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Instrumentation for status monitoring and protection of SST-1 superconducting magnets

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HIGHLIGHTS

- Details of status monitoring instrumentation are presented.
- Protection instrumentation details are presented.
- Instrumentation installation details, signal conditioning and DAQ system details and the results during SST-1 operation are presented.

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ABSTRACT

Superconducting magnets of SST-1 are extensively instrumented to continuously monitor the health of magnets during machine cool-down, plasma experiments and also during the machine warm-up phase. These instrumentations include temperature sensors, flow meters, hall probes, strain gages, displacement sensors, pressure sensors and voltage taps. The number of sensors and their locations has been optimized to systematically monitor all important magnet parameters to ensure its safety. In-house developed modular signal conditioning cards have been developed for these instrumentations. The data is acquired on a Versa Module Europa bus based data acquisition system (VME DAQ). This paper gives an overview of selection, installation, laboratory scale validations, and distribution logics of these instrumentations. Results during plasma campaigns and the up-gradation aspects of these instrumentations are also discussed in this paper.

1. Introduction

Superconducting magnets in tokamak generally operate at very high current densities and with limited operational safety margins. The magnet coil casings and its other support structures are under high steady state and cyclic electromagnetic loads and undergo about 300 thermal cycling during lifetime of the tokamak. As these magnets store high energies (few hundred MJ to few GJ), a single unprotected failure can lead to its permanent damage. Any repair activity on magnets can lead to a very long down-time of the tokamak as access to magnets for repair in tokamak configuration is very limited. To avoid such situations, these magnets are extensively instrumented with temperature sensors, flow meters, hall probes, strain gages, displacement sensors, pressure sensors and voltage taps etc. to monitor its behavior during different stages of tokamak operation and to initiate protection actions if magnet quench like faults conditions are observed. The logs of data from these instrumentations are also useful in analyzing the fatigue effects on magnet structures during its life time.

Steady-stead Superconducting Tokamak (SST-1) at the Institute for Plasma Research (IPR) is a medium size tokamak with a nominal toroidal magnetic field of 3.0 T at the major radius of 1.1 m. SST-1 is designed for steady-state 1000 s long pulse operations, in single-null and double null configurations [1]. Instrumentation of superconducting magnet system of SST-1 will be discussed in this paper.

2. SST-1 Magnet system

SST-1 Magnet system is a combination of resistive copper conductor based coils and superconducting coils. The toroidal field is produced by a set of 16 modified D shape superconducting toroidal field (TF) coils. The plasma shaping and position control magnetic fields are provided by 9 superconducting poloidal field (PF) coils, along with a pair of resistive PF coils, inside the vacuum vessel. The central solenoid magnet system is copper conductor

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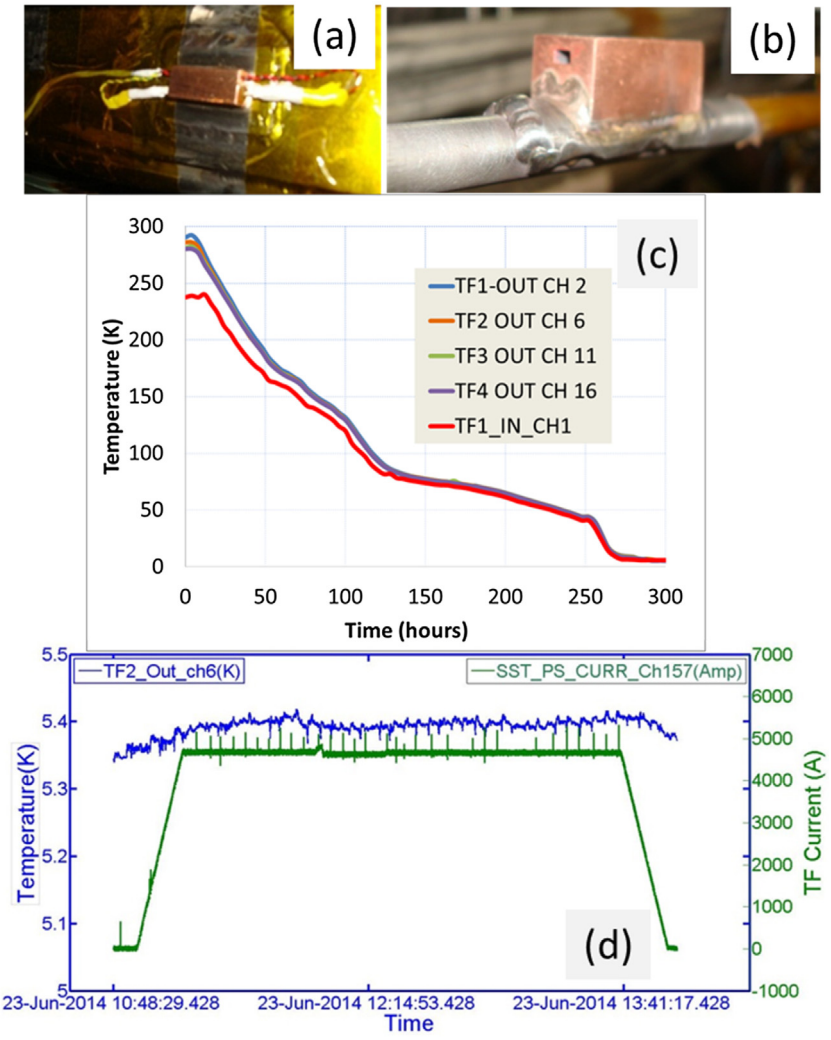

Fig. 1. Temperature sensor mounting blocks (a) & (b), temperature trends during TF coil cool-down (c), TF coil outlet temperature during coil current charging experiment (d).

Table 1
Superconducting TF Magnet System.

Number of TF coils	16
Conductor	NbTi/Cu based CICC
Winding Configuration	6 Double Pancakes (DP) per coil, 18 turns per DP
Cooling	4.5 K, 0.4 MPa supercritical helium with 1.25 g/s in each flow path (12 paths/coil)
Nominal current	10000 A
Total stored energy	56 MJ
Centering force	2.28 MN per coil
Overturning Moment	0.232 MN-m per coil
Twisting moment	0.054 MN-m per coil

based. Some important details of superconducting coils are given in Tables 1 and 2 and more details are available in Ref. [2,3].

3. Superconducting magnet instrumentation

SST-1 superconducting magnets have been extensively equipped with status monitoring and protection instrumentation. Instrumentations were selected considering the requirements of high vacuum, high magnetic field and cryogenic temperature environment of the tokamak. These were carefully distributed with across the magnet system to get sufficient redundancy at the critical locations while reducing the total number and the related wirings inside the cryostat.

Selection of well-established sensor technology, development of procedures for in-house installation and performance validations, careful cross checks of installed sensors during various stages of machine assembly to detect sensor or wiring damages has been the design philosophy of the instrumentation. In-house developed modular multi-purpose signal conditioning system and flexible data acquisition system were used to acquire the data from these instrumentations for on-line and off line analysis of the data. More specific details of these instrumentations are given in coming sections.

3.1. Temperature sensors

128 temperature sensors were installed on different coil inlet, outlet, coil casings, support structures and on intercoil joints. The maximum, minimum and average temperature information of all these locations were continuously transmitted to cryogenic plant to do cool-down and warm-up of all these magnets and structures in a controlled manner such that at no time, temperature difference between maximum and minimum temperature was more than 50 K. This was done to avoid excessive differential thermal stresses between different parts of magnets. A combination of two

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