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UPGRADING THE PERFORMANCE OF THE POWER SUPPLY FOR THE TPS BOOSTER DIPOLE MAGNETS*

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Abstract

The performance of the power supply for the dipole magnet is important for the TPS booster ring. The output current of the power supply follows the beam current from 150 MeV ramping to 3 GeV. The frequency of the power supply is 3 Hz. The power supply must thus push enormous energy into the dipole magnets at $\pm$1000 V and $\pm$1200 A, and can handle this job. Because the TPS booster dipole supply is bipolar and the voltage is large, the lodged capacitors have large effects that produce common-mode high-frequency current noise, which drives the power supply beyond specification. The TPS booster ring hence fails to meet the dc and ramping specification.

We designed a common-mode filter to solve the high-frequency current noise by absorbing the current noise from the path of the lodged capacitors to the ground pad. The TPS booster dipole supply thus works within the specification when the power supply is in the dc or ramping mode. The beam current from the 150-MeV dc mode for the injection mode can ramp the beam current to 3 GeV. This paper reports the excellent results.

INTRODUCTION

The booster ring of Taiwan Photon Source (TPS) uses 48 dipole magnets in series connection to build the topology. A bipolar switching-mode power supply pushes the booster dipole magnets from 47 A to 980 A, which maps 150 MeV to 3 GeV.

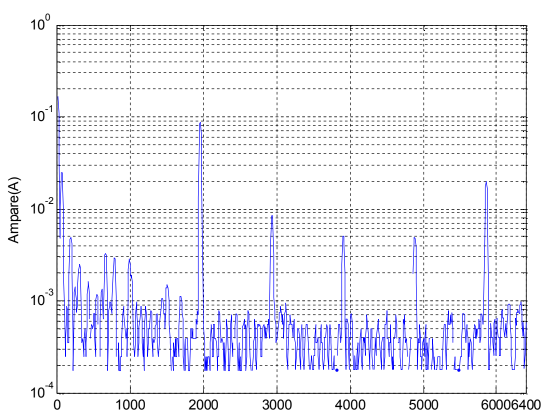

Figure 1: Current ripple in the dc mode (frequency from 0 to 6.4 kHz).

The current waveform follows the control system; the waveform is like a sine wave. Measured with instrument Agilent 35670A, the current ripple in the dc mode for the current set at 47 A for 150 MeV can be scanned from 0 to 51.2 kHz. When we read the current ripple in the frequency domain as shown in Fig. 1 and Fig. 2, we found that the current ripple is too large and beyond specification.

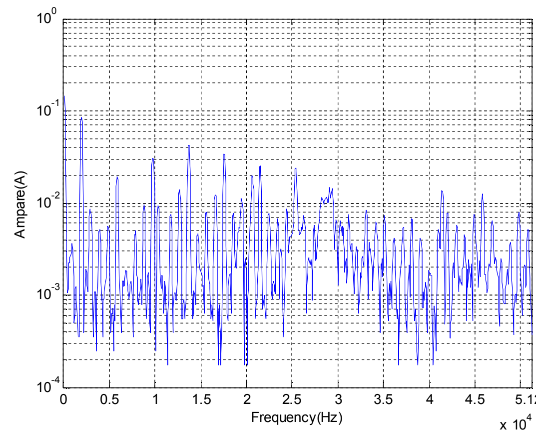

Figure 2: Current ripple in dc mode (frequency from 0 to 51.2 kHz).

As the dipole magnets act like a low-pass filter, the output current of the dipole power supply should possess a low-frequency current waveform, but the TPS booster ring has lodged capacitors that generate a high-frequency current ripple. The effect is especially large when the lodged capacitors for working voltage $\pm$1000 V are in the PWM mode. The ground current becomes large when the dipole power supply is in the ramping mode [1-2].

We added a common filter to the booster dipole power supply that can absorb the current noise in the path from the lodged capacitors to the ground pad. The filter is named a Y circuit. The TPS booster dipole supply can thus work within specification when the power supply is in both the dc and ramping modes. The beam current can proceed from the 150-MeV dc mode for the injection mode to ramp the beam current to 3 GeV, so the TPS booster ring can succeed in its task.

TOPOLOGY OF THE POWER SUPPLY

The topology of the booster dipole supply is an H bridge with a power bus at 1000 V. The power device is IGBT module. It can generate 1200 A to the dipole magnets. The power supply generates a unipolar current and a bipolar voltage to the magnets. The switching frequency is 2 kHz in the PWM mode. Figure 3 shows the topology of the H-Bridge.

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As the TPS booster ring works at 3 Hz, we can absorb the ramping down energy with many capacitors. The energy in these capacitors can charge the output energy when the power supply ramps up. We call this property energy recovery so that the booster dipole supply needs no hung power for operation. The power supply uses a 100-A fuse to protect the bank of capacitors. The booster dipole power supply has 12 banks of capacitors; each bank uses a high-current fuse for protection. The 100-A fuses burn when the power supply is in the ramping mode. We use a 200-A fuse instead of a 100-A fuse when we test the power supply in the ramping mode for long-term stability.

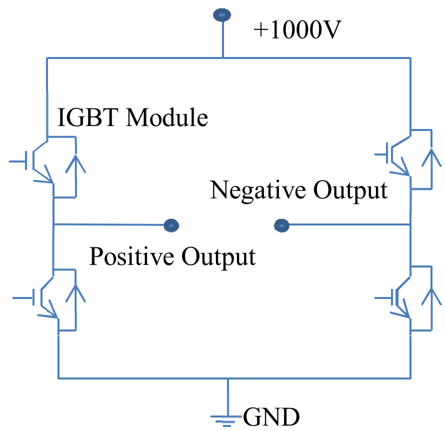

Figure 3: Topology of the dipole power supply.

POWER MODULE

The booster dipole supply has an H-bridge topology; the power bus is 1000 V. The power modules thus use 1700 V/2400 A IGBT modules that work in a switching mode. As these IGBT modules handle enormous power, the switching frequency works at only 2 kHz. Although the usual IGBT module can generally work at 20 kHz, the large IGBT module of the dipole power supply cannot reach that working frequency. If we raise the switching frequency, we find that the switching loss increases.

CONTROLLER

The controller of the booster dipole power supply is for regulation and tracking. The PID controller is used in the power supply. We tune the PID parameter as a step response. We can fine-tune the PID parameter for the rise time, overshooting and settling time. The power supply produces a satisfactory result when we obtain the parameters of the PID controller. The analogy PID controller implements R C components to assemble a controlled circuit. With the analogy controller it is difficult to obtain a satisfactory result.

The controller works in a regulated state when the power supply runs in the dc mode. The controller works in the regulation and tracking modes. The controller can operate with analogy circuits or fully digital regulation. We use analogy circuits to implement the PID controller at present, but we intend to have fully digital PID regulation in the future. We hope that the booster dipole power supply can deliver improved performance when we use fully digital PID regulation [3].

LODGED CAPACITORS

How can we improve the lodged capacitors existing in the TPS booster ring? We can use a LCR meter to measure the value of the lodged capacitors from the output stage to the ground line. We can also use the AC source connection output line and ground line to measure the current. If the current increases, that means that the lodged capacitors are larger.

Figures 4 and 5 show the lodged capacitors existing in the TPS booster ring. The AC source is set to work at 100 V and 60 Hz; the peak current is 36 mA.

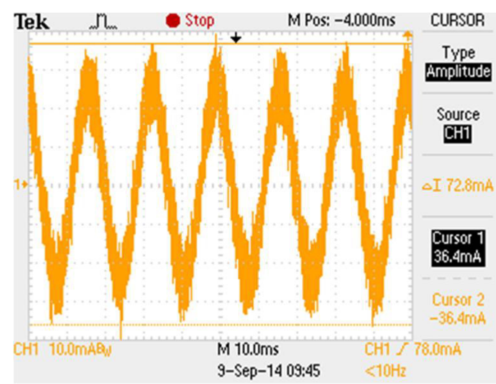

Figure 4: Using the negative output line and ground line of the AC source connection to measure the current.

Figure 5: Using the positive output line and ground line of the AC source connection to measure the current.

COMMON-MODE NOISE

The effect is large when the lodged capacitors in the booster ring work during ramping. As the lodged capacitors produce a current ripple in the common-mode path when the booster ring is charged with a positive and negative voltage, the greater is the voltage, the larger is the effect of the lodged capacitors on the performance of the power supply. The dipole supply dc bus of the booster ring is 1000 V and the topology is an H bridge; the magnets of the booster ring thus charge with positive and negative voltages when the power supply runs in the

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PWM mode. The large current ripples are produced in the common-mode path. The performance of the output current is beyond the specification [4].

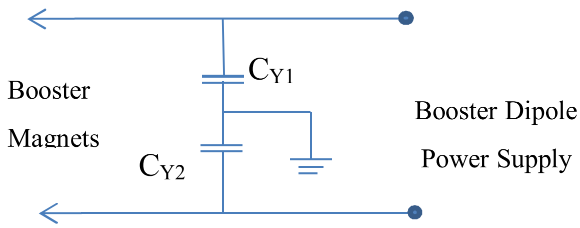

Figure 6: Adding a Y circuit to the output stage.

We referred to the design of the line filter to find the X-Y circuit application in the output stage, to analyze the output stage of the booster dipole power supply. When we found X circuit designed inside, we added a Y circuit in the output stage. By calculation, the capacitors of the Y circuit are 2 μF/5 kV when the power supply runs at 3 Hz. Figure 6 shows a block diagram of the Y circuit [5].

PERFORMANCE UPGRADE

We used Agilent 35670A to measure the output current ripple to verify the performance of the power supply, when we added the capacitors and a ground line of the Y circuit. We analyzed the measured results of the output current ripple to be within the specification. We found the common-mode current ripple solved to the ground pad. We easily found different results in the output current performance for the current ripple for the original condition and with the filter added. The excellent results are shown in Fig. 7 and Fig. 8.

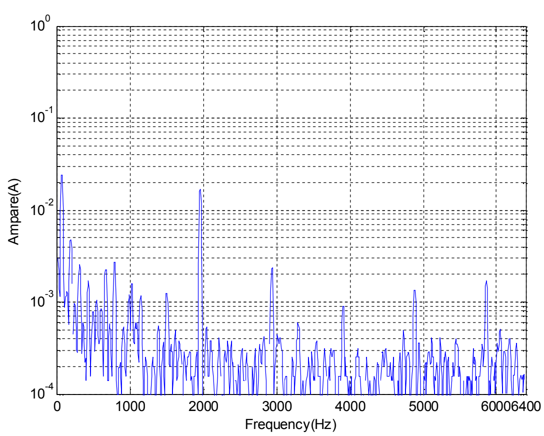

Figure 7: Current ripple in the dc mode and with an added common-mode filter (frequency from 0 to 6.4 kHz).

According to the original design, the ground current is too large. The resistance to measure the ground current becomes burnt when the power supply works during ramping. We must change the resistive impedance and power rating to attain a safe margin. The output current ripple is also decreased when the ground resistance is increased.

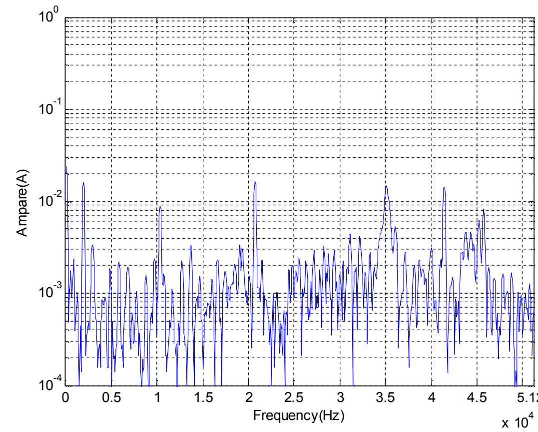

Figure 8: Current ripple in the dc mode with an added common-mode filter (frequency from 0 to 51.2 kHz).

CONCLUSION

The TPS booster ring uses 48 dipole magnets in series connection to build the topology. We use a bipolar switching-mode power supply to ramp the booster dipole magnets. We proved the lodged capacitors existing in the TPS booster ring and designed a filter to solve the high-frequency current noise. We use Agilent 35670A to prove that the TPS booster dipole supply can be upgraded with a common-mode filter that can absorb the current noise from the path of the lodged capacitors to the ground pad. The TPS booster dipole supply can thus work within specification when the power supply is in the dc or ramping mode. The beam current can form the 150 MeV dc mode for injection and the beam current can be extracted when the beam current ramps to 3 GeV in the ramping mode. The upgrade result is shown in this report. The performance satisfies the demands of the TPS dipole power supply.

We shall use fully digital PID regulation in the booster dipole power supply this year. We hope that the booster dipole power supply can have an improved performance when we use the fully digital PID regulation.

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