Quench protection of the central solenoid model coil for CFETR

Yuanyuan Ma[a,b], YuWu[a], Liuwei Xu[a], Yanan Wu[a], Yanlan Hu[a], Teng Wang[a,b]

[a]Institute of Plasma Physics，Chinese Academy of Sciences，Hefei 230031 China

[b]University of Science and Technology of China

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I. INTRODUCTION

China Fusion Engineering Test Reactor (CFETR) is a new project to be conducted in China and is being designed now. In order to develop and verify the technology of superconducting magnet, the development of CS model coil (CSMC) is carried out firstly. The CS model coil, which has the same scientific and physical parameters as the CS prototype coil, is wound with cable in conduit conductors (CICC).

The operate current of CSMC is designed to be 47.65kA, so the stored energy of coil will be up to 407 MJ. In order to ensure the safety of coil, such huge energy need to be released quickly enough to guarantee the maximum temperature of coil is lower than the qualified value. An active method for quench protection is adopted for CSMC. The quench protection circuit is composed of DC rapid circuit breakers, discharge resistor, diode and fuse. The main parameters of these component were selected. The quench protection control system was also introduced.

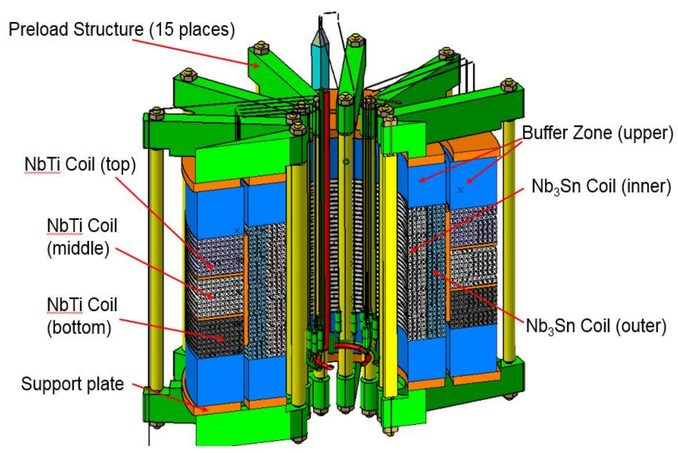

Fig.1. Structure of CS model coil

II. QUENCH PROTECTION CIRCUIT DESIGN

A. Magnet and power supply system

The CS model coil comprises five superconducting coils including Nb3Sn inner, Nb3Sn outer, NbTi top, NbTi middle, and NbTi bottom. The configuration of the Nb3Sn conductor is ((2sc+1 cu)×3×4×4+1 cu)×6. The configuration of the NbTi conductor is ((3sc)×3×4×4+1 cu)×6.The CSMC power supply system is a key component of superconducting magnet device. It is made up of 12 pulse thyristor converter unit, switching network unit, quench protection unit and other auxiliary component.

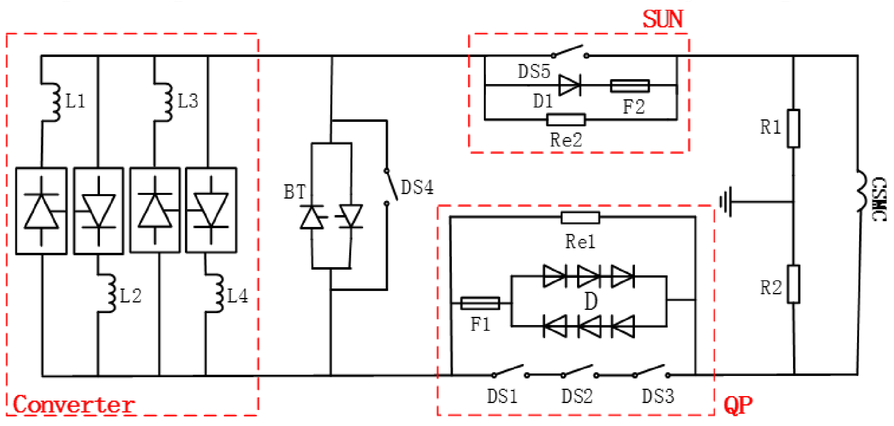

Fig.2. Schematic diagram of CSMC power supply system

B. Quench detection

Resistance voltage detection is the commonly used method to detect the quench of magnet due to its high sensitivity. We used a co-wound wire (CWW) embedded in the superconductor turn insulation and a co-wound tape (CWT) twisted around the conductors to measure the inductive voltage pick-up in the coil winding.

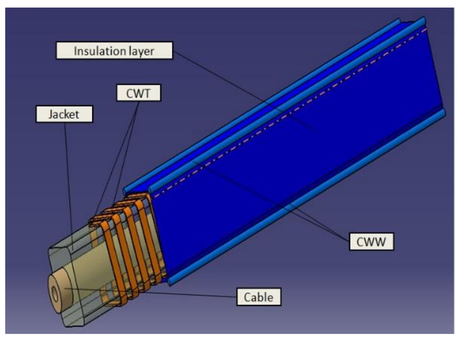

Fig.3. Schematic diagram of CWW and CWT wiring

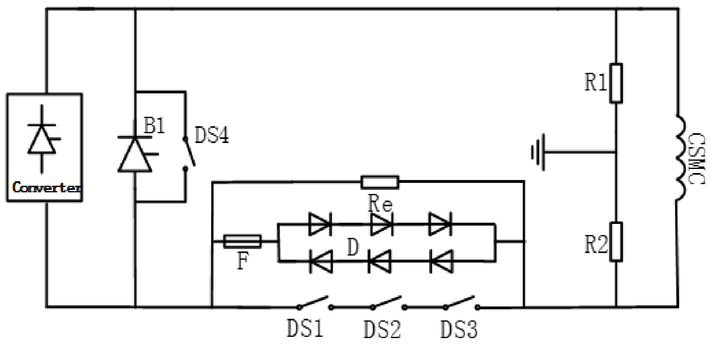

Fig.4 Main circuit of quench protection

C. Quench protection circuit

When a quench occurs at the maximum operating current which is 47.65kA, the coil current of the CS model coil should decay rapidly in order to avoid the temperature exceeding the limit of 150K.

Table 1. Parameters and requirements of CS model coil

Parameters	
Rated current (kA)	47.65
Limited voltage (terminal to ground, kV)	2.5
Quenching detection delay (s)	1
Quench protection switching delay (s)	0.5
Qualified hot spot temperature condition I^2t (A^2s)	7.95×10^9
Maximum energy dissipated in discharge resistor (MJ)	407.6
Maximum hot spot temperature(K)	150

To satisfy these requirements, the circuit of quench protection is designed. As shown in fig.4, the circuit is composed of the DC rapid circuit breakers (DS1, DS2, and DS3), discharge resistor (Re), diode and fuse. Three DC rapid circuit breakers are connected in series to improve the reliability of this protection system. In order to prevent the current go through the branch of fuse during normal operation of coil, the diode is connected with the fuse in series.

III. PARAMETER SELECTION OF COMPONENT

A. DC rapid circuit breaker

This breaker is a mechanical switch and has a large current and voltage rating. The contact resistance of breaker is about 5μΩ when the breaker is closed by electromagnet.

Table 2. The parameters of DC rapid circuit breaker

Parameters	Value
Rated frequency (Hz)	50
Rated voltage (kV)	2.5
Rated current (kA)	50
Rated breaking Voltage (kV)	3
Complete breaking time (ms)	~60
Mechanical life-time (operations)	5000
Electrical life-time (operations)	50

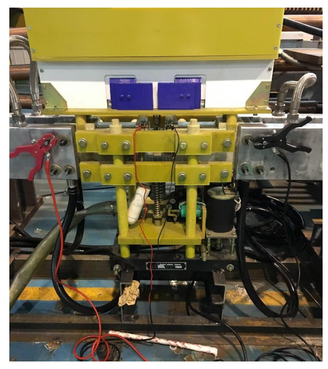

Fig.5 Contact resistance test of prototype

B. Discharge resistor

The discharge resistor need to have enough capacity to absorb the full energy stored in CS model coil. In order to ensure that the maximum temperature of coil is below 150K and voltage produced by coil current is less than 2.5 kV during the process of energy release, the resistance is selected as 51.2 mΩ.

C. Fuse

The fuse-element is copper and is put into a PVC tube filled with quartz sand to increase voltage grads and absorb more energy.

IV. QUENCH PROTECTION CONTROL SYSTEM

The quench protection control system consists of hardware control system and software control system to ensure the reliable control of the breaker's action in case of a quench. Three DS breakers are controlled to open in turn.

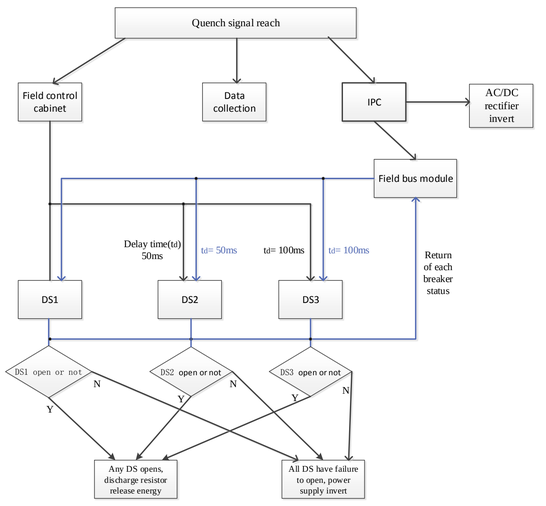

Fig.6 General flow chart of quench protection control system

V. CONCLUSION

A sensitive quench detection based on resistive quench voltage measurement is adopted. The prototype of breaker is developed and will be tested later. The parameters of discharge and fuse are calculated. Besides, the quench protection control system is descried in detail. The work of this paper will provide reference for the follow-up design work.

Author: Yuanyuan Ma, E-mail: mayuanyuan@ipp.ac.cn. Title: "*Quench protection of the central solenoid model coil for CFETR*"