PERFORMANCE EVALUATION OF THE SWITCHING MODE AC POWER SUPPLY

C-Y Liu, Y-C Chen, H-M Shih, NSRRC, Hsinchu 30077, Taiwan, R.O.C

Abstract

The AC power supply of the booster synchrotron of NSRRC must output high quality current waveform for the sake of enhancing the injection performance. The phase jitter of the AC power supply output current must be less than +/-4ns for the purpose of ensuring smooth and efficient injection of the booster ring. A new AC power supply is constructed and employed by IGBT modules operating at higher switching frequency than the old GTO-based system. Thus, two circumstances will be improved. First, the produced total harmonic distortion of the current waveform will be improved. Second, the injection and extraction efficiency of the booster ring by the new AC power supply will be increased. The measured dynamic range of the 10Hz sine wave current output of the new AC power supply is better than 75dB and total harmonic distortion(THD) is less than 0.015%. The advanced performance is illustrated in the paper.

INTRODUCTION

The booster ring AC dipole power supply, which sucessfully delivered 10Hz AC current (RMS=255Amp.) to the secondary-side of the dipole white circuit topology, was manufactured by Holec and has been installed in the booster area at NSRRC since September 1991. The basic contruction of the white circuit system as showed in figure 1. This AC current is passed through primary side of the white circuit trnasformer. Thus, current waveform of the secondary white circuit transformer is produced and superimposed on the DC current of the dipole magnet. The dynamic accurate current waveform is to achieve the required dipole magnet operating current to accelerate the beam energy in the booster ring from 50MeV to 1.3GeV.

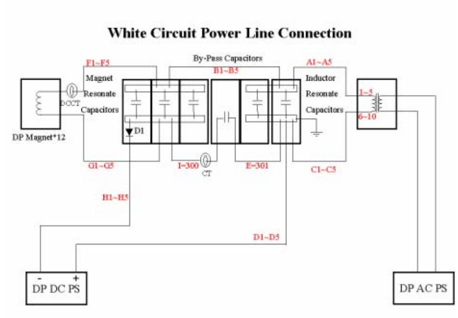

Figure 1: The basic construction of the white circuit system.

This dipole AC power supply source, which is a switched-mode power source with GTO module switching devices, doesn't generate enough current waveform no longer capability of supplying the energy to ramp the beam current in booster ring from 1.3GeV to 1.5 GeV, thus fails to fulfill the users' rising demand in beam current in booster ring.

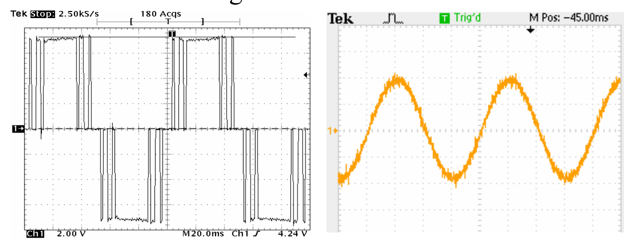

Figure 2: Output current waveform of the Holec and Danfysik AC dipole power supply.

For the purpose of satisfying the demand of energy upgrade, the efforts have been made to develop a new dipole AC power source specification. The power supply group of NSRRC cooperates with Danfysik to build a new AC power source in accordance with this specification. The new power supply has already been installed, fully tested and proven to be sucessful in delivering the required power for energy upgrade.

To define the specification of the new AC power source, the current power source operating condition at 1.3GeV is required to be examined in advance. The Figure 2 illustrates the output current waveform of the current AC power source at 1.3GeV operating condition. The phase jitter of the new AC power supply output current must be proved less than +/-4ns. DC current transformer that was called DCCT measures the output current of the power supplies. The DCCT resolution is 1-ppm resolution and frequency domain is from DC to 200kHz.

SPECIFICATION CONFIRMED

The magnet is required to be charged current by new power source when the absolute maximum operation rating is at 1.5GeV of the booster ring. The power supply derived from 1.3GeV operating energy condition is required to increase additional 20% margin to reach the absolute maximum operation rate as 1.5GeV. It is also added to tolerate changes of the white circuit's parameters in the practical operating environment.

We can calculate and design the new AC power supply specification of the booster ring by the working current of the old AC power supply. The specification of the new AC power supply as follows:

- Output Power Energy: ±420A/±550V (Peak to Peak)
- Working Frequency: 10Hz ±0.5Hz
- Switching Frequency: ≧ 13kHz
- Total Harmonic Distortion (THD): <0.015%
- Long Stability (8 Hours): ±10-ppm
- Analog Input Control Signal: 0~±10V
- Analog Output Signal: 0~±10V
- Switching Device: IGBT Modules

LOAD IMPEDANCE MEASUREMENT

According to above specification, the control gain of the new AC power has to be large enough to meet the requirement. The power supply output current of the long-term stability is under 10ppm. The output current waveform of the power supply oscillation may occur under following situations. First, control gain is enough and much higher. Second, there is resonance peak current in the white circuit system's resonance point. The load impedance frequency response is showed in figure 3. The frequency of current will be reacted only when the frequency is located at 10 Hz.

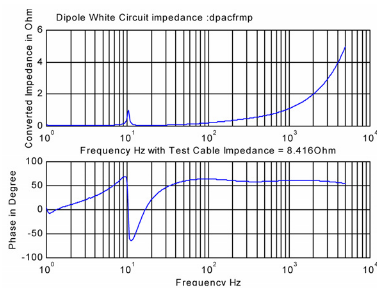

Figure 3: Load impedance's frequency response of the dipole magnet.

The load impedance's frequency response is measured by Agilent 35670A dynamic signal analyzer. This is to ensure no other resonance peak disturbed the related frequency span and to extract the system parameters for overall system simulation prior to AC power source manufacturing. The result is illustrated in figure 3, and it indicates only a resonance peak is at 10 Hz with 0.998ohm impedance. Based on this data, the gain of the control loop inside the AC power supply is designed and carefully simulated.

CONVERTER STRUCTURE

This new power source was built with four-quadrant H-Bridge circuit topology in which IGBT modules are used as switching device, as shows in figure 4.

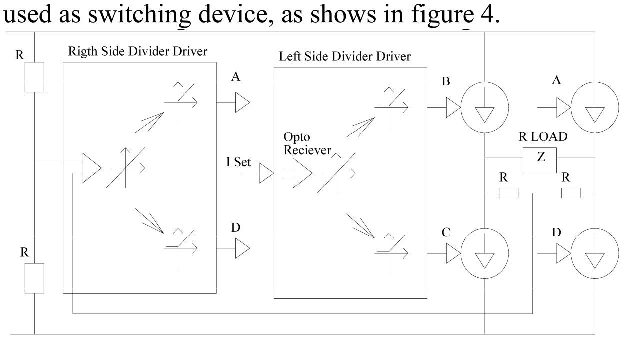

Figure 4: Block diagram of the dipole AC power supply.

The FQDRINT module (The topology of the four current source was built by the H-bridge in figure 4) generates four signals to command a current source controlled by H-Bridge. This is completed by following technique:

The output signal of the regulation board in the AC power supply must be a bipolar current in the range of ±5mA. This signal is divided into two unipolar lines for driving the left side of H-Bridge, function B and C are both current sources.

B delivers positive and C delivers negative output currents. The right side of the H-Bridge, A and D, is voltage controlled in such way, that its output voltage is exactly opposite of the left side. For example, under zero output current state, both right side and left side of H-Bridge should be balance.

CONTROL LOOP DESIGN

The following special features, which are implemented in the control feedback look design, are for the purpose of ensuring that the long-term output current drift is less than 10ppm. Figure 5 illustrates the total control loop of the AC power supply.

a) High impedance at output stage.
b) Implementation of following three internal loops:
- Current loop controlled power device.
- Inner feedback loop design for linearity of the load modeling.
- Outer feedback current loop for high precision control stabilization.

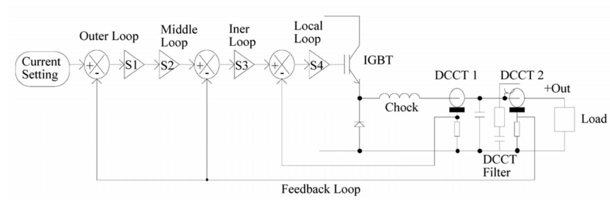

Figure 5: The total control loop of the AC power supply.

To a)

High output impedance will reduce load-and supply-fluctuation influences and load effectively.

To b)

- A internal local current feedback loop is designed for controlling output current loop and it generates the advantages as below:
  - Current transfer ratio almost follows loads independent.
  - To ensure the power supply gets high output impedance. (Item a)
  - Local cancellations of supply output current ripple and hum.
- The inner loop can be made easier and faster, and it is not required to spend much time in control gain design. Moreover, it is just adequate to cancel any phase shift and gain variations from the load and output stage. In the other words, the next current control loop will see a linear load model without nonlinear pole and zero in s-domain by laplace transform, which can be constructed by simplifies design ruler.
- The outer current feedback control loop ensures the output current stability of the power supply.

We can get the transfer function by the calculation, and the result shows in figure 6.

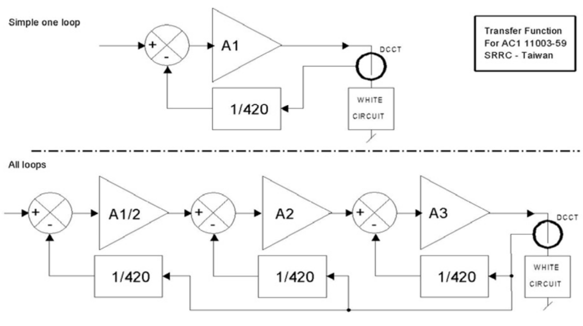

Figure 6: The Transfer function of the AC dipole power supply.

SIMULATION AND DESIGN

Load impedance simulation model is performed first to verify the validity of the new white circuit parameters for operation in 1.5GeV.

We can get the model of the white circuit by simulation, which is very close to the measured load frequency response data curve in figure 2. The feedback control loop gains and the verified load parameters are both required to be calculated. There are used to check the simulation model if the overall system is stable. Figure 7 shows the simulated gain and phase margin of the booster dipole white circuit system. The gain and phase margin obtained are 8.6639dB and 20.155 deg respectively. The results demonstrate that the system is working in stability region.

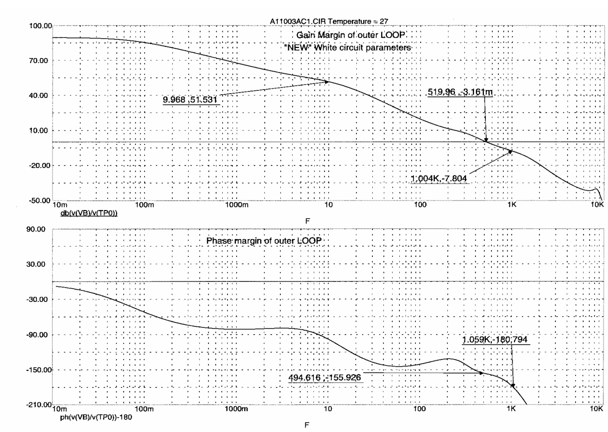

Figure 7: The gain and phase margin result by simulation. (1.5GeV)

ANALYSIS AND RESULTS

The output current frequency response of the old power supply (operation at 1.3GeV) and new AC power source operating at 1.3 and 1.5GeV respectively are illustrated in figure 8. The result indicates the noise margin of new AC power source, which is defined as the difference between the fundamental frequency and the 3rd harmonic frequency component, is 17.4936-(-61.9458) =79.4394 dB. By comparison, the old Holec AC power supply sources only exhibits 17.5816-(-30.6998) =48.2814dB. The equation 1 of total harmonic distortion shows as below:

$$THD_{C_{10Hz}} = \frac{\sqrt{C^2_{20Hz} + C^2_{30Hz} + \dots C^2_{90Hz}}}{C_{10Hz}} \qquad (1)$$

The result of $THD_{Danfysik}$=0.01453% and THD_{Holec}=5.28% that illustrated the output current performance. In conclusion, this noise margin is better than the old Holec AC power supply source.

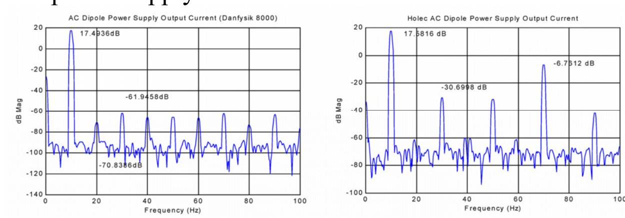

Figure 8: The output current performance of Holec and Danfysik AC dipole power supply.

CONCLUSION

A new Danfysik 8500-859 dipole AC power source for booster ring, which performs as high precision AB class current amplifier, is installed and operates successfully at NSRRC. This power supply possesses the features of lower jitter current output, better noise margin and excellent long-term stability.

The load impedance's frequency response is measured and simulated for control gain deign of the new supply. The new white circuit parameter's model is performed to verify the validity and stability of overall system design. This AC power source has been proven to be efficient to upgrade the booster beam energy from 1.3GeV to 1.5GeV.

In conclusion, the result of $THD_{Danfysik}$=0.01453% to illustrate the output current performance is good enough for the power supply. This noise margin is better than the old Holec AC power supply source.

REFERENCES

[1] Alexander Elkiar, "Magnet Power 859 System 8500", Danfysik, Copenhagen, Demark, 2006.

[2] K. Bürkmann, G. Schindhelm, T. Schneegans, "Performance of the White Circuits of the BESSY II Booster Syncrotron", BESSY, 1998.

[3] Kislovski, Redl and Sokal, ″Dynamic Analysis of Switching-Mode Power Supplies″, Van Nostrand Reimhold, 1991.

[4] Keith H. Billings, "Handbook of Switching Power Supply", McGraw Hill, 1989.