ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPHA040

STATUS OF AC POWER SUPPLIES FOR TPS BOOSTER RING

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Abstract

TPS is a third generation 3 GeV synchrotron light source under commission in Taiwan. The TPS Booster ring is concentric ring design sharing the same tunnel with storage ring. The booster ring power supplies are responsible of accelerating the 150 MeV Linac output energy to 3 GeV before the beam is preserved in the storage ring. The booster ring power supplies are required to operate at 3Hz sinusoidal waveform with 1000 A peak current for the dipole magnet. All power supplies' specifications and output performance are demonstrated here in this paper.

INTRODUCTION

Taiwan Photon Source (TPS) is a concentric ring with booster and storage ring allocated in the same tunnel. A combined function FODO lattice is chosen to be an optimal solution for the TPS booster ring lattice structure in terms of cost and performance. There are total six super-periods, in which each consists of 8 cells of combined–function FODO lattice. Figure 1 shows a portion of the super-period FODO lattice in the TPS ring [1].

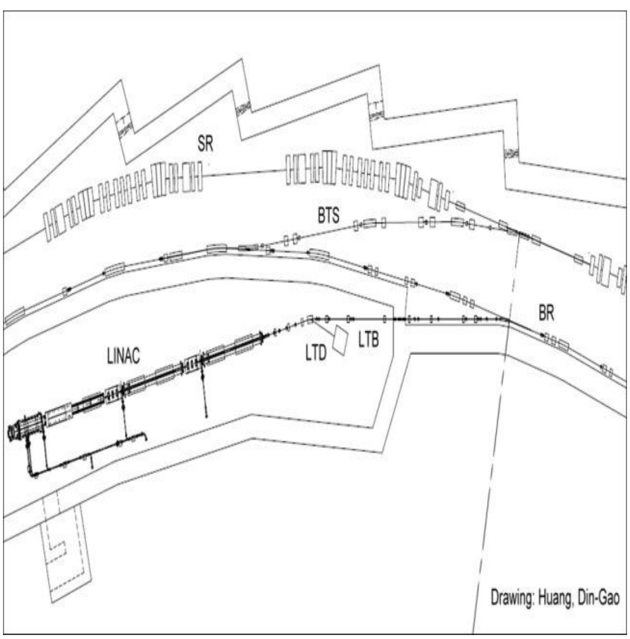

Figure 1: TPS concentric ring.

Based on this design, the TPS booster ring, with a circumference of 496.8m, includes 54 bending magnets, 72 quadruple magnets, 24 sextuple magnets and 96 corrector magnets. The detailed parameters of the booster magnets are listed in Table 1.

Table 1: Booster Magnet Specifications

Magnet	Qty	Load	Cable	Total
BD	48	1.973mH 9mΩ	29.18mΩ	94.854mH 467.2mΩ
BH	12	0.999mH 5mΩ		
Q1	12	4.683mH 49mΩ	67.86mΩ	56.196mH 655.8mΩ
Q2	12	2.298mH 33mΩ	67.86mΩ	27.567mH 463.8mΩ
QM	12	0.625mH 19mΩ	67.86mΩ	7.5mH 295.8mΩ
QF	48	4.683mH 49mΩ	67.86mΩ	224.78mH 2419.8mΩ

BOOSTER POWER SUPPLY

Dipole Power Supply

The two families of dipole bending magnets BD and BH are connected all together in series and driven by a single Dipole AC Power Supply (DPS). While, Q1, Q2, QM and QF of the quadruple magnets are powered independently by four quadruple power supplies (QPS1, QPS1, QPSM, QPSF). All magnets in the same family are also connected in series. The internal topology of the Dipole Power Supply is depicted in Figure 2.

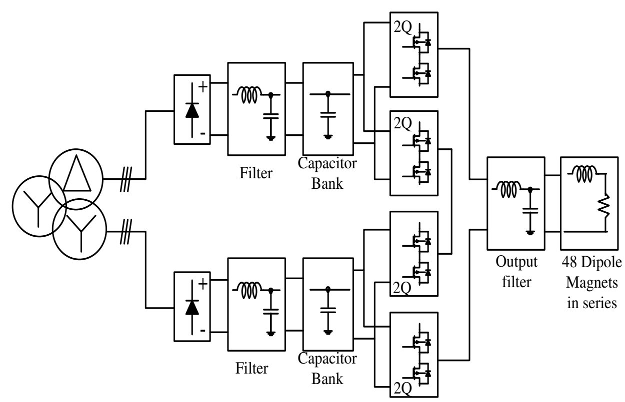

Figure 2: DPS functional diagram.

The DPS is composed of two identical DC voltage bank and 4-Quadrants IGBT switching module connected in series to boost up the output voltage as demanded. The 4-Quadrants IGBT switching module is made up of connecting two 2-Quadrants IGBT modules in parallel and the IGBT is switched with 4 kHz frequency.

The output filter is specially designed and fine-tuned to the magnet load with adequate cut-off frequency to minimize the output current ripple and earth leakage current due to the parasitic capacitance to earth ground from the magnet body.

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Quadruple Power Supply

While in the QPS family, the switching topology is similar to that of the DPS except that only a single DC voltage bank and 4-Quadrants IGBT switching module is implemented as shown in Figure 3.

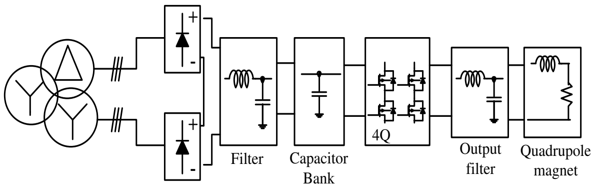

Figure 3: QPS functional diagram.

The switching frequency of QPS's 4-Quadrants IGBTs is 20 kHz.

Sextuple and Corrector Power Supply

The sextuple power supplies (SPS) and corrector power supplies (CPS) are designed and manufactured by NSRRC [2]. The supply is a high precision DC-DC converter with 4-Quadrants MOSFETs, which are switching at 40 kHz frequency. Figure 4 shows the SPS/CPS power supplies racket located in one of the CIA room. A single racket is capable of housing up to 8 cards of the NSRRC-made converter. Each converter receives analogy command from an EPICS interface control board inserted in the middle of the racket. The custom-made control card accepts digital commands through Ethernet, converts the commands to analogy ones and then distributes to all 8 converter modules using high-precision 20Bits DACs.

Figure 4: SPS/CPS power converter modules.

Two versions of the converter are manufactured. One is ultra-high precision version in which DCCT module is employed as current feedback instead of resistor shunt. The other is quick-acting version with resistor shunt for fast corrector with compromised output ripple performance. The long-term output current ripple of the ultra-high precision DCCT and FAST version is illustrated in Figure 5. The ripple stability is around ±5ppm for the DCCT version, while in the fast version one, the stability fluctuation is about ±10 ppm. Both show excellent output stability during 8 hours period.

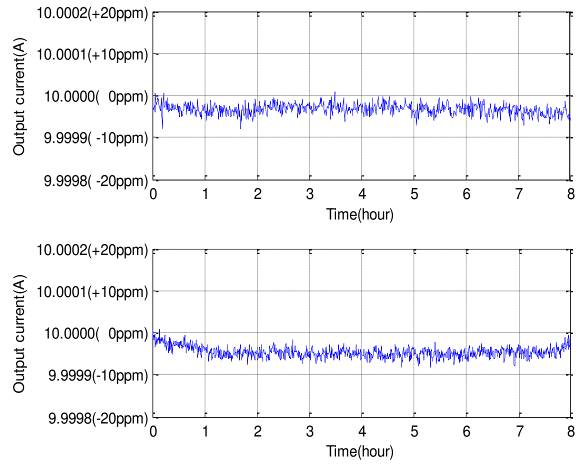

Figure 5: SPS/CPS Output ripple performance: upper is DCCT version, lower diagram is FAST version.

The detailed Booster power supplies' specification is listed in Table 2.

Table 2: Booster Power Supplies' Specifications

Power Supply	Input Spec.	Output Spec.	Short Term Stability	Long Term Stability
Dipole	AC 3Φ 380V 900A	±1600A ±1200V	10ppm	50ppm
Quadruple	AC 3Φ 380V 900A	±120A ±425V	20ppm	100ppm
Sextuple Corrector	DC 48V	±10A ±48V	5ppm	10ppm

CONTROL AND COMMISION

The DPS and QPS use analogy PID regulation loop, while SPS/CPS adopt an analogy PI loop only. In the DPS and QPS converters, all the analogy commands come from a centralized EPICS interface IOC racket, where digital current DC commands or ramping waveform commands are imported and stored in the local memory through Ethernet and then converted to analog ones using 18Bits DAC [3].

The DPS and QPS's output current are measured by using LEM IST Ultrastab 6 channels DCCT transducer unit and acquired by DT8837 DAQ with 24-bit Delta-Sigma resolution for performance evaluation.

The step responses of all of the Booster Power Supplies are tested, by which the all converters are fine-tuned to an optimal operation point in terms of rise time and overshoot by varying the PID gains of the analogy control loop. During this phase of test, all the output slew rate of the Booster Power Supplies is set to their maximum.

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PERFORMANCE

For the booster ring power supplies are responsible for accelerating the 150 MeV Linac output energy to 3 GeV before the beam is stored. The current output of DPS/QPS power supplies, running at 3Hz repetition rate, are required to have an re-productivity tracking error as minimal as possible, especially right at the injection point, in order to maintain consistent magnet fields of the booster dipole and quadruple magnets throughout the energy ramping process.

Two indicators are chosen to serve as measuring the tracking performance of the AC power converters during the energy ramping. To serve this purpose, a dedicated EPICS data acquisition utilities and programme is set up to serve this purpose,

Individual Tracking Error

First, the tracking error for individual DPS and QPS converter is acquired and analysed. The tracking error is fined simple as:

$$ITR_{error}(\mathrm{i})(\mathrm{t}) = \frac{\mathrm{I}_{dipole}(\mathrm{i})(\mathrm{t}) - \mathrm{I}_{dipole}(1)(\mathrm{t})}{\mathrm{I}_{dipole}(1)(\mathrm{t})} \mathrm{X}100\%$$

Depicted in Figure 5 are the tacking errors for the DPS and Q1 quadruple converter.

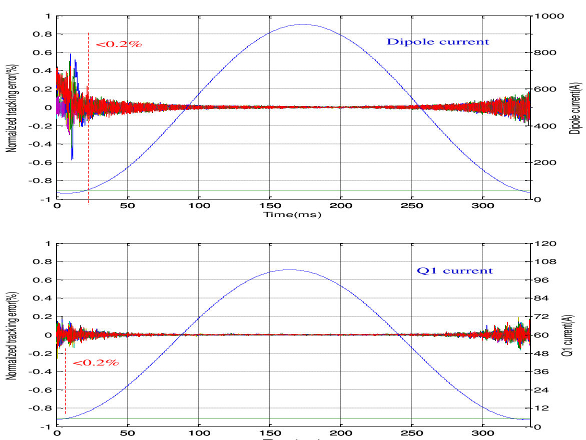

Figure 5: DPS and Q1PS tracking error.

Unlimited iterations number of ramping cycle data can be acquired and the tracking error can be then computed. As shown in Figure 5, the tracking error increases as the current decreases with 10 iterations of data cycle. The DPS and QPS track itself with error less than ±0.6% and ±0.2% respectively.

Relative Tracking Error

The QPS converters relative as DPS are also compared to check if the magnet fields for both families remain consistence in the current ramping cycle.

The relative normalized relative error is defined as:

$$NRE(\mathrm{i})(\mathrm{t}) = \frac{\mathrm{I}_{quad}(\mathrm{i})(\mathrm{t}) - \mathrm{I}_{dipole}(\mathrm{i})(\mathrm{t})}{\mathrm{I}_{dipole}(\mathrm{i})(\mathrm{t})} \mathrm{X}100\%$$

The normalized Q1PS tracking with respect to DPS is illustrated in Figure 6. For most of the cycle, the error is well within ±0.2% range, especially at the 150MeV injection point.

The ramping waveforms for all the booster AC converters can be compensated according to several strategies developed by NSRRC [4], hence NRE is further improved.

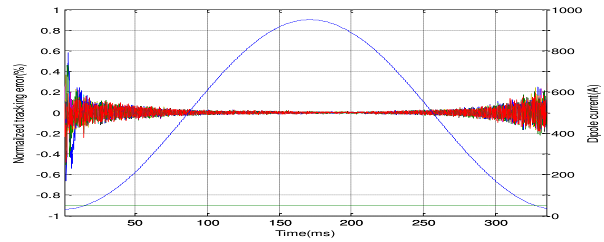

Figure 6: Q1PS vs DPS tracking error.

CONCLUSION

The TPS booster magnets topology, associated power converters and their current output performance is presented in this paper.

The power converters meet the specifications as demanded by the initial design report. The booster successfully ramps the electron beam energy from 150MeV to 3 GeV with good beam stability and efficiency [5].

However, further works still remain to be done in order to suppress the overall tracking error in the ramping cycle in hope of better energy boost efficiency.

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