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Full scale prototype of the JT-60SA Quench Protection Circuits

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HIGHLIGHTS

- Quench Protection Circuit (QPC) for the JT-60SA superconducting magnets.
- Advanced design solution based on a mechanical-static Hybrid Circuit Breaker.
- Development and manufacturing of the QPC full scale prototype (25.7 kA–4.2 kV).
- The paper principally describes the factory type tests to qualify the main components.
- The results were very satisfactory proving the suitability of the design.

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ABSTRACT

This paper deals with the development, manufacturing and testing of the full scale prototype of the Quench Protection Circuit (QPC) for the superconducting magnets of the JT-60SA Satellite Tokamak, which will operate in Naka, Japan.

After the completion of the system detailed design in summer 2011, the manufacture of the poloidal and toroidal prototypes was launched and completed at the beginning of 2012. Several factory type tests on the main components have been done at the manufacturers' premises and are described in this paper. Then, two main campaigns have been performed to test the operation of the overall poloidal and toroidal QPC prototypes; the main results are reported in the paper too.

1. Introduction

The Satellite Tokamak JT-60SA [1] is a full superconducting device which is being built in Naka, Japan. The superconducting magnets will be protected by Quench Protection Circuits (QPC), which provide a fast removal of the magnetic stored energy in case of quench, diverting the coil current into a discharge resistor.

An advanced design solution based on a mechanical-static Hybrid Circuit Breaker (HCB) was worked out [2,3]. It is composed of a mechanical By-pass Switch (BPS) for conducting the continuous current, paralleled to a Static Circuit Breaker (SCB) based on Integrated Gate Commutated Thyristor (IGCT) technology for current interruption; an explosive actuated breaker (pyrobreaker) connected in series to HCB assures the backup protection.

Large amount of work was made in the last years to develop and analyze this design solution and to perform experimental tests to prove the feasibility of the identified scheme [4,5].

Nevertheless, considering that there are no industrial or research applications with this hybrid technology for a level of power comparable to the JT-60SA case, it was scheduled to develop a full scale prototype both for the poloidal and the toroidal QPC to perform a wide range of type tests to check the design and to prove the performance.

2. The QPC prototype

The overview photograph of the full scale QPC prototype for the toroidal field (TF) coils is shown in Fig. 1; the BPS is the blue device on the left and the pyrobreaker is behind it; on the right within the gray cubicle there is the SCB with the QPC control on the right side; behind these devices there is the TF QPC discharge resistor composed of three cubicles.

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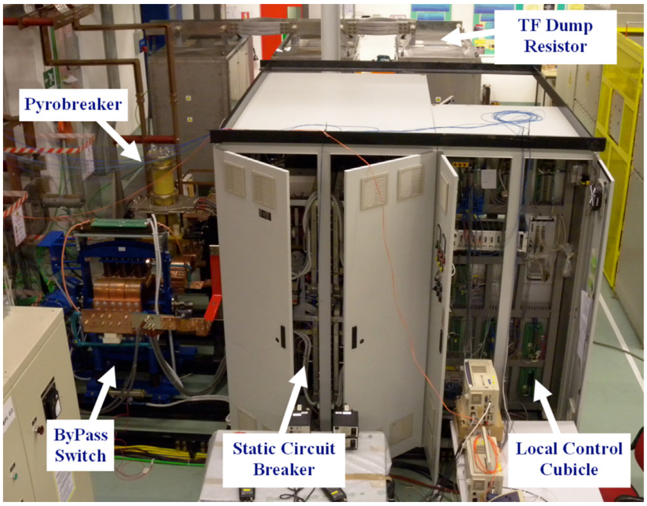

Fig. 1. Full scale QPC prototype for the TF coils.

Table 1
Main data of the TF and PF QPC.

Data	TF circuit	PF circuit
Units	3	10
Nominal/maximum voltage per unit (kV)	2/2.8	±3.8/±5
Nominal current (kA)	25.7	±20
Maximum current to be interrupted by the hybrid CB/pyrobreaker (kA)	25.7/25.7	±21/±22.5
Current polarity	Unidirectional	Bidirectional
Discharge resistance (Ω)	0.075	0.19
Duty cycle	Steady state	250 s/30 min
Delay time from the command (s)	0.35	0.35
Pyrobreaker operation delay (s)	0.001	0.001
Maximum allowed I^2t in the coil after quench detection (GA^2s)	4.6	2

The main QPC data, confirmed by the results of the tests on the prototypes are summarized in Table 1. They show improvements with respect to the technical specification (TS) values, summarized in [3], in the terms of operation time and voltage applied to the magnets.

3. The main features of the QPC system

The number of JT-60SA QPCs are thirteen in total, three for the TF coil circuit and ten for the poloidal field (PF) one. The features of the system and the design are described in detail in [3]; the basic scheme is recalled in Fig. 2. The main circuit breaker (CB) is composed of the mechanical BPS and the SCB in parallel. The TF SCB interrupts unidirectional current while the PF one is bi-directional, because this is required for plasma start-up and control.

The SCB and the control of the overall QPC unit was directly developed by Nidec ASI (formerly Ansaldo Sistemi Industriali), while the BPS manufacturing was sub-contracted to Siemens company, the pyrobreaker to Efremov Scientific Research Institute and the discharge resistors to Telema company.

4. The By-pass Switch tests

Although the current and voltage ratings of TF and PF QPCs are different (see Table 1), the supplier has proposed the same BPS for both, rated for the maximum current and voltage (25.7 kA–5 kV). This choice improves the modularity level and gives advantages in terms of maintenance and spare management, even if it implies a certain degree of over-rating.

The type tests, which had been differently specified for TF and PF QPC units, were performed on the single prototype at the highest values, the TF ones for the current values and the PF ones for the voltage values.

The withstand voltage capability was proved to be higher than the requirement: 20 kV_{rms}–50 Hz voltage was applied for 1 min both between the terminals of the open BPS and between the close BPS terminals and the earth according to IEC 60071 (Fig. 3).

The measure of the BPS closed contact resistance was 3.3 μΩ, thus less than the specified value of 5 μΩ.

The BPS is provided with an attached compressed air storage tank and non-return valve, so that it is possible to perform at least one opening operation even in case of full or partial loss of pressure from the compressed air supply system. This capability was tested by interrupting the connection of the BPS to the compressed air system and successfully performing one opening operation. The tightness and the pressure withstand of the gas-filled compartments of the BPS were verified following the IEC standards.

The BPS opening and closing mechanism were tested by means of 1000 complete opening-closing operations without replacements of any mechanical/electrical parts. No mechanical problems were detected at the end of the operations. The measured delay

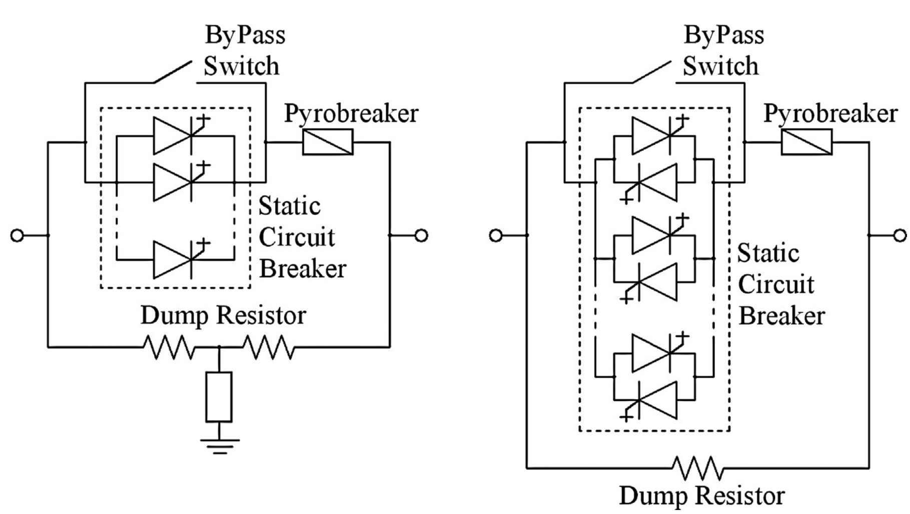

Fig. 2. Schematics of TF (left) and PF (right) QPCs.