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solenoid power supply***

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The Design and Development of The EBIS LEBT Solenoid Power Supply

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Abstract— This power supply was designed and developed at Brookhaven National Laboratory (BNL) as part of a new ion pre-injector system called EBIS (Electron Beam Ion Source). It consists of a charging power supply, a capacitor bank, a discharge and recovery circuit and control circuits. The output is fed through cables into a solenoid magnet. The magnet's inductance is 1.9mH. The maximum charging voltage is 1000V. The power supply output is a half sine wave of 13ms duration. The repetition rate is 5Hz. The power supply output can be set to any value between 250A and 1900A in one second in order to accommodate the varying species of ions specified by different machine users.

Keywords: EBIS, Power Supply

I. INTRODUCTION

A new heavy ion pre-injector based on EBIS is being constructed at BNL [1]. The function of EBIS is to produce ions of various elements, and inject them into a particle accelerator complex. The final (highest energy) stage of the complex is the Relativistic Heavy Ion Collider (RHIC). In RHIC two opposing beams are accelerated to near light speed, then collide head to head so that the resultant subatomic particles can be studied.

The LEBT (Low Energy Beam Transfer) section transports the beam from the high current EBIS and matches it to the RFQ (Radio Frequency Quadrupole). A pulsed magnet solenoid lens focuses the beam into the RFQ [2]. The specifications of the solenoid power supply are shown in Table 1.

TABLE I. SOLENOID POWER SUPPLY SPECIFICATIONS

Current Range	250A-1900A
Maximum Voltage	1000V
Pulse Waveform	Half Sine
Pulse Flattop Duration	200us
Pulse Flatness	+/-0.2%
Pulse Repetition Rate	5Hz
Solenoid Inductance	1.9mH
Solenoid Resistance	22.4 mΩ
Users	>2
User Switch Time	1second

II. DESIGN AND DEVELOPMENT

A. Schematic

An LC circuit serves as the main discharge circuit. In order to make full use of the capacitor energy, a recovery choke is used to augment capacitor bank recharging, (i.e., returning to a positive voltage level). A simplified schematic may be seen in Figure 1.

Figure 1. Simplified schematic

The capacitor bank is comprised of 10 1mF/1kV capacitors connected in parallel by copper bus bars. A TDK-Lambda LC1202 1kV power supply is used to charge the capacitor bank. The combination of the capacitance value and the LC1202 was chosen to provide a 10% margin above a specified expected maximum operating current of 1900A. The LC1202 also has the high level of stability required for the system. The 10mF capacitance value allows for a pulse flatness parameter superior to the specified 0.2% requirement.

No charging resistor is used. Instead, an IGBT connected in series between the LC1202 and the capacitor bank is used. This configuration both decreases the charge time and conserves energy.

Diode D1 prevents voltage reversals from damaging the LC1202 charging power supply.

The bleeding IGBT is only allowed to conduct when the capacitor bank voltage is higher than the voltage level defined by the new setpoint during a mode switch. The bleeding resistor assembly consists of 5 50Ω/200W wire-wound resistors connected in parallel. Diode D2 keeps the bleeding IGBT from reverse conducting.

High current goes through the magnet, the recovery choke, and the two SCRs. Therefore, these components are all water cooled in order to prevent overheating. A calculation was performed to determine the water flow requirements. E.g., 1 GPM water flow can keep the recovery choke temperature increase to less than 22°C.

B. Controls

Three imported signals are required to control and configure the solenoid power supply output. These are received by a timing board located in one of the solenoid power supply enclosures. Two of these signals are TTL level pulses: the discharge trigger and the mode switch trigger. The third is a digitally derived setpoint.

The discharge trigger and the mode switch trigger, upon entering the timing board, initiate a timing sequence which switches the two SCRs and two IGBTs on and off. The timing board also generates an inhibit signal which controls the LC1202. The timing sequences are illustrated in Figure 2 and Figure 3, and are as follows.

The discharge trigger initiates an inhibit signal which simultaneously turns off the LC1202 and the series IGBT. Subsequently, the timing board generates its own discharge trigger which, in turn, fires the main SCR. Later the timing board generates two recovery SCR triggers.

Figure 2. Timing sequence after the discharge trigger

The series IGBT is vulnerable to failure under certain conditions. To prevent this eventuality two levels of protection have been incorporated into the system. The first is the redundancy of the recovery SCR triggers. This procedure will

assure the firing of the recovery SCR so that the capacitor bank voltage will be at a positive value when the series IGBT is turned on. As a backup measure a circuit has been incorporated into the timing board which will prevent the series IGBT from turning on while the capacitor bank voltage is in a negative state.

The mode switch trigger is used to prepare the solenoid power supply for a change in the ion species to be transferred. Different species of ions, having different masses, require different levels of power from the solenoid power supply in order for the transfer to be successful. To this end a setpoint specific to each ion species is generated and sent digitally to the solenoid power supply by accelerator operators, via a PSI (Power Supply Interface) unit.

When the mode switch trigger is received by the solenoid power supply, the timing board compares the extant capacitor bank voltage level with the voltage level defined by the new setpoint. If the setpoint specifies a capacitor bank voltage greater than the voltage presently in the capacitor bank, the LC1202 will immediately charge the capacitor bank to the new level.

If the setpoint demands a lower voltage than is extant in the capacitor bank, the bleeding IGBT will turn on and the capacitor bank voltage will be reduced to a voltage level just below that defined by the new setpoint. The LC1202 will then proceed to charge the capacitor bank to the voltage level designated by the new setpoint. The solenoid power supply will then be ready for the next discharge trigger.

Figure 3. Timing for mode switch

With regard to the digital commands and states, the solenoid power supply is interfaced with the PSI unit through an Allen-Bradley SLC 551. An Allen-Bradley PanelView Component 600 (PVC600) serves as the local user graphic interface. Both the SLC-551 and PVC600 are connected to the Ethernet, providing the convenience of remote programming.

III. TESTS

The solenoid power supply was tested at its maximum voltage of 1000V and the frequency of 5Hz continuously for half an hour. The output was 2100A, 13ms of duration. The recovery current was 3500A because of the low inductance of the recovery choke. The waveforms are shown in Figure 4 and Figure 5. The test was terminated prematurely because of an overheating condition of the beam pipe in the solenoid magnet aperture.

Figure 4. Capacitor bank voltage and current at 1000V

Figure 5. Capacitor bank voltage and current at 1000V, 5Hz

The mode switch was also tested. One setpoint was 250A, and the other was 1900A. The mode switch occurred every 2 seconds. The solenoid power supply worked as designed. The waveforms are shown in Figure 6. The only issue was the bleeding resistors were getting very hot after a few minute. In the future, the bleeding resistor assembly may be redesigned to incorporate the use of high power resistors and heat sinks.

Figure 6. Capacitor bank voltage and current at mode switch

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