Experimental Characterization Of The Hydraulic Behavior Of Cooling For Toroidal Field Magnet Of SST-1

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In order to validate the cooling configuration of the Steady State Superconducting Tokamak (SST-1) Toroidal Field (TF) magnet system, an experiment has been proposed on the actual TF magnet without having cooling channels for the casing, which houses the winding pack. A special cryostat has been designed for this purpose. The test magnet has been cooled with the Helium Refrigerator/Liquefier (HRL) in automatic mode. Appropriate temperature, pressure and flow sensors have been implemented at strategic locations. The paper will describe the test arrangements as well as results emphasizing the understanding on mechanism of SST-1 TF magnet cool down.

INTRODUCTION

The SST-1 superconducting magnet system (SCMS) [1] comprises of sixteen Toroidal Field (TF) coils and nine Poloidal Field (PF) coils. Cooling of large scale forced flow magnet system has been a point of debate and limited experience is available as far as superconducting magnet in Tokamak configuration is concerned. In order to build confidence and gather experience before cooling the SST-1 SCMS, it is planned to perform a test on integrated system of actual TF magnet with electrical isolators/helium feed-through, joints without actively cooling the casing of the magnet. The aim of the experiment is to study the temperature profile of the casing of the TF magnet without actively cooling the same while maintaining flow in the hydraulic path, identical to the actual flow requirement. Each of the TF coil is modified D shaped and made up of six double pancakes. Therefore, 12 nos. of flow paths, each with 48 m path length, are available for passing the coolant. An NbTi based Cable-in-Conduit-Conductor with 40 % void fraction for flowing the coolant, has been used for winding both the TF and PF coils of SST-1 [2]. The TF coil casing consists of two side plates, an inner ring and outer ring. The thickness of casing is 10 mm everywhere except at the inner leg, where it is 25 mm. The TF winding pack (vacuum pressure impregnated) is shrink fitted inside the casing, keeping a gap of 5 mm for the winding pack to move under thermal/electromagnetic stress. The bore dimensions are 1190 mm (radial) and 1746 mm (vertical), whereas the outer dimensions are 1560 mm (radial) and 2120 mm (vertical).

SYSTEM DESCRIPTION

Figure 1 shows the schematic diagram of the test set up. The single TF magnet is assembled inside a specially designed cryostat (3 m diameter, 3.2 m height) and hydraulically connected to the helium refrigerator/Liquefier (HRL) through vacuum insulated transfer line mounted with appropriate cryogenic valves for the process flow control. The cryostat has been specially designed in 3 parts, namely the top dished end, bottom dished end, and the shell in order to facilitate ease in assembly of the TF single magnet with all sensors and diagnostics. Four support columns with heat intercepts are raised from the bottom-dished end and the TF magnet is assembled from the support bars with specially designed hangers for minimum contact. Load on per support hanger is approximately 500 kg. The TF magnet assembly is

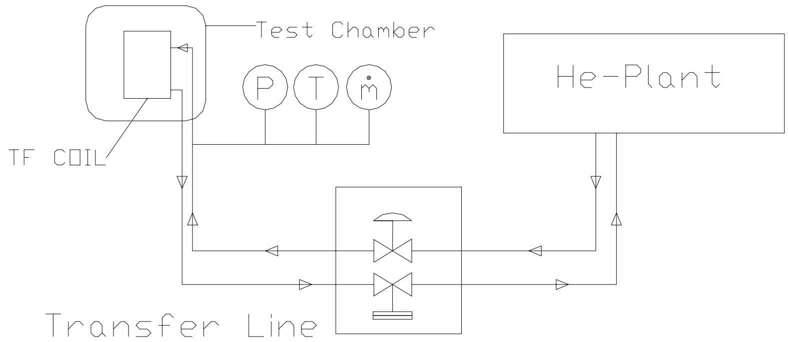


Figure 1 Schematic diagram of Test Setup

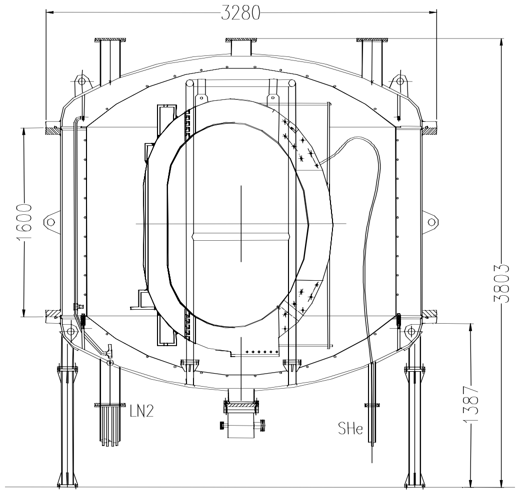
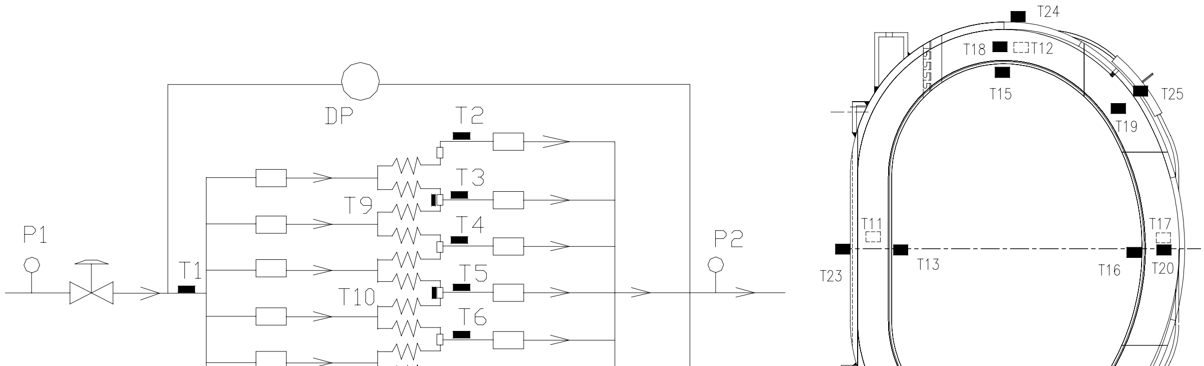


Figure 2 Assembly of TF magnet in cryostat

surrounded by an actively cooled liquid nitrogen (LN_2) shield, which is also made in 3 parts (top & bottom dished end and shell). LN_2 cooling paths are adjusted in such a way so that all the 3 parts of the LN_2 shield are able to cool simultaneously. Figure 2 shows the assembly of TF magnet in the cryostat on the support bars with hangers. Figures 3 (a) and 3 (b) show the location of the temperature sensors mounted on the hydraulic paths and on the casing of the TF magnet. All the temperature sensors are calibrated CERNOX sensors suitable to measure temperature in the range of 300 K to 4.2 K. Temperature Sensors T1 to T8 have been mounted on the hydraulic paths and T9 -T10 have been mounted on inter - pancake joints. Temperature sensors T11 to T 27 have been mounted at distributed locations on the TF magnet casing. Two numbers of KELLER make absolute pressure sensors at the inlet and outlet paths have been mounted to monitor the entry and exit pressures of the TF magnet. A differential pressure sensor across the magnet has been mounted to monitor the pressure drop. The total flow across the magnet is measured with a calibrated orifice flow meter. Four nos. of LAKESHORE make PT-102 (one no. each at top and bottom dished end and two nos. at the opposite sides of the shell) have been mounted on the LN_2 shield to monitor the temperature. A supervisory control and data acquisition system has been developed with programmable logic controller (PLC) to acquire all the measured parameters for analysis. All the necessary software has been developed indigenously on a base platform "WONDERWARE". In order to acquire the data, all the process parameters are first converted into the engineering range of 4-20 mA and fed to the PLC for processing. MIMIC pages display the on-line data as well as trend plots obtained continuously. The cryostat along with a 12 m long transfer line is pumped to a base vacuum of 2 $X10^{-5}$ mbar with the help of 1000 l/s turbo-molecular pump. The background for helium gas inside the cryostat has been continuously monitored with a quadrupole mass analyzer.



3(a) 3(b)

Figure 3 Location of the temperature sensors mounted on the hydraulic paths (3a) and on the casing of the TF magnet (3b)

COOLING SCHEME

Figure 4 shows the cooling scheme of the TF magnet along with the HRL. A 1 kW class HRL has been commissioned [3,4,] to cater the cryogen requirement at 4.5 K. On the down stream of the cold end of the HRL, an integrated flow distribution and control system (IFDC) [5,6] has been commissioned to distribute the SHe/LHe for the SST-1 SCMS. A branch line has been taken from the main supply and return line within the IFDC system and suitably connected to the test TF magnet with flow control valve. It is proposed to cool the single TF magnet in the same way as in the SST-1 SCMS, that is, by maintaining 50 K temperature difference between the inlet and outlet. Moreover, the pre-commissioning mode of the SCMS along with the HRL and on-line purifier also used for preparation of cleanliness inside of CICC.

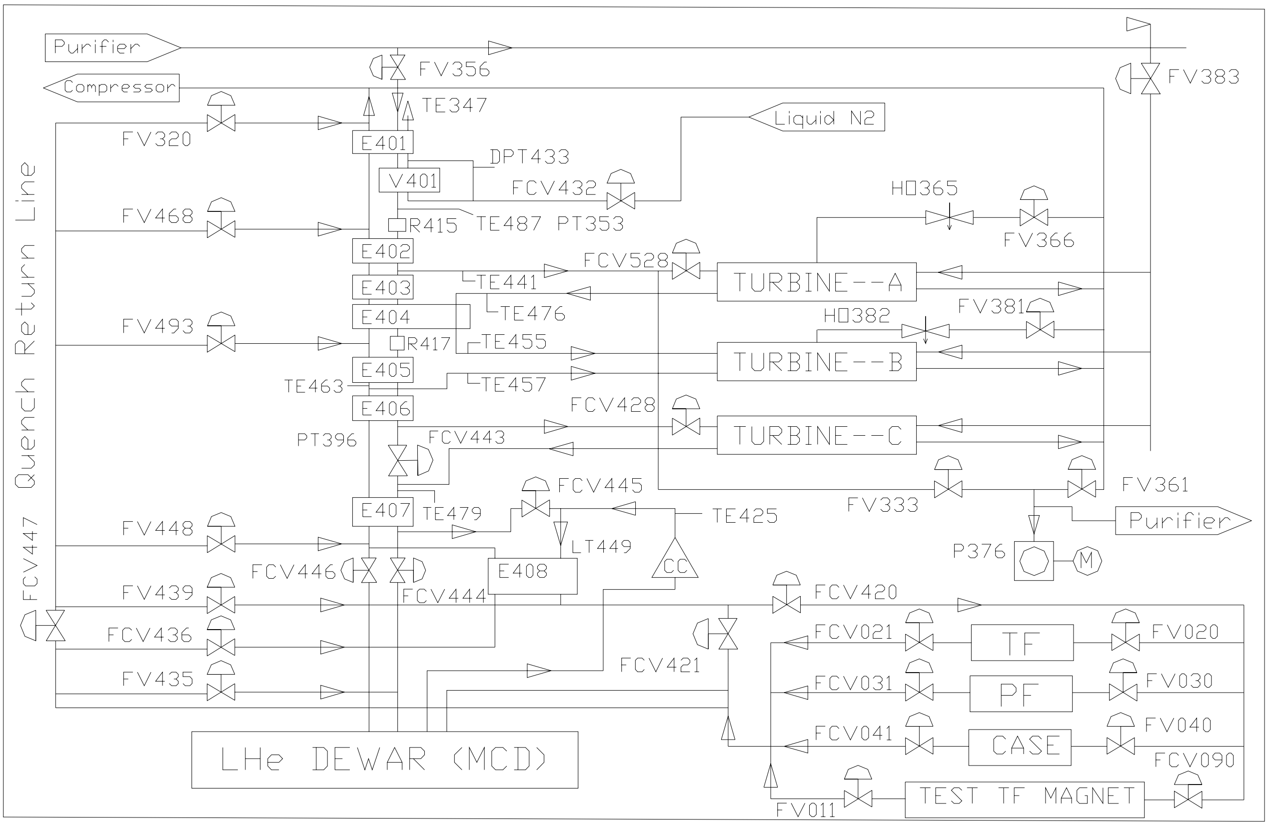


Figure 4: The cooling scheme of the TF magnet along with the HRL

The HRL consists of 7 nos. of heat exchangers to take care of the whole process. E 401/V401 are the first stage heat exchangers in the cold-box of the HRL. These have been designed with large margin to take care of the cool-down of SCMS of SST-1, for a cool-down flow rate adjusted at a maximum value of helium gas flow 50 g/s. The refrigeration capacity of the HRL, considering only E 401 is in the range of 15 kW and it is possible to cool-down the SCMS of SST-1 up to 100 K using the LN_2 exchanger. Turbines are, therefore, not operated. The outlet temperature is automatically controlled using valve FCV 432 which looks at the control loop for regulation. The control loop sequentially looks at the controlling parameters and adjusts the valve opening. The same procedure has been followed for cooling down the test magnet. The maximum of all the 27 temperature sensors is fed to the control loop as one of the controlling parameter for opening of valve FCV 432. The temperature-controlled flow of helium gas is diverted through FCV 443 – FCV 445 – FCV 420 and the return flow is back to the process circuit via FCV 447. The SCMS cool-down circuit of the HRL is adjusted in such a way that the return flow from the load joins the process circuit at appropriate location depending upon the temperature. The only problem, which was anticipated and was also observed, that for a single coil, the flow requirement at 300 K is very low and remains low throughout the whole temperature range of cooling in comparison to the SST-1 SCMS. Therefore, if the flow at the outlet of the HRL is regulated as per the requirement of the test TF coil, the coldbox circuits are warmed up. Therefore, in order to cool the cold-box circuits as well as to maintain the required flow in the test coil, sufficient flow has been taken from FCV 445 - FCV 420 and part of the excess flow is by-passed through FCV 031 – FV 030 of the IFDC system. The orifice flow meter at the outlet of the test coil ensures the flow rate requirement for cool down.

RESULTS AND DISCUSSIONS

Vacuum of the order of 5×10^{-5} mbar was successfully achieved in the cryostat. The TF coil inside circuit was pumped and purged 3 times with 10 ppm, pure helium gas before connecting the same with the HRL. The inlet temperature to the test TF magnet has been first set at 250 K keeping 50 K temperature difference. It has been observed that the HRL has automatically regulated the inlet temperature keeping 50 K temperature difference. The inlet temperature has been successfully reduced to 163 K while reporting the results. Thermo-hydraulic calculation shows that the flow requirement is 2.5 g/s at 300 K and increases to 4.5 g/s at 80 K and the actual flow was found to be in agreement. Figure 5 shows the typical cooling data obtained from the experiment. The results show that the overall average temperature is following the inlet to the hydraulics. The cooling time is, however, restricted due to the lagging in maximum temperature.

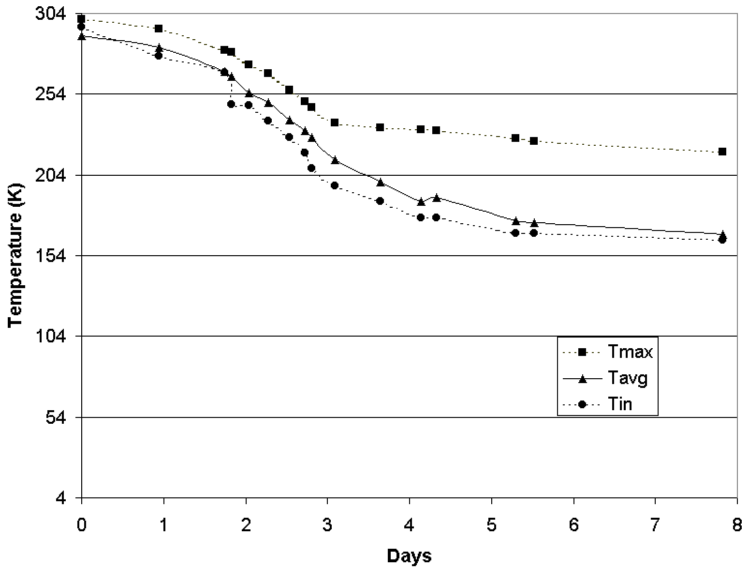


Figure 5 Typical cooling data obtained from the experiment

CONCLUSION

In order to develop confidence in operation of large volume superconducting magnets, such as in SST-1, it is necessary to perform test on at least one coil in actual configuration. In the present experiment, it is observed that the hydraulic paths are well cooled and follow the inlet temperature, whereas the casing lags. However, it is not possible to conclude the significant contribution of radiation cooling from the LN_2 shield to the casing as the inlet temperature is still above 90 K. In case any such contribution is observed during the experiment, active case cooling might probably reduce the lagging in temperature.

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