Design and Performance of Power Supplies for Superconductor Insertion Devices at TLS 1.5GeV Ring

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Abstract
A sophisticated Power Supply system was developed, installed and successfully put into operation for the Superconducting Insertion Devices at the 1.5GeV Taiwan Light Source (TLS). These magnets includes Superconducting Wave Length Shifter (SWLS), Superconducting Multipole Wiggler (SMPW) and three In-Archmate Superconducting Wigglers (IASWs). The power supply, with ±50A/±5V output power, is a four-quadrant bipolar switching step-down converter. The power supply, employing multiple regulation loops, slew rate control and ultra-high precision current transducer for feedback loop, is capable of delivering highly stable and reliable current to the superconducting loads. The topology, control scheme and its performance are described in this paper. The power supply system’s performance and reliability will be further improved and adopted to power low-temperature superconducting devices at NSRRC in the future.

Electrical Properties of TLS Superconducting Insertion Devices

<table>
<thead>
<tr>
<th></th>
<th>SWLS</th>
<th>SW6</th>
<th>IASW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Strength</td>
<td>6T</td>
<td>3.2T</td>
<td>3.1T</td>
</tr>
<tr>
<td>Coil Inductance</td>
<td>6H</td>
<td>0.75H</td>
<td>0.4H</td>
</tr>
<tr>
<td>Operation</td>
<td>285A</td>
<td>215A</td>
<td>265A</td>
</tr>
<tr>
<td>Current Lead</td>
<td>HTC</td>
<td>Vapor-Cooled</td>
<td>Vapor-Cooled</td>
</tr>
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To boost up the photon beam energy into the hard x-ray spectral range at the 1.5GeV TLS ring, and to take the limited space into consideration, superconducting magnet insertion devices are chosen to be the right candidates to meet the increasing need of protein crystallography and novel material researches. Five superconducting magnets have been installed and commissioned over the past few years, where they operated successfully providing the beam energy as expected.

Superconducting Magnets Main Power Supply Architecture

The main power supply is responsible for charging the main coils while the trim power supply is connected to the side coils to eliminate the first and/or second field integral. A hardware quench dump circuit is implemented to dissipate the stored energy from the superconducting coils so the coils are protected from overheating if a quench should occur.

Multi-Loops Control Scheme of the Main Power Supply

The four-loops control scheme is adopted to simply the overall design and stabilize the output current with wide load inductance variation. The control loops include:
1. Local loop
   This cycle-by-cycle based current regulation is to cancel current ripple, maintain high output impedance and decouple the current loop transfer ratio from the load.
2. Inner loop
   The inner loop is aimed to compensate phase shift and gain variations from the output stage and the load. The outer loop sees only a linear load without any phase shift and gain variation. This technique greatly simplify the control outer loop design.
3. Middle loop
   The current slew rate control is implemented here with excellent linearity independent of the set value and load by a hardware loop coupled as an ideal integrator.
4. Outer loop
   The outer loop built on analog operational amplifiers is designed mainly to ensure the overall current output stability of the main power supply.

As shown in the bode plot of the Outer Loop Transfer function, traces for 0.4H and 40H overlap above each other. This is because the inner loops has removed the load influences, in other words, the outer loop cannot see any load changes at all. The overall gain margin and phase margin are about 60dB and 90 deg.

The ripple fluctuation as shown is within ±10ppm for SWLS and SW6 loads and within ±5ppm for the IASW loads measured during the 8 hours period. The performance is far better than ±10ppm as specified.

Conclusion
For increasing the beam intensity in the hard x-ray spectral range at the 1.5GeV TLS ring, superconducting magnet insertion devices are installed and all these devices function very effective to boost up the proton beam energy as desired. These superconducting magnet insertion devices require high precision bipolar power supplies to maintain excellent beam output stability. The main power supply, with a dedicated four-loop control scheme, performs like a class AB current amplifier to provide precise current output with ultra-low ±1ppm long term and ±30ppm short term output stability. And these power supplies have been proven to be successful and reliable in delivering the expected beam quality at TLS ring. The developed power supplies has been successfully employed to charge the other superconducting magnets and could be further modified and upgraded to power other superconducting insertion devices in the future for other applications demanding high beam brilliance.