A NEW POWER SUPPLY SYSTEM FOR THE IEX PROJECT AT THE APS *

B. Deriy[#], M. Jaski, J. Wang, ANL, Argonne, IL 60439, U.S.A.

Abstract

A new IEX beamline providing circularly polarized x-rays that will cover photon energies from 250 eV to 2.5 keV is under development at the APS. Because of the unique requirements of the electromagnetic variably polarizing undulator (EMVPU) constructed for this beamline, a new power supply system design is required. The undulator will contain sixteen sets of electromagnetic coils--two main, two quasi-periodic, and twelve correctors. The undulator will incorporate variable polarization control and reduction of the magnetic fields at so-called quasi-periodic pole locations for the purpose of suppressing the higher-order radiation harmonics. The challenges met in the power supply system design for the project will be discussed.

INTRODUCTION

A new power supply system (PSS) was designed to satisfy the unique requirements of the EMVPU providing circularly polarized x-rays. The undulator is expected to be 38 periods (Fig. 1). To specify the required parameters for the final device, a four-period prototype of the EMVPU was built and tested. The downstream part of it is shown on Fig. 2.

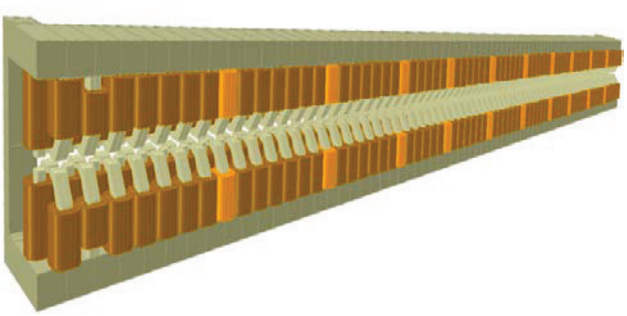

Figure 1: 38-period electromagnetic undulator.

THE PSS SPECIFICATION

The EMVPU power supply system has sixteen outputs:

1. two bipolar outputs for the main horizontal and vertical field coils,
2. two bipolar outputs for quasi-periodic coils, and
3. twelve bipolar outputs for correction coils.

The power supplies have to be bipolar to provide the demagnetizing of the device. The final requirements for the main coils power supplies were determined after the EMVPU prototype testing; they are shown in Table 1. The number of poles for the quasi-periodic magnet was determined to be any number between 16 and 22, and required to be changeable. That defined the

Table 1: Main EMVPU Specifications

General	Period	12.5	cm
	Gap	10.5	mm
	Periods per device (including end poles)	38	Periods
Horizontal Linear Polarization	Minimum Photon Energy	250	eV
	Required vertical effective field	4510	Gauss
	Current density in the copper conductor[2]	4.7	A/mm^2
	Current	47.6	A
	Turns per coil[1]	62	turns
	Ampere-turns[1, 2]	2951	Ampere-turns
	Watts per coil[1, 2]	44.9	Watts
	Total number of coils	152	Each
	Total power[2]	6630	Watts
	Maximum temperature of coils	100	°C
Vertical Linear Polarization	Minimum Photon Energy	440	eV
	Required horizontal effective field	3310	Gauss
	Current density in the copper conductor[2]	4.9	A/mm^2
	Current	50.3	A
	Turns per coil[1]	46	turns
	Ampere-turns[1, 2]	2314	Ampere-turns
	Watts per coil[1, 2]	40.2	Watts
	Total number of coils	304	Each
	Total power[2]	11,868	Watts
	Maximum temperature of coils	100	°C
Circular Polarization	Minimum Photon Energy	440	eV
	Required horizontal and vertical effective field	2340	Gauss
	Current at vertical effective field	20.7	A
	Current at horizontal effective field	34.2	A

[1]End coils are smaller
[2]At the required effective field

requirements for the power supplies for the quasi-periodic coils Bxqp (50.26A/3536W max) and Byqp (47.54A/1978W max).

Correction Magnets PS

Since the undulator has nonlinearities, especially during transients, and the fields are very sensitive to misalignment, the system has to be improved to correct

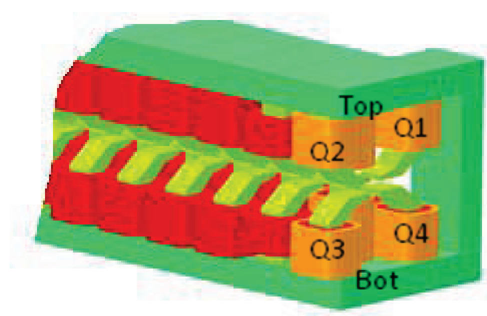

Figure 2: Downstream portion of the EMVPU prototype. Six trim coils are shown in orange.

*Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
#bderiy@aps.anl.gov

all measurable EMVPU perturbations. The correction system consists of twelve channels. Each end of the undulator has 6 trim coils for steering the electron beam. In Fig. 2 the trim coils are shown in orange.

Based on the calculation and test results of the EMVPU prototype, the following numbers were specified for the correction magnets power supplies:

- Top and bottom: 5.5 A max, 45 W max
- Quadrants: 5.84 A max, 40 W max

Depending on the current flow in these six coils, the corrector can be configured as either a normal or a skew trim magnet - dipole, quadrupole, sextupole, or octupole.

Other Requirements for the EMVPU Power Supply System

The output currents have to be synchronized with any of the following sources: internal timer, storage ring timing system trigger, a user's trigger, or another external signal.

Software should provide programming output currents for routine procedures with a single command, e.g., soft-start, soft-shutdown, programmable slew rate, degaussing. Degaussing should be run every time the power supply turns off. A support for both long and short degaussing methods has to be implemented. The long method includes sequential energizing of all coils with bipolar ramping-down currents. The short method includes an empirical to find a current of opposite polarity to compensate the residual field.

THE EMVPU DEVICE PS SYSTEM

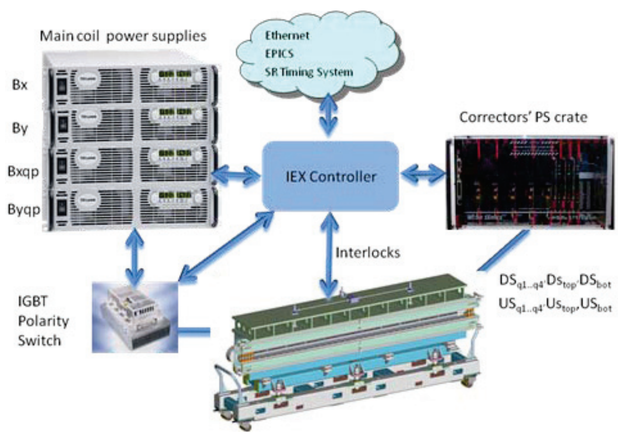

Figure 3: The EMVPU Device PS System.

The EMVPU PS System includes two 15-kW TDK-LAMBDA power supplies for Bx and By coils, two 5-kW TDK-LAMBDA power supplies for Bxqp and Byqp coils, a BIRA MCOR crate containing twelve 12 A power amplifiers for correctors coils, and four IGBT polarity switches.

To "glue" all of these power components into a system, an in-house EMVPU controller was designed. At the prototyping phase a set of modules was designed and tested (Fig. 6). At the final phase it is converted into one module, the EMVPU controller, occupying the leftmost position within the MCOR crate. A similar approach was used for the CPU designed at the APS a few years ago [1]. The major difference is that this time a VME IOC is not required – the EMVPU controller will talk to EPICS directly.

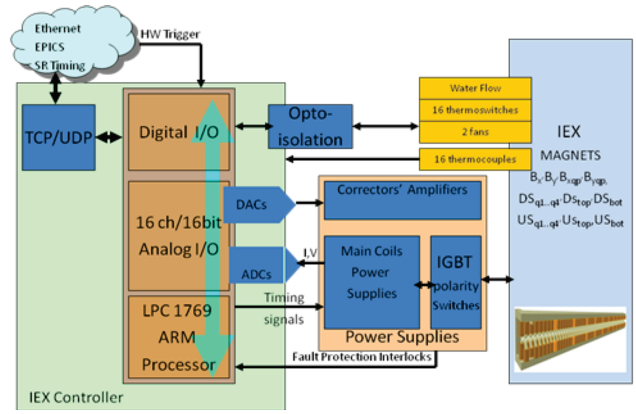

Figure 4: The EMVPU Controller Connection.

The ARM-based Microcontroller(Fig. 5)

In the heart of the EMVPU controller is an ARM Cortex M3 32-bit 120-MHz LPC1769 processor. The PCB has a 68-pin DIP connector that is mounted on a socket of the baseboard. Unlike its well-known 40-pin MBED predecessor, which has to be programmed over a USB port, it uses a standard JTAG connector for programming and debugging the program. An extended pinout allows exploiting of all features of the processor. At the same time, the MBED library was adopted, allowing programming of the embedded module on the pinout level with the Keil µVision4 IDE. The IDE combines project management, source code editing, program debugging, and complete simulation in one powerful environment. The RealView Real-Time Library --including the RTX kernel, flash file system, and the TCP/IP protocol suite--was also utilized.

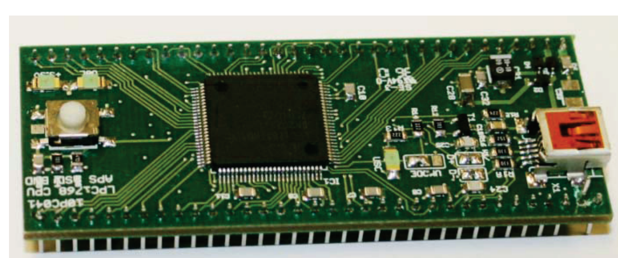

Figure 5: The ARM-based microcontroller.

To facilitate the firmware design, C++ classes were developed for all of the major components of the EMVPU controller: ADC AD7608, DAC DAC8718, TDC ADT7411, thermo-sensors LM75 and LM83, DIO Expander PCA9539, and LCD TFT display.

Communication with EPICS asynDriver was tested over Telnet, TCP, and UDP. Implementation of a set of high-level commands for communication with EPICS over asynDriver has begun.

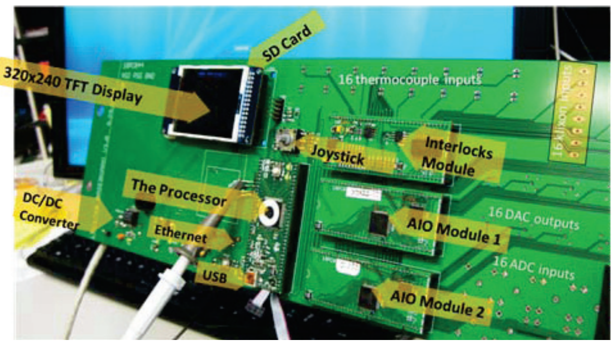

Figure 6: A 19" baseboard and full set of modules built for the IEX project development.

Analog I/O

The 16-channel 16-bit analog I/O is built around two top-of-the-line products: AD7606 from Analog Devices and DAC8718 from Texas Instruments. AD7606 is a pin-to-pin compatible version of the 18-bit ADC AD7608. This fully integrated device facilitates building of a high-resolution data acquisition system. It has remarkable parameters, such as 8 simultaneously sampled inputs; true bipolar ±10 V, ±5 V analog input ranges; single 5-V analog supply; 2^{nd} order anti-alias analog filter; analog input overvoltage clamp protection; over-sampling capability with digital filter; 200 kSPS throughput rate for all channels, 90 dB SNR at 200 ksps; and on-chip accurate reference and reference buffer.

Another member of the analog I/O, DAC8718, has 16-bit resolution with 8 channels; flexible ±2 V to ±16.5 V bipolar output; up to +33 V unipolar output; with its system calibration it can be calibrated down to ±1 LSB; 15 µs settling time; channel monitor output; programmable gain and offset; and up to 50MHz SPI.

Interlock Module.

The undulator has 16 thermocouples (one thermocouple on a coil for each power supply) and 16 pairs of thermal switches (two switches on a coil for each power supply in parallel, NC, 110°C). It also has two fans with programmable turn on/off condition. The following interlocks will shut down the power supplies and give an indication on the local control panel and via the remote control line:

- AC input over-current
- AC input voltage failure
- DC output over-current
- DC output over-voltage
- Over-temperature on power components
- Over-temperature on magnets
- Cooling water failure
- Cabinet door open
- Power components failure
- Three external interlock inputs with normally closed contacts for ASIC, MPOB, and E-stop.

To monitor and serve the interlocks, the following devices are implemented on the interlock module:

ADT7411: 16 analog channels for T/D conversion with 0.25°C resolution. A HW interrupt is generated when preset window limits are exceeded. It communicates over a fast I2C bus.

PCA9539: 16-channel parallel port expander has latched outputs with high-current drive, open-drain active-low interrupt output; 5-V tolerant I/O ports; 400-kHz fast I2C bus.

FM25V10: 1Mb Ferroelectric Nonvolatile RAM has 10 year data retention and up to 40-MHz serial peripheral interface SPI. It is a direct hardware replacement for serial flash. With an SD card it will be used for keeping historic data for fault analysis.

The Firmware

The high-level state diagram for the PSS is shown in Fig. 7. All functional blocks on the diagram will be implemented in the EMVPU controller firmware.

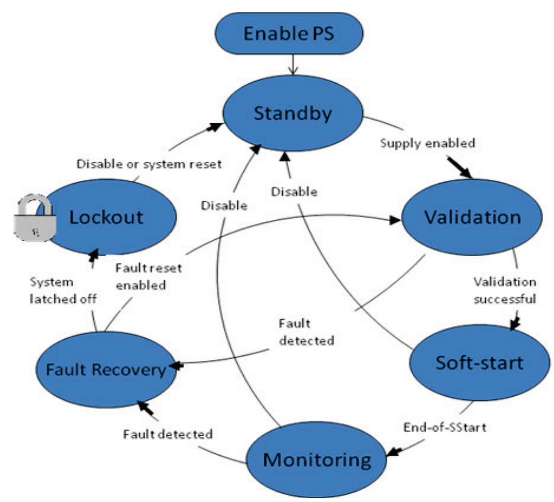

Figure 7: The PSS high-level state diagram.

CONCLUSION

The development of a new beamline providing circularly polarized x-rays at the APS has progressed from testing of the prototype to building the final system. Major details of the new power supply system designed for this electromagnetic undulator were discussed in this paper.

ACKNOWLEDGEMENTS

The authors would like to thank Al Hillman, Tony Puttkammer, Marty Smith for valuable help in this project, and Thomas Meier for his efforts in building electronics .

REFERENCES

[1] B.N. Deriy, O.A. Makarov, I.B. Vasserman, "An arbitrary function generator for the electromagnetic insertion devices at the APS," Rev. Sci. Instrum. 73, (2002) 1427