OCEM
POWER ELECTRONICS

> CURRENT-CONTROLLED POWER CONVERTER FOR THE TRIUMF CYCLOTRON

TRIUMF is a world-class subatomic physics research laboratory located at the University of British Columbia in Vancouver, Canada, where it is owned and operated by a consortium of 17 Canadian universities. It boasts the world's largest cyclotron, a special type of particle accelerator that accelerates the particles as they follow a spiral path inside a vacuum chamber. TRIUMF produces negatively charged hydrogen ions that the 520 MeV (million electron volts) variable energy cyclotron then accelerates with a high-frequency alternating electric field. OCEM was awarded the contract to build a new 20 kA, 80 V power converter for the

cyclotron's main magnet coil. This was to replace the original power supply, which was based on a series pass regulator and was commissioned in 1976. The project required high current stability at a level of ±2 parts per million (ppm) and a lifetime of at least 20 years.
The new power supply had to fit within the same floor space as the original power supply, meaning it had to be designed as a set of five cabinets of no more than 250 x 150 x 205 cm. OCEM delivered and assembled the new power supply in Vancouver in early 2018, successfully completing site acceptance tests in March. The supply integrates a sophisticated control system and a precise current measurement system developed at CERN for the Large Hadron Collider (LHC). It also features a temperature-regulated cabinet for the controls electronics. The first cabinet houses the input circuit breaker and pre-charge circuit. The second and third cabinets house the rectifier stages, each composed of a transformer, diode stack and inductor DC filter. In the fourth cabinet there are the 16 switching modules, and located in the fifth are the two high-precision Direct-Current Current Transducer (DCCT) heads. The design had to conform to Canadian electrical rules and safety standards, which were confirmed by certified inspectors through a preliminary in-factory review and a final on-site inspection.

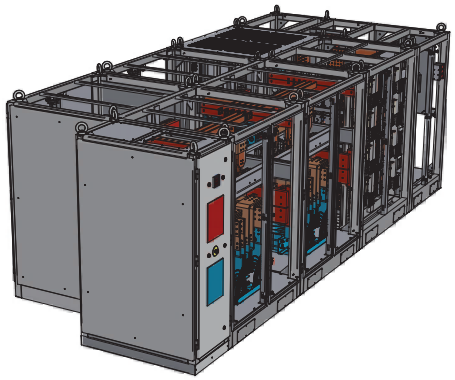
MAIN POWER SUPPLY RATINGS PARAMETER	VALUE
Output Current/Voltage	20000 A / 80 V
Output Power	1600 kW
Mode of operation	DC
Regulation Mode	Constant Current
Topology	IGBT based buck converter
Equivalent Output Switching Frequency	16 x 10 kHz = 160 kHz (10 kHz for each module and 8 PWM carriers phase-shifted)
Absolute Accuracy	±1 part in 10^4
Current Ripple	±2 ppm of 20 kA (17 kA ÷ 20 kA)
Short Term Stability (5 min) @ max I_{OUT}	≤ 2 ppm of 20 kA
Long Term Stability (8 hour) @ max I_{OUT}	≤ 5 ppm of 20 kA
Power Factor	≥ 0.96
THD	Current THD: 5.1% Voltage THD: 4.3%
AC Input	3ϕ, 3-wire, 800 VAC
Cooling	Air and Water cooling
Footprint	20.7 x 8.4 feet

> ABOUT OCEM

OCEM is a leading company in power electronics for scientific and industrial research, with a flexible customer-oriented approach and main commitment in Plasma physics, Particle accelerators, Superconductivity, Radio Frequency Systems, Transportation, Food processing and Medical Particle Therapy.

HIGH-PRECISION CURRENT MANAGEMENT SYSTEM

TRIUMF's cyclotron uses a massive six-sector magnet to confine the beam and guide the particles in an outward spiral trajectory. The cyclotron magnet has an inductance of 120 mH and a resistance of 3.9 mΩ. The time constant is thus about 30 seconds and the stored energy will be 24 MJ at 20 kA. To achieve the required current stability, OCEM decided to incorporate a reliable control system developed at CERN. The FGC3 is a third-generation Function Generator / Controller that evolved from the controls originally created for the power supplies used in the Large Hadron Collider. It implements a digital high-precision current loop using two DCCTs and the FGC3's internal ADCs (Analog-to-Digital Converters).
Moreover, it uses an additional ADC input to digitize the flux-loop signal and modulates the current reference based on this measurement to further stabilize the field.



The TRIUMF application requires short-term stability for the current of ±2 ppm of nominal (20 kA), after the first 5 minutes following a current change. Repeatability must be of the same order and current ripple must be within ±2 ppm of 20 kA for the range from 17 kA to 20 kA.
The performance of the current regulation, in particular stability and repeatability, greatly depends on the current measurement system. The current measurement system for the new power supply is composed of two high-precision DCCT heads inside the last power supply cabinet, plus DCCT electronics and corresponding FGC3 internal ADCs installed inside the temperature-controlled rack. Two independent DCCT's are used for redundancy purposes and to allow a cross-check of the calibration between channels.

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