desired fast access.

The degrader system consists of:

1. Beam diagnostics (beam position, profiles and intensity) in order to position the beam properly at the entrance of the degrader.
2. A beam stopper-Faraday cup: It has a hole for the beam passage at normal operation, and it also serves as a beam stopper when the beam is kicked off the beam axis to interrupt the beam at the target. To stop the beam, the Faraday cup is shifted further into the beam in ≤ 0.5 s, and the current can be measured accurately.
3. Stack of scatter foils: At higher energies the scattering in the degrader may be too small. This may lead to an increase of possible control/stability uncertainties. To increase scattering, various foils can be inserted. This decreases the beam transmission from the cyclotron exit to the target, but may possibly make the dynamic range of the beam intensity more constant.
4. Dual degrader unit.
5. Adjustable stack of collimators with apertures ranging from 1 to 15 mm in diameter to select the beam spot size.
6. Collimator of graphite to suppress the beam halo.

REFERENCE

- [1] H. Reist, Anforderungen an den PROSCAN Degrader, P22/RH85-161.3



Figure 3: Degrader system with the dual degrader unit that is set-up on a girder. The beam enters the vacuum chamber at the front side. Schematically shown are the diagnostics box, the beam stopper-Faraday cup, the set of retractable scatter foils, the degrader unit, the adjustable set of collimators and the collimator to stop the beam halo.