The Story of Commissioning the TPS

On December 31, 2014, an electron beam was stored in the TPS storage ring and the first synchrotron light emitted by a 3-GeV electron beam was observed. The TPS control room was filled with extreme joy and excitement. This is an exhilarating moment for the accelerator staff of the TPS project. The process of commissioning the accelerator is reported and the preliminary results summarized in this article.

The TPS project received official approval from the Legislative Yuan in December 2007. The ground breaking for the civil construction occurred on February 7, 2010. According to the project schedule submitted to the Ministry of Science and Technology, the TPS team was expected to store a beam in the storage ring by the end of 2014. Due to unexpected delay of civil construction, the installation of the major accelerator components began in October 2013. The installation of accelerators inside the shielding tunnel was completed in July 2014. To achieve the project schedule, an intensive commissioning plan was implemented.

The TPS Linac was commissioned before August 2014. Beam-based testing of the hardware and improvement of the booster began at 16:30, August 12, 2014. Several hardware glitches were discovered; the solutions were implemented swiftly. For example, the power supply of the booster dipole magnets failed a few hours after commissioning was initiated because a resistor on the circuit board overheated. Problems were quickly solved and testing of the booster hardware resumed the next day. Several accelerator staff sacrificed their weekends to fix the glitches professionally as quickly as possible. A major setback that stalled the progress of testing the booster hardware was the unexpected magnetization of the stainless-steel beam pipes. A booster beam pipe has a small elliptic cross section, 35 mm x 20 mm, and thickness 0.7 mm. Stainless steel SUS304 was used; the beam pipe was manufactured by cold drawing without annealing. It was not recognized until November 13, 2014 that many booster beam pipes were magnetized after their fabrication. This problem was discovered using a small neodymium magnet (NdFeB) by the staff, who is responsible for the quality of magnets' field. Figure 1 depicts the discovery of this significant problem.

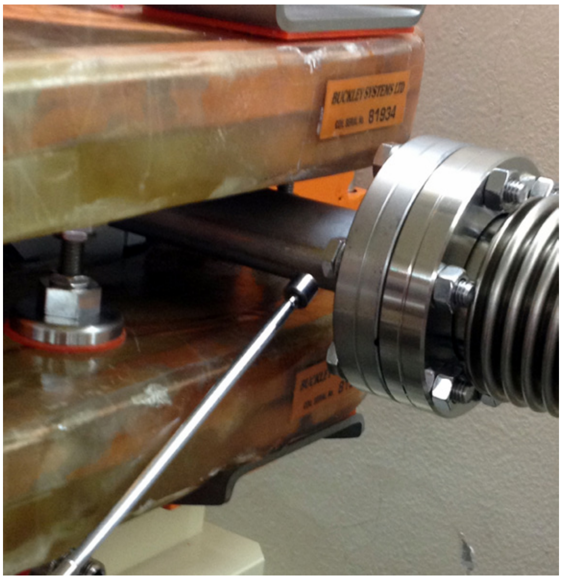

Fig. 1: A booster beam pipe is discovered to be magnetized on using a small neodymium magnet (NdFeB) at the tip of a pointer.

Based on computer simulations and the measured data for combined-function dipole magnets with a beam pipe, some magnetized beam pipes were found to have relative permeability μ_r = 1.8, in contrast with a typical specification for a stainless-steel beam pipe, μ_r = 1.01. The effect of the magnetized beam pipe is illustrated with a computer simulation shown in Fig. 2. These simulations showed that the magnetic field was significantly distorted by the beam pipe without annealing process. These pipes resulted in magnets' field errors ten times as large as the design specifications.

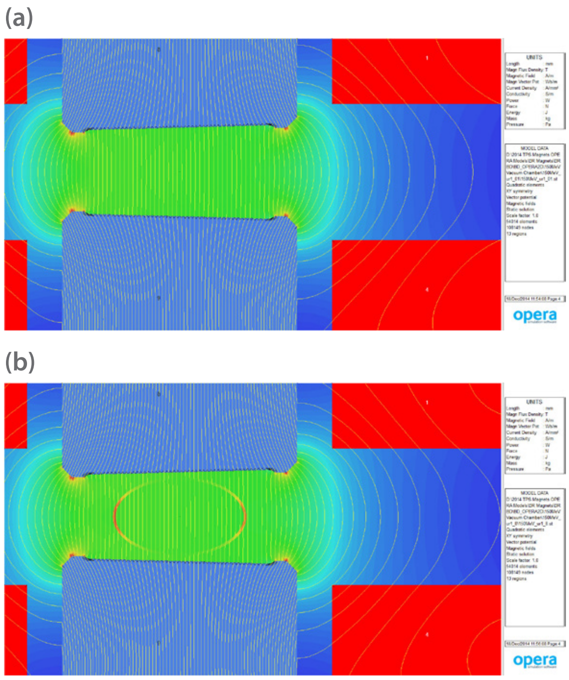

Fig. 2: (a) Distribution of field lines of a combined-function dipole including a beam pipe with μ_r= 1.01. (b) Distribution of field lines for the beam pipe with μ_r= 1.8.

The demagnetization of the booster beam pipes requires a thermal treatment up to 1050 °C. Because of the length of these pipes, a vacuum furnace capable of treating an object of length 2 m was required. A company (XHT) located in Tainan was fortunately found to meet the urgent need of the TPS project. The booster magnets were opened; 104 beam pipes were delivered to XHT vacuum group on December 1, 2014. Seven vacuum furnaces were operated around the clock for 35 h. The results were satisfactory. The beam pipes had a clean surface and reduction of relative permeability after the thermal treatment. Figure 3 shows the vacuum furnace and the shiny beam pipes after that treatment. The beam pipes and magnets were re-installed; the hardware was ready for commissioning the beam by December 10, 2014.

Commissioning of the booster beam began on December 12, 2014. The energy of the booster beam was

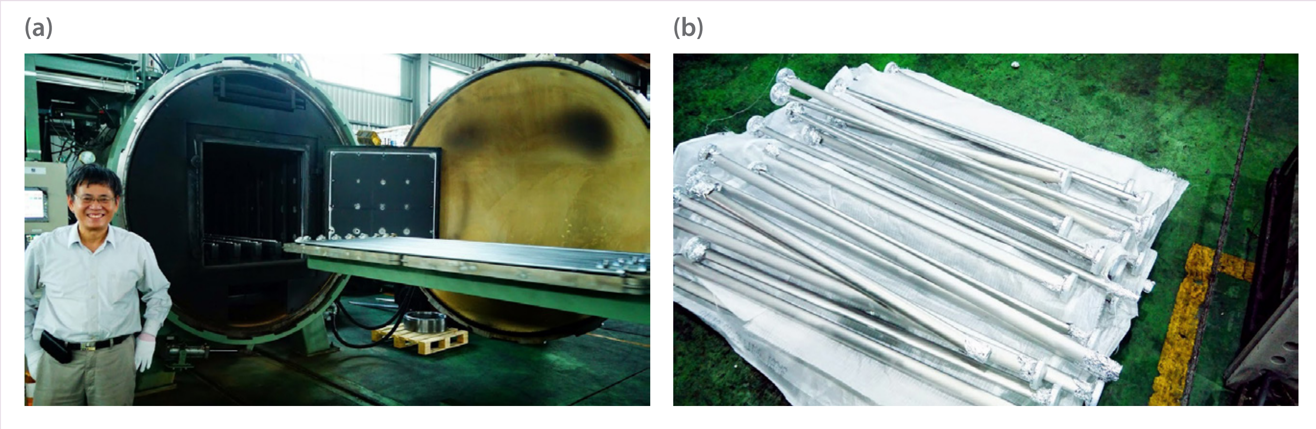

Fig. 3: (a) TPS project director Chien-Te Chen standing by the vacuum furnace. (b) Booster beam pipes after the thermal treatment with clean and shiny surfaces.

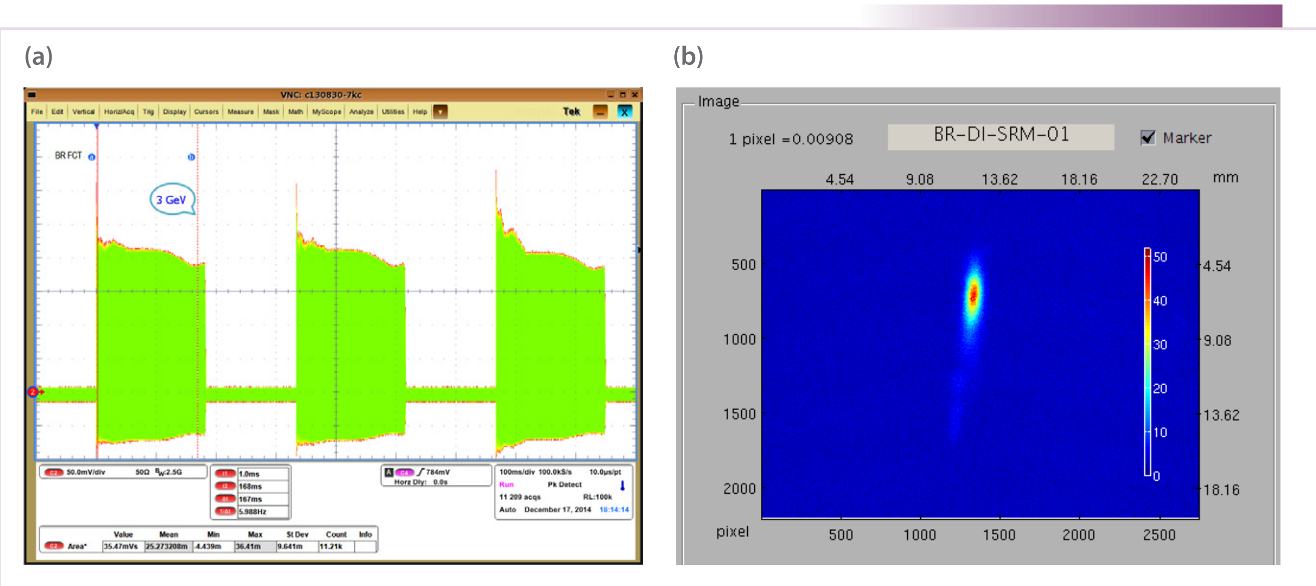

Fig. 4: (a) Signal of the beam current of the booster at each injection cycle from beam energy 150 MeV to 3 GeV. (b) Transverse beam profile measured with the synchrotron radiation monitor in the booster.

ramped to 3 GeV on December 16, 2014. The efficiency of the beam transmission of booster attained 62% on December 17, 2014 without ramping the strength of correcting magnets. Figure 4 shows the beam current of the booster at each injection cycle from beam energy 150 MeV to 3 GeV.

The commissioning of the beam of the storage ring at 3 GeV was impeded by a leakage field from the booster DC extraction septum. The TPS team was surprised at the effects of leakage field due to the DC extraction septum on the injection efficiency of the beam transmission from Linac to booster. Intensive work to improve the hardware was undertaken; commissioning of the beam of the storage ring began on December 29, 2014. At 12:20, December 31, 2014, the electron beam was injected into the storage ring and circulating over 80 turns without activating the sextupole magnets, correcting magnets and RF cavities. Once the multi-turn beam storage was attained, everybody in the TPS control room understood that the long awaited great moment was only one step ahead. They readily activated the sextupole magnets and RF cavities. After optimizing the parameters of four injection kickers, the 3-GeV electron beam was finally stored in the storage ring at 12:39 without using correcting magnet, as shown in Fig. 5.

Figure 6 depicts the orbit of the stored 3-GeV electron beam with zero current setting of correcting magnet in the storage ring. At 13:58, the beam current in the TPS storage ring accumulated to 1 mA, as shown in Fig. 7. The first synchrotron light was observed and the excitement showed on the face of everybody in the TPS control room; cf. Fig. 8. Before the end of the commissioning shift on December 31, 2014, the beam current accumulated up to 5 mA in the TPS storage ring. The members of the TPS team achieved their goal: the synchrotron light shone from the TPS storage ring by the end of 2014 as they had promised.

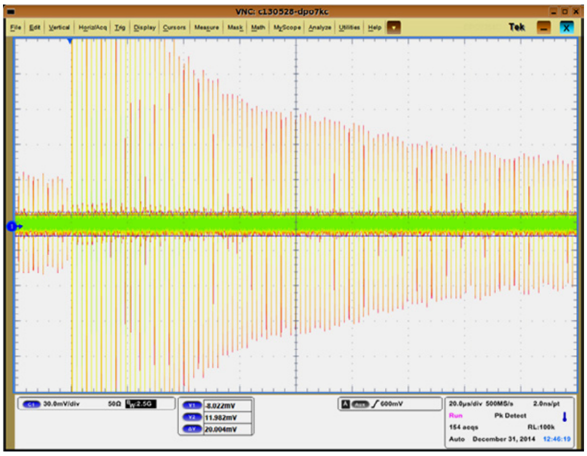

Fig. 5: The 3-GeV electron beam was stored in the TPS storage ring at 12:39, December 31, 2014.

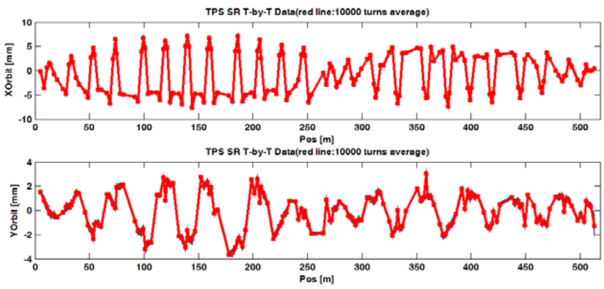

Fig. 6: Orbit of the stored 3-GeV electron beam. (top) Horizontal orbit (± 8 mm). (bottom) Vertical orbit (± 4 mm). No correcting magnet was used.

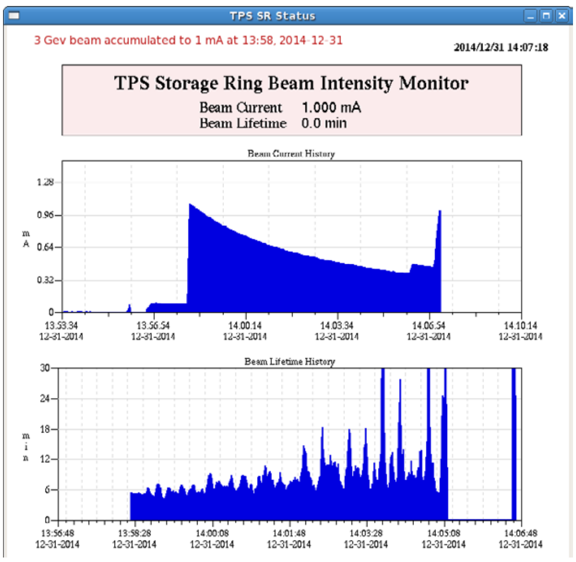

Fig. 7: The 3 GeV electron beam was accumulated to 1 mA in the TPS storage ring at 13:58, December 31, 2014. Not a single correcting magnet was used.

Fig. 8: (a) The first synchrotron light was emitted from the 3-GeV electron beam in the TPS storage ring on December 31, 2014. (b) Celebration of the successful commissioning of the TPS storage ring in the control room.