ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-MOPO011

DESIGN AND OPERATION OF THE NEW FAST BEAM CHOPPER BETWEEN TANDETRON AND CYCLOTRON

T. Fanselow†, J. Bundesmann, A. Dittwald, A. Denker[1], U. Hiller
Helmholtz-Zentrum Berlin GmbH für Materialen und Energie (HZB), Berlin, Germany
[1]also at Berliner Hochschule für Technik, Berlin, Germany

Abstract

In collaboration with Charite - Universitätsmedizin Berlin, patients with ocular melanomas are treated with protons at Helmholtz Zentrum Berlin. Accompanying research includes beam delivery for Flash irradiation, thus it became necessary to set up a fast and reliable beam Chopper. The new beam Chopper can deliver much shorter pulses than needed for Flash irradiation, minimum pulse widths down to 70 ns at 1 kV amplitude can be delivered. A short description of the design and installation process, which occurred in 2020, and the experiences of the first 2 years of operation with the new fast beam Chopper system is presented.

INTRODUCTION

At the cyclotron of the Helmholtz Zentrum Berlin two injectors can be used for tumor therapy and experiments. A 6 MV Van-de-Graaff injector and a 2 MV Tandetron (Fig. 1). Due to its stability and reliability, the Tandetron is mainly used for tumor therapy and Flash experiments [1]. For rapid beam on/off switching in Flash experiments, a mechanical scissor-like beam stop has been used in Tandetron operation to date. Due to the sluggish mechanics, the beam stop requires 40 ms to fully open and 47 ms to fully close. Since Flash experiments require beam pulses between 1-100 ms, the mechanical beam stop can only be used to a limited extent. Due to this limitation, it was necessary to build a fast beam Chopper that can realize minimum pulse widths of 1 ms. For this purpose, 1 m beamline is available directly behind the Tandetron. The deflection of the beam is to be done via two deflection plates. The setup of the new Chopper is to be done via an existing CAMAC power supply controller, whereas the Beam control runs via the FPGA and LabVIEW of the flash control.

DESIGN OF THE NEW FAST BEAM CHOPPER

An existing 94 cm long vacuum chamber with deflector plates was selected for the fast on/off switching of the beam. The available area directly behind the tandetron is 1m long and has so far only been used for steerer tests. For the complete setup of the Chopper, in addition to the vacuum chamber with the deflection plates, a fast semiconductor switch, processing and control electronics including power supply, a HV power supply for the deflection plates and a cooling system are required.

† timo.fanselow@helmholtz-berlin.de

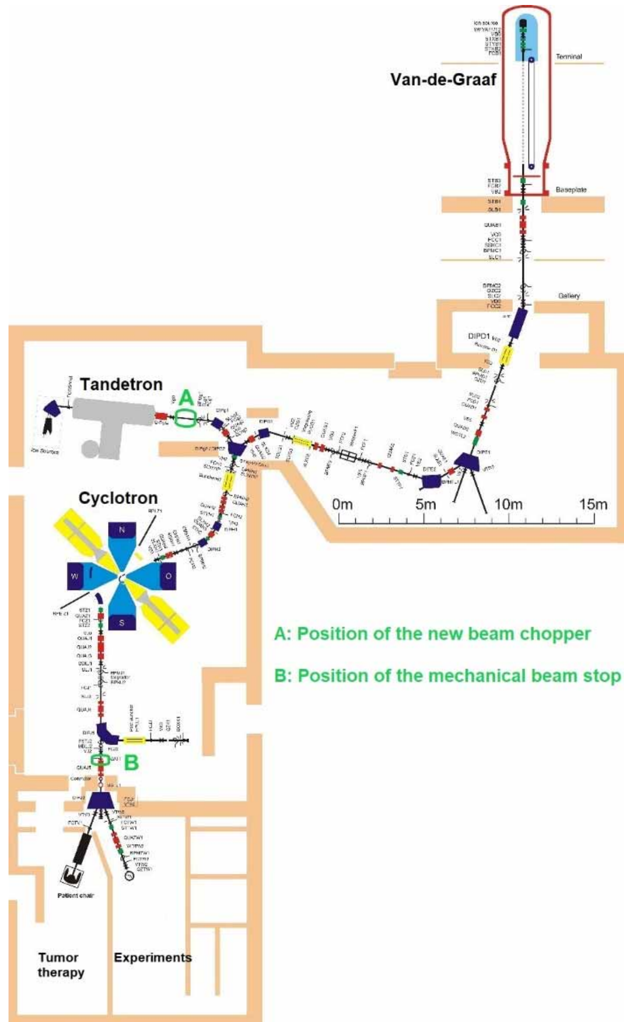

Figure 1: Layout of the accelerator complex including the location of the mechanical beam stop and the new Fast Beam Chopper.

VACUUM CHAMBER AND DEFLECTION PLATES

The existing vacuum chamber with deflection plates is 94 cm long and has 2 DN 160 CF flanges at the inlet and outlet. Another DN 200 CF flange is provided for an ion getter pump. Furthermore, there are two flanges for the HV voltage feed-through of the deflection plates as well as 4 adjusting screws for the adjustment of the plate distance. The already existing 4 cm wide deflection plates were reworked and shortened to 90 cm to avoid interference at the input and output of the Chopper. The two deflection plates made of V4A steel were then aligned with the beam axis and adjusted to 2 cm spacing (Fig. 2).

ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-MOPO011

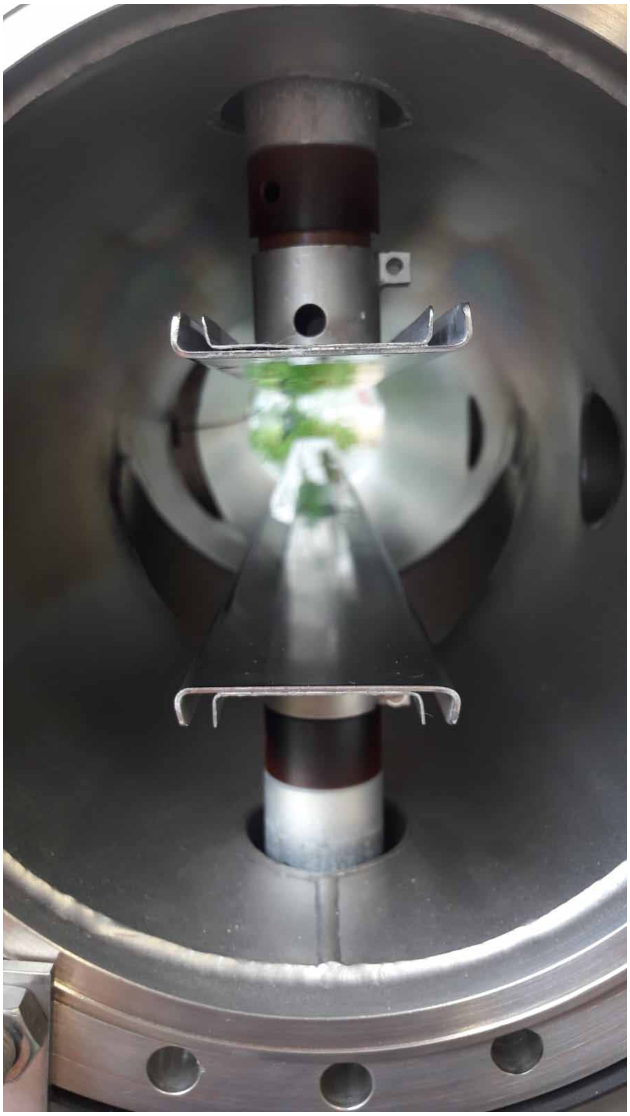

Figure 2: Deflection plates.

Furthermore, the vacuum feedthroughs of the plate connections were renewed and provided with new seals. For the installation in the Beamline behind the Tandetron, a frame made of Item profiles was built that accommodates the vacuum chamber itself as well as the 19-inch electronic crates units and the ion getter pump (Fig. 3).

FAST SWITCHING HALF BRIDGE MOSFET MODULE

A half-bridge Mosfet module from the Behlke company was used for fast switching on and off of the deflector plate. The Fast Square Wave Pulser FSWP 41-03 from Behlke is designed for operating voltages up to 4 kV and can handle a peak current of 30 A. The maximum switching frequency is 3 MHz with sufficient cooling and power losses up to 1500 W can be dissipated. Depending on the capacity of the connected load, a pulse rise and fall time of 8 ns can be achieved with a minimum pulse duration of 50 ns. For the Chopper the FSWP Mosfet module with direct liquid cooling was chosen to allow higher switching frequencies than

Figure 3: Vacuum chamber with the frame made of Item profiles.

needed for the flash measurements. For this a liquid cooling including heat exchanger had to be provided. For the operation of the FSWP Mosfet module, two supply voltages of 15 V 1.5 A and 120 V 1 A are required in addition to the HV voltage to be switched (Fig. 4).

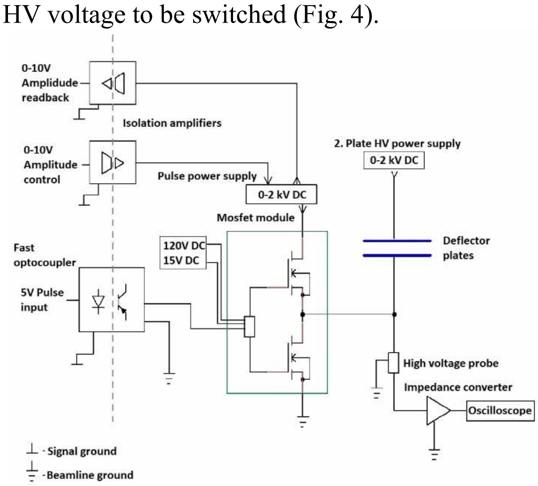

Figure 4: Operating principle of the fast Chopper.

ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-MOP0011

The FSWP Mosfet module is controlled by a 5 V TTL signal with an input impedance of 100 Ohm. For the galvanic decoupling between Chopper and control two isolation amplifiers and fast optocouplers were used.

PROCESSING AND CONTROL ELECTRONICS

The pulse electronics mainly consists of 4 segments the power supply, the control electronics, the pulse processing and the FSWP Mosfet module itself (Fig. 5). The power supply section provides the 15 V and 120 V for the FSWP Mosfet module, further 15 V for the isolation amplifiers and 24 V for the control electronics. For the control electronics a Siemens LOGO PLC is used, which handles the sequence control of the Chopper including the connection to the CAMAC Power Supply Controller and the FUG MCP 2800-2000 Power Supply. In addition, the control electronics is responsible for monitoring error conditions of the FSWP Mosfet module, the power supply and the flow meter. Pulse processing provides galvanic isolation between the Chopper and the control system. Fast optocouplers for the pulse signals and isolation amplifiers for the analog amplitude setting and readback are used.

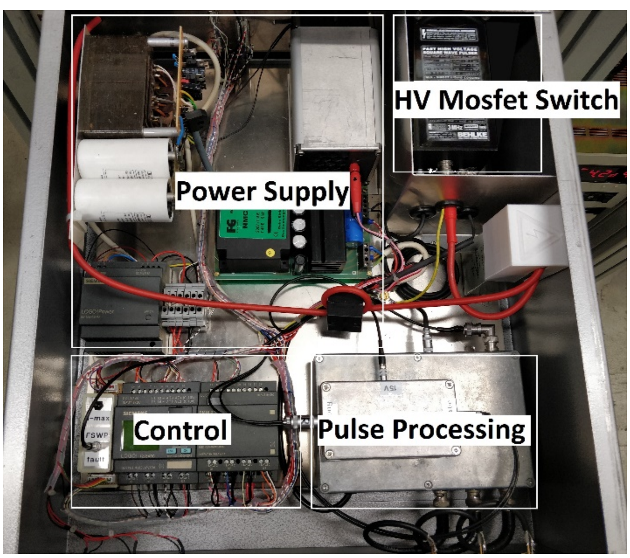

Figure 5: Processing and control electronics crate.

HV POWER SUPPLIES

For each of the two deflection plates, an HV power supply is required which is controlled by a CAMAC power supply controller. For the fixed voltage supply required to deflect the beam, an HMI N102N power supply unit with 0-5 kV 0.2 mA housed in the NIM frame is used. The voltage of the other deflector plate required to deflecting in the beam again is supplied by a FUG MCP 2800-2000 0-2kV 1.2 A, this voltage being switched via the FSWP Mosfet module (Fig. 6).

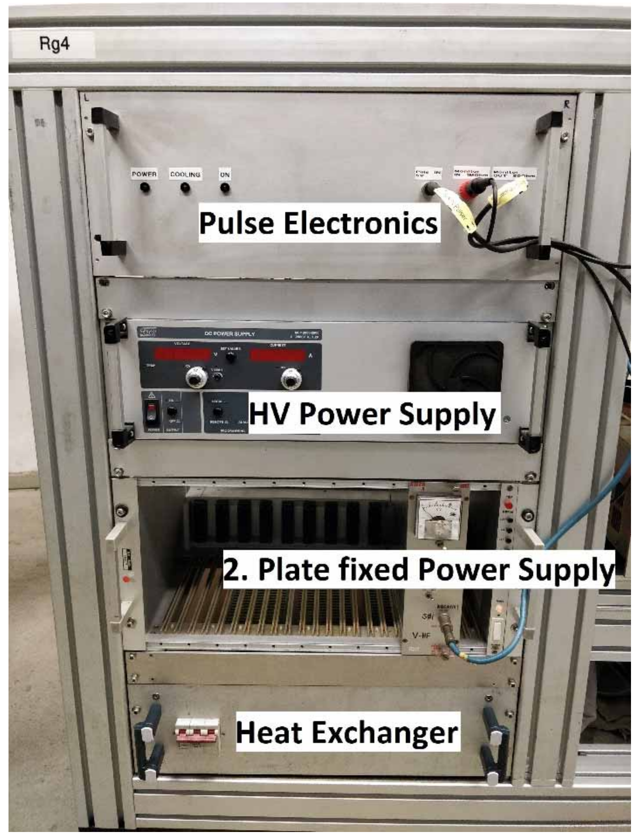

Figure 6: Chopper crates.

COOLING

For the direct liquid cooling of the FSWP Mosfet module the non-conductive HT135 PFPE Cooling Fluid from Galden is used. To remove the heat, the cooling fluid is pumped through a Behlke HE-10 heat exchanger using an EHEIM universal 600 pump, with counter-cooling provided by an external cooling compressor. Both the temperature and the flow rate of the cooling fluid are monitored and lead to the shutdown of the FSWP Mosfet module in the event of a fault. The temperature monitoring is done directly in the FSWP Mosfet module itself. For flow monitoring a UCC DFC.9000 flow meter is used which is evaluated by the control electronics. The waste heat generated in the Pulse Electronics Crate is dissipated directly to the outside via an 80 x 80 mm fan.

INSTALLATION

The preparations for the installation started already at the beginning of 2020 and included the ordering of the required components, the reworking of the vacuum chamber including leakage test, the construction of the Item frame, the Processing and the Control electronics. In addition, the CAMAC connection to the control system and the mains voltage line with 3x400 V 16A were installed. The actual installation took place in summer 2020 and had to be done between 2 beam time blocks within 3 weeks. After ventilating the vacuum section behind the tandetron, the relevant beamline was removed and the Item frame including the Chopper vacuum chamber was installed. The vacuum

ISBN: 978-3-95450-212-7 ISSN: 2673-5482 doi:10.18429/JACoW-CYCLOTRONS2022-MOPO011

chamber including deflector plates was measured optically on the beam axis using theodolites and reference points. The beamline section was then evacuated and baked out again, and finally a leak test and residual gas analysis were performed using a mass spectrometer. Initial functional testing included manual application of static voltages of 0-2 kV to both deflection plates and subsequent commissioning of the control electronics and remote operation via the CAMAC Power Supply Controller.

Figure 7: Beamline behind the Tandetron before installation of the Chopper.

Figure 8: Beamline behind the Tandetron after installation of the Chopper.

EXPERIENCES OF THE FIRST 2 YEARS

The first test with the beam showed that amplitudes between 0.7 kV-1 kV are sufficient for a complete deflection of the 3.6 MeV proton beam. In the first flash measurements pulse widths of 1ms could be achieved without any problems with a rise and fall time of only 18 ns. Subsequent measurements with continuous pulses showed that from a frequency of 2.5 MHz strong reflections occur at the pulsed deflection plate. Therefore, frequencies above 2.4 MHz should be avoided for stable operation. The minimum pulse width to be achieved is 70 ns, whereby the pulse shape is determined to a large extent by the rise and fall time. When performing Flash measurements, much more precise rise and fall times of the beam were found. Together with the possible shorter pulse times, a more precise Flash irradiation is now possible. Problems were encountered with static charging of the deflector plates during the beamtime with the Chopper turned off, which damaged one FSWP mosfet module and broke several suppressor diodes. After switching off the Chopper, both deflection plates are now manually grounded to prevent static charging. Furthermore, a leak in the cooling system caused the Chopper to fail during test measurements.

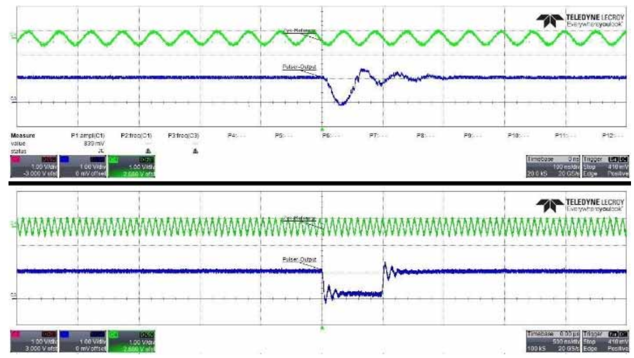

Figure 9: Above in blue is a 70 ns pulse and below in blue is a 500 ns pulse. The green signal is in both cases the cyclotron frequency of 19.3178 MHz.

CONCLUSION

The beamline area behind the Tandetron provided enough space for the mechanical setup of the Chopper. The flat beam profile at this location allows a small plate spacing of only 20 mm and thus a deflection amplitude of less than 1 kV. The achievable pulse frequencies and pulse widths are far better than required for Flash irradiations. For experiments, pulses synchronized to the cyclotron frequency with repetition rates up to 2.4 MHz and minimum pulse widths of 70 ns can be achieved with the DC beam of the Tandetron.

OUTLOOK

Work is being done on automated grounding of the deflector plates when the Chopper is switched off. In addition, a solution is being worked on to detect leaks in the cooling system earlier. Due to the supply difficulties of spare parts as a result of the Covid 19 pandemic, timely procurement of spare parts is necessary.

REFERENCES

[1] G. Kourkafas *et al.,* “Expanding proton FLASH capabilities to kGy/s within ms for clinical applications at HZB”, presented at the Flash Radiotherapy and Particle Therapy Conf. (FRPT’22), Barcelona, Spain, Nov. 2022. `doi:10.14293/S2199-1006.1.SOR-.PPRDNQW.v1`