# PERFORMANCE OF SWITCHED MODE AC POWER SUPPLY

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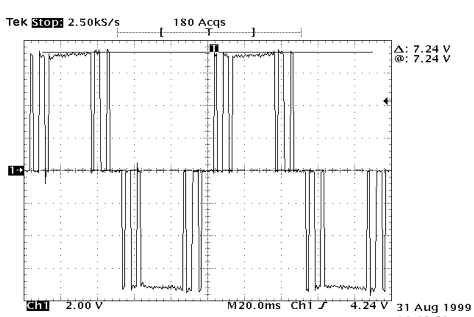
*Abstract*

In order to enhance the injection performance, the AC power supplies of the booster synchrotron of SRRC must output high quality current waveform. To ensure smooth and efficient injection of the booster ring, the phase jitter of the AC power supplies current must be small than +/-4ns. A new AC power supplies are constructed and employ IGBT modules operating at higher switching frequency than the old GTO-based system. This will not only improve the phase jitter produced but also increase the operating efficiency of the power supplies. The measured dynamic range of the 10 Hz sine wave current output of the new AC power supplies is better than 75dB and phase jitter is less than +/-4ns. The improved performance is illustrated in the paper.

## 1. HISTORY

The booster ring AC dipole power supply manufactured by HOLEC has been installed in the booster area at SRRC since September 1991. It sucessfully deliver 10Hz AC current (RMS=255Amp.) to the secondary-side of the dipole white-circuit. This AC current is superimposed on the dipole DC current to achieve the required dipole magnet operating current to accellerate the beam in the booster ring from 50 MeV to 1.3 GeV.

This dipole AC power source, which is a switch-mode power source with GTO switching devices, is no longer capable to supply the energy to ramp the beam energy from 1.3 GeV to 1.5 GeV, thus fails to meet the increasing beam energy demand of the user.




DCCT : 42Amp/V

Fig. 1 Holec AC Dipole Power Supply Output Current.

To meet the energy upgrade demand, efforts have been made to work out a new dipole AC power source specification, based on this specification, the power supply group of SRRC cooperates with Danfysik to build a new AC power source. The new power supply has already installed, fully tested and proven to be sucessful in delivering the power required for energy upgrade.

To define the specification for the new AC power source, the current power source operating condition at 1.3GeV has to be examined in advance. The output current waveform of the current AC power source at 1.3GeV operating condition is shown in Fig 1. The output AC current is measured by DC current Transformer DCCT (Danfysik DCCT 860R + 860S).

## 2. SPECIFICATION FOR NEW AC POWER SOURCE

The absolute maximum rating at 1.5 GeV for this new power source is derived from 1.3 GeV operating condition 20% additional the margin is also added to tolerate changes of the white circuit's circuit parameters in the practical operating environment.

Specification:

Output Power: +/- 420A/550V (Peak to Peak)
Working Frequency: 10Hz
Switching Frequency: >10kHz
Trigger jitter: < +/- 4us
Stability (8 Hours): +/-10 ppm
Analogy Input Control: 0~+/-10V (Full Current)
Analogy Output Signal: 0~ +/-10V(Full Current)
Switching Device: IGBT

## 3. LOAD IMPEDANCE MEASUREMENT

According to the specification above, the control gain of the new AC power has to be large enough to meet the long term 10ppm stability requirement. Output oscillation may occur when control gain is high and if there is resonance peak in the load impedance frequency response except the intentional one located at 10 Hz.

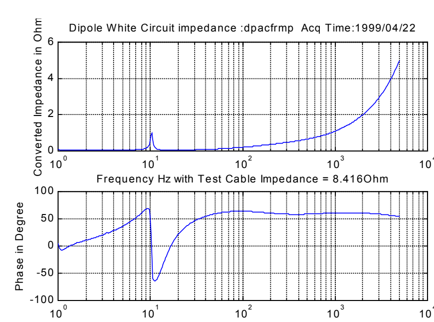



Fig 2: load impedance's frequency response of the dipole magnet.

To make sure there is no other resonance peak in the interested frequency span and to extract the system parameters for overall system simulation prior to AC power source manufacturing, the load impedance's frequency response is measured by HP 34570A Dynamic Signal response Analyzer.

The outcome is illustrated in Fig 2. From this figure, there is only a resonance peak 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.

## 4. SYSTEM STRUCTURE

This new power source is built with four-quadrant H-Bridge circuit topology in which IGBTs are used as switching device, as show in Fig 3.

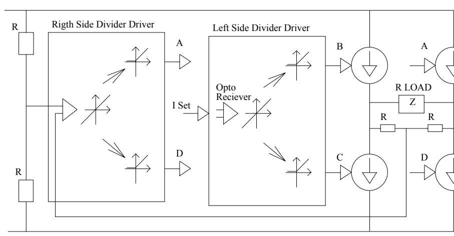



Fig.3. Block Diagram of the Dipole AC Power Supply

The FQDRINT (four current source of the H-bride in Fig 3) module generates four signals to a current controlled H-Bridge. This is done by the following technique:

The output signal of the regulation board must be a bipolar current in the range of +/- 5mA. This signal is divided into two uni polar lines for driving the left side of an H-Bridge, B and C that both are current sources. B delivers positive and C negative output currents. The right side of the H-Bridge, A and C, is voltage controlled in such a way, that its output voltage is exactly opposite of the left side. For example, at zero output current will both the left and right side of H-Bridge be at half of the supply voltage.

## 5. WORK PRINCIPLE

To ensure that the long-term output current drift is less than 10 ppm, special features are implemented in the control feedback loop design. These special features are:

a) High impedance output current stage.
b) Three loop realization.
   1. Current controlled power output loop.
   2. Inner loop for load linarization.
   3. Outer loop for ppm stabilization

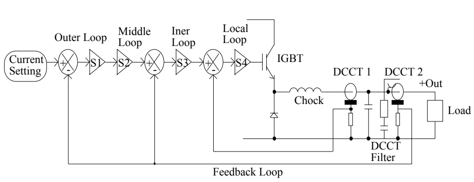



Fig4: The control loop of the AC power supply.

To a)

A high output impedance will reduce load-and supply- fluctuation influences.

To b)

1. A local current controlled output loop has the following advantages:
   - Current transfer ratio almost load independent
   - Ensures the high output impedance (item a)
   - Local cancellation of supply ripple and hum
   - The inner loop can be made faster, with-out too much gain, just adequate to cancel any phase shift and gain variations from the load and output stage. In other words, the next loop sees a linear load without any phase shift and gain variation, which simplifies construction.
2. The outer loop ensures the over all stability of the power supply.

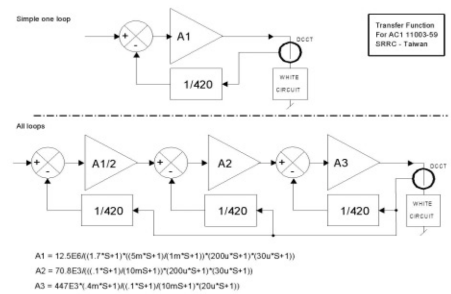



Fig 5: The Transformer Function of the AC dipole power supply [ref. From Danfysik]

## 6. DESIGN SIMULATION

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

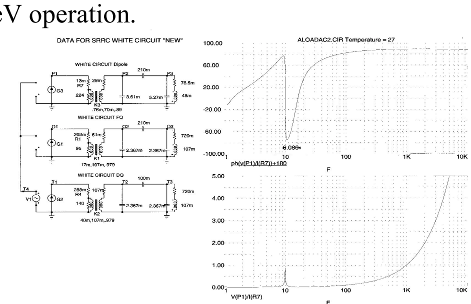



Fig 6: Load impedance frequency response (1.5GeV)

Fig 6 shows the simulation circuit and result, which is very close to the measured load frequency response curve in figure 2. Second, the calculated control loop gains together with the verified load parameters are used to simulate if the overall system is stable. Figure 7 shows the simulated gain 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 show that the system is in stability region.

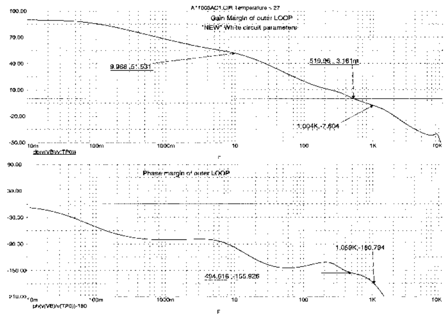


Fig 7: The gain and pahse margin by sumilation (1.5GeV)

## 7. RESULT AND ANALYSIS

Figure 8 and 9 demonstrate the output current frequency response of the old (operation at 1.3 GeV) and new AC power source operating at 1.3 and 1.5GeV respectively. It is shown that the noise margin, which is defined as the difference between the fundamental frequency and the 3$^{rd}$ harmonic frequency component, is 17.55979-(-67.07260) =84.6705 dB. This noise margin is far better than that of the old Holec AC power supply source, which exhibits only 17.5816-(-30.6998) =48.2814dB.

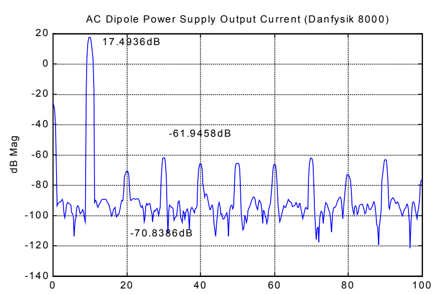



Fig 8: Danfysik AC Dipole Power Supply output current

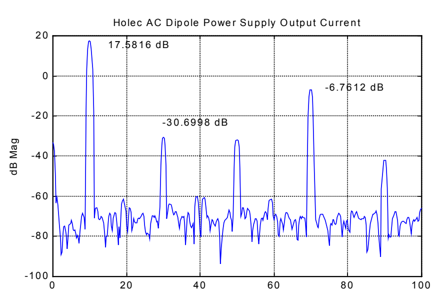



Fig 9: Holec AC Dipole Power Supply output current

## 8.CONCLUSION

A new Danfysik 8000-859 Dipole AC power source for booster ring is installed and operating successfully at SRRC. This power supply acts like a high precision current amplifier, which exhibits lower jitter output, better noise margin and excellent long-term stability.

This AC power source has been proven to be efficient to upgrade the booster beam energy from 1.3GeV to 1.5GeV.

## 9. REFERENCES

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