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Progress on PEP-II Magnet Power Conversion System*

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Abstract

The various power systems for supplying the PEP-II DC magnets rely exclusively on switchmode conversion, utilizing a variety of means depending on the requirements. All of the larger power supplies, ranging from 10 to 200 kW, are powered from DC sources utilizing rectified 480 V AC. Choppers can be used for the series-connected strings, but for smaller groups and individual magnets, inverters driving high-frequency transformers with secondary rectifiers comprise the best approach. All of the various systems use a "building block" approach of multiple standard-size units connected in series or parallel to most cost-effectively deal with a great range of voltage and current requirements. Utilization of existing infrastructure from PEP-I has been a cost-effective determinant. Equipment is being purchased either off-the-shelf, through performance specification, or by hardware purchase based on design-through-prototype. The corrector magnet power system, utilizing inexpensive, off-the-shelf, four-quadrant switching motor-controllers, has already proven very reliable: 120 of the total of 900 units have been running on the injection system for four months with no failures.

Introduction

The PEP-II project will consist of two storage rings, the Low Energy Ring (LER) and High Energy Ring (HER), both contained in the same 2.2 km circumference tunnel, plus an additional 4.6 km of extraction, bypass, and matching beam line sections. The complex is being built to produce B-mesons (also called a B-factory) for the BaBar detector. It is being built at SLAC as a cooperative effort among the three DOE laboratories in the SF Bay area: LBNL, SLAC and LLNL. The Magnet Power Conversion is one of the areas that because of its relatively large size, diversity of systems, and technical complexity requires close cooperation among the three technical groups involved in the design and construction.

One important issue that influenced the initial decisions on work division was the need to maximize the uniformity of systems (i.e. all power supplies of a similar power level must be of the same technology and manufacture) to reduce the impact of personnel training in new systems and the cost of the stock of spare components and redundant on-line systems. For this reason the division of work by type of power supply is different than the overall machine division of work which goes mostly by type of ring, interaction area, or injection.

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1. POWER SUPPLY SYSTEM ENGINEERING

The system design uses two general architectures, one for multiple channel power supplies, employing small drivers for corrector and trim, and a single channel system for all other requirements. The single channel power supply system consists of a voltage regulated/voltage controlled power supply as its power train, driven by a current regulation loop with a high stability (<2ppm/C) error amplifier. The current regulation loop workpoint is set by an analog reference generated by the control system interface. Current is measured by two identical Zero Flux Transductors (ZFT), mostly of the integrated type where the magnetic head and electronics are in the same package. One of the ZFTs is used for the current regulation loop, and the other one as an independent diagnostic readback. The system has a single ground fault detector. The multiple channel systems have similar features, in different implementations, as described later in this paper.

2. FACTORS INFLUENCING THE CHOICES ON POWER SUPPLY TECHNOLOGIES

Many factors have been considered to arrive at solutions of the technical problems presented by the PEP-II machine design specifications. The individual performance issues were initially evaluated, including stability, accuracy and tolerances for periodic and random deviations. Overall performance issues such as availability, initial and operating system costs and MTTR are then weighed. Included under cost are the solutions that allow the use and recycling of existing components of PEP-I such as parts of the cable plant (AC & DC) and the power distribution systems (transformers, switchgear) that will be refurbished and reused. The power distribution decisions were for AC distribution, because of the simplicity of the protection systems and easier compliance with safety regulations. The exception is the large string power supply system, where existing DC distribution systems were recycled. Other influences on the technical solutions are EMC concerns, both EMI generation and susceptibility, and power supply efficiency.

3. CONTROL SYSTEM INTERFACES

A new control system interface/error amplifier/power supply controller will be used in the power conversion systems for PEP-II. The interface is connected to the control system by means of a digital serial line (Bitbus). A microprocessor is used as the communications controller and as the intelligence for the power supply controller for functions such as data I/O, diagnostics routines and ramping. The use in the controller unit of an intelligent programmable processor allows for a large improvement in the performance of the data conversion components. An internal calibration process, running while the supply operates, makes possible the transfer of the accuracy and precision of a high quality reference to the DAC and ADC performance. The process corrects for offset, gain and linearity imperfections and drifts for the DAC and offset and gain for the ADC. This gain in performance allows the use of data conversion units of less stringent specifications, which of course are less expensive.

4. DESCRIPTION OF THE MAJOR GROUPS OF POWER SUPPLIES

4.1 Power supplies for correctors and trim coils

Approximately 900 individual X-Y corrector magnets will be installed on the PEP-II rings, arcs, and injector lines. Each magnet will require a bipolar current of up to 12 A, with a 24 hour stability of better than 0.05%/C, and a 1 hour stability better than 0.01%/C. A 16 channel, modular power supply design has been developed to meet this requirement with emphasis placed on reliability, repair time, and installed cost per channel. Each drive module consists of an H-Bridge MOSFET switching array, input and output filter networks, two isolated precision current sensing elements (feedback and monitor), and an error amplifier, plus extensive fault detection and current limiting circuitry.

A modular crate architecture is utilized in this design, in order to maximize the flexibility and serviceability of each installation. The physical crate is a standard 6U by 220 mm Eurocard format available off-the-shelf from Schroff. The crate has 17 slots, one for a control system interface card, and 16 slots for power conversion modules. Each power module has a 'personality card', which is mounted directly onto it. This personality card contains passive components that determine the maximum output current limit, the transfer function of command voltage to output current, and the compensation network for the error amplifier section. If a power module is replaced, the personality card is removed from the old module and installed on the new one. In this way, all of the operating parameters specific to the load will be in effect with the new module.

All cards and modules are accessible from the front of the crate, and connect to the backplane using standard Eurocard connectors. Air cooling for the crate is provided by a fan set, also offered by Schroff, which draws in cool air from the aisle and passes it through the crate and into the rack, thus keeping the rack interior at positive pressure. A single hinged front cover provides access to the 16 power modules.

A unipolar bulk power supply provides the main DC power to the crate through 180A Powerpole connectors on the rear panel. Command and synchronization signals are provided through the backplane by the interface card. The main DC power is distributed to the individual modules along with utility voltages and control signals also via the backplane. A standard 48 pin, type 'E" DIN connector is used for all signal and power connections between each power module and the backplane. The interface card plugs into the same backplane, and uses the VME format for connector type, positioning, and module width. By using the card to backplane approach, all internal wiring has been eliminated, except for the 120 VAC power and the main DC power wires from the Powerpole connectors to the back-plane busses. All other external connections, including the outputs to the magnets, are accomplished through printed-circuit-mount connectors on the backplane, thus allowing the assembly work to be performed by outside board fabricators. Since the crate enclosures come pre-assembled from Schroff, the only in-house assembly work to be performed is to bolt on the backplane, front and rear panels, and insert 16 power modules and the appropriate interface card. The personality cards are then added to give each power module its own specific characteristics. A computerized test bench is used for testing the finished crate.

For the PEP-II rings the control system communicates directly with the power supplies through the interface card and the serial Bitbus data link. The interface card contains a DAC and ADC, each multiplexed 16 channels wide, plus logic glue and the Bitbus-specific support circuitry.

The function of each power module is to provide a regulated drive current to its respective load, in proportion to the command signal from the interface card. The power module also returns a redundant current signal to the interface card, as well as status and fault data.The switchmode servoamplifier used in this design is a commercial unit, the 30A8, manufactured by Advanced Motion Controls, operating as a voltage amplifier. This model was chosen for its compact size, ruggedness, PC mount capability, and its internal fault protection system, which provides protection against thermal overload and output short circuits (to either rail). The fault signal provided is applied to an external latch on the power module, which will shut down the servo amplifier if a fault condition persists for more than a few seconds. The 3OA8 produces unfiltered DC pulses from its H-bridge output stage, and must therefore be filtered appropriately before delivery to the load. The filter design employed is a variation of the classical Praeg filter, arranged to be symmetrical around power ground. The filter is set to be critically damped, and attenuates both the differential and common-mode components of the output ripple. Up to eight of the 16-channel crates are mounted in a double-rack above a 40 kW, 1000A power supply located across the bottom of both racks. The six double racks and power supplies (one in each region) are recycled from the PEP-I corrector power system.

4.2 Power supplies for medium power individual magnets and small strings

The 30 kW and smaller range of individual power supplies has the largest number of units. It was decided early on to use a single type of technology for the whole range, based on similar requirements for performance and with the goal of simplifying maintenance procedures, reducing spares stock, personnel training and MTTR. The decision on which type of power supply technology to be used, based mostly on performance, costs, and past experience, is for the use of switchmode inverters driving various turns-ratio high-frequency transformers followed by rectifiers to achieve the great variety of DC output voltages and currents required for the various magnet loads. Similar supplies are commercially available with 3-phase AC power input. The units also all have provisions for being paralleled in multiple units.
The first group of 86 supplies, purchased to provide equipment for the High Energy Ring (HER) will be fabricated by Inverpower Controls, Inc., Toronto, Canada. The second group of 118 power supplies for the Low Energy Ring (LER) will be provided by Electronic Measurements, Inc.(EMI), Neptune, NJ.

4.3 Power Supplies for individual magnets/small strings, medium-high and high power.

When it became clear that switchmode/inverter technology now extends up into the megawatt power region, and is competetive in cost over the whole range compared to standard 12-pulse line-comutated thyristor-controlled power supplies, it was decided to utilize this technology throughout all the power supplies sizes to be purchased to specification. The medium-high powered group of 22 supplies were specified for rack mounting and are similar to the intermediate size supplies described above in every respect . This group of supplies will be purchased from EMI. A group of nine free-standing power supplies ranging from 50 to 270 kW will also incorporate insulated-gate-bipolar-transistors (IGBT) inverter/transformer/rectifier technology. These supplies will feed quadrupoles and dipoles around the single interaction point in the HER, and the LER Wiggler magnets in Region 6.

4.4 Power Supplies for Large Magnet Strings

There are 25 circuits of large string series-connected magnets in the two rings, 18 for the HER and 7 for the LER. These circuits encompass the entire tunnel and include a total of 882 magnets. The maximum operating power is 4550 kW total, 2550 kW (56%) for the HER and 2000 kW (44%) for the LER strings. All the power supplies are in one location, the Region 8 support building, to simplify personnel-safety interlocking for the tunnel.

The HER and LER magnet strings are each powered from a large bulk dc power supply followed by switching-type dc-dc converters (choppers) for individual control of each string. There are a total of 41 choppers rated at 200 kW each for the 25 circuits. The large dipole strings are split in half and use 4 choppers per half string in series/parallel. The other string circuits have 2 choppers in series or only one chopper depending on the voltage. The overall architecture is very similar to that of PEP I.
Two sets of air-insulated indoor switchgear and 12-pulse thyristor-controlled rectifiers are being purchased for the PEP-II bulk dc power supplies. One set is for the HER strings and one for the LER. They are fed from two existing 2500 kVA transformers used for PEP I. Each rectifier produces an unregulated and unfiltered positive and negative 600 Vdc at up to 2400 A to the downstream choppers. All dc bus filters are distributed into the racks with the choppers. The rectifiers provide low inrush currents and fast fault protection. The rectifiers are being designed and built by Alpha Scientific of Hayward, California.

The 500 V, 400 A chopper modules are designed conservatively. Two Toshiba 600 A, 1200 V IGBT modules alternately conduct at 10 kHz, producing a net 20 kHz internal frequency. Turnon and turnoff loss snubber networks are both used to minimize IGBT power dissipation. The IGBT's, free-wheeling diodes, snubber diodes, and snubber resistors are all mounted on water-cooled, cold-plate style heat sinks. The electrical connections are primarily done with laminated bus bars to minimize inductance. The efficiency of the chopper at rated output is 96.5% with more than one-half of the losses in the snubber resistors. The maximum IGBT junction temperature is 104 °C at a maximum loss of 800 W and a maximum inlet water temperature of 35 °C. In addition to the water cooling, two fans are also used to cool the output inductor and to cool the bus bars. The choppers use current-mode control with an outside voltage feedback loop. This enables parallel operation of the chopper modules. The chopper module was designed and a prototype was tested by LLNL. The production units are now being fabricated.

5. REFERENCES

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