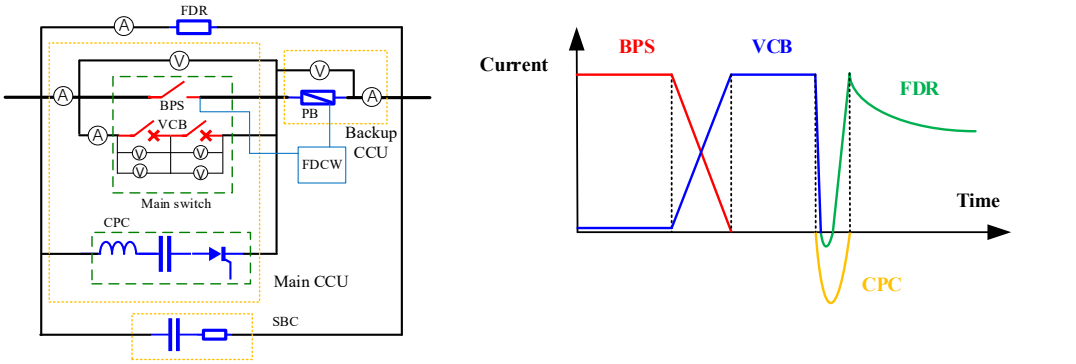
Design and Testing of Quench Protection System for ITER Magnet Cold Test Bench

Abstract: The Quench Protection System (QPS) incorporating a fast permanent magnet bistable mechanical bypass switch, an electromagnetic repulsion-based vacuum circuit breaker with reverse current zero-crossing, and a pyrobreaker backup achieves ≤240 ms response time for 70 kA DC interruption, validated by 72 consecutive successful interruptions.

1. Design scheme of Quench Protection System

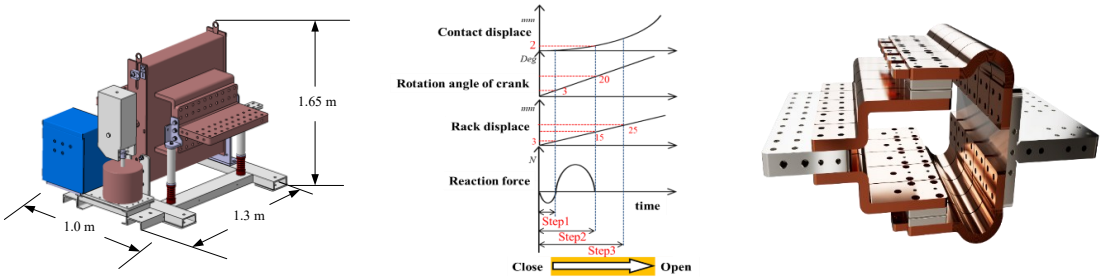
The circuit topology of Quench Protection System (QPS) is shown in Fig.1. The design of each part of QPS, including BPS, VCB and pyrobreaker, should consider many aspects including structure, cooling, contact pressure and resistance, etc, which have to meet the requirement from QPS normal operation(70 kA steady-state, 100kA short-time current for 100 ms). As the result, the structure, operation principle and contact are designed based on theoretical analysis and simulation, which are briefly shown as follows.



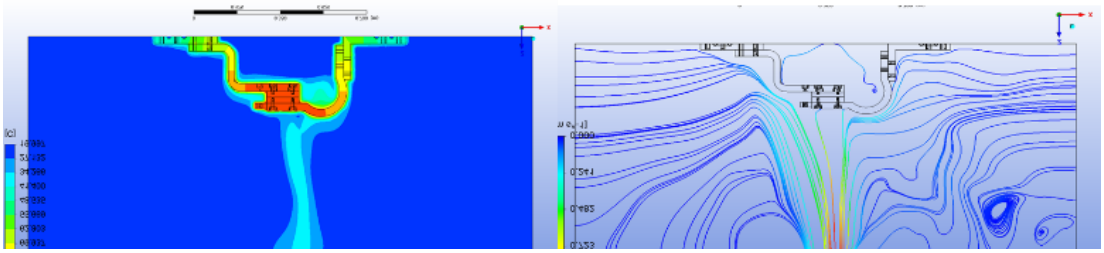
(a) The single line diagram of QPS (b) Operation program diagram of main QPS

Fig.1 The circuit topology of Quench Protection System (QPS)

1.1 Mechanical bypass switch (BPS)



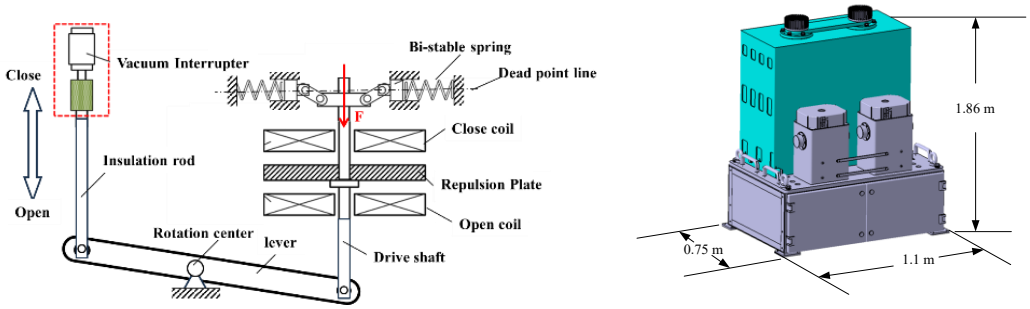
(a) Overall structure of BPS (b) The action process of the BPS (c) Contact structure of the BPS



(d) Center section temperature distribution (e) Center section velocity distribution

Fig. 2 Design of BPS

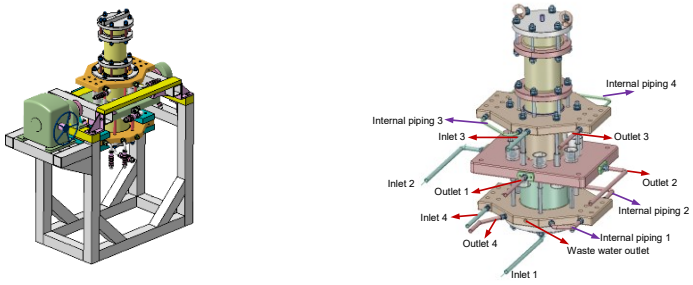
1.2 vacuum circuit breaker (VCB)



(a) Structure of VCB (b) Overall structure of VCB

Fig. 3 Design of VCB

1.3 Pyrobreaker (PB)



(a) The 3D model of pyrobreaker (b) Overall structure of VCB

Fig. 4 Design of PB

2. Test of Quench Protection System

The test of each component of QPS, including BPS, VCB, and pyrobreaker, is critical to validate their performance under extreme conditions. Key parameters such as breaking capacity, response time, and operational reliability must be verified to ensure compliance with QPS requirements. These tests involve factory acceptance tests, on-site commissioning, and simulation validation, as outlined in the following sections.

The BPS was tested under 100kA short-time current for 100ms, validating its thermal stability and contact resistance (<13μΩ). Factory acceptance tests (FAT) confirmed mechanical durability (2000 cycles) and rapid operation (<200ms opening time). VCB successfully interrupted 103kA DC in CRAFT trials, demonstrating reverse zero-crossing capability. Simulations validated static strength (261MPa) and dynamic response (≤20ms), while 5000-cycle mechanical endurance tests ensured reliability. PB achieved 100kA interruption within 200μs, verifying μs-level response and redundant protection. These tests collectively confirm QPS meets 70kA steady-state/100kA short-time requirements, with <240ms response and 72-cycle reliability, ensuring safe and efficient quench protection.

Conclusion: It is concluded that the QPS design has been demonstrated to provide reliable high-current protection (<70 kA DC) with sub-240 ms response time through integrated bistable mechanisms, electromagnetic repulsion technology, and redundant pyroprotection, while successfully undergoing 72 consecutive reliability tests this year.