Power Supply and Instrumentation Division

The Power Supply and Instrumentation (*PSI*) Division is a constituent of the Accelerator Technology Group of Variable Energy Cyclotron Centre, Kolkata. In the following, the major activities of this Division are reported.

Development of power supply for the radio-frequency system of k-130 cyclotron:

The high power, 20kV/ 20A anode power supply of the radio-frequency system of k-130 room temperature cyclotron consists of four numbers of epoxy cast water-cooled transformer (96kVA, 415V / 5kV), 400kW oil cooled rectifier stack, and filter capacitor bank for the required unregulated high voltage. The regulation topology incorporates a 175kW series pass tube. The output feedback signal from the voltage divider after comparing with a reference voltage is fed to the driver amplifier using 5 MHz amplitude modulated signal transmission system through a 30kV isolation pulse transformer. The AM signal after demodulation is used to drive the driver amplifier floating at high voltage, which in turn drives the series pass tube. A fast crowbar operating system designed to operate within 5micro-sec protects the RF tube (Burle 4648 Tetrode) in case of an overload.

Development of deflector power supply for the k-130, room temperature cyclotron:

A high electric field gradient of 112kV/cm has been achieved between the deflector electrodes of the room temperature cyclotron using a DC, 120kV / 5mA power supply. The power supply consists of a self-sustaining Colpitts oscillator of frequency 100 kHz. A high frequency air-core step-up transformer boosts the primary ac voltage and Cockroft-Walton multiplier multiplies the output voltage to the desired level. The error signal after comparing the output feedback signal with the reference gives drive to a series pass tube to give modulating signal to the plate and screen of the oscillator tube. An adjustable crowbar is used to control the spark energy during electrode bake-in-period.

Commissioning of Main Magnet and Beam Line Power Supplies for the k-130 (Room temperature) cyclotron:

As a part of the Modernization Program of the room temperature cyclotron, the following power supplies have been installed and commissioned:

- **Main Magnet Power Supply (MMPS)**: 2000A / 115V (dc) 10ppm stability, Current Controlled linear regulator with thyristor pre-regulator.
- **Quadrupole Magnet Power Supplies (QMPS)**: 300A / 30V (dc) 10ppm stability, Current Controlled linear regulator.
- **Switching Magnet Power Supply (SWMPS)**: 300A / 115V (dc) 10ppm stability, Current Controlled linear regulator with thyristor pre-regulator.
- **Steering Magnet Power Supplies (STMPS):** ± 10A / 100V (dc) 100ppm stability, Full-bridge PWM pre-regulator followed by series regulator.

The link with the remote PC is done in RS-485, 2-wire multi-drop bus at a speed of 9.6kbps where each of the supplies is electronically attached with a specific integer address for its identification amongst others.

Communication with the power supply is accomplished by sending ASCII commands from the personal computer. The intelligent control board in the power supply processes the command strings and performs the desired function corresponding to that command. The developed intelligent, user-friendly Graphical User Interface running in the control console guides a user's interaction with the power supplies.

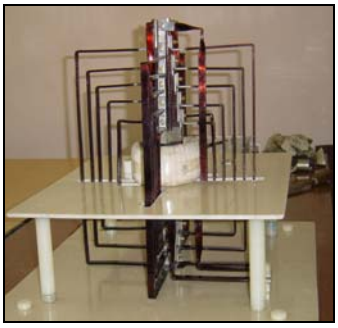
Commissioning of Trim Coil Power Supplies for the k-500 (Superconducting) cyclotron:

Eighteen numbers of DC current regulated power supplies (10ppm stability) for the super-conducting cyclotron are required to energize trim coils mounted on the pole tips of the cyclotron to produce the desired magnetic field for proper beam dynamics. The power supplies are current regulated with a high current transistor bank as a series pass element. The power supplies with specifications: a.) 400A / (18V-14V-10V)—7nos. b.) 400A / (26V-22V-18V)—4nos. c.) 400A / (32V-28V-24V)—7nos. are installed at site (basement and mezzanine of super-conducting cyclotron vault). Thorough and detailed testing of all the power supplies as per the specifications are done. All power supplies are given unique addresses and are connected in a multidrop fashion using RS-485 serial link. This link is then connected to an Ethernet switch using an Ethernet-to-Serial data converter. This enables the power supplies to be operated and monitored over the control LAN.

R&D Activities

Precision DC Current Transducer (DCCT):

The long-term stability of the output current is an important parameter of the magnet power supply and for that high precision DCCT is one of the major components. Precision dc current transducers of 400A, 1000A and 2000A has been designed and developed and implemented in indigenously developed high current power supplies. The important parameters of the DCCT such as reliability, repeatability, sensitivity, accuracy and preciseness are accomplished by selecting correct core material (Permalloy '80), a zero-flux detector and flux balancing control circuit.



2000AT Transducer Head

DAC Board for precision current setting of Magnet power supply:

In order to ensure the precise setting of the power supply current an 18-bit DAC board has been designed and fabricated. Higher the resolution, a single bit of the DAC device then represents a smaller current step to the power supply output (4-ppm for 18bit, 16ppm for 16bit). The design of the 18-bit DAC board is based on the combination of two, highly

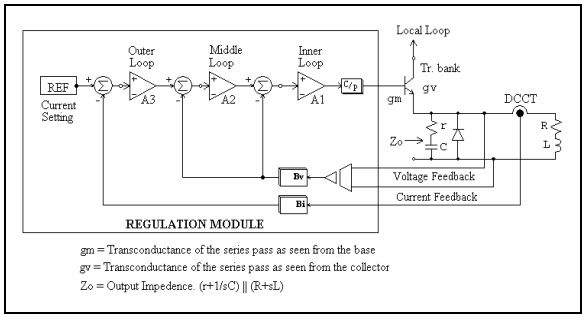
monotonic and low thermal drift 12-bit DACs. The Range-Overlap technique along with weighted gain using imported precision operational amplifier and highly stable resistors of 0.01% tolerance are used to accomplish the 18 or 16-bit resolution DAC board of required specification / stability class. The voltage reference, the DAC are all temperature controlled to approximate 0.2ºC drift by means of Thermo-Electric Cooler. Since the TEC can heat and cool, the temperature in the reference and DAC circuit is set above the room temperature to 37ºC.

Three-loop regulation topology for precision high current magnet power supply:

The dc precision of a magnet power supply, which generally defines the absolute tolerance of its current, can be split up into three distinct parts --- ripple, short-term and long-term stability. To ensure that the output current is within an error-band of 10ppm or less, a three-loop regulation topology has been developed and implemented in a high current indigenously developed magnet power supply (750A/12V) that uses transistor bank as the series pass element.

The inner fast voltage control loop (without too much gain) is adequate for cancellation of supply ripple, provides line regulation against any input mains perturbations for short-term stability. The fast middle loop in addition to the inner loop adds more rejection of the input supply ripple and line fluctuations.

The magnet load with a large time constant (L/R) comes into the outer current control loop. Hence the loop is closed at a low frequency so that the pole introduced by the load is above the bandwidth of the circuit and does not affect the current loop stability. The slow outer type–1 (integrating type) current loop helps in getting a zero steady state error. This outer current loop meets the required load regulation and tracks the reference for long-term current stability.



Regulation Scheme

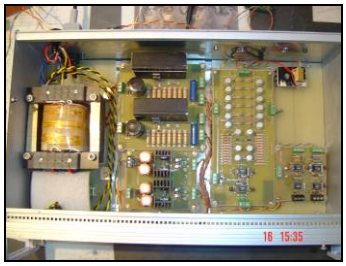
Front panel of 750A/12V power supply

The regulation topology adopted for the development of precision magnet power supply and implemented in a 750A/12V power supply complies well with its high stability specification of 10ppm. This regulation topology with proper compensation and feedback can be used for the precision high current power supplies of stability 10ppm class.

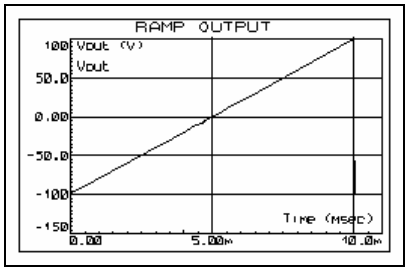
High-speed bipolar power supply for plasma diagnostics:

The Langmuir probe power supply required for the plasma diagnostics has been designed and developed. The power supply is designed to sweep the probe voltage from –100V to +100V in 100msec for an input sweep of +10V to –10V (100msec) from DAC card. The supply circuit consists of highly stable low-offset voltage operational amplifiers and a voltage booster circuit using discrete high speed npn and pnp transistors. The gain of the system is

fixed at a value 10 to satisfy the required sweep voltage. The minimum time of the sweep (-100V to +100V) that has been achieved from the circuit is ~10msec.



High speed ramp power supply unit



Ramp output

Current Regulated Bipolar Switch Mode Converter for the injection line solenoid of the super-conducting cyclotron:

A novel topology of high-performance smooth-varying dc current regulation based on "Pulse-Width-Modulation with Unipolar Voltage Switching" has been adopted for the development of such power supplies. The specifications of the power supplies are as follows: (a) Output Current: +/-5A, (smoothly varying) (b) Output Voltage: +/-20V (c) Stability: 100ppm (d) Current Setting: 12-bit DAC (e) Current Read Back: 12-bit ADC (f) Computer Interface: RS-485 (g) Cooling: Air Cooled.

Bipolar switch mode converter unit

Transformer inrush current detector:

To measure the inrush current of a power transformer there was a need of a current transformer to measure high di/dt during putting on of the transformer. An air core current transformer with electronics was designed, fabricated and calibrated. The air core coil, works by sensing the magnetic field in the space around the conductor.

Half-bridge parallel resonant dc-dc converter for high voltage application:

In all high voltage power supplies, the high voltage transformer is the most crucial element. Its large number of secondary turns and insulation results in pronounced non-ideal characteristics of the transformer. In the design an attempt has been made to absorb these non-idealities in the High Voltage Power Converter topology. Using the half bridge parallel resonant dc-dc converter topology with 4-stage Cockroft-Walton multiplier power supply of

10kV / 1mA and –10kV / 1mA has been developed. The tracking ± 10KV / 1mA, power supply is for the inflector of the k-500 super-conducting cyclotron.

High voltage power converter