COMMISSIONING AND TESTING OF THE FIRST IBA S2C2

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Abstract

The first unit of the IBA superconducting synchrocyclotron (S2C2), used in the Proteus®ONE compact proton therapy solution, has been installed and commissioned in Nice. In this communication, we will present some selected results of the commissioning with the main focus on the accelerator aspects, showing the influence of machine parameters on beam properties like stability, energy and intensity, which are key elements in proton therapy applications.

THE PROTEUS®ONE LAYOUT

Figure 1 shows the S2C2, installed at the testing facilities in Louvain-la-Neuve (Belgium), and the layout of the compact gantry, which is attached to the S2C2. Together, they constitute the main components of the Proteus®ONE proton therapy system. More information on the S2C2 characteristics can be found in [1]. The compact gantry is described in [2]. A main feature of the compact gantry is the integration of the energy selectrion system (ESS) in the gantry itself (see Fig. 1). At the end of the ESS, the dispersion is maximized and a slit is present to select the needed proton energy.

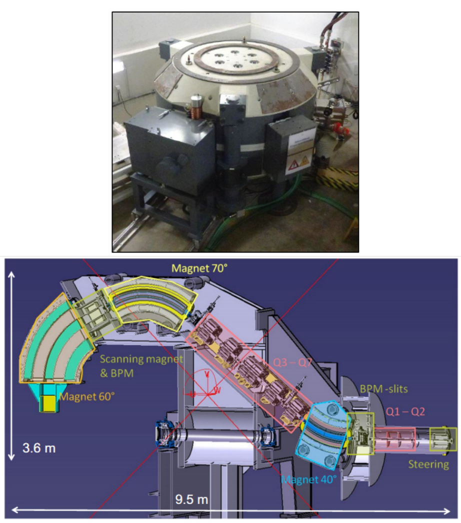

Figure 1: (Top) The S2C2 installed at the testing facilities. (Bottom) the compact gantry layout. The S2C2 and the compact gantry constitute the Proteus®ONE system.

THE S2C2 TIMING

Figure 2 shows the timing properties of the S2C2. The green line shows the source arc current feedback (pulsed cold cathode source), the red line shows the RF frequency sweep (periodicity of 1 ms) and the black line shows the dee voltage profile during acceleration. The blue line is the measured beam signal induced on a senstive diamond probe [3]. These timings are repeated at a frequency of 1 kHz, which is the periodicity of the RF frequency sweeps.

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Table 1: S2C2/Proteus®ONE Main Properties and Key Figures

Nominal beam energy	230 MeV
Max. clinical charge at isocenter	4.5 pC
Energy spread at nominal energy	≈400 keV
Pulse repetition rate	1 kHz
Pulse duration	10 μs
RF frequency range	60-90 MHz

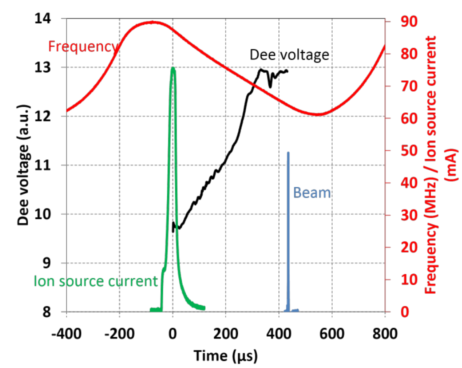

Figure 2: Timing properties of the S2C2 in the Proteus®ONE system: the source timing, dee voltage regulation, RF frequency sweep and the beam signal.

EMITTANCE

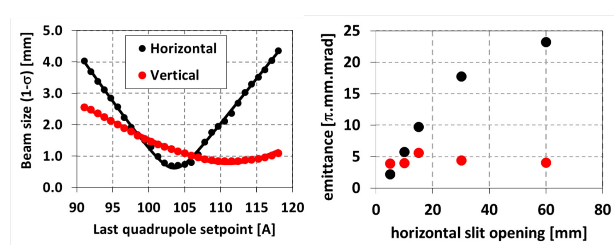

Figure 3: (Left) the horizontal and vertical beam spot size on the degrader position (≈2.0 m after the S2C2 exit port) (Right) the evolution of the horizontal and vertical emittance as a function of a horizontal slit, installed prior to the degrader.

Figure 3 shows the measured beam size on the position of the energy degrader, 2 m downstream from the S2C2 exit port. Two quadrupoles and a horizontal slit are positioned

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between the S2C2 exit port and the Beam Profile Monitor (BPM), which is part of the degrader system. A small and symmetric beam spot of 1 mm can be obtained at this position. From a variable quadrupole measurement, the horizontal and vertical emittance of the S2C2 has been measured. The horizontal emittance is much larger than the vertical emittance, but can be reduced by closing the horizontal slit. For the high energies this is necessary to have the optics in the compact gantry independent from the orientation of the gantry. Figure 4 shows the calculated horizontal and vertical emittances with a fitted RMS-emittance. The measured and calculated emittances agree very well.

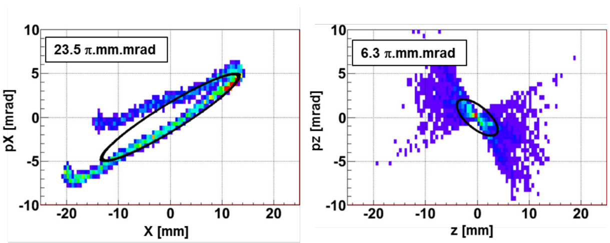

Figure 4: Simulated horizontal and vertical emittance at the exit port of the S2C2.

PULSE INTENSITY MODULATION

Figure 5 shows the total pulse charge as a function of the applied dee voltage. The dee voltage is expressed in percentage of the maximum dee voltage, which is clinically allowed in the current configuration of the treatment mode in the Proteus®ONE. The latter is imposed by the maximum allowed dose deposition in one pulse at the isocenter, taking into account the transmission efficiency from the S2C2 to the isocenter. The pulse-to-pulse charge variability has a Gaussian distribution and the standard deviation, measured over 1000 pulses (1 s), is shown in Fig. 5 as percentage of the mean charge.

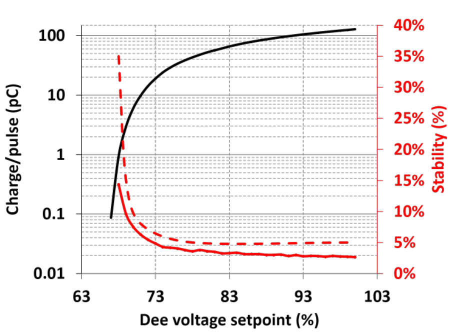

Figure 5: (Black) Pulse charge as a function of the dee voltage setpoint, expressed as % of the maximum allowed setpoint. (Red) Stability of the pulse charge, observed over 1000 pulses. The dashed line indicates the specification on the stability of the pulse charge in Pencil Beam Scanning.

BEAM ENERGY

As was shown in [1], the orbit centering in the S2C2 depends crucially on the source position in the central region. It was found that the orbit centering can be different for different dee voltages, in case the source is not well centered. Tests were performed to assess the sensitivity of the extracted beam energy on the source position. Figure 6 shows the measured beam profile on the BPM at the end of the ESS as a function of dee voltage, for a shifted source and for a well centered source. As expected, the distribution on this BPM changes (the mean position shifts) as a function of dee voltage for a shifted source position. This

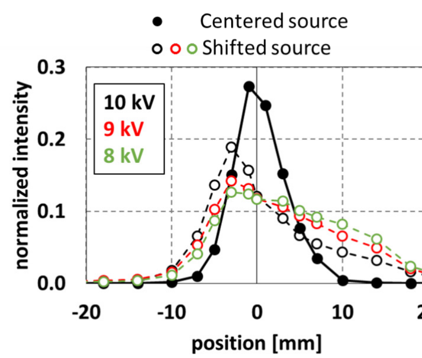

Figure 6: Beam profile observed at the end of the Energy Selection Systems (ESS, see Fig. 1) as a function of dee voltage for a centered (filled symbols) and a shifted source (open symbols) in the S2C2.

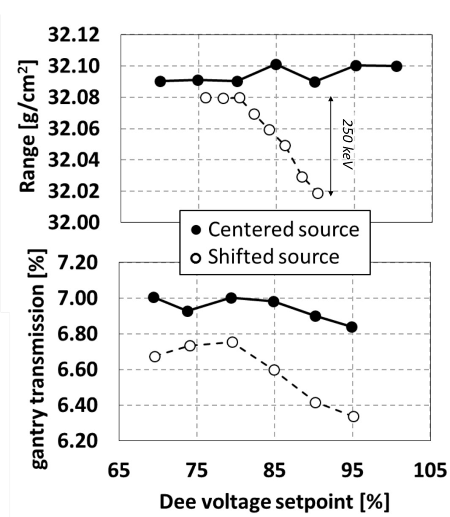

Figure 7: Measured range at isocenter -without energy degrader- (top) and measured gantry transmission (bottom) as a function of dee voltage for a shifted and a centered source.

indirect observation of small extracted beam energy shifts is confirmed by a range measurement in a water phantom at isocenter. Figure 7 shows the range for the shifted and centered source positions. Clearly, the beam energy is stable

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and maximized for a well centered source. The bottom part of Fig. 7 shows the gantry transmission efficiency for the different source positions. The influence of the changing energy (open symbols) is clearly seen as well. A precise and reproducible source positioning system has been developed to ensure the correct positioning of the source in the S2C2.

DEE VOLTAGE REGULATION

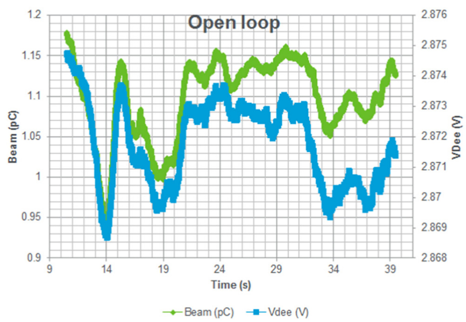

Figure 8: Slow fluctuations of the dee voltage amplitude influences the beam intensity over longer period (without regulation).

The dee voltage is regulated precisely to ensure a good stability of the dee voltage during the capture in the central region (which determines the pulse-to-pulse charge stability) and to prevent beam losses during acceleration. Figure 8 shows the measured pulse charge and the measured dee voltage at capture over a long period of 30 s, illustrating the sensitivity of the total pulse charge to the exact dee voltage amplitude at capture. The drift, observed in Fig. 8 over longer periods can be minimized by a closed regulation loop of the dee voltage, which is currently implemented in the S2C2 control system. The dee voltage regulation during the acceleration is based on the measurement of the bucket area of the separatrix, where the idea is to keep the bucket area either constant or growing during the acceleration. A dee voltage profile before and after optimization of the regulation is shown in Fig. 9 together with the measured bucket area.

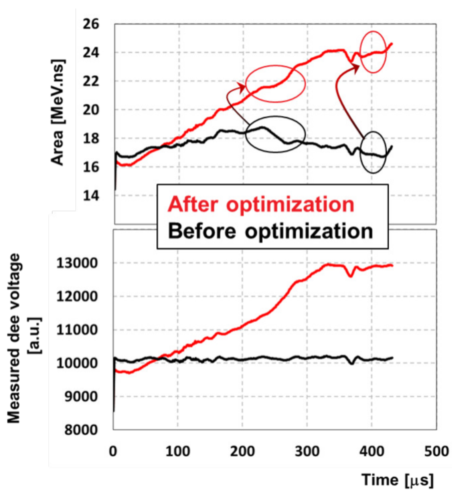

Figure 9: Measured dee voltage and calculated bucket area of the separatrix before and after optimization of the dee voltage profile during acceleration, to prevent beam losses.

CONCLUSION

During the clinical commissioning of the S2C2 with the Proteus®ONE system, challenges encountered have been investigated in depth. Solutions presented in this contribution have been successfully implemented.

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