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COMMISSIONING OF SHANGHAI ADVANCE PROTON THERAPY

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Abstract

Shanghai advance proton therapy (SAPT) is a dedicate facility for cancer treatment. The commissioning of the accelerator started at the end of April 2017, and the proton beam has been already transported to the treatment room. This paper shows the commissioning results of synchrotron and transport line.

INTRODUCTION

Due to the excellent dose distribution of proton and hadrons, so called 'Bragg peak', proton therapies are installed all around the world. Shanghai advance proton therapy (SAPT) [1] is a synchrotron based proton therapy. There are 3 treatment rooms and 4 beam lines at the first stage. As shown in Fig. 1, they are an ocular beam line, an experiment beam line, a fixed beam line and a gantry beam line. The proton beam is produced by an ECR ion source and accelerated to 7 MeV by a RFQ and a DTL. Then, the beam is transported by a low energy transport line (LTB) and injected to the ring by multi-turn injection. The synchrotron ring accelerates the proton beam to 70-235MeV. And is extracted to the high-energy transport line (HTB) by 3rd order resonance extraction. Then the proton beam is transported to the target at each treatment room. The installation of SAPT started at the end of 2016 and the commissioning of the accelerator started at the end of April 2017. The proton beam has been already transported to the fixed treatment room. And the commissioning of nozzle and treatment control system is under going. This paper will describe the commissioning results of synchrotron and transport line.

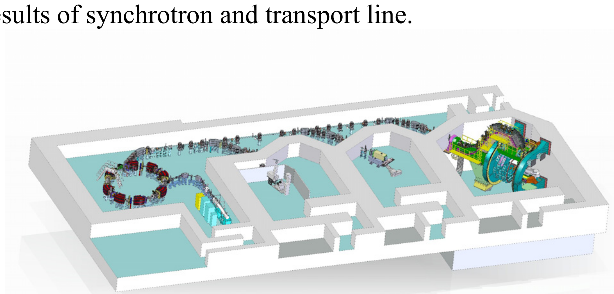

Figure 1: Layout of the SAPT.

INJECTOR AND LTB

The injector of SAPT is a turn key project and maded by ACSYS, an american company. The commissioing of the injector and FAT had been done at the factory. It takes 3 weeks installtion and 2 weeks recommissioing at SAPT. LTB transports the proton beam from injectior to the ring and matches the twiss parameters at the injection point. And also the beam parameters such as beam current, time structure, emmitance and so on, are measured at the diagnostic elements at the LTB. Figure 2 shows the beam current measured ath the faraday cup.

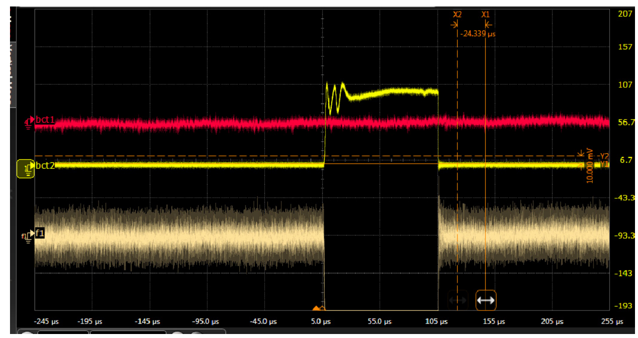

Figure 2: Beam current of injector.

SYNCHROTRON RING

Multi-turn Injection and Stored Beam

In order to reach the dose rate requirement of the treatment, a multi-turn injection scheme is employed for beam accumulation. The beam intensity is limited by space charge effect. The space charge effect can be reduced by enlarge the beam emmitance via phase space painting method. Horizontal phase space painting is performed by around 30 turns bump decrease. Vertical phase space painting is realized by twiss parameters and orbit mismatch. Figure 3 shows the real space of the beam at the profile after half turn transport in the ring.

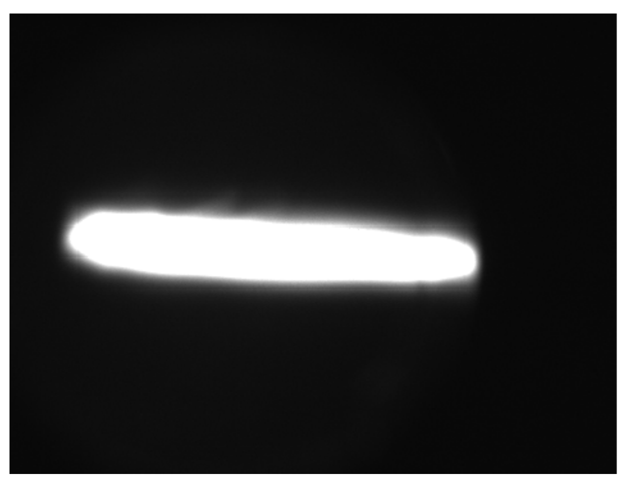

Figure 3: Painted real space at profile 2.

The beam is stored by tuning the match of injection beam orbit and stored beam orbit. The injection efficiency is around 35% and the maximum beam intensity after injection is around 1.5×10^{11}.

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Capture

The proton beam is captured by an adiabatic procedure. The frequency of RF cavity and dipole current are scanned to find the well-captured bunch signal at the BPM as shown in Fig. 4. Figure 5 shows the dipole and frequency scan result. If they are matched, the current is higher. The captured parameters are also carefully tuned by maximum the ramped beam current, such as cavity voltage, capture time and so on. The maximum particle number after capture is 1.5×10^{11}.

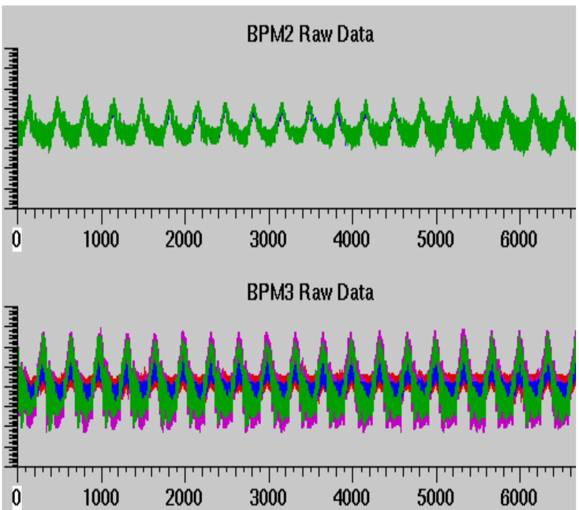

Figure 4: The bunched beam signal at BPM.

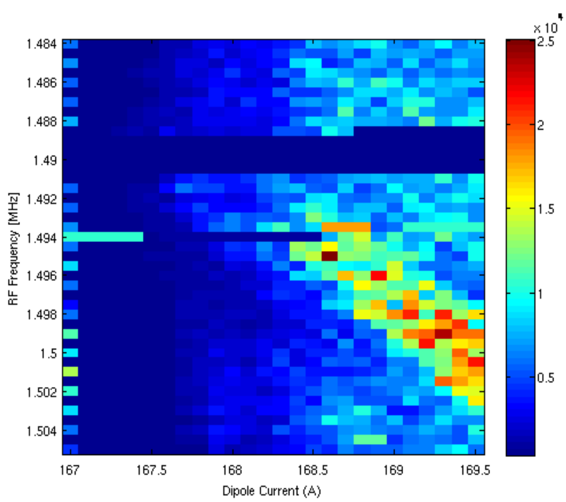

Figure 5: Frequency and dipole current scan.

Ramping

After capture, the dipole current, frequency and voltage of RF cavity are synchronous increased to accelerate the proton beam. This process is called ‘ramping’. In order to increasing the ramping efficiency, the ramping curve of all magnets and RF cavity should match very well to each other. The B-I curve conversion process according to the magnet field measurement decides the quadrupole and dipole current. And according to the eddy current measurement results, the dipole current is compensated. The RF frequency is also determined by the dipole magnet field and thus the energy. A procedure called ‘ramping curve generator’ is written to calculate all the ramping curves. The timing delays of all the curves also are carefully tuned. Figure 6 shows the beam current signal measured at the NPCT. Second and third harmonic of RF system are used to reduce the space charge effect. The maximum particle number after ramping is 1.3×10^{11}, which is 2 times large than that one only with first harmonic. The efficiency of the ramping is nearly 85%.

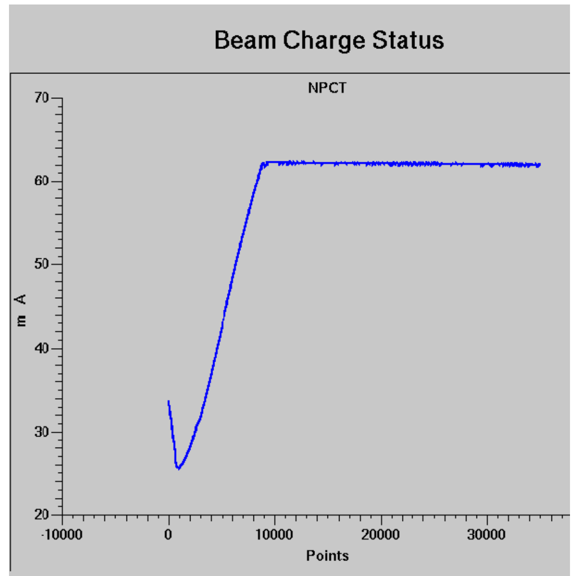

Figure 6: The beam current during ramping.

Extraction

The proton beam is extracted by a 3rd order resonance slow extraction. The horizontal tune should be around 1.68. The frequency of RFKO is scanned to excite the oscillation of beam orbit. And the tune is observed through the FFT at an oscilloscope as shown in Fig. 7. The current of QF and QD is changed to make the horizontal tune at the right value.

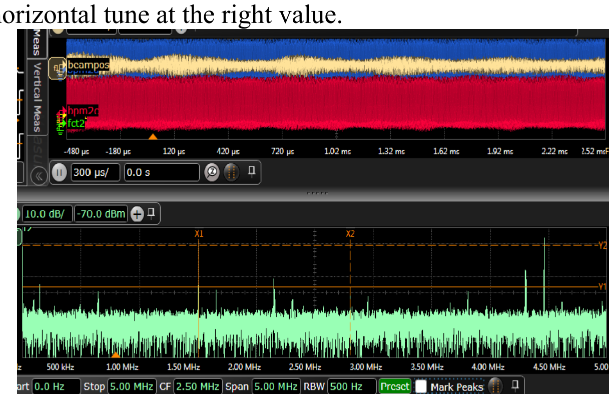

Figure 7: Frequency analisys at oscillscope.

Beam orbit is another important parameter for the slow extraction. At the first stage before the Beam Position Monitor is ready, the Beam Based Align method using sextupole is used. If the beam don’t pass thourgh the center of a sextupole, it will feel a quadrupole field. Thus

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the tune will change if the sextupole is turned on or off. The changed value is directly proportional to the beam orbit at the sextupole. In the ring there are 4 sextupoles which are powered by differenet power supply, and also the orbit in sextupole should be pay special attention. Then the orbit is corrected by the SVD method and there are 12 correctors who are mounted on the quadrupoles.

After the orbit and tune correction, extraction was obtained at the first Profile Monitor at the high energy transfer line, as shown in Fig. 8.

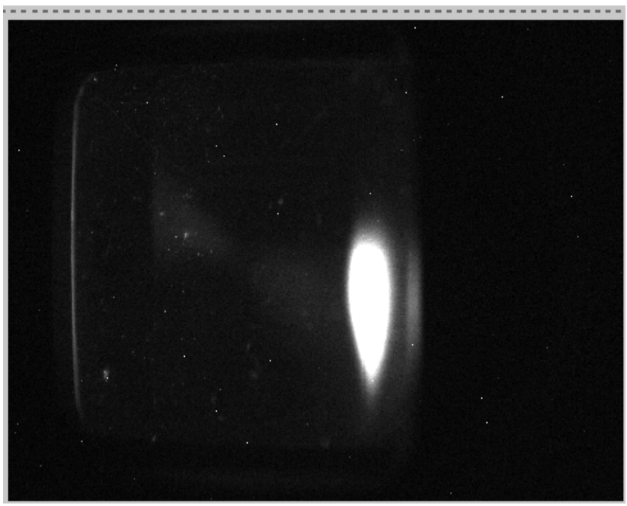

Figure 8: The first extraction beam at the profile monitor.

The other important parameter for slow extraction is the angle of separatrix. It should match the extraction tunnel very well. Optimizations of many parameters have been done for the extraction efficiency, such as the angle and strength of extraction electronic septum, tune, the strength of resonance sextupole, chromaticity, RF cavity and so on. Figure 9 shows the strength of dipole and quadrupole scan. The maximum extraction efficiency is around 75%. It is 20% lower than the design value. optimization is still under going.

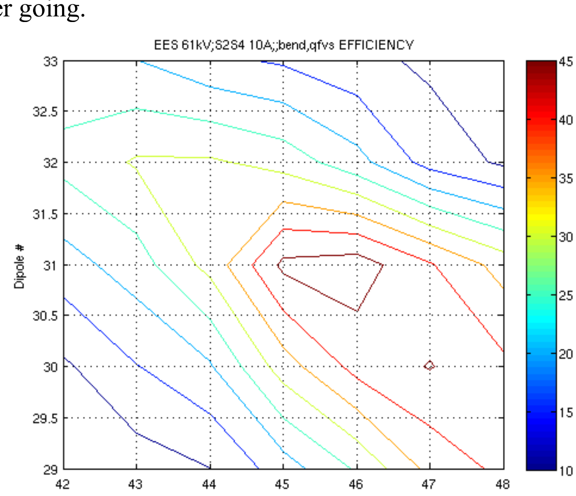

Figure 9: Dipole and quadrupole strength optimization.

Flat and fast turn-off/on beam is requested by the treatment. The slow extraction is controlled by a RFKO with fast quedrupole scheme. The kicker strength of the RFKO is changed for the flat extraction. Beam is turned off by powered off the RFKO and fast quadrupole at the same time. The former one disturbs the beam emmittance blow up. The later one moves the tune far from the 3rd order resonance line. All the parameters affect the extraction beam flatness and cut-off time have been simulated and tuned at the real machine. And they are match with each other very well. The extraction beam current is shown in Fig. 10.

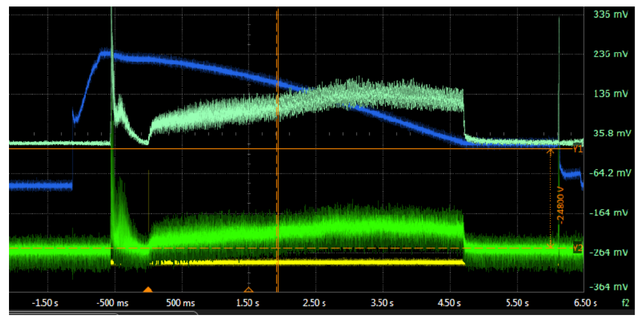

Figure 10: Extraction beam current.

HIGH ENERGY TRANSPORT LINE

The HTB transport the beam into different treatment rooms. The HTB was divided to several sectors. The first sector is the match sector that matches the extracted beam to dispersion free and alpha to zero. Other sectors are almost the same. The commissioning of each sector shows the real machine match with the design very well. The beam parameters are measured at the ISO center of the fixed beam line. Figure 11 shows the beam position during one spill.

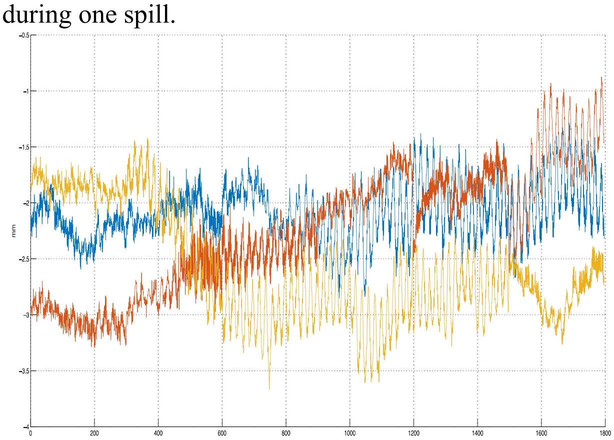

Figure 11: Beam position in a spill.

SUMMARY

The commissioning of SAPT accelerator lasts around one year. The LTB, injection, acceleration, extraction and HTB are well tuned. All of the 94 energy beams from 70MeV to 235 MeV are transported to the fixed beam room. The optimization is still under going. The commissioning of gantry will start at the end of July.

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