Logic of Quench Protection Assembly for BEPCⅡ Interaction Region Superconducting Magnet

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Abstract Two superconducting magnet complexes are used in BEPCⅡ interaction region. The corresponding quench protection system divides all related faults into two classes and takes different protection actions according to the urgency degree. Since BEPCⅡ has two operating modes and the superconducting magnets use different power supplies in different operating modes, the quench protection system must take the mode switching into consideration.

Key words BEPCⅡ IR superconducting magnet complex, quench protection system, quench protection logic

1 Introduction

BEPCⅡ is an upgrade project of BEPC, the Beijing Electron Positron Collider. It is designed not only as an electron-positron collider in the energy range of 1.55GeV to 1.89GeV, but also as a dedicated synchrotron radiation facility at the energy of 2.5GeV. In order to meet the machine requirements, a superconducting magnet complex will be used on each side of the interaction point (IP). The BEPCⅡ interaction region (IR) superconducting magnet complex consists of 3 anti-solenoid (AS1, AS2, AS3), 1 quadrupole (SCQ), 1 dipole (SCB, also used as a horizontal dipole corrector HDC in collider mode) and 2 sets of corrector coil (VDC, SKQ). AS1, AS2 and AS3, together named AS, are powered with one 1300A unipolar power supply in series while AS2 and AS3 have their independent trim power supplies to achieve fine tuning[1—3]. The magnet coil layout is shown in Fig. 1 and the power connection configuration for AS is shown in Fig. 2. Table 1 gives the main parameters of the magnet coils.

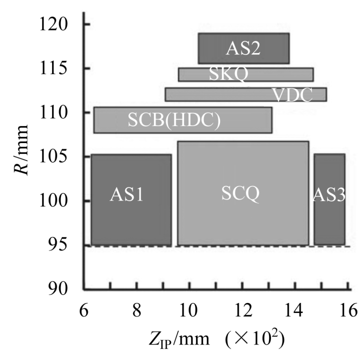

Fig. 1. The coil layout schematic.

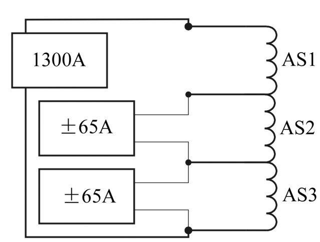

Fig. 2. The power connection configuration for AS.

Simulations indicate that the stored energy at the operating current is high enough to burn the coils if the magnet quenches without a protection system[3]. An active quench protection system is necessary to switch off the power supplies and extract the stored

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energy. The quench protection system for this magnet includes the quench detector (QD), the quench protection assembly (QPA) and the interface chassis (QPAIC) between QD and QPA. The digital quench detector based on DSP technology monitors the voltage taps from magnet coils and the current signals from DCCT of QPA. When a quench or fault case is detected, QD sends a quench link input (QLI) signal to QPAIC. QPAIC inspects all the signals from QD, the magnet power supplies, QPAs, the cryogenic system and the central control system, and makes judgment based on the protection logic resided in PLC, then sends commands to relevant systems. QPA implements corresponding protection actions according to the QPAIC commands[4].

Table 1. Main parameters for BEPCⅡ IR superconducting magnet coil.

	inductance/ mH	operating current/A	stored energy/kJ	power supply I_R/A
AS	78	1120	48.92	1300
AS2	10	±55	–	±65
AS3	14	±55	–	±65
SCQ	143	460	15.13	580
SCB	25	495	3.06	580
(HDC)		±50	0.03	±65
VDC	62	±24	0.02	±65
SKQ	102	±45	0.10	±65

2 Quench protection assembly and power supply

The quench protection assembly acts as a switch between the power supply and the magnet. When QPA receives the fault signal from QPAIC, it shuts off the power supply and triggers the IGBT driver board to open IGBT. The power feeding loop is interrupted and a dump loop is set up while IGBT is opened. The dump resistor and snubber circuit are switched into the dump loop to extract the stored energy from the magnet. Snubber circuit can remarkably reduce the instant voltage pulse at the moment of dump resistor switching into the dump loop[4].

The magnet uses three types of power supplies: 1300A unipolar, 580A unipolar and 65A bipolar, also called corrector power supplies. A different type of QPA is used for unipolar and bipolar power supply. Fig. 3 and Fig. 4 give the inner structure of QPA.

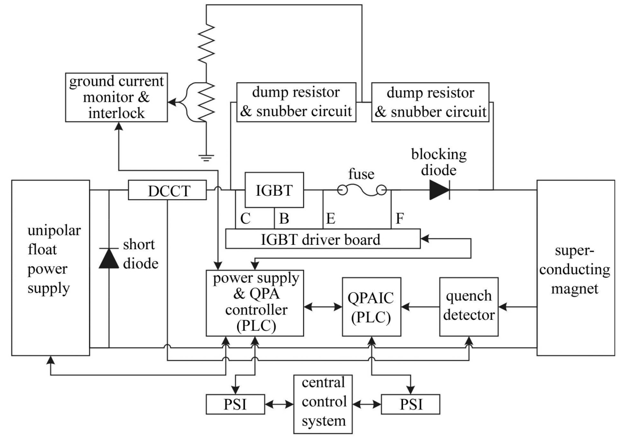

Fig. 3. The quench protection assembly block diagram for unipolar power supply.

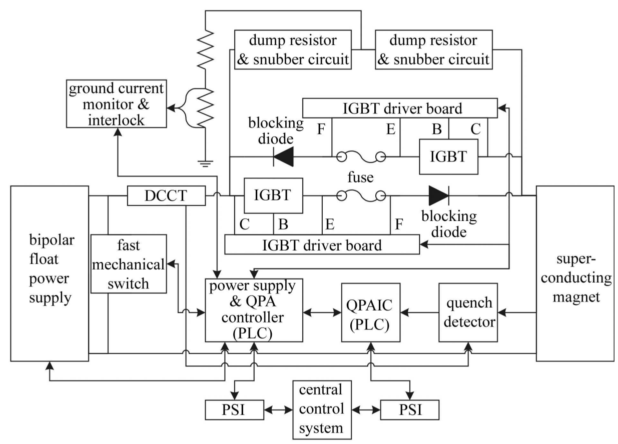

Fig. 4. The quench protection assembly block diagram for bipolar power supply.

The power supplies and QPAs must be float to ground. The whole system is grounded through the mid-point of dump resistor and snubber circuit. This connection method halves the maximum absolute voltage induced in the coils to ground. The ground current is monitored as a safety interlock parameter.

3 Quench protection assembly interface chassis and protection logic

The quench protection assembly interface chassis is the brain of the whole system. Fig. 5 is the structure of the QPAIC cage, which is composed of a group of PLCs, a monitor computer, a PSI module and a UPS module.

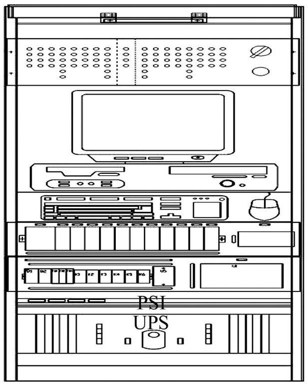

Fig. 5. The quench protection assembly interface chassis structure.

3.1 Basic consideration and design principle of protection logic

Ensuring the safety requirement of magnets is the basic function of the quench protection system. Convenient troubleshooting and fault diagnostics are also necessary for a flexible system. These goals require, firstly that the protection logic should be simple, effective and fast response; secondly, all faults should be monitored as interlock and logged into database. Because the general protection logic treats all faults equally, any inessential fault will also trigger the whole protection system to switch in the dump resistor that results in the magnet quenches since the current drops too fast. To reduce the potential damage from those avoidable quenches, faults are divided into two classes and different protection actions will be performed for different classes of fault.

For the BEPCⅡ IR superconducting magnets, the quench protection logic shall be designed to have two operating modes corresponding to BEPCⅡ.

3.2 Faults related to quench protection system

Faults related to the quench protection system come from the following systems:

1) **PS fault.** PS Fault denotes all types of faults which occur in power supply.

2) **QPA fault.** QPA faults include Fuse Fault, IGBT Fault, Ground Over Current, QPA Thermal Fault and Fan Fault. QPA Thermal Fault denotes the temperature of dump resistor or heat sinks is higher than the threshold value.

3) **QLI.** Quench link input signal indicates that a quench is detected or the quench detector crashes.

4) **Cryo fault.** Two signals come from the cryogenic system. Cryo Fast Discharge signal means a fatal fault and Cryo Slow Discharge signal a common fault.

5) **SSM fault.** A superconducting solenoid magnet SSM is used in BESIII (Beijing Spectrometer III), the detector on BEPCⅡ southern interaction point. The BEPCⅡ IR superconducting magnets are located inside SSM. The SSM fault may affect the BEPCⅡ IR magnets in some unknown ways.

According to the degree of urgency, these entire faults are divided into two classes. The classification is listed in Table 2.

Table 2. Fault classification list.

first-line fault	secondary fault
QLI	PS fault
fuse fault	QPA thermal fault
ground over current	fan fault
IGBT fault	cryo slow discharge
cryo fast discharge	SSM fault

3.3 Function of quench protection assembly interface chassis

QPAIC receives those entire fault signals listed in Table 2, makes a judgment based on the protection logic and sends commands to the related subsystems. Fig. 6 shows the logic diagram of QPA and QPAIC.

Definition of "system ready"

If all power supplies, QPA, and relevant systems have no fault and all power supplies' main loop turns on (PS Ready), QPAIC sends a "System Ready" signal to central the control system.

Precondition of current ramping

When the Local/Remote switch on power supply turns to "Remote", any ramping operation on local is disabled. Only when the Set-Point is zero, can the central control system turn on the power loop (PS Ready). The central control system enables the ramping operation only when the "System Ready" signal is received.

Protection actions for first-line faults

QPAIC sends a "first-line fault" signal to all controllers for PS and QPA on the fault occurrence side. The controllers turn off the power loop and open the

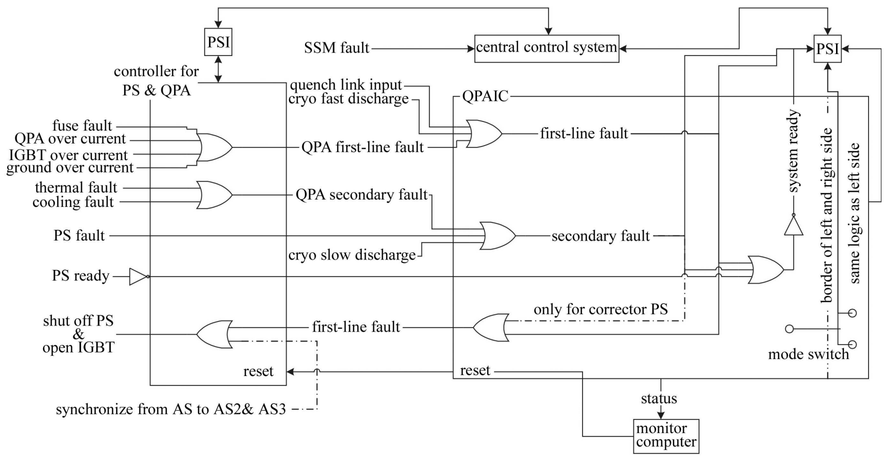

Fig. 6. The logic diagram of the QPA and QPAIC.

IGBT to switch dump resistor into dump loop. In the meantime, the fault signal is also sent to the central control system through PSI. The central control system set the current point to zero. All these faults will be latched, logged and indicated on the local panel.

Since the current of corrector coils is small and a rapid drop of current may not result in quench, to simplify, the "secondary fault" from the corrector power supplies and QPA is treated as "first-line fault", that means the dump resistor can be switched into dump loop.

Protection actions for secondary faults

The "secondary fault" signals from AS, SCQ, SCB power supplies and their QPA are sent to the central control system through PSI while the QPA takes no action. The central control system ramps the current of all PS on the fault occurrence side to zero. "SSM fault" is sent directly to the central control system from the BESⅢ control system. The central control system ramps the current of all PS on both sides to zero. All these faults will be latched, logged and indicated on the QPAIC local panel.

If any first-line fault was detected during the protection actions for secondary faults, the whole system turns to first-line fault status immediately.

System recovery after faults removed

After the faults are removed, press the reset button on controller for PS and QPA first, and then press the reset button on QPAIC. QPAIC will send "system ready" to the central control system.

Operating mode of BEPCⅡ [1]

BEPCⅡ has two operating modes: the Collider mode and the synchrotron mode. The collider mode uses 7 power supplies, including AS, AS2, AS3, SCQ, HDC, SKQ and VDC. The synchrotron mode uses 2 power supplies, which are SCB and VDC. SCB and HDC power the same coil under different modes. A switch will be used to connect the correct PS to power loop.

Operating mode switching

Since different operating mode use different power supplies, a mode switch is needed to shield the signals from the unused power supplies. The operating mode information is also sent to central control system and the local panel.

4 Conclusions

The BEPCⅡ IR superconducting magnets' quench protection system adopts fault classification method to reduce the possibility of quench caused by current drop. Mode switch is used to alter the operating mode without more configurations. All the fault signals will be logged into the monitor computer for diagnostics. Therefore, the logic of this QPA makes the whole system smart and practical.

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BEPCⅡ 对撞区超导磁铁失超保护系统逻辑

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摘要 在BEPCⅡ对撞区中采用了两块结构复杂的超导磁铁. 该超导磁铁的失超保护系统的逻辑将所有相关的故障分为两类, 并根据两类故障的紧急程度采取不同的保护措施. 因为BEPCⅡ有两种运行模式, 所以该超导磁铁的失超保护系统还必须要考虑运行模式的切换问题.

关键词 BEPCⅡ对撞区超导磁铁 失超保护系统 失超保护逻辑

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