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QUENCH PROTECTION IN DIGITAL POWER SUPPLIES FOR SUPER-CONDUCNTING MAGNETS IN ADS

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Abstract

The front-end demo superconducting Linac for Chinese ADS (Accelerator Driven Sub-critical System) project is under construction at institute of modern physics (IMP) in Lanzhou. It will demonstrate the key technologies and the feasibility of a high power beam for the future national project "the Chinese Initiative Accelerator Driven Subcritical System (CIADS)". In this system, there are about 60 superconducting magnets, including solenoids, vertical corrector and horizontal corrector. They are utilized to focus and correct the proton beam. Quench protection of the superconducting magnets is key to reliability of the facility. A full digital power supply is developed and employed as excitation source for all of these superconducting magnets. In this paper, an FPGA-based Quench protection scheme implemented in the power supplies is mainly described. The commissioning results show that it is feasible.

INTRODUNCTION

The front-end demo for Chinese ADS project is constructing at the Institute of Modern Physics (IMP) in Lanzhou. It is one of the major tasks of the China accelerator driven sub-critical system (China ADS) proposed by Chinese Acadamy of Sciences (CAS) is one of "Stratage Tecnology Pilot Project" started in 2011. The 25 MeV, 10mA, continuous-wave (CW) superconducting proton Linac will to the key technologies and the feasibility of a high power beam for the future national project "the Chinese Initiative Accelerator Driven Subcritical System (CIADS)".

There are about 60 superconducting solenoids in this in this facility. The objective of the superconducting solenoid is to focus and correct proton beam. The effective length of a superconducting solenoid is 200 mm. And each solenoid has one vertical correction and one horizontal correction. The quench of the magnets is an important question for this project, so it is necessary to talk about implementation of quench. In this project, A quench protection scheme which is carried out inside power supplies for the superconducting magnets was adopted.

POWER SUPPLIES FOR SUPER-CONDUNCTION MAGNET

Main Circuit

The power supplies for the superconducting magnets are a full digital power supply [1]. They are specially developed for the superconducting magnets in Chinese ADS project. The rated value of power supplies for the superconducting solenoids is ±180A/5V, and the rated value of the power supplies for their corrector is ± 25A/5V. A schematic diagram of main circuit structure is show in Figure 1. The C1 is energy-storage capacitor, the K1~K4 means H bridge structure. The discharge circuit consists of the K5, K6, R1, R2 and L (R2 and L are parameters of load). The inductance of the superconducting solenoid is about 1.4 H. And the inductance of their corrector is about 0.036H. The discharge circuit is controlled by the quench signal from the superconducting magnets. The discharge circuit has two state: normal state and quench state. In normal state，the two switcher (K5 and K6) keep open; in quench state, the K5 is closed and K6 is open if current is positive. In quench state, the K6 is closed and K5 is open if current is negative. The state transition of all the switchers is in charge of the FPGA-based digital controller.

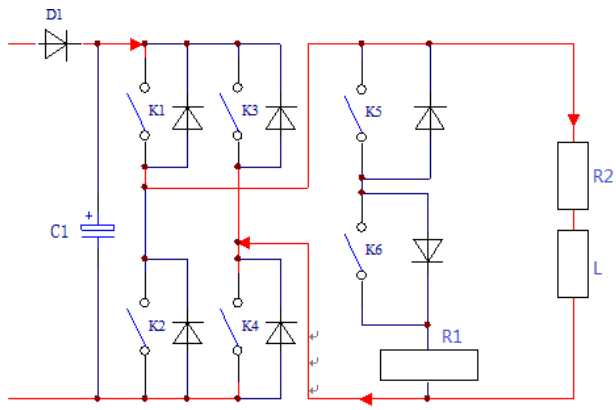

Figure 1: A schematic diagram of main circuit structure.

FPGA-based Digital Controller

The digital controller is a key component for the power supplies [2]. Figure 2 shows the structure of the digital controller of the power supplies. Its core unit is an FPGA (Cyclone II, Altera company). And there are two CPUs (NIOSII) in the FPGA. The CPU1 is used to transmit control data, the CPU2 controls the regulator to generator current. All control data and parameter is saved in the SDRAM. The ETHERNET is main communication interface between the controller and the accelerator control system. And the quench protection module is designed for quench protect of the superconducting magnets. For the fast protection and high reliability purpose, the module is implemented by VHDL. VHDL (VHSIC Hardware Description Language) is a hardware description language used in electronic design automation to describe digital and mixed-signal systems such as field-programmable gate arrays and integrated circuits. VHDL can also be used as a general purpose parallel programming language.

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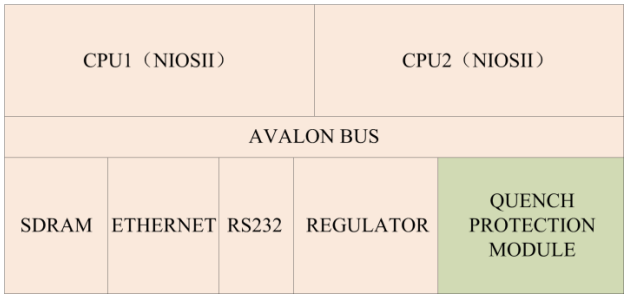

Figure 2:The structure of the digital controller.

QUENCH DETECTION MODULE

Quench protection module of the superconducting magnets is key to reliability of the facility, so it ensures not only fast response but also good veracity. A requirement is that the response of quench protection action is less than 100 us. The interface of the quench protection module is described in Figure 3. The Ut is the terminal voltage of the superconducting magnet, and the T is its temperature and Uo is the output voltage of the power supplies. G and /G are utilized to control the K5 and K6.

According the change of the T, Ut and Uo, exact quench detection can be realized in this module. The parameters of the quench protect and protection could be set and saved to the controller through the Ethernet. One of the parameters is sensitivity of quench detection. It is a 32-bti integer, whose resolution is 0.5 us. This parameter should be set appropriate, it has an important influence on the reliability and accuracy of quench detection.

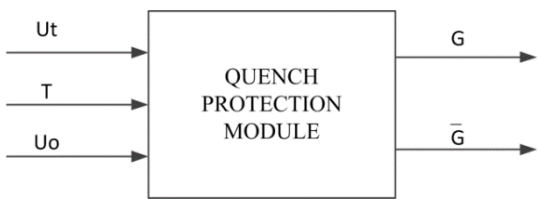

Figure 3: The interface of quench protection module.

The quench protection module is designed as an independent avalon-bus module [3]. The current value, Ut and Uo are sampled each 3 us, which exist for computing and judging the quench conditions. The threshold voltage and the threshold current are written in advance into this module. In order to compare with the threshold values, the Ut, Uo and T are transformed by a series of operations. To speed up the operation, these operations are implemented in the module through using the parallel hardware multiplier inside the FPGA. In this case, the module works independent of the operating system (μ COSII) based the CPUI and CPU2. So as long as the parameters are set correctly, the module could run fast and reliably. The quench detection and protection process is mainly decided by the Ut and Uo, because the variation of T is slower than the voltage and the area of temperature change is great, it difficult to detect the change exactly. In the project later, the detection way based parameter T is not used actually.

In addition, as soon as the quench state is detected in each power supply, a fast interlock signal will send to the interlock protection system.

RESULTS

The quench protection detection has been successfully varied in the simulator platform of laboratory. And the on-line current curve of quench state of a superconducting solenoid is showed in Figure 4. The curve shows the discharge process of the superconducting magnet after quench. The current value closes to zero until the process keeps more than ten seconds. The current value is about 48A before quench state is detected.

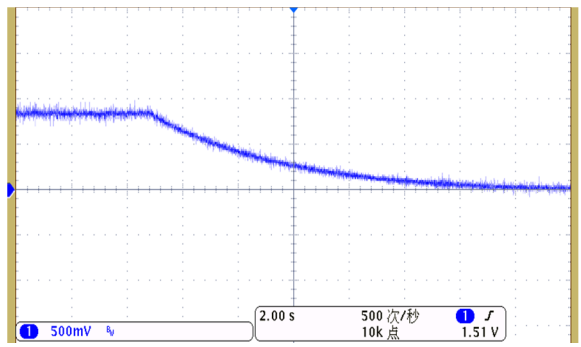

Figure 4: On-line current waveform of quench state.

CONCLUSIONS

An FPGA-based quench protection scheme was implemented in the superconducting power supplies for Chinese ADS. For the fast protection and high reliability purpose, the quench protection module is implemented by VHDL. The on-line test results testify that the feature of the quench detection and protection is feasible. In the future, an improved quench protection method would be development based on the engineering experience of Chinese ADS and the more advanced technology.

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