CONTROLLER OF POWER SUPPLIES FOR CORRECTOR MAGNETS OF EUROPEAN XFEL

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Abstract

The European XFEL is under construction now in Hamburg [1]. It is a big international project. Budker Institute of Nuclear Physics (BINP) developed, produced and delivered power supplies for corrector magnets of XFEL. A controller for these power supplies was developed. It provides an 18 bits resolution of digital-to-analog converter and 6 channels of precise analog-to-digital converter with high accuracy and resolution. A combination of the general-purpose functions with the specific function for power supplies allowed using the same controller for different equipment of corrector magnet subsystem. Here is described the controller, its properties and main applications.

INTRODUCTION

The European XFEL is 3.4-kilometre-long facility, which is located mainly in underground tunnels. It consists of a linear accelerator, undulators, electron and photon beam transport system. Eleven countries make the joint efforts for this international project. The Budker Institute of Nuclear Physics (BINP) takes participation in creating the European XFEL. BINP produces and delivers warm magnets, vacuum chambers, some cryogenic equipment and so on.

In frame of this works the BINP develops, builds and commissions the family of power supplies for corrector magnets. The family consists of models with output current 5 and 10 Amperes and with different output voltages. The quantity of power supplies to be 330 pieces [2]. Really the quantity should be above 400 pieces, it will be explained below. The Fig.1 shows the power supply.

Figure 1: The power supply for corrector magnets.

The requirements to power supplies includes high accuracy (less than 100 ppm), low output ripples (less than 10 ppm) and high reliability (MTBF >100000 hrs). The high reliability is required to reduce the pause in XFEL operation during replacing failed power supply by spare one. To reduce this time there is used the same trick like in most DESY installations- each rack with power supplies (up to 7) is equipped by spare power supply and controlled switch. When control software detects a failed power supply it tries to restart it and this attempt was not successful it replaces a failed power supply by spare one.

CONTROLLER OF POWER SUPPLIES

There was decided to use analog regulation for power supplies. That means we need a precise digital-to-analog (DAC) channel, a few of precise analog-to-digital (ADC) channels and discrete input/outputs. Using a modular approach in developing power supply we can implement the controller as a universal module (Fig.2.) which may be used in different applications.

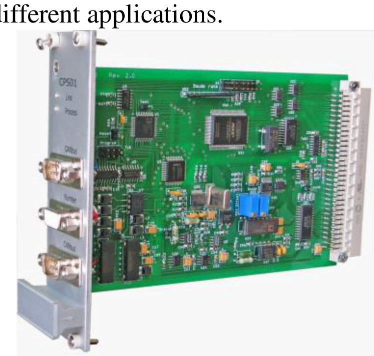

Figure 2: Controller CPS01.

The second possible application is providing an interface for the controlled switch. All power supplies for corrector magnets are located in 48 euro-racks. So, we have 48 controlled switches (one per rack). For this purpose is suited more simple device which have not ADC and DAC. But even the simple device should have network interface, microcontroller and something else. And more important we should have separate documentation, separate production order and separate certification for European standards. More cheap way is to increase total quantity of identical controllers.

Most power supplies for magnet system in XFEL use CANbus as lowest level network. So, it is the reason for our choice of the same interface.

The controller was implemented using typical structure for similar applications (Fig.3.).

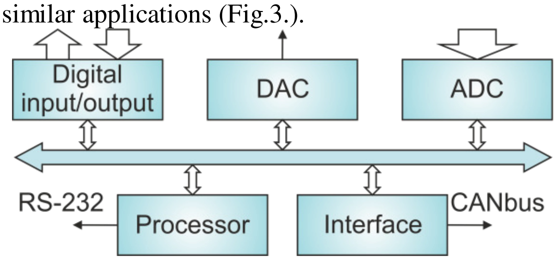

Figure 3: The structure of controller CPS01.

As for DAC, there is used chip AD5781- 18-bits DAC (Analog Devices). We use circuitry recommended by producer. The parameters of this chip satisfy the specification requirements. When we choose DAC chip

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we kept in mind that Analog Device has AD5791 chip which is pin-to-pin and bit-to-bit compatible but it provides resolution 20 bits. So, if we would need in increasing DAC resolution for some power supplies we could replace the DAC chip only. The firmware of microcontroller will work with this chip without any changes.

As for ADC, we need to satisfy specifications for power supply:

- DC accuracy better than 100 ppm
- output noise less than 10 ppm (rms) in bandwidth 0÷2kHz

Choosing ADC chip and schematics we kept in mind that for mass production of 400 power supplies we need a lot of precise equipment. We need to have a few precise stands for testing and tuning power supplies and we need a multichannel system for 24 hour burn-in test. It means to have ≈10 amperemeters with accuracy at least 20 ppm. Using industrial voltmeter for these stands is expensive choice and it means many problems with integration this equipment in united measurement system.

We considered as an optimal choice to make this equipment with DCCT as sensor and ADC of controller as digitizer.

To provide high DC resolution the sigma-delta ADC is more suitable. Here was chosen ADS1255 chip (Texas Instruments). It provides high resolution and acceptable rate of measurements. Fig.4 shows structure of ADC.

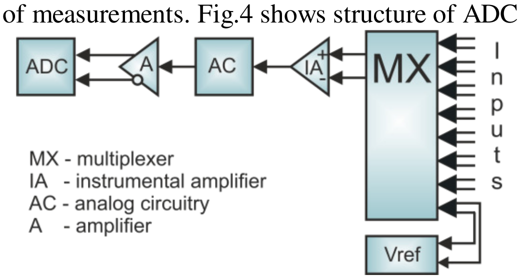

Figure 4: Structure of ADC.

The device works with differential input signals. After two-wire multiplexer the selected signal accepted by instrumental amplifier. Then common-mode signal is processed by analogue circuitry. Here the signal is converted from ±10 V range to 0,5÷4,5 V range. The circuitry suppresses high frequency components of signal. And then the signal is converted to differential mode. It allows to reduce the noise of ADC (using full input range of chip) and to improve linearity of digitizing.

Input multiplexer provides 8 inputs. 6 from them are used for measurement of external signals. Two inputs are used for calibration of system and are connected with ground and the precise reference source (AD688, Analog Devices) with typical drift near 1 ppm/°C. In main (multichannel) mode ADC digitizes predefined input channels (from 0 to 5, for example). Before each scanning these channels the microcontroller performs calibration of zero and range for all system. It consumes some time of course but it ensured the accuracy.

Described schematic provides high DC parameters and acceptable AC parameters. For low data rate (from 2,5 to 50 measurements/second) it has linearity 10 ppm and noise from 1 to 5 ppm (peak-to-peak).

For measurements of ripples we need a highest data rate. ADC has data rates 1, 2 and 3.75 kHz. On highest data rate the ADC noise is 30÷35 ppm (peak-to-peak). This resolution is enough for detecting ripples out of specification. Additionally the power supply circuitry extracts the error signal from output current, amplifies it by 100 and connects this signal with ADC input.

For measurements of ripples the oscilloscope mode of ADC is recommended. It this mode the microcontroller performs one calibration cycle and then digitizes a signal without time losses.

Controller has digital inputs and outputs. Outputs are used to switch bulk power supply on or off, reset the circuitry. Inputs are used to inform control system about status of power supply (overload, over temperature and so on).

Controller has two interfaces. One of them is CANbus and the second is RS-232. Users like to have a display which shows the output current at the moment. Usually developers use one from two ways. The first way is to use a cheap voltmeter with digital indication. The second way is to have display controlled by microcontroller of power supply. In this case the firmware of microcontroller should know which model of power supply it serves (or which device).

We have chosen the compromising approach. Most properties of controller are independent from controlled equipment. For example, range of ADC and DAC is always ±10 V. All measurement data is transmitted through RS-232 to smart module with OLED display and microcontroller. This module is part of power supply and it knows which equipment it serves. It allowed making important part of firmware more conservative. Any possible improving of user interface (accumulating data, additional processing, graphics etc.) may be done with intact firmware of controller.

The CANbus is used for interaction with control system. The firmware of microcontroller provides the following functions:

- control and monitoring components of power supply including some high level functions
- interaction with the control system providing a flexible set of functions. The command set was created in collaboration with XFEL people from software department
- low level primitives which allows for control software to use resources of controller as general purpose independent devices

APPLICATION OF CONTROLLER

It was mentioned above that we have chosen the one universal controller for different applications. Here we use it for replacing failed power supply («hot swap»). In this application only digital input/output ports are used. Usually we call it «redundancy system». It is shown in

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fig.5a. The reserved power supply is located in lowest floor and controlled switch is located in highest floor.

The second additional application is the final acceptance test. It performed with special test rack (fig.5b). Instead of controlled switch the measurement crate is installed here (top floor in rack).

Figure 5: Racks with power supplies: with redundancy system at XFEL (left) and the burn in rack with the measurements crate (right).

The measurement crate has 7 home-made precise amperemeters. There are 7 sensors based on DCCT (Ultrastab, LEM) and precise shunts VPR221 (Vishay). As digitizers here are used 3 controllers. They measure 7 voltages on shunts (actually it is current) and temperatures of shunts.

All components of measurement circuitry have high linearity and low drift (1÷2 ppм/°C). But we checked stability with calibrator 5730A (Fluke). It provides 2 A maximal output current only. Fig.6 shows deviation of output current from reference (error signal) and temperature of shunt (ambient temperature) for one channel.

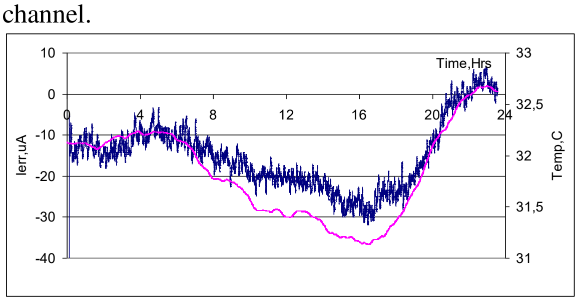

Figure 6: Error of current measurement (blue) for channel 4 and ambient temperature (red).

The graphics shows that the drift of measurement is 30 μA when temperature is changed on 1,5°C. The measurements for negative current and zero current confirmed that the drift for all measurement channels is less than 3 ppм/°C.

The measurement of current inside the power supply is built with the similar components and circuitry. So, it means we can rely on stability both power supply and measurement system.

CONCLUSION

At the moment all power supplies are produced, tested and delivered to XFEL. Most of power supplies passed acceptance tests at installation already. The control system of XFEL serves first racks more than 1 year [3]. No ideological problems were detected. Commissioning full system will be completed at end of 2016.

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