STATUS OF THE HZB CYCLOTRON

A. Denker#, J. Bundesmann, T. Damerow, T. Fanselow, W. Hahn, G. Heidenreich, D. Hildebrand, U. Hiller, U. Müller, C. Rethfeldt, J. Röhrich, HZB, Hahn-Meitner-Platz 1, 14109 Berlin, Germany
D. Cordini, J. Heufelder, R. Stark, A. Weber, Charité, Berlin, Germany

Abstract

The therapy of ocular melanomas in Berlin started 1998 as cooperation between the Benjamin-Franklin Klinikum (now Charité) and the Hahn-Meitner-Institut (now Helmholtz-Zentrum Berlin). More than 2222 patients have been treated since. The facility is still the only facility in Germany treating ocular melanomas with protons.

In the beginning, tumour therapy used about 10 % of the overall beam time and its accelerator operation was embedded in the operation for physics experiments. The end of the physics programme in 2006 had severe consequences: Beam time, and consecutively funds and resources, were cut-down remarkably.

The accelerator operation continued mainly for therapy since 2007 with reduced man-power, requiring changes in the set-up and operation regime of the accelerators. Maintaining a high reliability is a key issue. The stability of the proton beam is of utmost importance for the therapy, both on the short-term and the long-term scale.

ACCELERATORS AND OPERATION

The main user of the facility is since 2007 the Charité, using a 68 MeV proton beam for eye tumour therapy. In addition, several small scale experiments, like radiation hardness testing and dosimetry are performed. This changed the operation regime from ~ 4500 hours of beam time to 12 therapy weeks distributed evenly over the year.

Since 2009 our cyclotron is again served by two different injectors. The van-de-Graaff Injector beam line offers the acceleration of a variety of different ion species and a beam bunching for high transmission within the cyclotron. The Radio Frequency Quadrupole, used for heavy ions, has been transferred to iThemba Labs and was replaced by a 2 MV tandetron from High Voltage Engineering Europa B.V. [1]. As standard ion source, the 358 duoplasmatron with direct off axis extraction of negative hydrogen ions was chosen.

Development of the ion source resulted in safe source operation times of more than 600 h and extremely stable beam current [2]. After extensive beam tests, the authorities granted the permit for using the tandetron-cyclotron combination for therapy in 12/2010. The tandetron is in full operation for therapy since 01/2011. It proved to be a reliable machine with extremely high stability, causing no measurable down time.

As shown in Figure 1, operation of the accelerator went very smoothly. Since the successful commissioning of the tandetron the amount of time for beam tests decreased, while more beam time was used by experiments. The downtime of the accelerator over the last five years due to failures was less than 5%. This was achieved by a step by step process addressing all sub-systems of the accelerator complex with:

- Modernisation, e.g. the exchange of the shunt against transducer regulation in the quadrupole power supplies yielding a gain in stability of factor 10 or the replacement of discrete rectifiers by complete 3-phase modules.
- Increased redundancy, e.g. using smaller variety of pumps, vacuum gauges, or power supplies. The operation of the turbo-pumps on 60% of the rotational speed (standby mode) once a good vacuum has been reached increases the service intervals by a factor of five.
- Improved diagnosis, e.g. routinely applied residual gas analysis in the cyclotron for an early determination of a water leak or the logging of the electricity supply.
- Better display of machine parameters like 24 h charts, also available during the periods between the therapy weeks and accessible via world-wide-web interface.

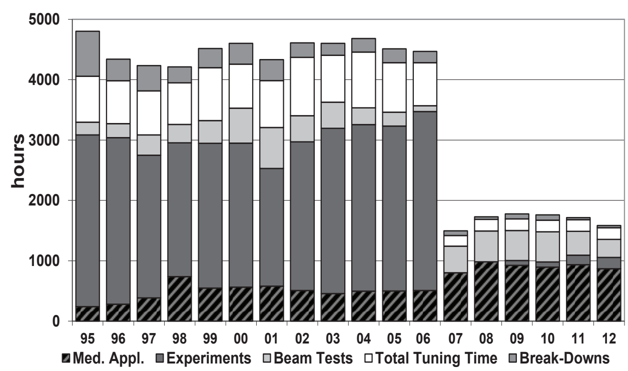

Figure 1: Operation statistics of ISL (1995-2006) and the new operation regime with the main use of the cyclotron for therapy (since 2007).

Between 10 and 30% of the annual downtime is due to failures in the electricity provision by the power supplier. In 2012 alone, six failures of the electricity supply with a duration above 0.1 seconds occurred. However, the peak power consumption of the cyclotron during the ramping procedure of the main magnet would require a large uninterruptible power supply (UPS), which was considered to be too expensive as well as too labour-intense. However, the computers of the control system have been equipped with UPS in order to prevent also data losses.

denker@helmholtz-berlin.de

ISBN 978-3-95450-128-1

TIME STRUCTURE OF THE BEAM

The Van-de-Graaff was considered to be a temporary backup for the tandetron after its successful installation. However, new requests for pulsed beams with a very specific time structure occurred, which can be provided only with the Van-de-Graaff-cyclotron beam line.

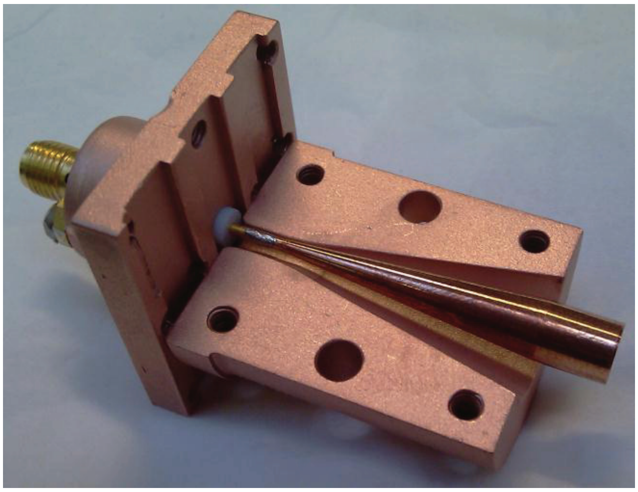

Figure 2: The open coax-cup without the acrylic glass in front (dielectric and support) and without shielding.

The bunching systems of our accelerators were designed and optimised for heavy ions yielding a transmission through the cyclotron of 100%. For heavy ions the time structure of the beam is well known and pulse widths below 0.3 ns have been achieved [3]. For protons, this was never measured experimentally. In addition, only two of the three bunchers can be used, as the third buncher – directly in front of the cyclotron – requires for protons high voltages well above its specification. To be able to measure the expected pulse length in the order of nanoseconds at low beam intensities, a special Faraday cup was developed. The beam impinges on a copper target which is adjusted to 50 Ω impedance: the diameter changes from 1.2 mm at the SMA plug to the 6 mm at the front in order to avoid reflections. The dielectric is acrylic glass at the front and vacuum for the rest. The copper target is surrounded by a copper block (see Figure 2), and the whole cup is placed in a copper shielding. The signal from this "Coax-Cup" is amplified using two broad band (100 kHz – 1.7 GHz) amplifiers with 30 dB each in series. These amplifiers have been developed and built in-house. A 3 dB attenuator between the amplifiers is used to prevent oscillations. The signals are read out with an oscilloscope WavePro 725Zi from LeCroy™, which has 2.5 GHz and a maximal sample rate of 40 GS/s. The system works fine with beam intensities from 0.1 nA to 10 nA. Above this level, heating of the acrylic glass leads to outgassing, inducing vacuum problems. Therefore, for higher intensities, a pick-up tube is employed using the same electronic setup.

For therapy purposes a DC beam is injected into the cyclotron. A pulse width of 5 ns was measured (Figure 3) for this so-called quasi-DC beam. Using the bunchers in the high voltage terminal of the Van-de-Graaff and in the beam line, the pulse width of the beam extracted out of the cyclotron is reduced to 1 ns. Time-of-flight measurements confirmed that the second small peak visible for the bunched beam is not induced by protons but is caused by reflections in the electronic system [4].

In addition, a suppressor permits further influence of the time structure by kicking out non-wanted pulses.

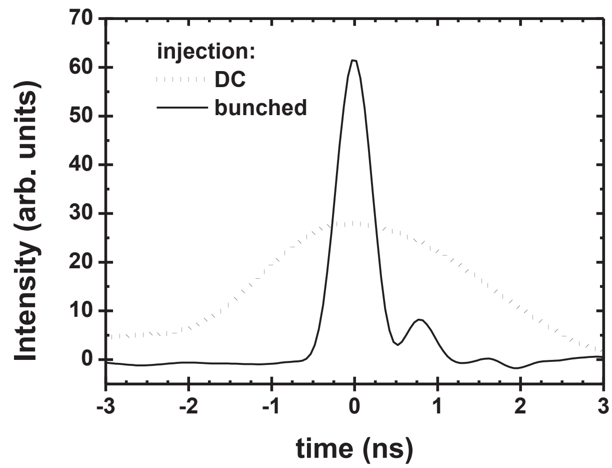

Figure 3: Pulses of the extracted 68 MeV proton beam measured with the coax-cup. The injected beam was a DC beam (dotted line) or a bunched beam (solid line). The second small peak visible is due to reflections.

Single pulses of 1 ns with a maximum repetition rate of 75 kHz were produced. The limitation of the repetition rate is due to existing high-voltage power supply of the suppressor which runs into its specification limits for the high voltages requested for protons. A new power supply is under development in order to permit higher repetition rates. On the test bench a rate of 2 MHz has been successfully achieved so far.

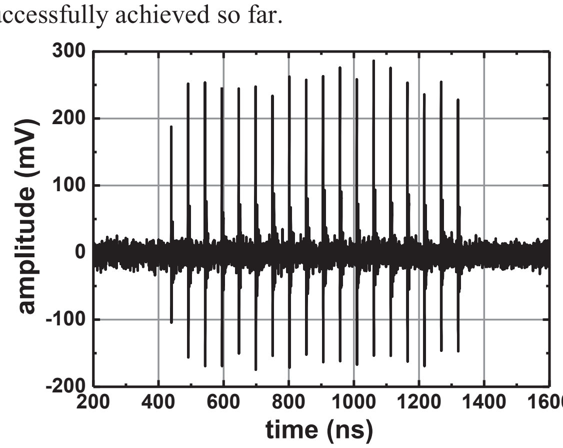

Figure 4: 1 μs pulse packet of 68 MeV protons, measured with the pick-up. This time structure was used for the creation of pulsed neutron fields for dosimeter tests.

Long pulse packets with a length between 1 µs and 10 µs with a repetition rate of 100 Hz (Figure 4) and intensities in the pulses ranging from 5 nA to 1 µA were provided for experiments of the EURADOS working group 11 [5]: This beam impinged on a tungsten target in order to produce pulsed neutron radiation with dose rates between 0.044 nSv to 90 nSv per pulse. The goal was the systematic study of the behaviour of neutron survey meters and personal neutron dosimeters in pulsed neutron fields.

15 YEARS OF EYE TUMOUR THERAPY

Eye tumour therapy with protons started in Berlin in 1998. Although the cyclotron was designed originally as a heavy ion accelerator, it proved to be an ideal machine for eye tumour therapy in terms of intensity, time structure, beam stability, and beam energy:

- The required intensities of about 30 nA extracted from the cyclotron are very easily achieved, and allow short irradiation times of 30 to 60 s, depending on the prescription, as well as a straightforward and reliable passive scattering system.
- The 68 MeV proton beam has a repetition rate of 20 MHz which excludes possible interferences with the modulator wheels, which rotate with 20 turns per second, applying 160 spread out Bragg Peaks.
- The short and long term stability of the beam is better than 2%.
- The sharp distal dose fall-off of less than 1 mm from 90% to 10% of the prescribed dose permits to treat tumours located very close to critical structures with low or no dose application (see Figure1 and 2 in [6]).

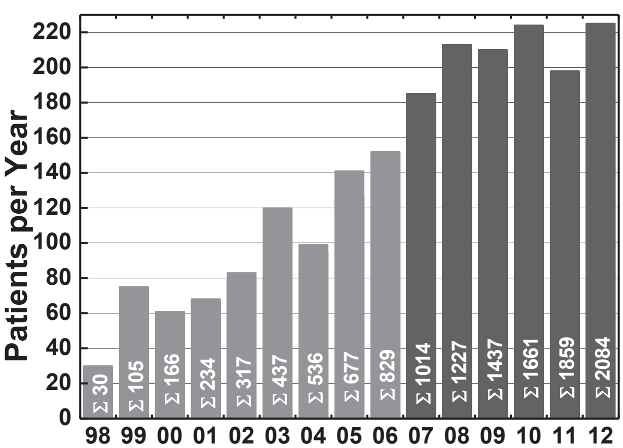

Figure 5: Patient figures treated per year (bars) and in total (white numbers).

In the last 5 years, the number of patients treated per year stabilised at around 210. By far most of the patients origin from all over Germany, but they are coming also from other European countries like Austria, Poland, and Norway.

In addition to a resinous therapy work flow, the beam was also used for research activities concerning proton dosimetry and individual tumour treatment adaptation.

In cooperation with the Institute of Nuclear Physics in Krakow, Poland, the applicability of newly developed 2D TL-detectors in the dosimetry of the proton beam was studied very intensively and in detail [7].

A new dosimetry device for radiobiological experiments was investigated in cooperation with the Helmholtz-Zentrum Dresden-Rossendorf [8].

Further studies concerned the influence of lid retractors on the depth dose profile as well as the influence of silicone oil, which is used as tamponade in ophthalmology, and its consequences in proton beam adaptation [9].

SUMMARY AND OUTLOOK

Although major breakdowns have a huge impact on the up-time due to the small number of beam time hours, breakdowns over the past years amounted to only 5 % or less of the beam time.

Pulse structures of a high variability, from single pulses of 1 ns at a maximum repetition rate of 75 kHz to pulse packets with a length up to 100 µs, were tested and provided for experiments. In order to improve the variability of the repetition rate, a new power supply has been developed and is under test. To improve the transmission through the cyclotron the use of the buncher directly in front of the cyclotron is mandatory. However, this requires a complete re-design of the existing buncher, which is at the moment under consideration.

For 15 years, eye tumours are treated with 68 MeV protons in collaboration with the University Hospital Benjamin Franklin, now Charité - Campus Benjamin Franklin. Twelve therapy weeks are performed each year. In a routine workflow, about 210 patients are treated each year. The tumour control rate of choroidal melanomas after five years is 96%. In mid-2012 we could celebrate the treatment of the 2000th patient.

A variety of radiobiological experiments with possible impact on the dose prescription for the proton treatment is planned. Furthermore we want to study the prompt Gamma detection which occur during the irradiation as a tool for online proton range (and maybe position) detection.

REFERENCES

[1] http://www.highvolteng.com/media/Brochures/Tandetron_broch.pdf
[2] J. Röhrich et al., Rev. Sci. Instrum. 83 (2012) 02B903.
[3] W. Bohne et al, Nucl. Instr. Meth. A 240 (1985) 145.
[4] Ralf Nolte, PTB, private communication.
[5] www.eurados.org/~/media/Files/Eurados/documents/Working_Groups/WG11_Progress_Report.pdf
[6] C. Kunert et al., “Multi-Leaf Faraday Cup Especially for Eye Tumour Therapy”, CYCLOTRONS’13, Vancouver, Canada, TH2PB04, these proceedings.
[7] S. Pensold, “Charakterisierung von Dünnfilm-TLD des Typs LiF: Mg, Cu, P für die Dosimetrie am 68MeV-Protonenstrahl in der Augentumortherapie der Charité Berlin”, diploma thesis (2010).
[8] C. Richter et al., Phys. Med. Biol. 56 (No. 6) (2011) 1529.
[9] A. Weber et al., Phys. Med. Biol. 57 (2012) 8325.

ISBN 978-3-95450-128-1