SST-1 Commissioning and First Plasma Results

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Plan of the talk:

- Machine Description
- Current Leads :
  - Development and test Results
- Cool down of SC Magnets
  - Cool down Scenario
  - Results
- Summary

SST-1 : A STEADY STATE SUPERCONDUCTING TOKAMAK

OBJECTIVES:

- **Study Physics of Plasma Processes in tokamak under steady-state conditions.**
  - Particle Control (fuel recycling and impurities)
  - Heat removal
  - Divertor Operation (radiation, detachment , pumping etc)
  - Current maintenance
    - LHCD, Bootstrap, advanced configurations
- **Learning new Technologies relevant to steady state tokamak operation:**
  - **Superconducting Magnets**
  - **Large scale Cryogenic system (He and LN_2)**
  - **High Power RF Systems**
  - **Energetic Neutral Particle Beams**
  - **High heat flux handling**

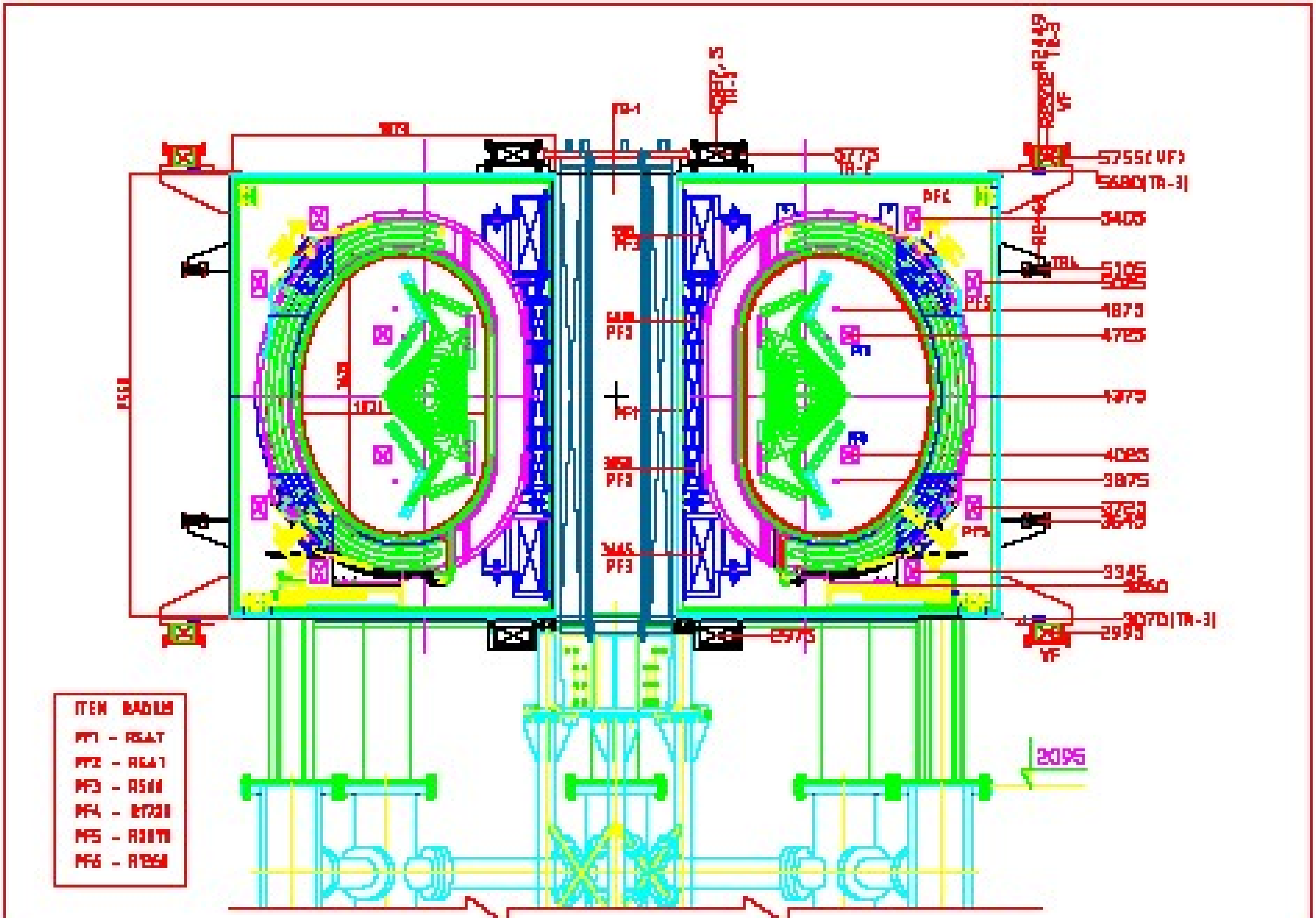
Parameters

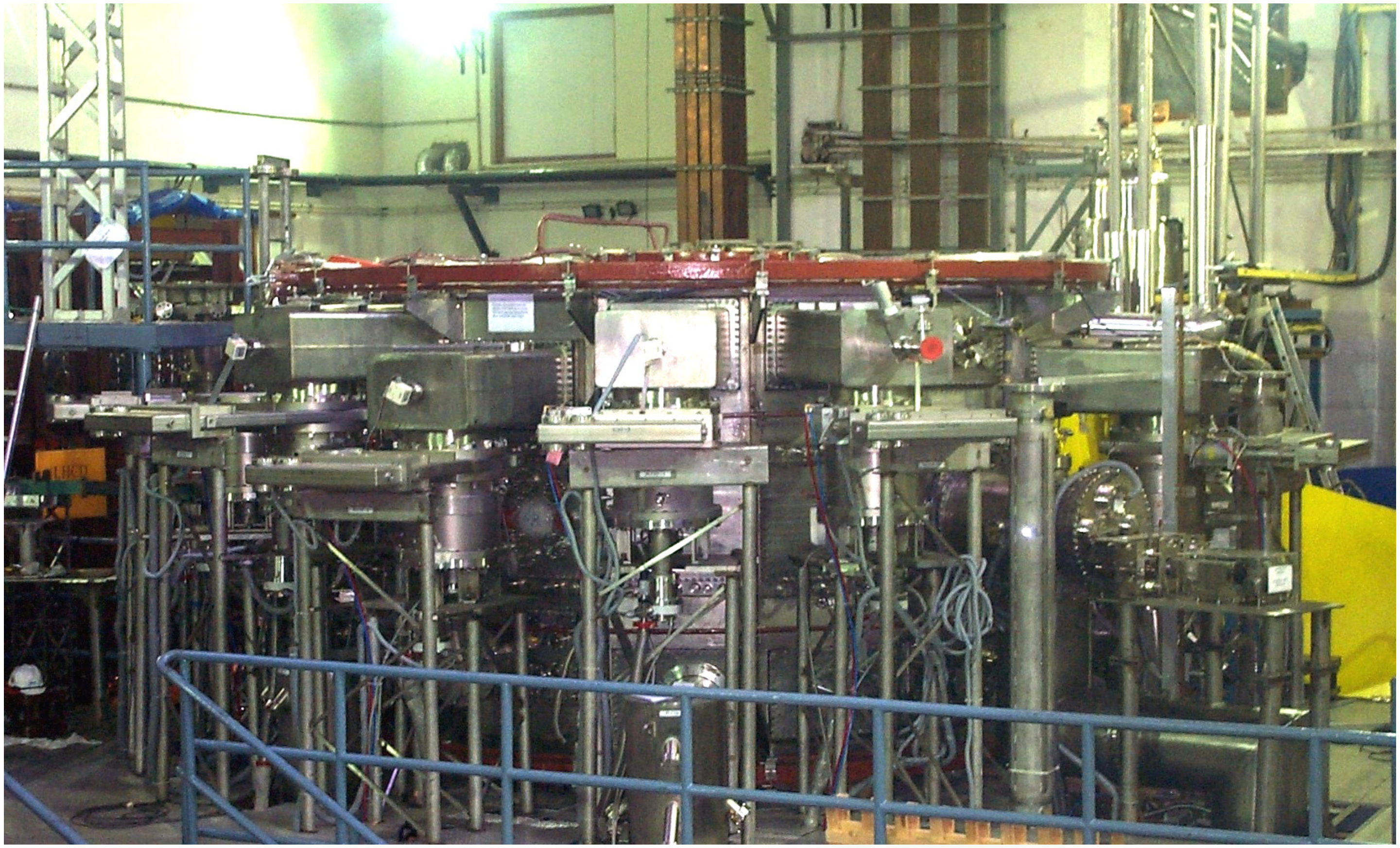
- Major radius : 1.1 m
- Minor radius : 0.2 m
- Elongation : 1.7-2
- Triangularity : 0.4-0.7
- Toroidal field : 3 T
- Plasma Current : 220 kA
- Average density : 1×10^{19} m^{-3}
- Average temp. : 1.5 keV
- Configuration: Double/Single null poloidal diverter

Current drive & heating

- LHCD (3.7 GHz) : 1.0 MW
- ECRH (84 GHz) : 0.2 MW
- ICRH (22-91 MHz) : 1.0 MW
- NBI (50 keV) : 0.8 MW

SST-1 Cross-section





A view of SST-1

Assembly was completed in first quarter of 2005

A DC bus & switching system, has been installed and tested for powering the Ohmic and vertical field coils of SST-1 from power supplies of ADITYA tokamak. Remote operation of the Power supplies from SST-1 control system has been established.

One pair of current leads for operating current of 10 kA at 4.2K has been designed and fabricated indigenously and tested successfully for required ramp rate and steady currents.

The leads have been integrated with the CFS of TF magnets.

The cryogenic systems, at 4.2K and 80K, have been commissioned and tested.

First phase diagnostics have been installed and the data acquisition and control system have been tested and commissioned.

A pair of radially movable poloidal limiters on outboard side and a pair of fixed limiters on inboard side, have been installed in the vacuum vessel preparatory to production of circular Ohmic plasma.

SUPERCONDCTING MAGNETS

PARAMETERS OF TF COILS:

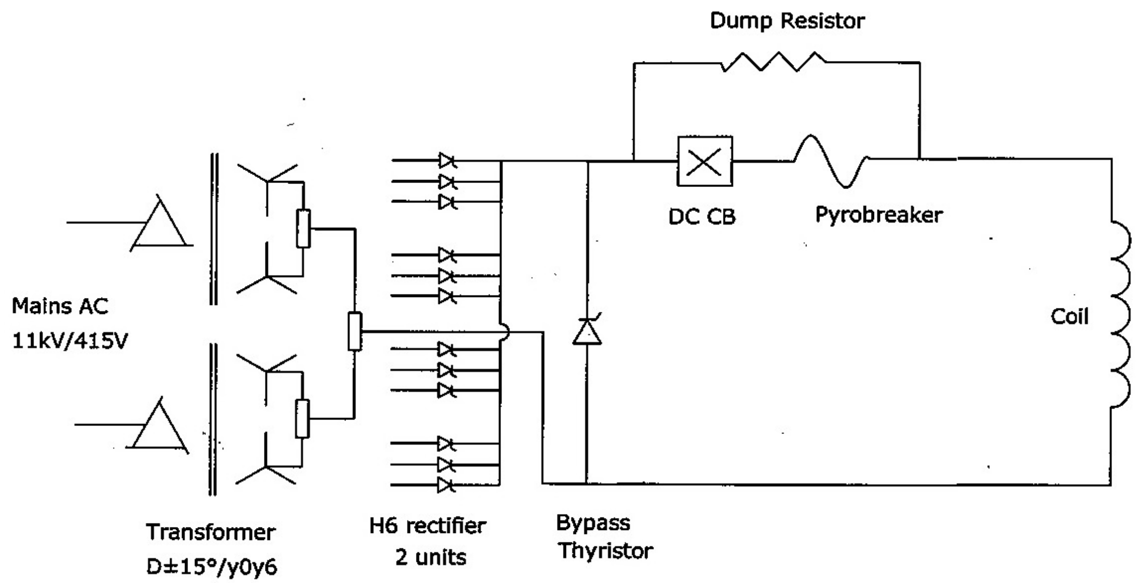
- Total No. of Coils : 16
- Turns per Coil : 108
- Current per turn (3T Field): 10 kA
- Max. Field at Conductor: 5.1 T
- Maximum Field Ripple : 0.35%
- Total Inductance : 1.12H
- Total Stored Energy: 56MJ
- Dump Time Constant: 12 s
- Peak Dump Voltage: 1.1 kV

PF Coils :

- Support single & double null equilibria
  - Triangularity (0.4-0.7),
  - Elongations (1.7-1.9), l_i (0.75 -1.4),
  - β_p (0.01-0.85) & slot divertor configuration
- Limiter operation during Plasma current ramp up

Coil type	# coils	Coil Radius (m)	Vertical Location (m)	Winding Cross-section (mm^2)	# turns
PF1	1	0.45	0.0	71x320	80
PF2	2	0.45	±0.43	71x163	40
PF3	2	0.50	±0.93	136x380	192
PF4	2	1.72	±1.03	85x136	40
PF5	2	2.01	±0.65	85x136	40
PF6	2	1.35	±0.35	100x100	16

A 10 kA DC power supply, using thyristor based, phase-controlled rectifiers, for TF Coils, has been installed & tested



The TF energy dump system :

DC circuit breakers (thyristor arrays with capacitor commutation circuits)

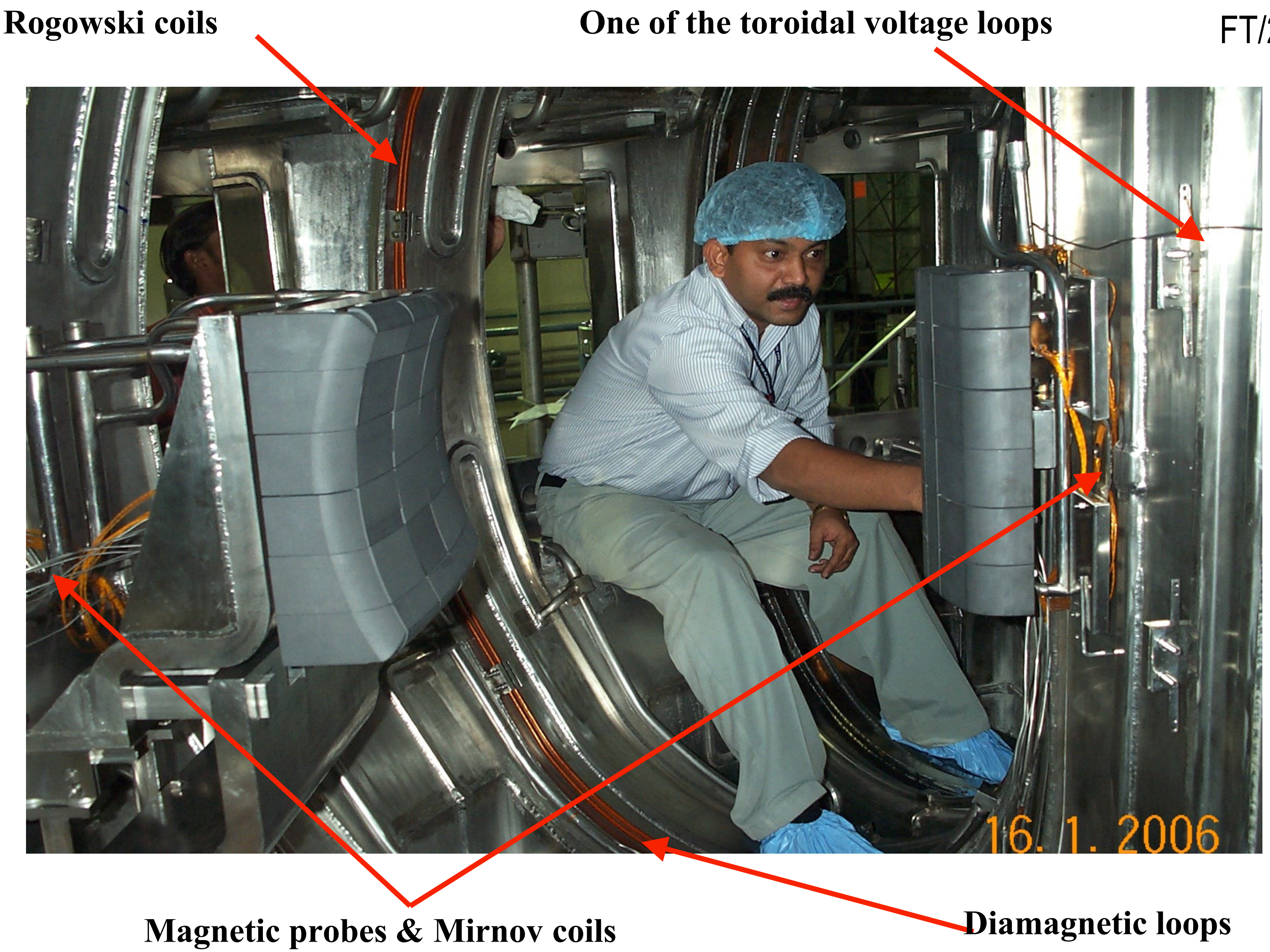
A set of resistors across the DCCBs.

Pyro-breaker are included in series with the DCCBs as second level of protection.

SST-1 DIAGNOSTICS

- **Electromagnetic Sensors**
  - Rogowskii Coils -- Plasma current & Halo Current
  - Mirnov Coils -- Magnetic Fluctuations & Eddy Currents
  - Magnetic Probes -- Plasma position and shape measurements
  - Saddle Loops -- Locked mode detection
  - Fiber Optic Current sensors -- Plasma current
  - Hall Probes -- Plasma current and position
  - Flux Loops -- Loop Voltage
  - Diamagnetic Coils -- total stored energy

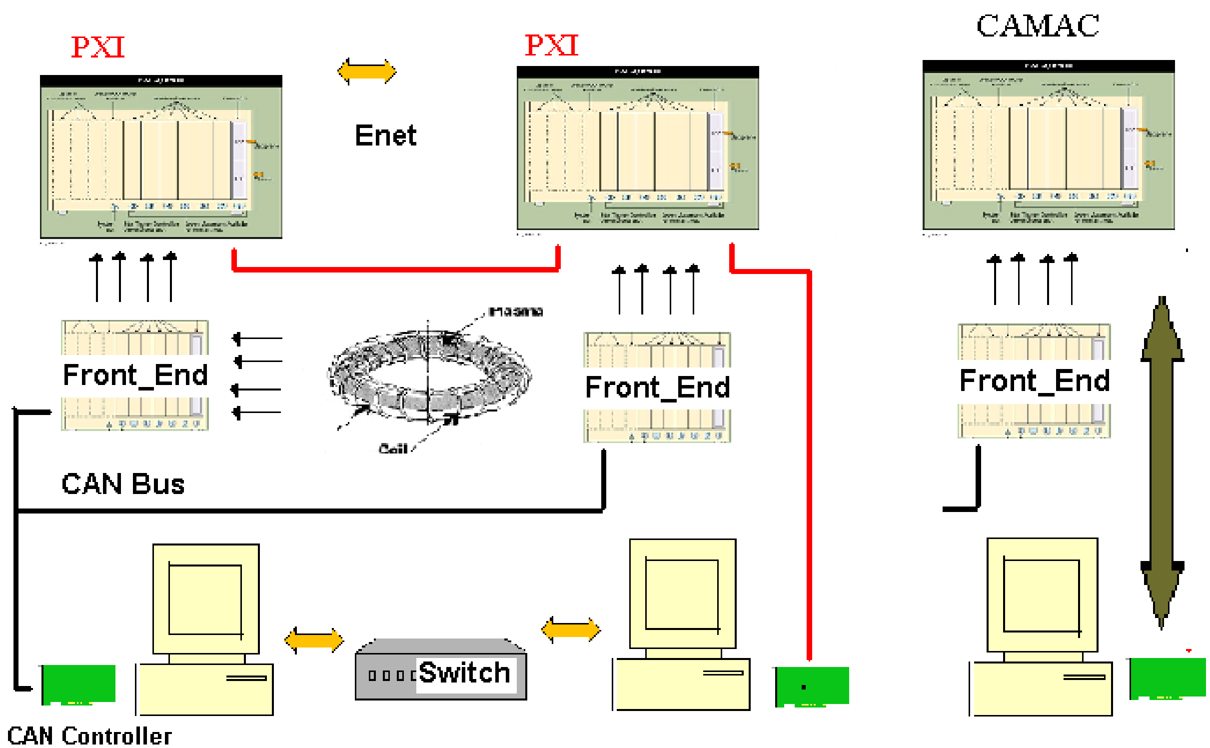
- **Langmuire Probes** Divertor Plasma
- **Far Infrared Interferometers --** Density measurement and Control
  - Vertical , Lateral and Tangential
- **Electron Cyclotron Emmission**
  - Radiometer 91-130 GHz
  - Fast Scanning Fouririer Transform Michelson Interferometer 75-1000 GHz
- **Thermography**
- **X-Rays**
  - Soft X-Ray imaging; Hard X-Ray Monitors; Vacuum Photodiode Array
- **Motional Stark Effect**
- **Spectroscopy**


Rogowski coils
One of the toroidal voltage loops
16. 1. 2006
Magnetic probes & Mirnov coils
Diamagnetic loops

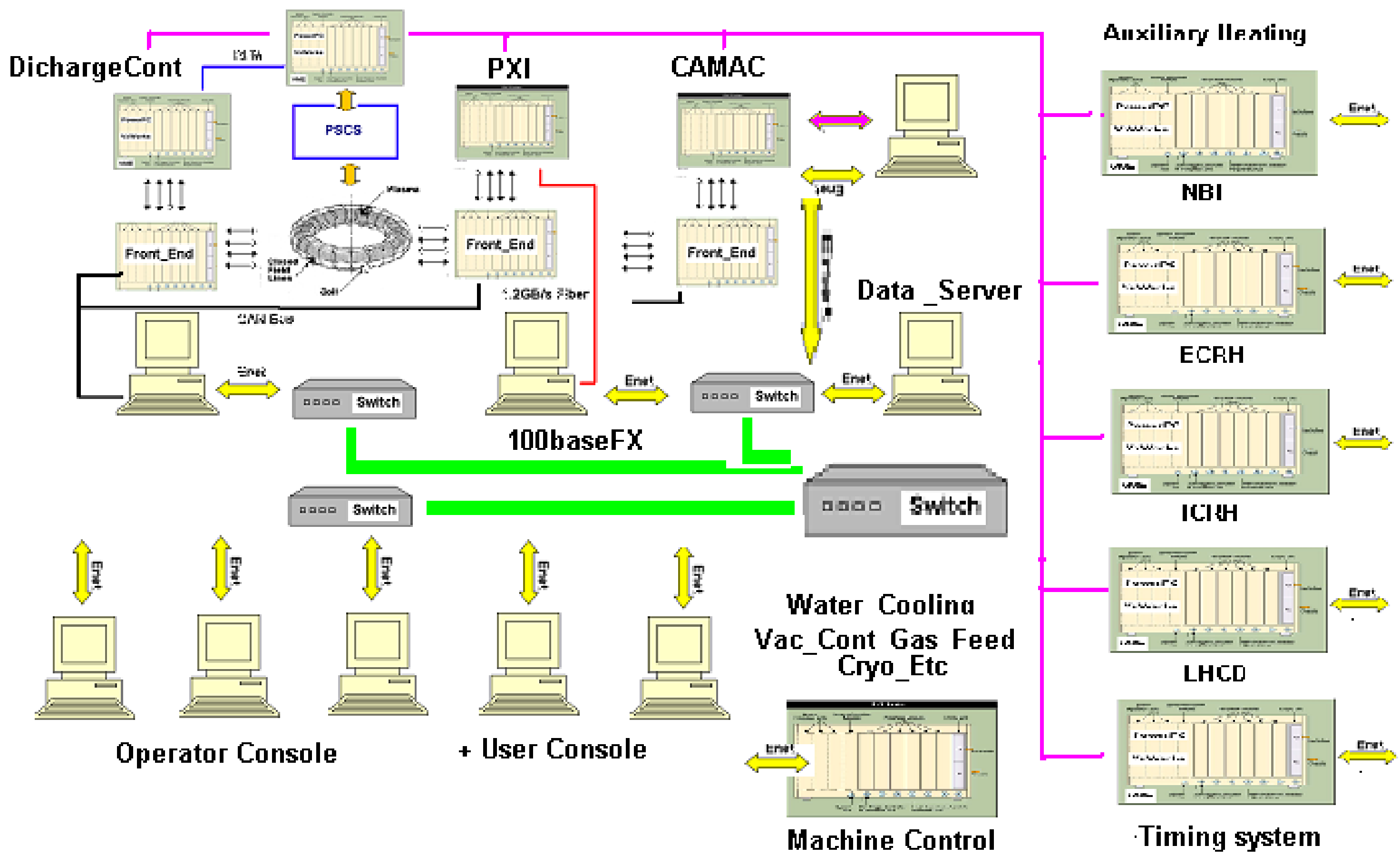
Data Acquisition System for SST-1

PXI Based Loss less Continuous Data Acquisition: Platform Windows 2000; Development Tool Lab Windows/CVI Data; Socket based Client/Server Architecture; Direct Data Streaming to Hard Disk; 1.2GB/s Fiber Optic Link.

Standalone CAMAC system with on board, multiple segments, memory for fast acquisition.



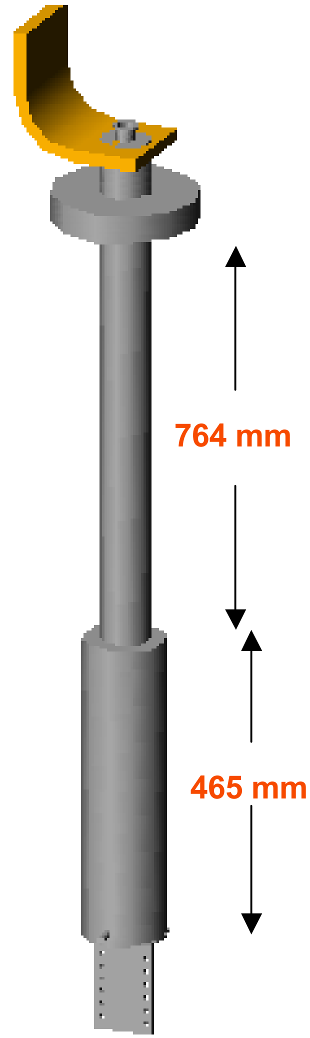
SST-1 Control System



VAPOR COOLED CURRENT LEADS

SPECIFICATIONS:

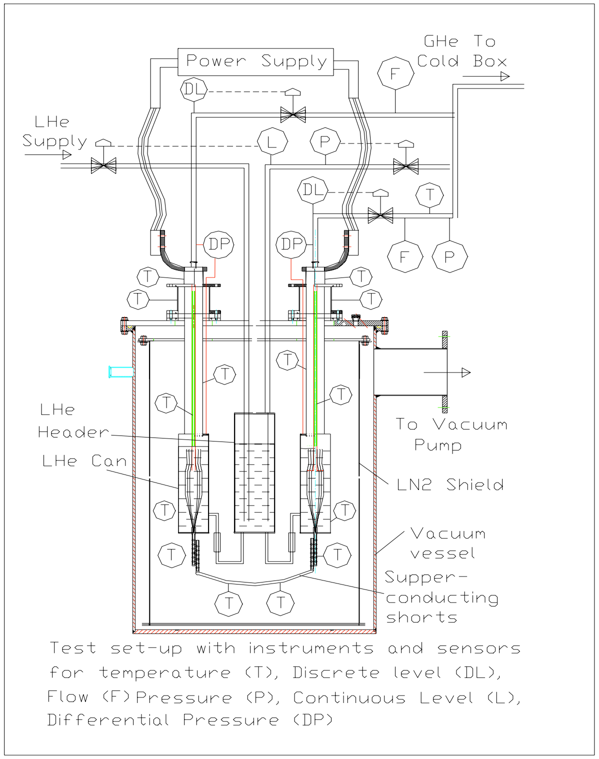
- Operational Current : 10 kA
- LHe Boil off :
  - 1.5 l/hr/kA/Pair at I=0
  - < 3.5 l/hr/kA/Pair at I = 10 kA
- T_{cold} = 4.2 K ; T_{warm} = 300 K
- Voltage withstand capacity : 2 kV
- Burnout time : 3-4 min
- Pressure drop along the CL:
  - < 2 mbar at I = 0
  - < 4 mbar at I = 10 kA
- Voltage drop at 10 kA : 80-100 mV

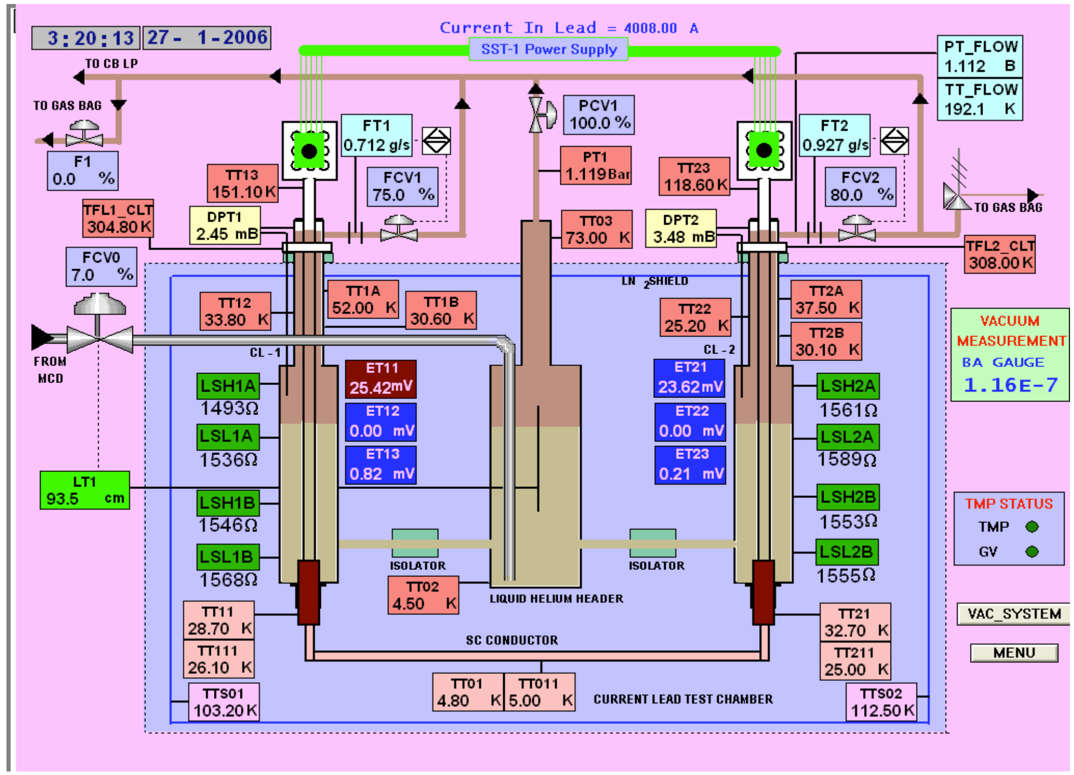


- Current carrying material is copper with RRR=30
- Heat exchanger, is a bundle of copper rods inserted in concentric SS tubes, jacketed in a jacket of SS304L material
- Helium flows in the annular space between rod and tube
- Superconducting transition, immersed in LHe, is used to transfer current from rods to the bottom terminal, which in turn is connected to SC Bus by demountable joint.
- Special Features:
  - LHe *can* with each lead
  - SHe *can* enclosing connection to bus duct

Current Lead Assembly

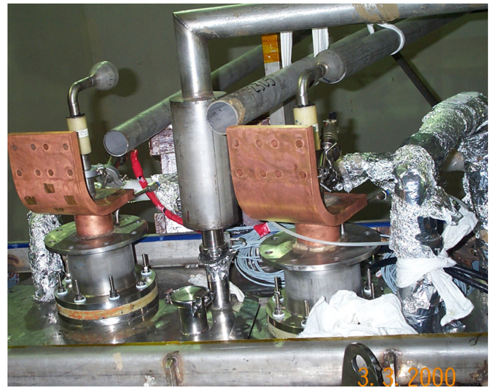
TEST SETUP FOR CURRENT LEADS

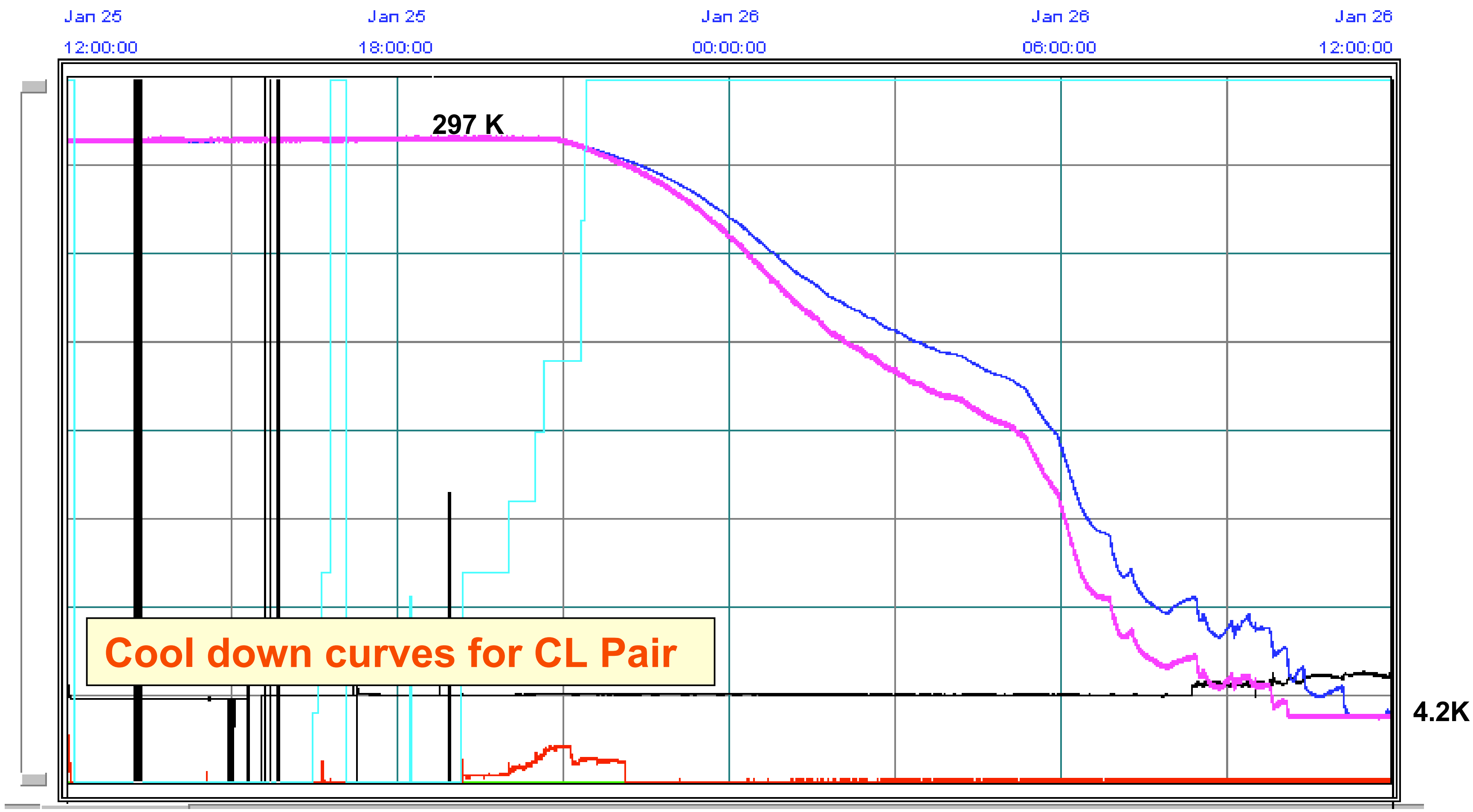




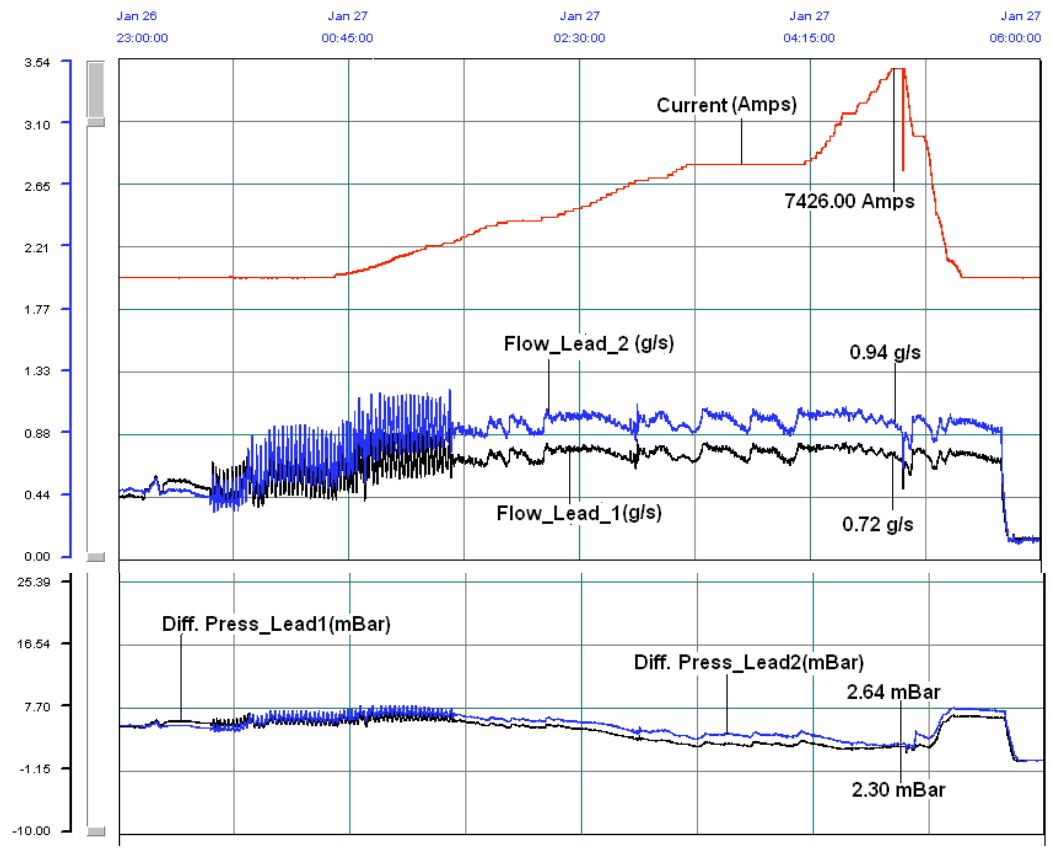
- Temperature, pressure, voltage drop, pressure drop, liquid level and flow rate sensors were deployed.
- Liquid level in header was controlled very precisely by inlet valve with active dependency of header level and passive dependency of level of lead.
- Header pressure was controlled with the outlet control valve

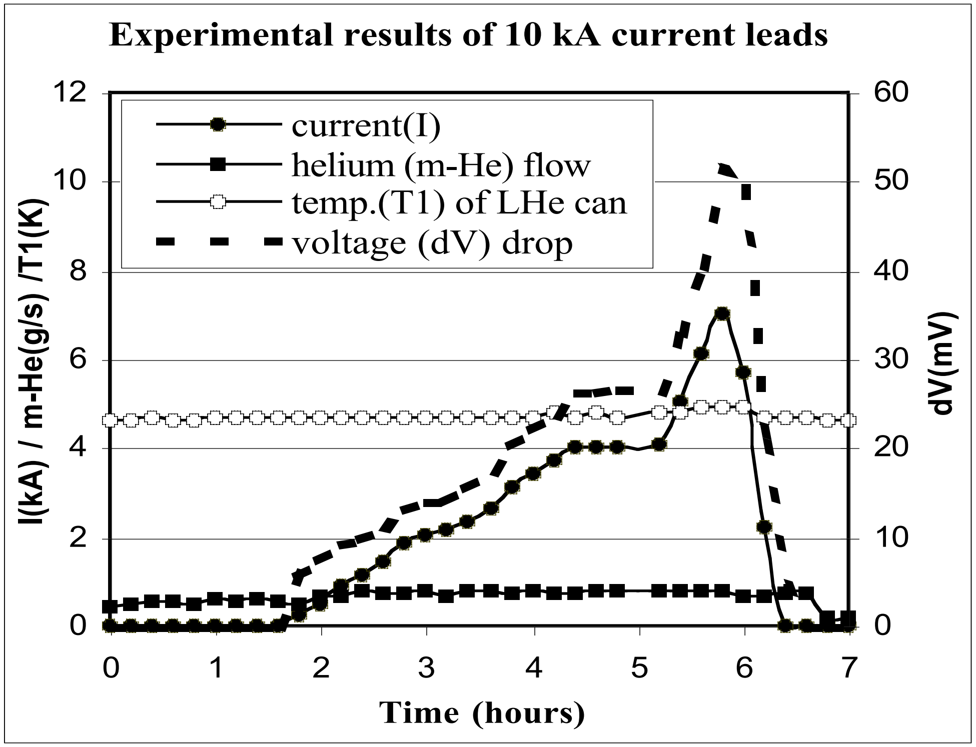
TEST SET UP FOR THE CURRENT LEADS




Jan 25
12:00:00
Jan 25
18:00:00
Jan 26
00:00:00
Jan 26
06:00:00
Jan 26
12:00:00
297 K
Cool down curves for CL Pair
4.2K

CL Test Results



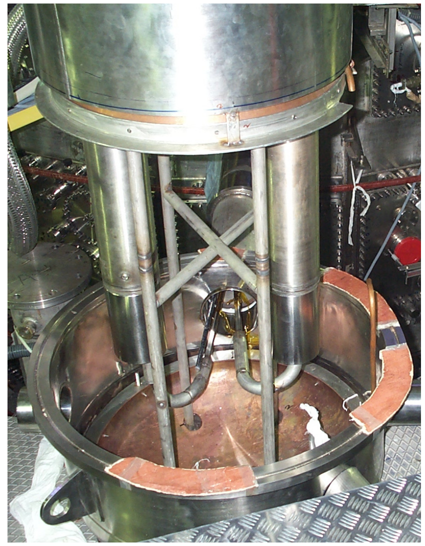


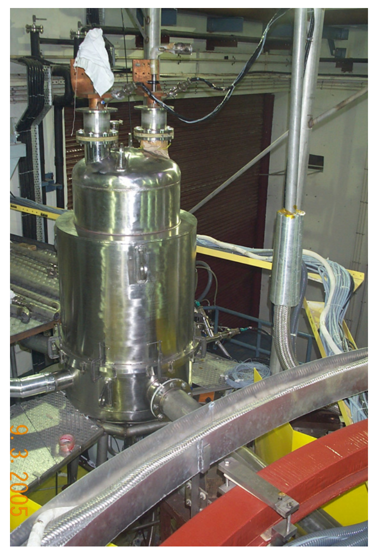
A higher LHe consumption rate of 5 l/hr/kA/pair compared to the design value of 3.5 l/hr/kA/pair was observed.

Conduction cooled joints and the super conducting link received additional heat load estimated to be a total of 3 w per lead.

If we exclude this, which will be removed by SHe in real application, the actual consumption of leads comes to be 3.9 l/hr/kA/pair, slightly higher than the design value of 3.5 l/hr/kA/pair.

Integration of CL wth TF Current Feeder





Commissioning Activity :

- Pump down of Cryostat and Vacuum Vessel
- Leak detection and repairs in Cryostat and Vacuum Vessel
- Cool Thermal down of Shields
- Pump out and purification of Helium circuit
- Simultaneous cool down of the thermal shields and SC magnets

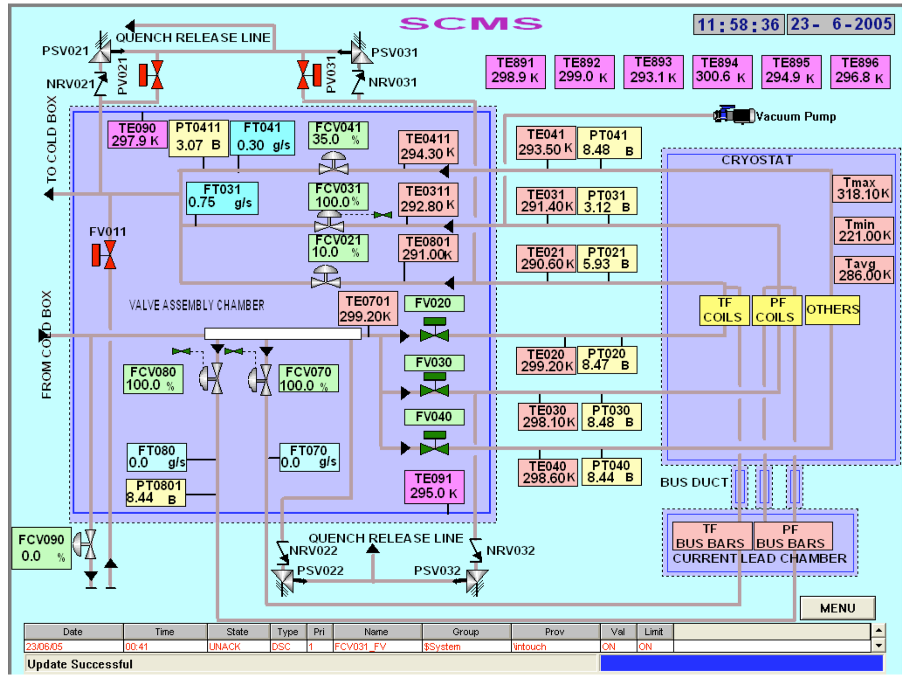
An ultimate vacuum of 8_10^{-7} mbar has been achieved in vacuum vessel without baking.

Glow Discharge Cleaning of vacuum vessel, initiated at about 850 VDC and about 1 _ 10^{-2} mbar pressure of 80 % hydrogen and 20 % helium gas mixture, is sustained at about 350 VDC between anode and wall, at pressure of about 8 _ 10^{-4} mbar.

Base vacuum of 6 _ 10^{-6} mbar has been achieved in the cryostat.

Cool down scenario of SST-1

- 35 Tons of cold mass (TF, PF & support structure, is cooled along with Helium Refrigerator.
- The distribution of fluid from the refrigerator is divided into three supply headers, namely, TF, PF and support structure.
- The TF header supplies to all sixteen TF coils through the supply sub-header with equal distribution.

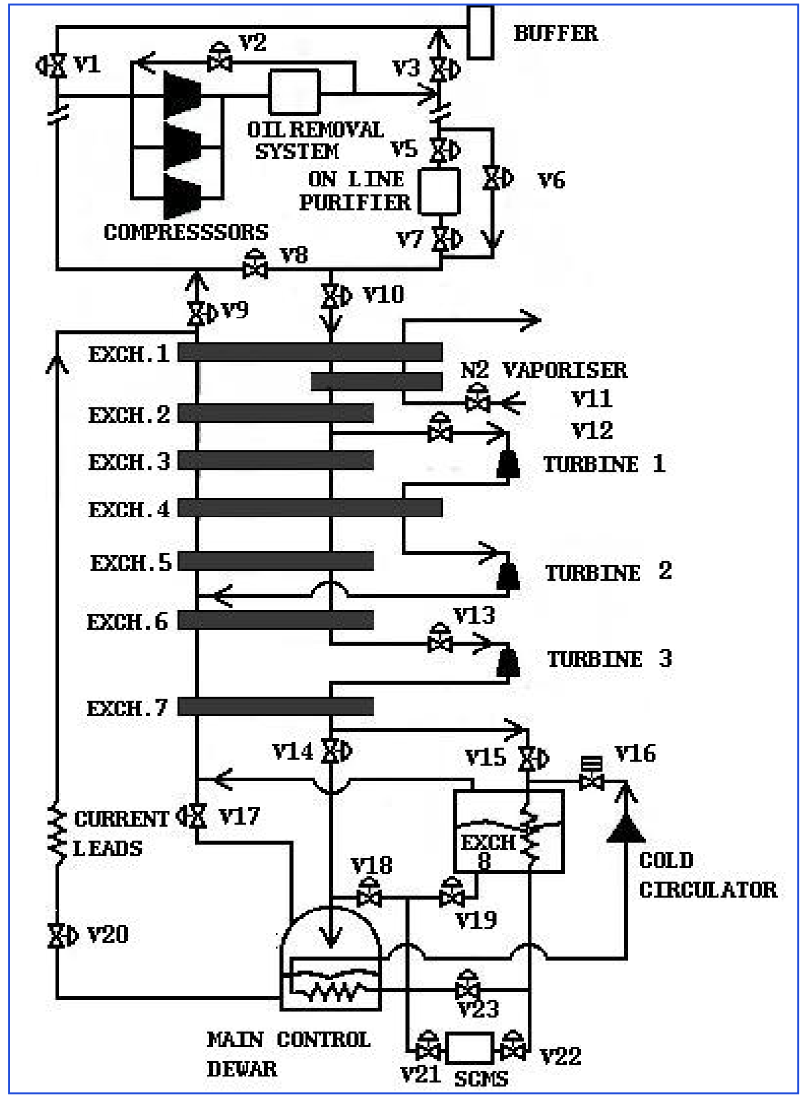


Flow distribution scheme of SST-1

Coil Type	No. of Coils	Flow paths/coil	Path length (m)	Flow per Path (g/s)	Total Flow (g/s)
TF	16	12	48	1.25	240

19 Flow paths in PF require a total flow of about 40 g/s at 4.5K

- Controlled cool down of SCMS from 300 K to 4.5 K is achieved using the helium refrigerator/liquefier in the normal cool down mode.
- The refrigerator operates in a feedback loop with T_{max} from the SCMS and T_{min} from the refrigerator for the SCMS inlet, maintaining a difference of less than 40K.
- SCMS cool down up to 90 K is achieved using the LN2 heat exchanger of the helium refrigerator, with 15 kW capacities. Automatic setting of the valves with integral time constant controls the gradual cool down of SCMS.
- Further cool down is from 90 K is achieved by authorizing the turbines.



COOL DOWN SEQUENCE FOR SCMS

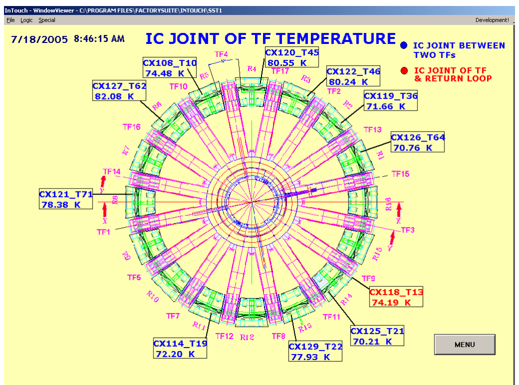
1. Preparation of SCMS
    - Evacuation and purging
    - Impurity levels of < 1 ppm achieved by flowing gas from magnets through online purifier in closed loop.
2. Simultaneous cool down of SCMS and thermal Shields to 80k
3. Cool down to 4.5 k in two phase mode
4. Establishing the 300 g/s SHe Flow with cold Circulator

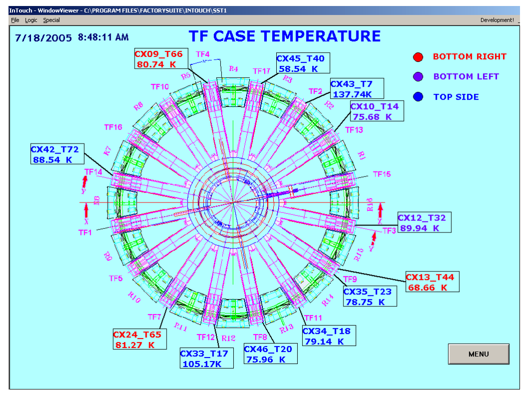
- The thermal shields are cooled with sub-cooled liquid nitrogen.
- The flow to thermal shield is divided to three parts, namely, cryostat, vacuum vessel and inner cylinder.
- The cool down of the thermal shield is started prior to the SCMS cool down.
- The flow of helium gas at ambient temp is established first in the SCMS.
- Once the average temperature of 250 K is achieved in the thermal shield, the SCMS cool down is initiated through the logic and then the cool down of both thermal shield and SCMS follows.

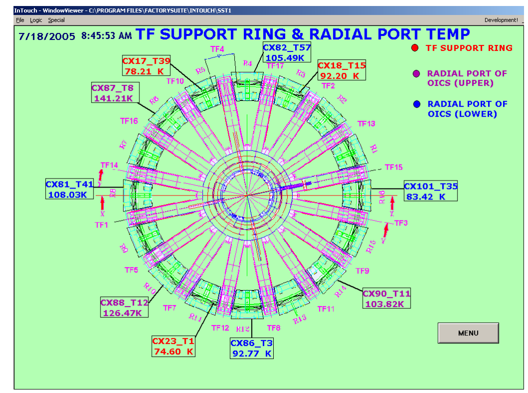
Results of First Cool down

First cool down was attempted in July 2005. Thermal Shields were cooled to 80K and magnets to 70K.

Cold leaks at these temperatures prevented further cool down.



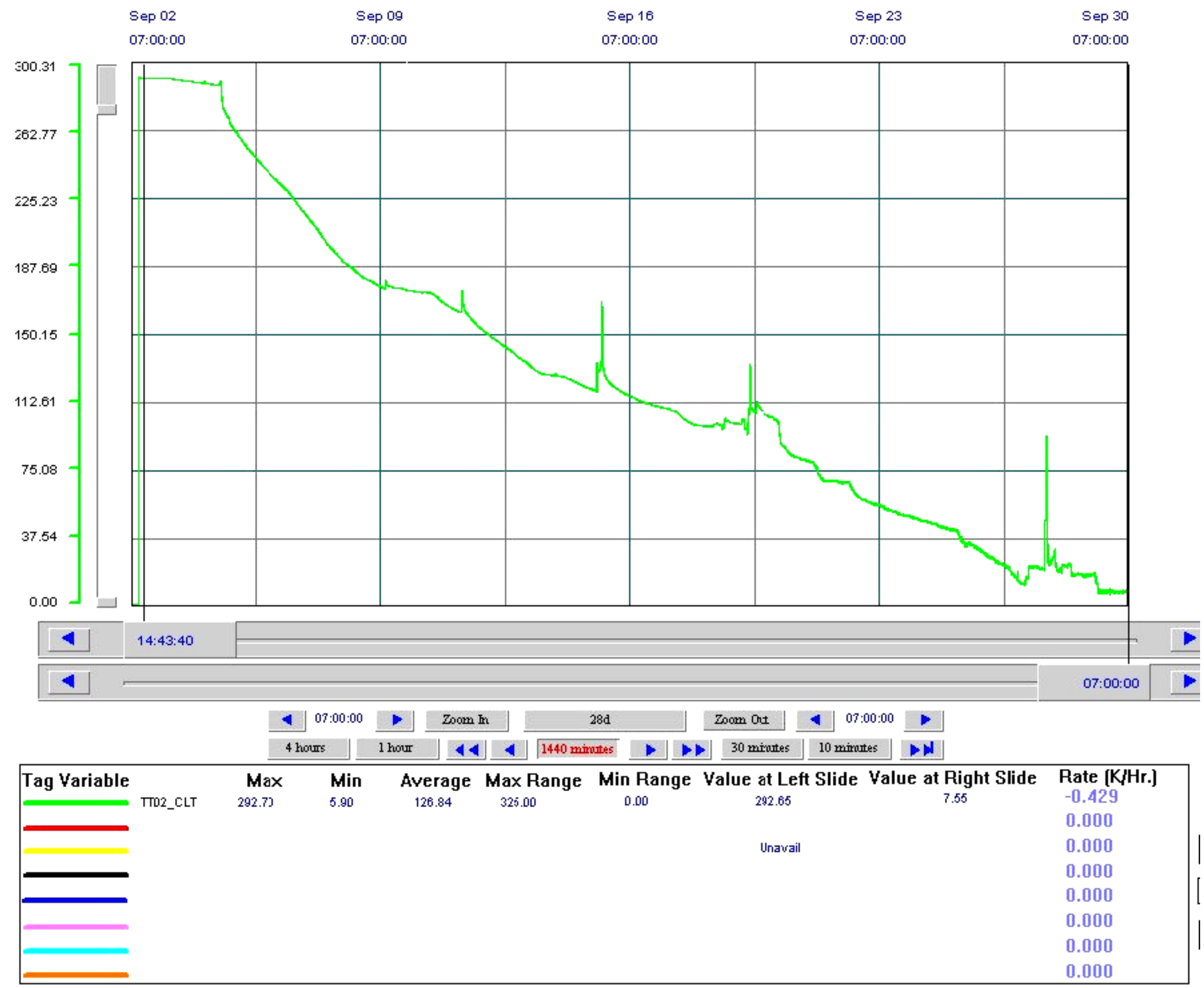




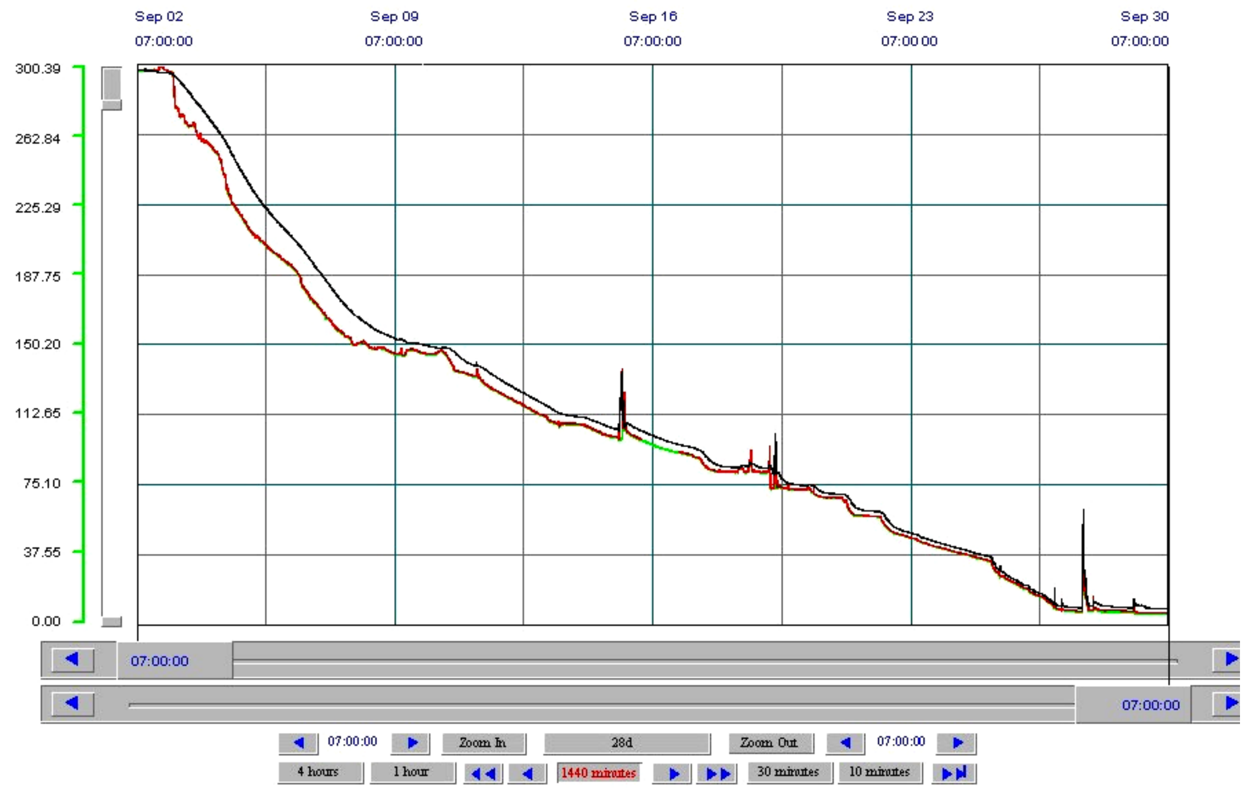
Leaks were identified and repaired.

Cool down of SCMS to 4.5K was achieved in September 2006.

Cool down plot of the thermal shield; T18: Thermal intercept, T24: Vacuum vessel, T 19: Cryostat



Cool down plot of the TF current feeder system



Tag Variable	Max	Min	Average	Max Range	Min Range	Value at Left Slide	Value at Right Slide	Rate (K/Hr.)
TE0701	299.90	5.20	107.02	320.00	0.00	298.43	5.63	-0.436
TE020	300.00	6.20	108.02	320.00	0.00	298.45	6.25	-0.435
						Unavail		0.000
TE021	299.00	8.20	113.86	320.00	0.00	298.25	8.30	-0.431
								0.000
								0.000
								0.000
								0.000

Cool down curves of SCMS of SST-1

Summary

SST-1 assembly was completed in first quarter of 2005.

First cool down of Magnets attempted in July 2005. Thermal Shields were cooled to 80K and magnets to 70K. Cold leaks at these temperatures prevented further cool down.

Leaks were detected and repaired.

Cool down of magnets to 4.5 K, with 2 phase fluid, has been achieved in September 2006. SHe flow in magnets is to be established.

Tuning of TF power supply controls & the quench detection circuit is in progress.

Thank you for your attention