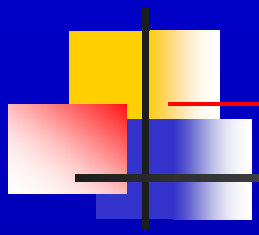
Indian Contribution to the Large Hadron Collider project CERN

Under DAE-CERN Collaboration

Mangesh Karmarkar

Centre for Advanced Technology, Indore


DAE and CERN signed a long term
cooperation agreement -28 March 1991
DAE signed a protocol for making
Indian contribution to the LHC
29 March 1996



Motivation for India's Participation in LHC

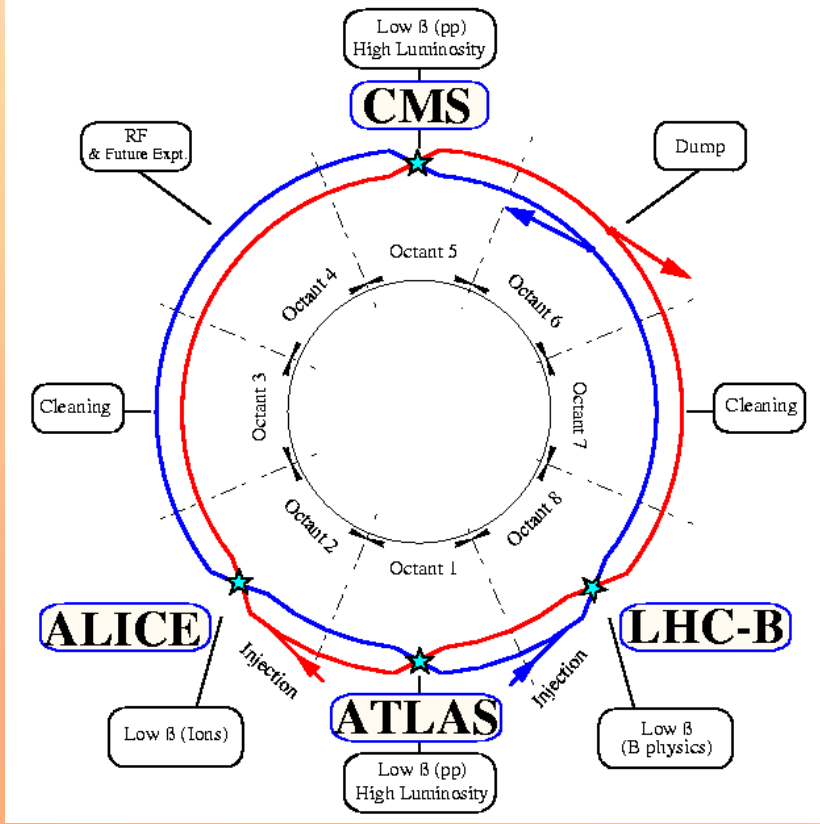
- *Long Tradition of High Energy Physics Research in India.*

- *The HEP groups desired to use LHC for experiments—CMS and ALICE*

- *Demonstration of India's strength in the frontiers of science and technology*

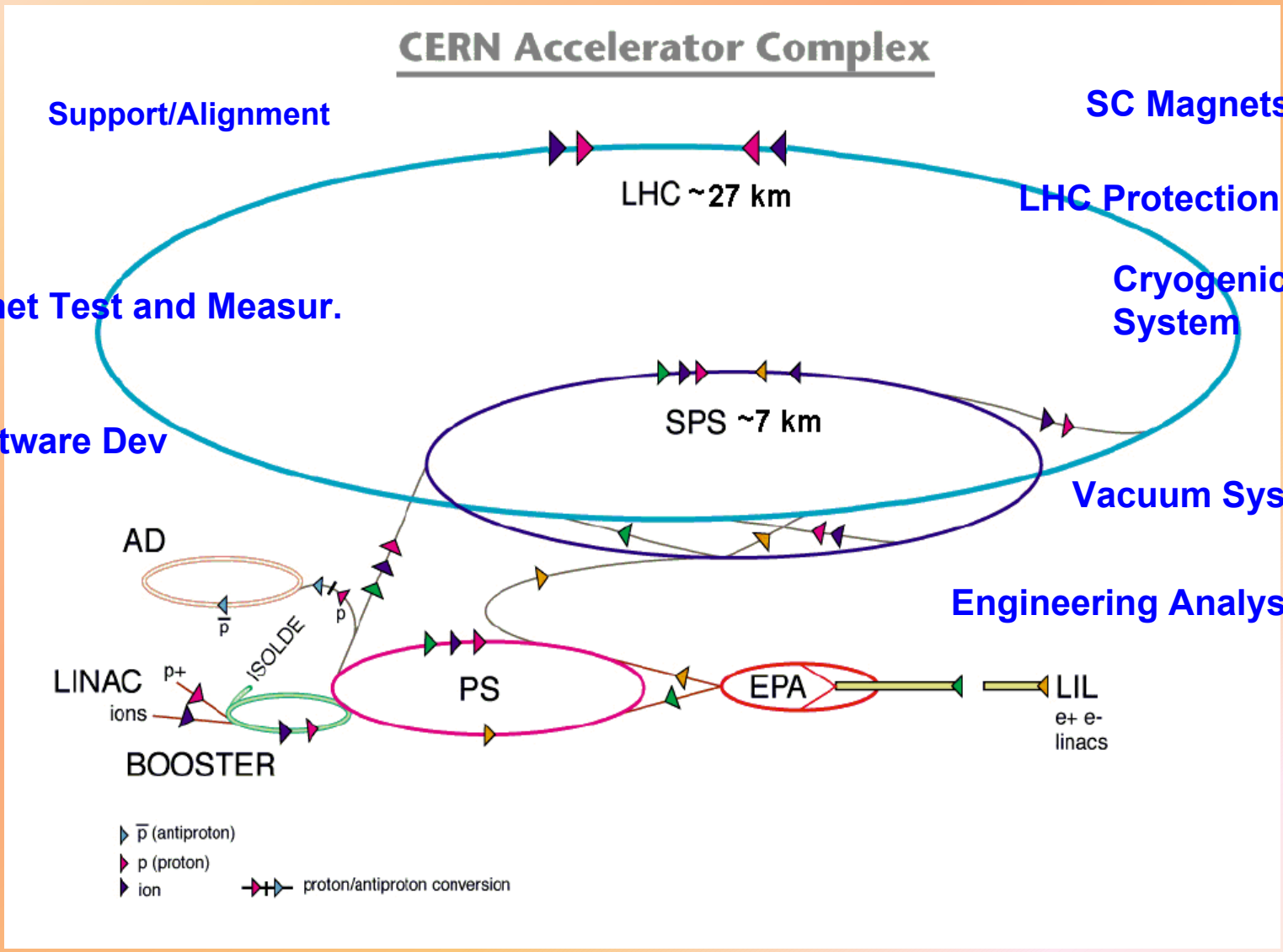

Aerial view of CERN site
Geneva Lake
LHC tunnel
~27kM (~100m under ground)circumference
Geneva Airport
SPS Tunnel
(~7 kM cir)
CERN Prevessin site
St. Genis village (F)
CERN-Meyrin site
Meyrin Village (Swss)

Parameters of the LHC as proton collider



General LHC Layout with four detectors

Beam Energy in collision	7 TeV
Beam Energy at injection	0.45TeV
Circumference	~27,000m
Dipole Field at 7TeV / 1.9K	8.33 T
Beam separation Twin aperture magnets	194mm
Beam aperture	50mm
Beam intensity No of P per bunch	0.56A 1.1×10^{11}
Luminosity Luminosity life time	10^{34} $cm^{-2}.s^{-1}$ 10h
Energy loss per turn Critical photon energy	7 keV 44.1 eV
Stored energy per beam Total radiated power per beam	350MJ 3.8kW



Indian Contributions – LHC domains

Items identified in various Domains of LHC for Indian Contributions

- **Superconducting Magnets**

Sextupole(MCS), Decapole(MCD) and Octupole (MCO) (1848 units)

- **Electronics and controls- Protection system**

Quench Protection System Power supply (5500 units)

Control Electronics for Circuit Breaker - Energy Extraction System (70)

- **Mechanical System**

Precision Magnet Positioning system (PMPS)Jacks (6800 units)

- **Cryogenic System**

4.2K test facility for testing of large no of SC magnets

Liquid Nitrogen Tanks(Large Capacity)

Engineering Design Studies

#QRL-SSS Jumper Flexibility Analysis # LHC Dumps Vacuum Lines

- **Software Development**
- **Test and Measurements of Cryomagnets (50man-yrs)**

LHC String-2 assembly with components supplied by India

Various DAE Units participating in LHC machine

B A R C

VECC, IGCAR

C A T ….*also acting as the nodal agency*

And Industries

ECIL

KECL, CG

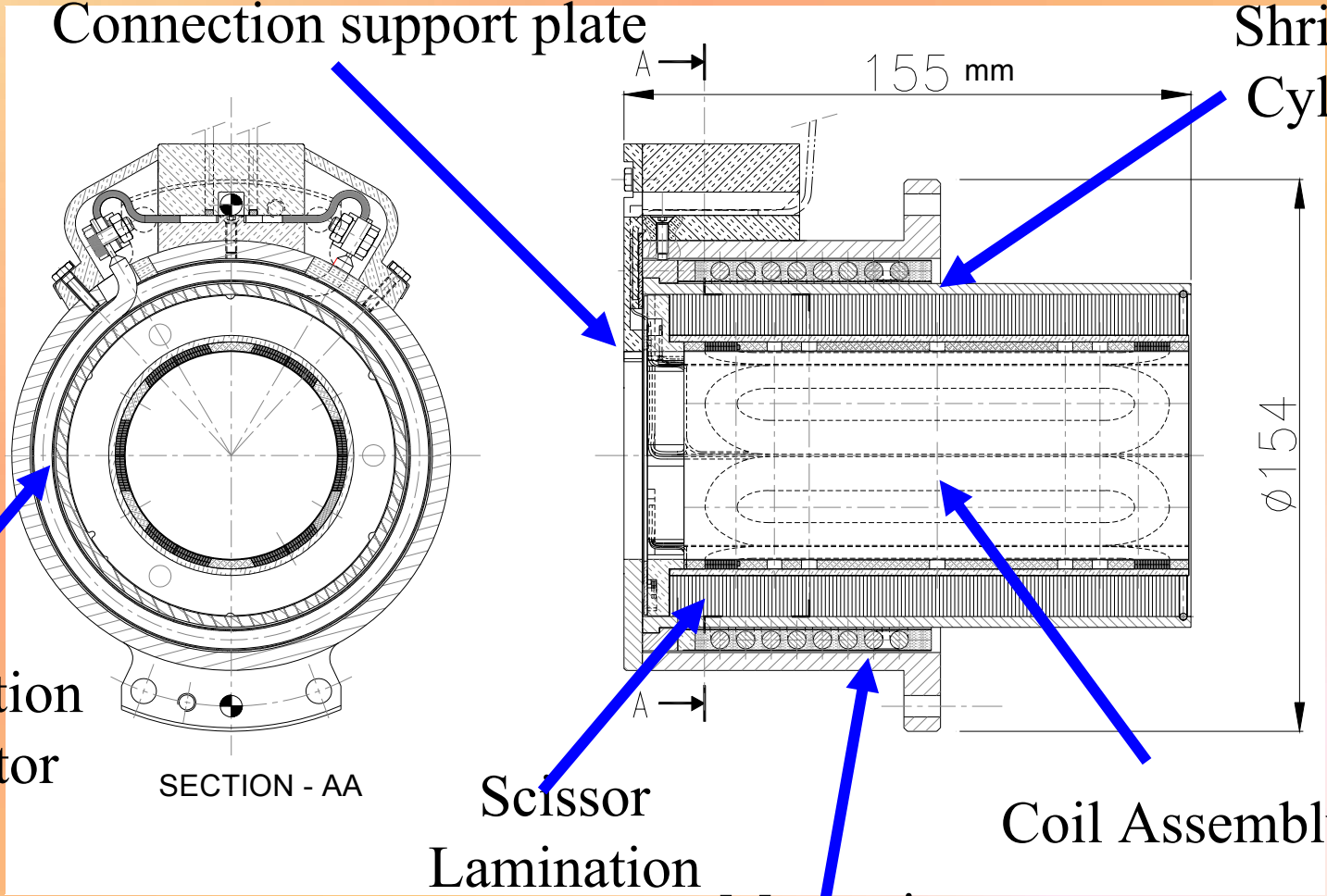
AAL, IGTR

Inox India

+ ***their sub-contract industries***

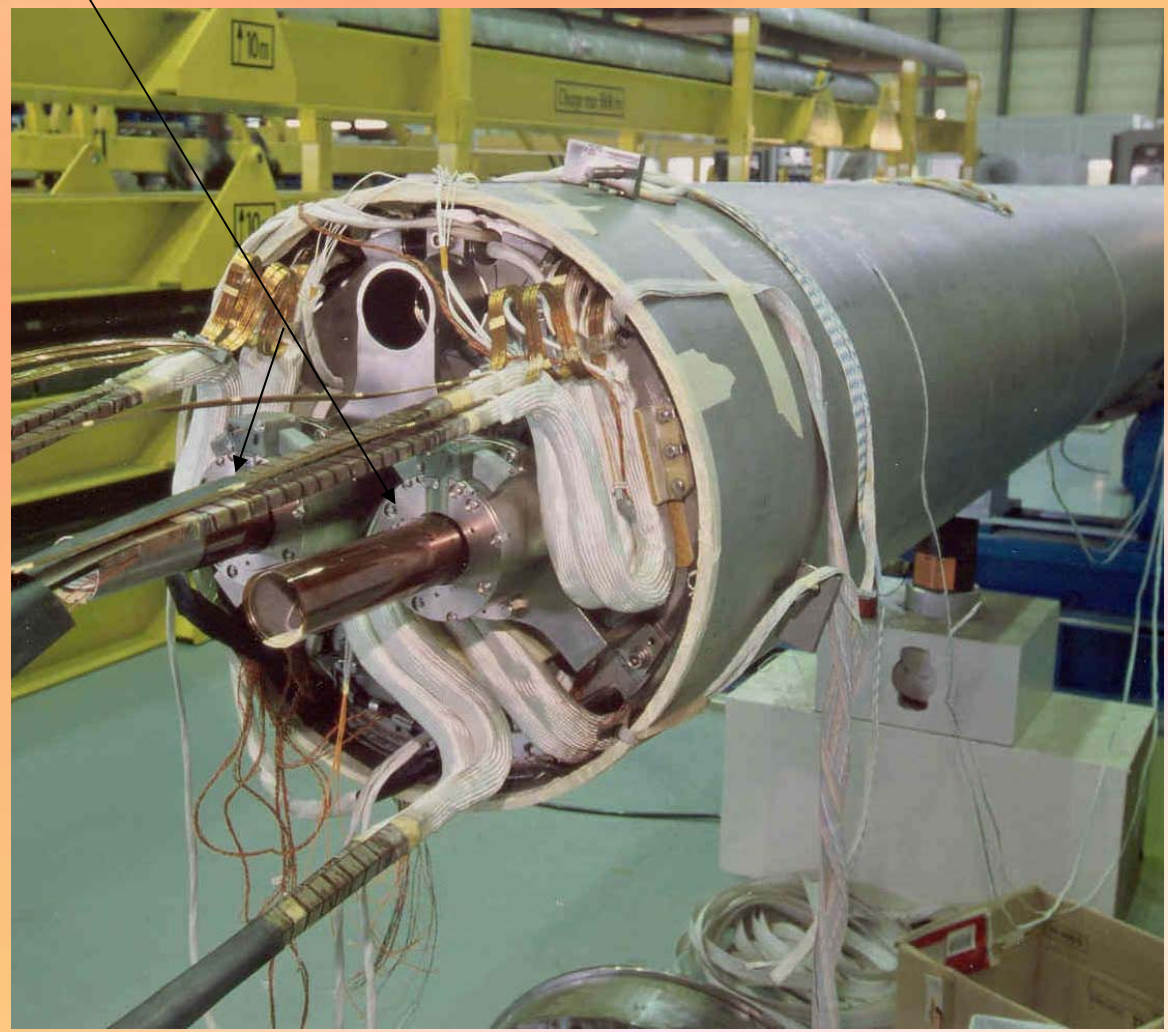
Tank capacity: 50,000 Litres Liquid N2
Diameter/Height: 3.42 M / 10.5 M
Insulation technique :Vacuum + Perlite
Working pressure: 3 bars (abs)
Maximum evaporation loss : 145 Lit./day
Withdrawal rate: 2 Kg/sec.

Superconducting Spool Corrector MCS Magnet



MCS & MCDO Corrector Magnet on main dipole magnet

- To correct the systematic field errors of the LHC Main Dipole
- They Share the same cryostat as that of Main Dipole
- Their proper functioning is as important as Main Dipole



End view of the LHC main Dipole

Major Parameters	MCS	MCD	MCO
Nominal current (A)	550		100
Field gradient	1970 T/m2	1.2 x 10^6 T/m4	8200 T/m^3
Turns per coil	2 x 13	2 x 20	43
Working temperature (K)	1.9		
Peak field (T)	1.9	2.4	2
Theoretical quench current at 1.9K / 4.2K(A)	1300/ 950	1250 / 915	297 / 195
Inner / Outer diameter of the coil (mm)	58 / 63	64 / 69	60 / 61.5
Dimension of wire (mm)	1.25 × 0.73		0.73 x 0.38
Critical current (5T, 4.2K) (A)	770		100
Mass (Kg)	5	4	
Self Inductance (mH)	0.8	0.4	
Material	Nb-Ti in Copper matrix		
Cu / Sc ratio	1.6		4

Parts and assembly of first MCS prototype

Highlights of major developments in India For Superconducting MCS, MCDO magnets

*Coil winding machine

* Ultrasonic Welding system

* SC joint resistance measurement scheme at 4.2K

* 4.2K CTF-- Cryostats, inserts, 3V-1500 A P/S with PC based Quench data acquisition system.

* G11- CI, ES parts -both molded and machined

* Coil to ground insulation Leakage current monitor

* Warm Magnetic Measurements system

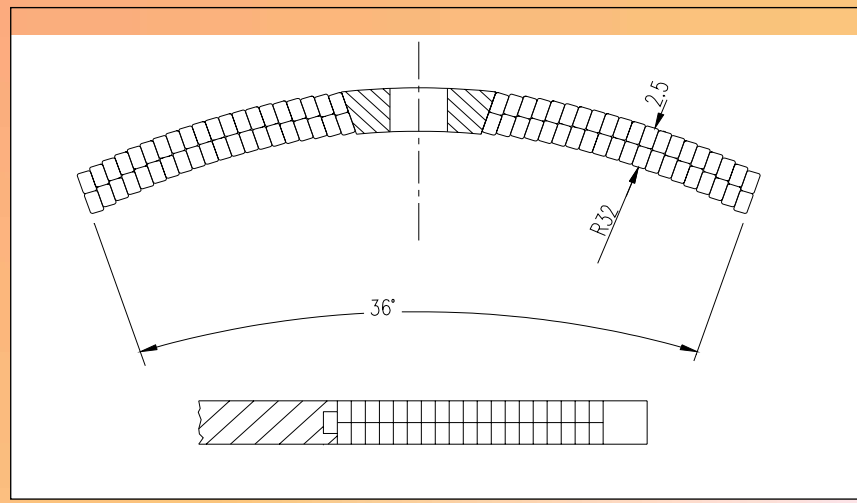
* Epoxy molded caps, Welded flexi- Cu connectors etc.

*Tooling and fixtures for coil assembly & curing

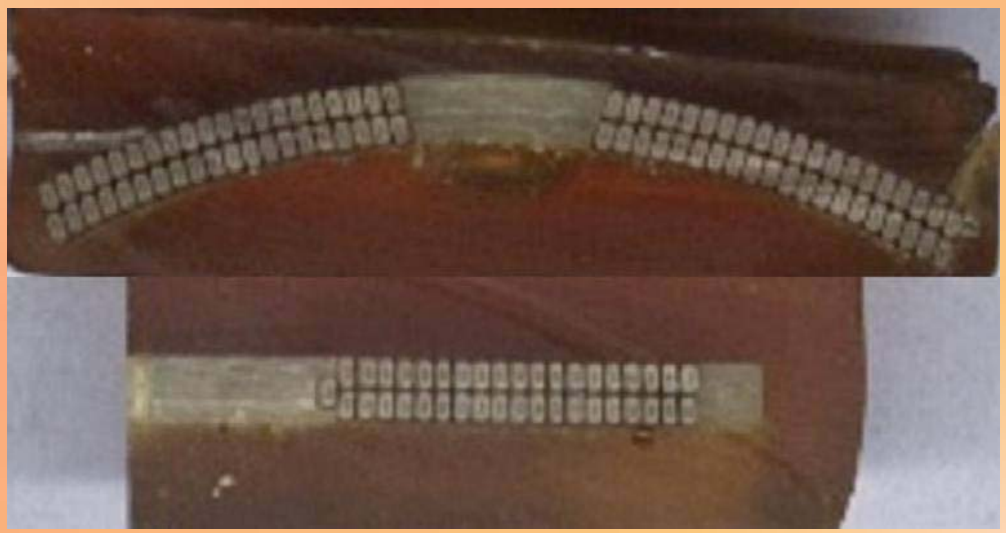
SC Coil Winding machine

Qualification of tooling and coil winding machine

By destructive testing of coil for conductor position



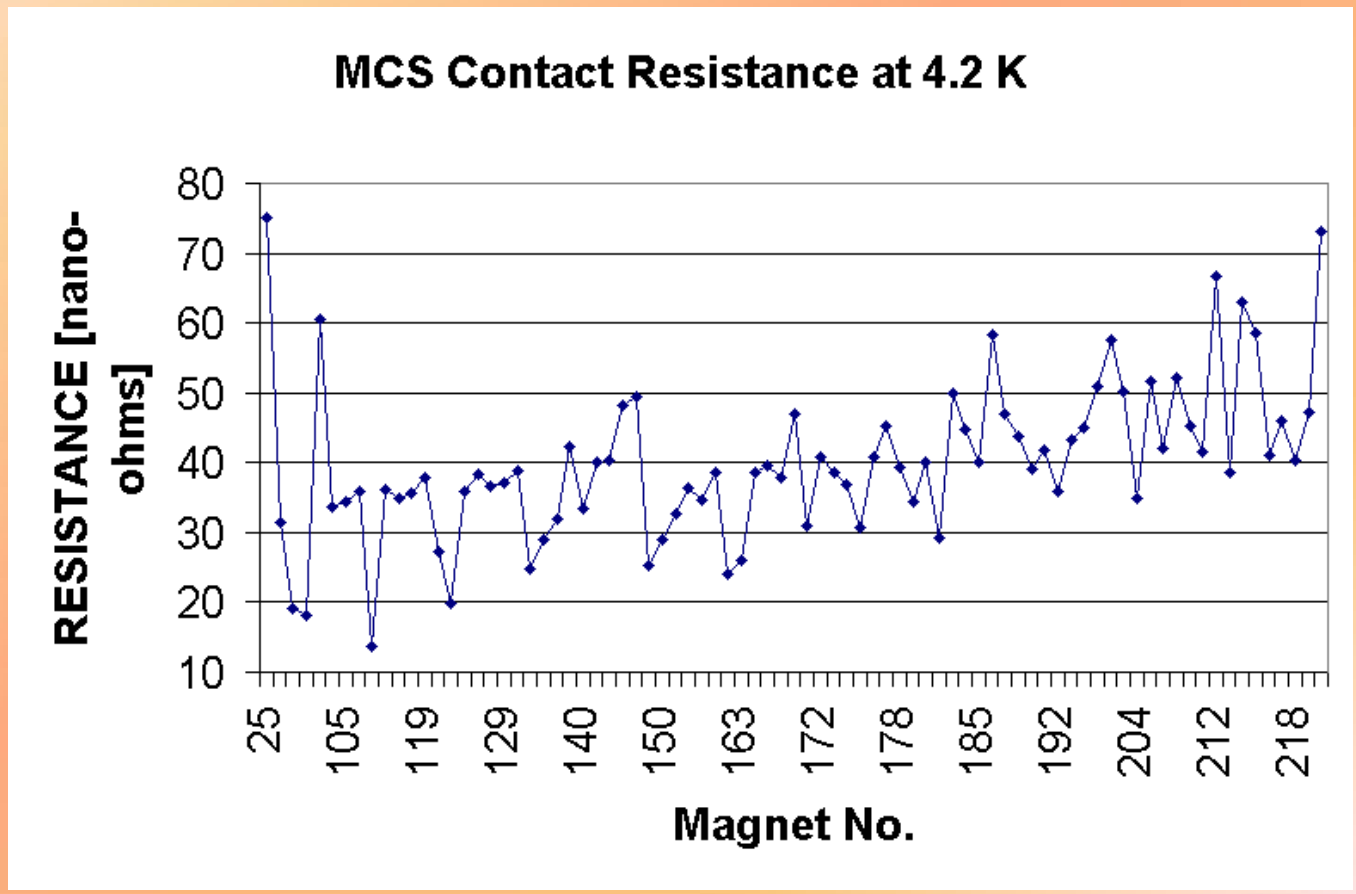
Desired conductor position



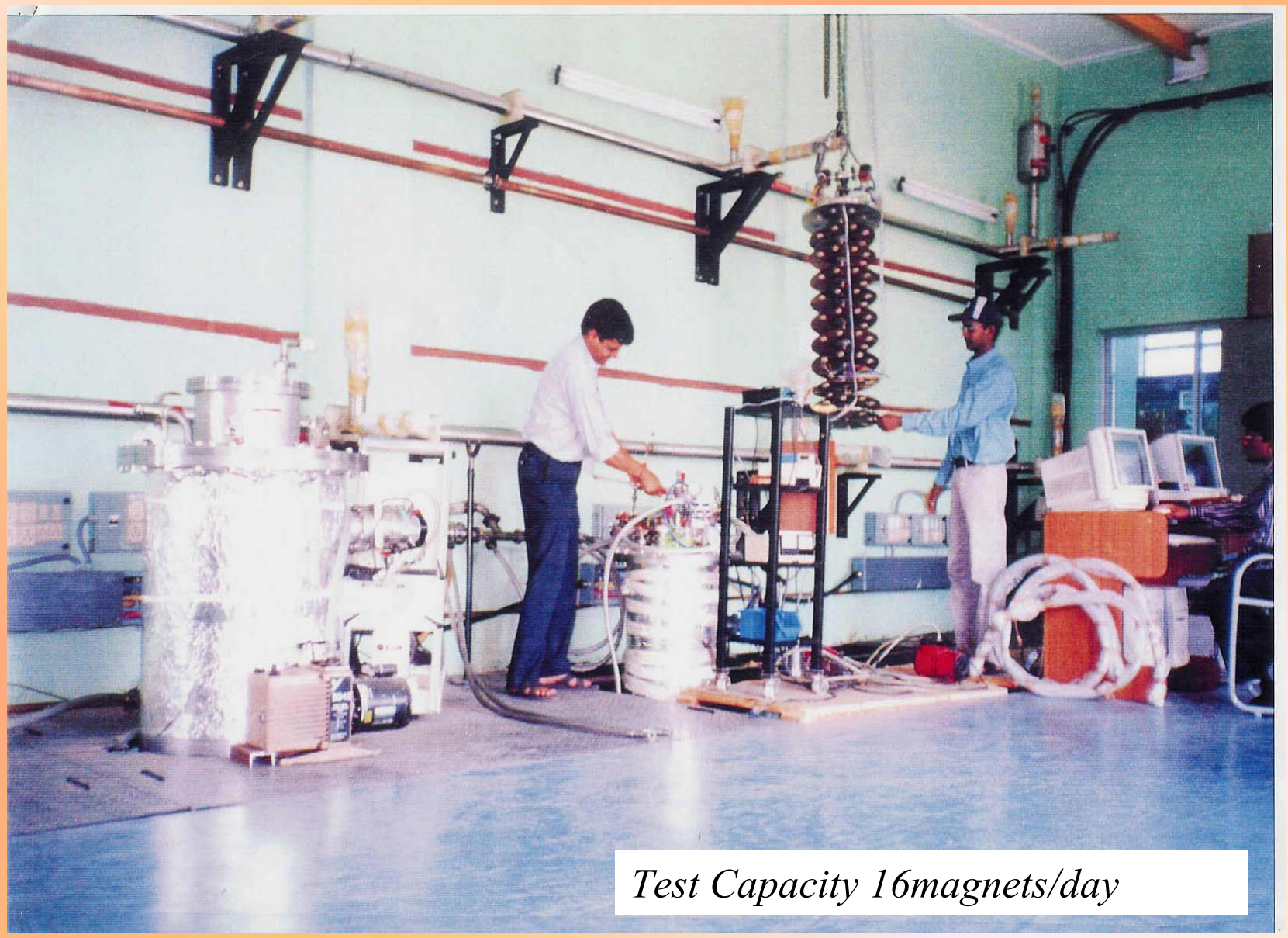
Conductor position achieved

Ultrasonic Welding System

- Ultrasonic welding machine
- Very low contact resistance
- <3 nΩ per joint TYP


MCS Contact Resistance at 4.2 K
RESISTANCE [nano-ohms]
80
70
60
50
40
30
20
10
25
105
119
129
140
150
163
172
178
185
192
204
212
218
Magnet No.

4.2 K test facility for series testing



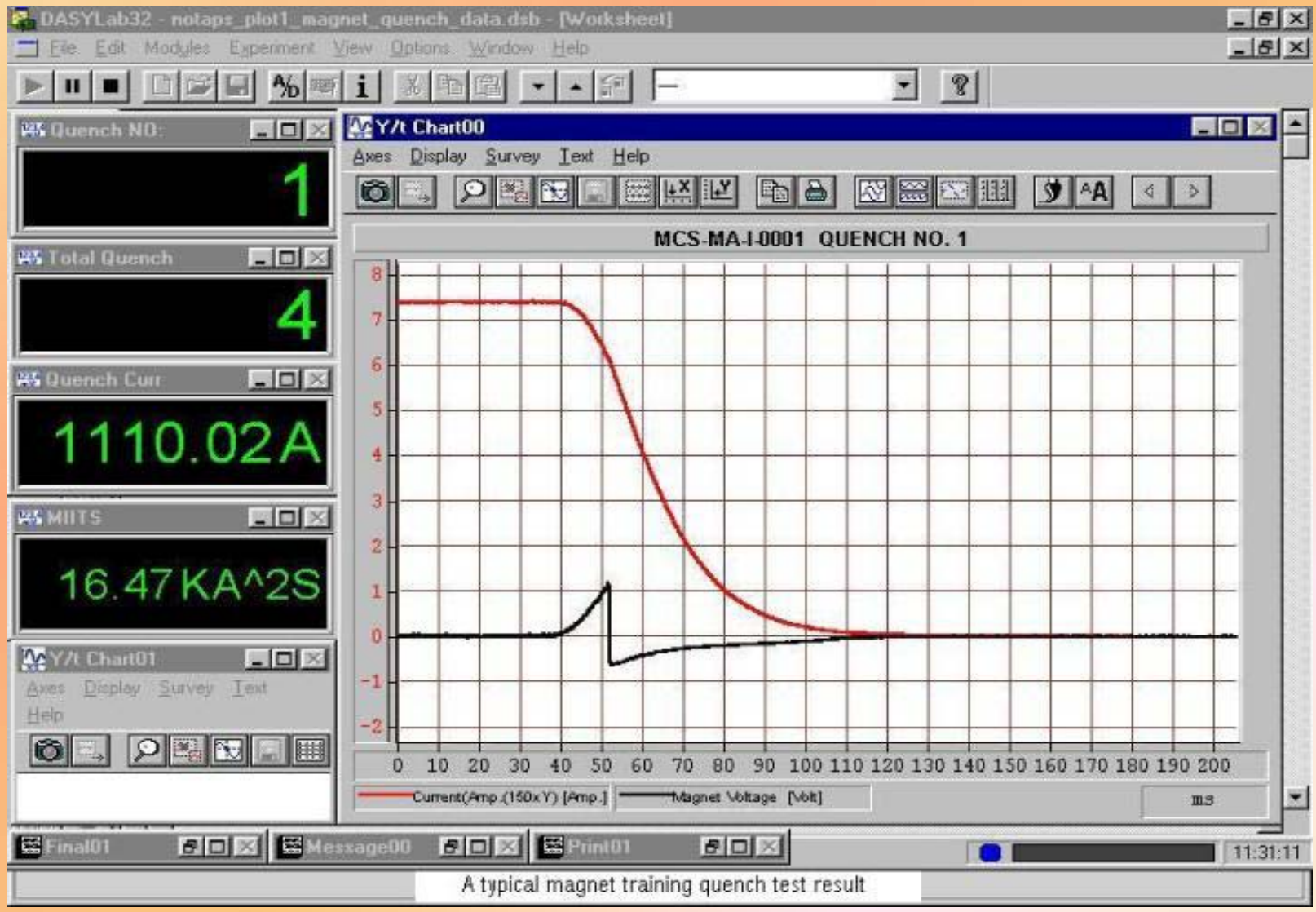
Test Capacity 16magnets/day

Cryogenics ACCEPTANCE standards

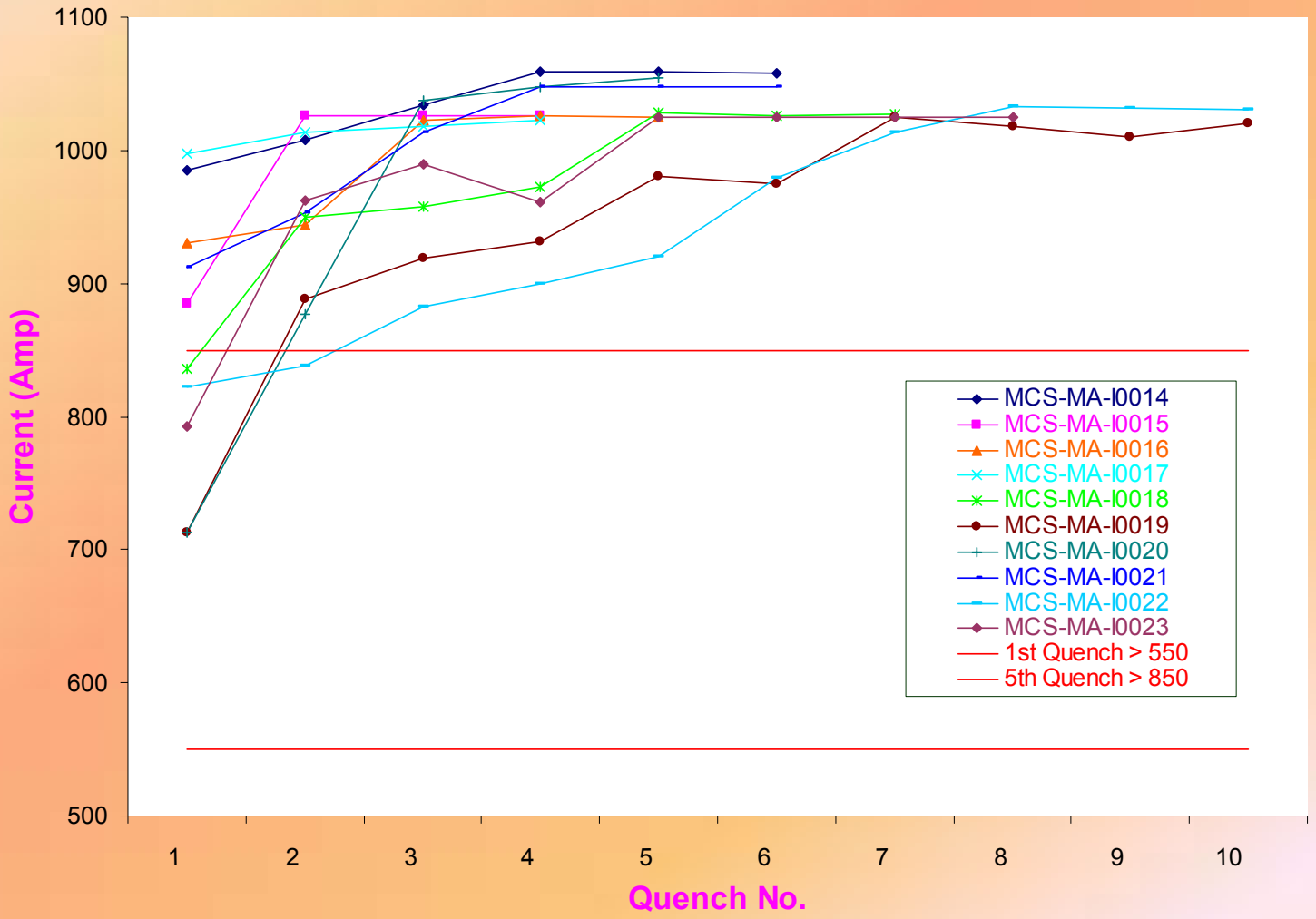
Acceptance criteria for performance at 4.2K			
Type of Corrector Magnet	Nominal current in Ist Quench (A)	Minimum current to be reached in 5^{th} quench(A)	Contact Resistance nΩ
MCS	≥550	≥ 850	≤ 35
MCD	≥ 550	≥ 800	≤ 30
MCO	≥ 100	≥ 150	≤ 50

Quench Data Acquisition

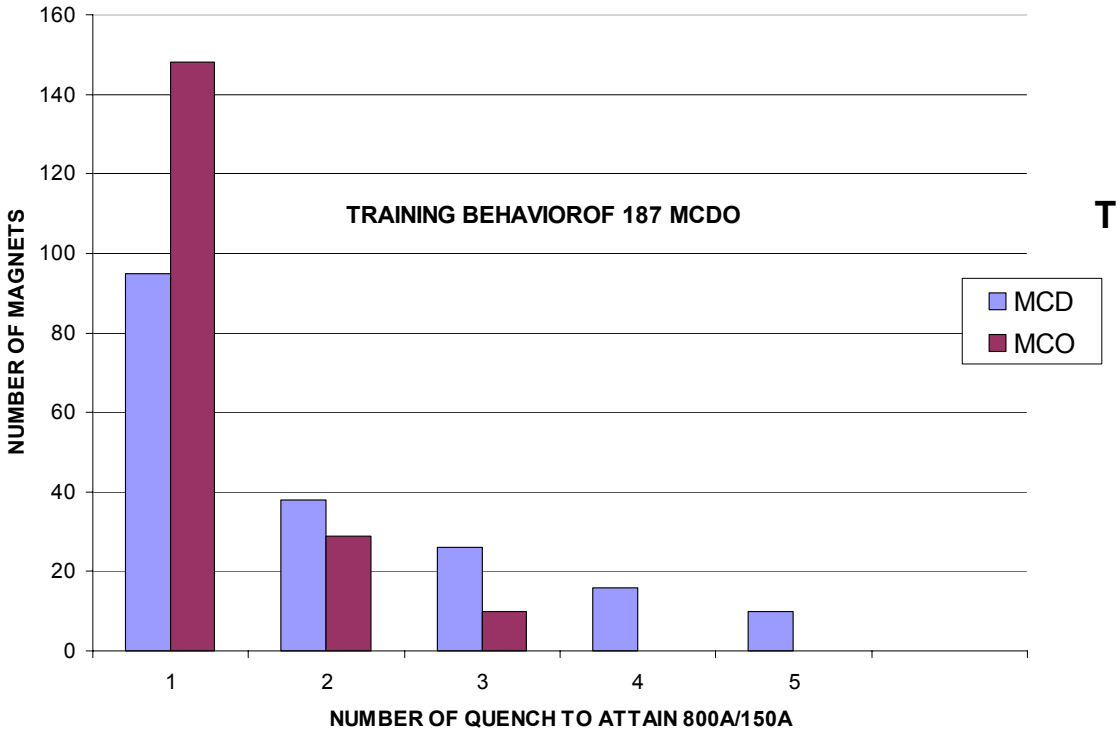
A Typical quench record

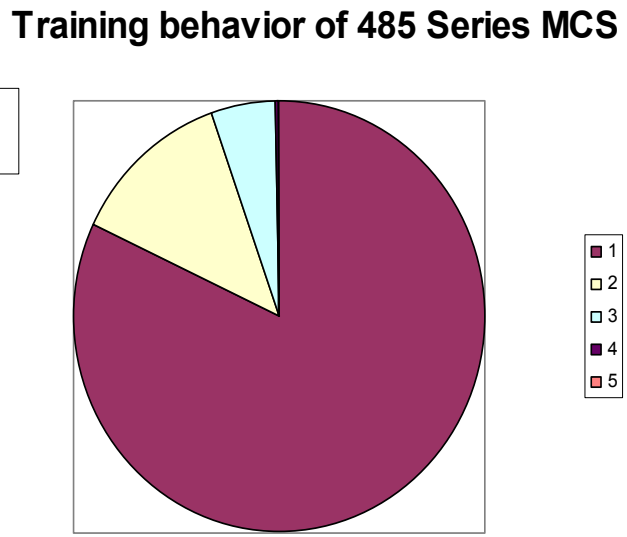


Training Performance of KECL MCS Pre-Series Magnets

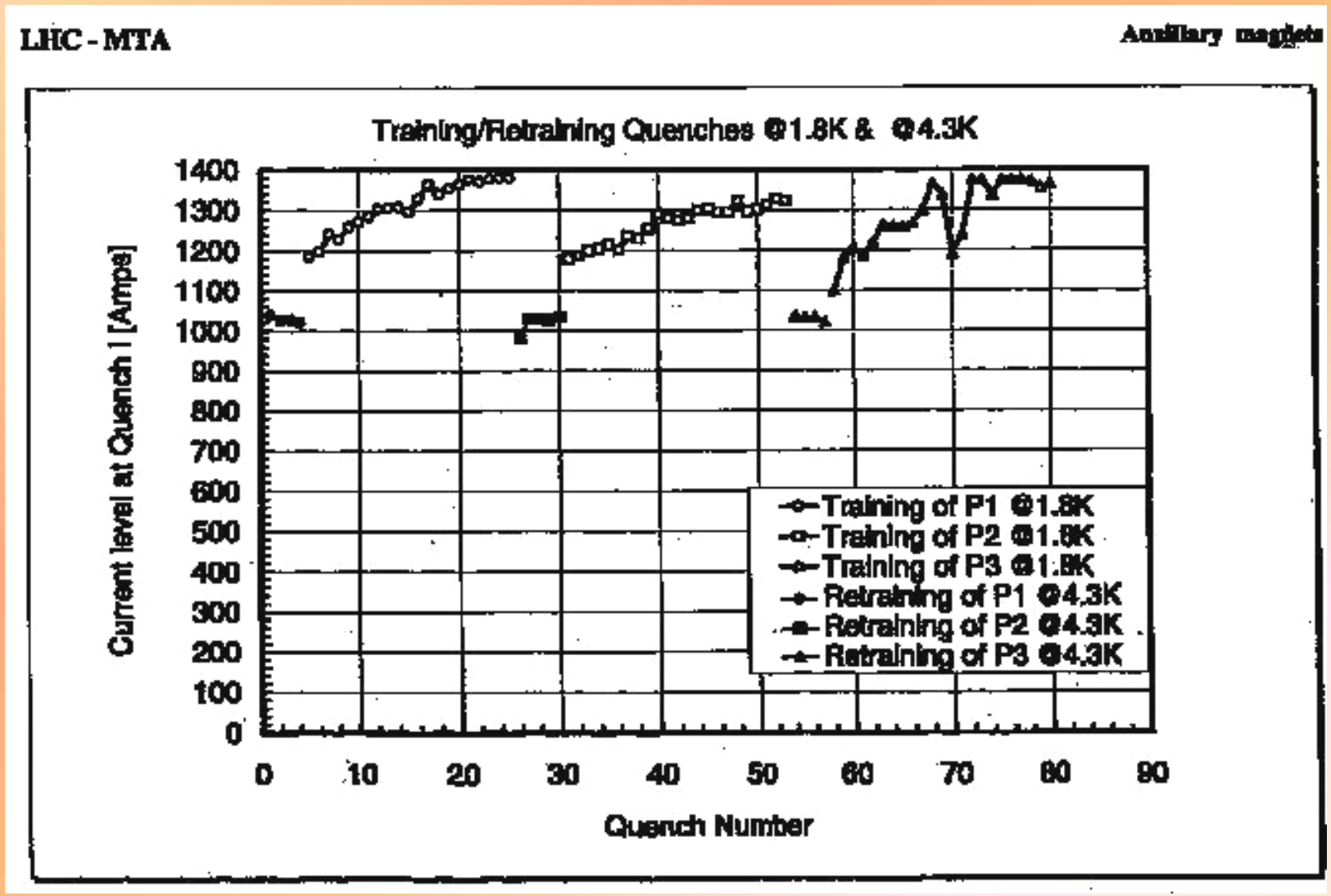


Cryogenic test results of series magnets:





Training & Retraining of MCS at 4.2 K & 1.9 K at CERN



Acceptance criterion for WMM

Alignment precision	Parameter	MCS	MCD	MCO
	dx (mm)	≤ 0.3*	≤ 0.3*	≤ 0.3
	Dy (mm)	≤ 0.3*	≤ 0.3*	≤ 0.3
	dT (mrad)	≤ 3.0	≤ 4.0	≤ 4.0
For quality control	Field strength	< 1% of main field component at 17 mm radius		

*The mean & standard deviation of dx & dy calculated using a sample set numbering at least 50 magnet should be ≤ 0.1mm

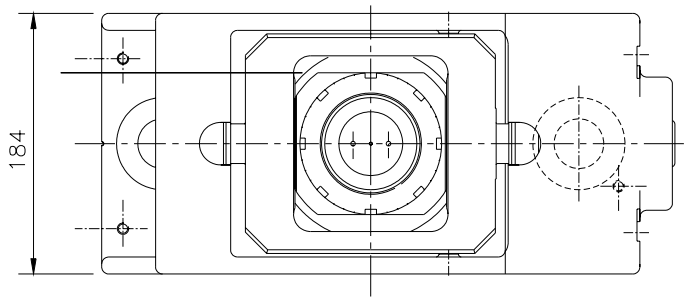
Magnetic measurement setup(WMM) for characterization of MCS magnets

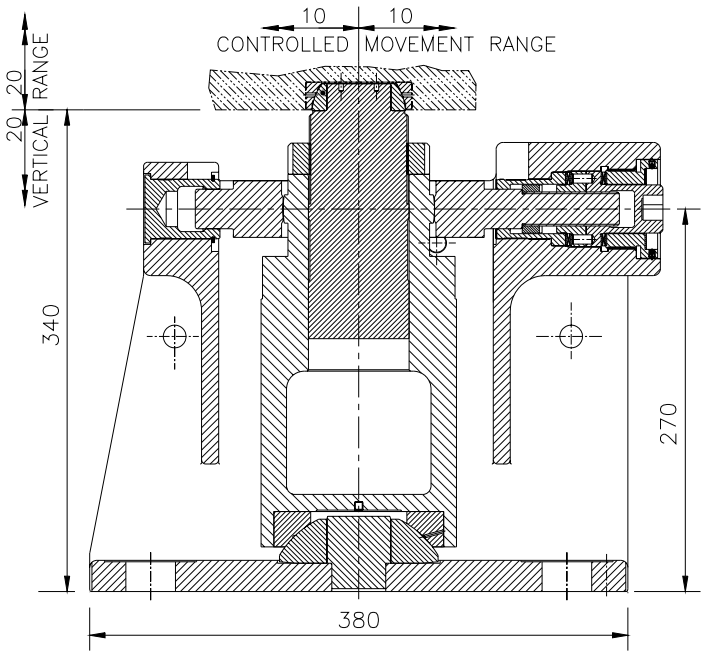

HANDLE WITH CARE
HANDLE WITH CARE

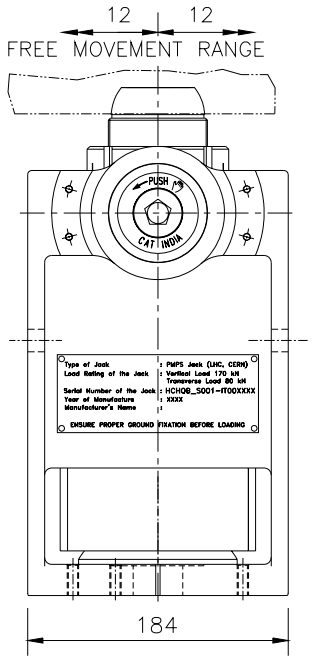
First prototype of PMPS jack being inspected

PMPS Jack main specs

X-Y strokes	+-10mm
Z stroke	+- 20mm
Cross couplings	<.025 -.06mm
Max op torque for	
Lateral movement	60Nm



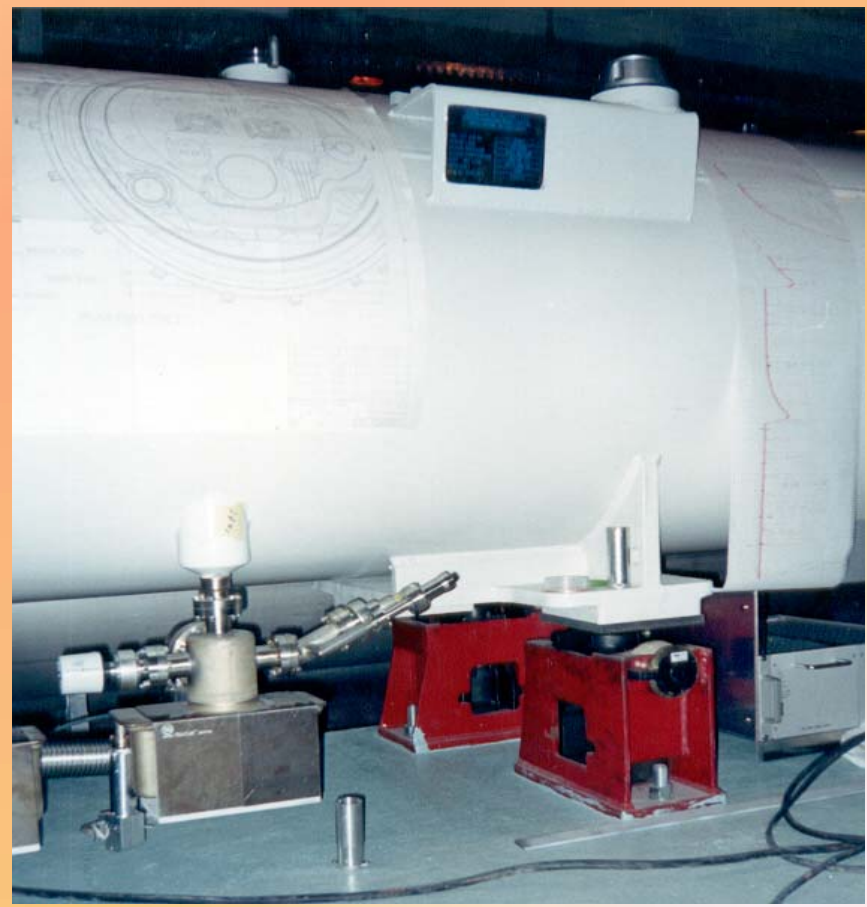




PMPS JACK

PMPS Jack Stiffness

Load	Deflection
Tr load 5.2kN (normal)	0.1mm
Under Vacuum	1mm (res difl<0.1)
Barrier force	



Testing of PMPS Jacks under Dipole Magnet

Requirements of range, resolution and torque

Requirement	Value
Adjustable range required in X & Y directions	≥ ±10 mm
Adjustable range required in Z direction	±20 mm 15 mm for alignment, ±5 mm margin)
Maximum cross-coupling of Z position for a 1.0 mm X-Y plane movement (within a ±7 mm range)	< 0.025 mm
Maximum cross-coupling of X-Y position for a 1.0 mm Z movement	< 0.060 mm
Setting resolution (min. incremental movement) • vertical movement (all jacks) • radial movement (radial jacks)	 0.05 mm 0.05 mm
Long term stability (vertical and transverse position)	≤ 0.1 mm/year
Max. operating torque/force in nominal realignment (jacks within ±5 mm of their median transverse position, floor slope error within ±0.2 %)	60 Nm/250 N

Jacks Stiffness consideration

Change in set Position due to 2mm alignment movement of adjacent magnet

- < 0.1 mm in transverse directions
- < 0.3mm in longitudinal direction,

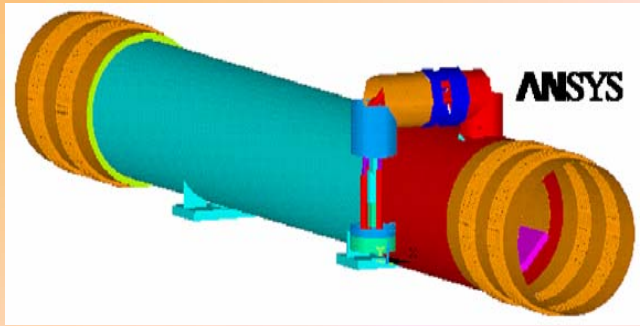
External Loading

Derived from complicated multiple situations possible in operation and installation

Design Loads:
170 kN for vertical and 70 kN for transverse

Series Produced PMPS Jacks in Indian Industry

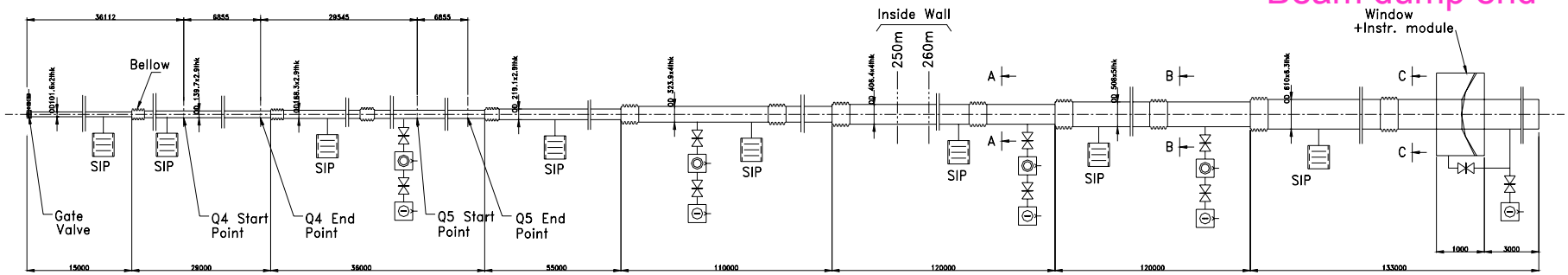
QRL –SSS Jumper studies and Modeling of Flexible for structural analysis



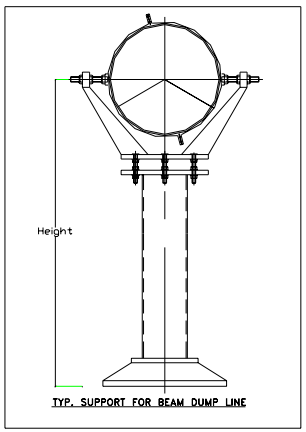
Two 631 m long Vacuum lines for LHC Beam Dumps - design

LHC end

Beam dump end



SIP 31 Numbers distributed.



SIP

TMP

GATE VALVE

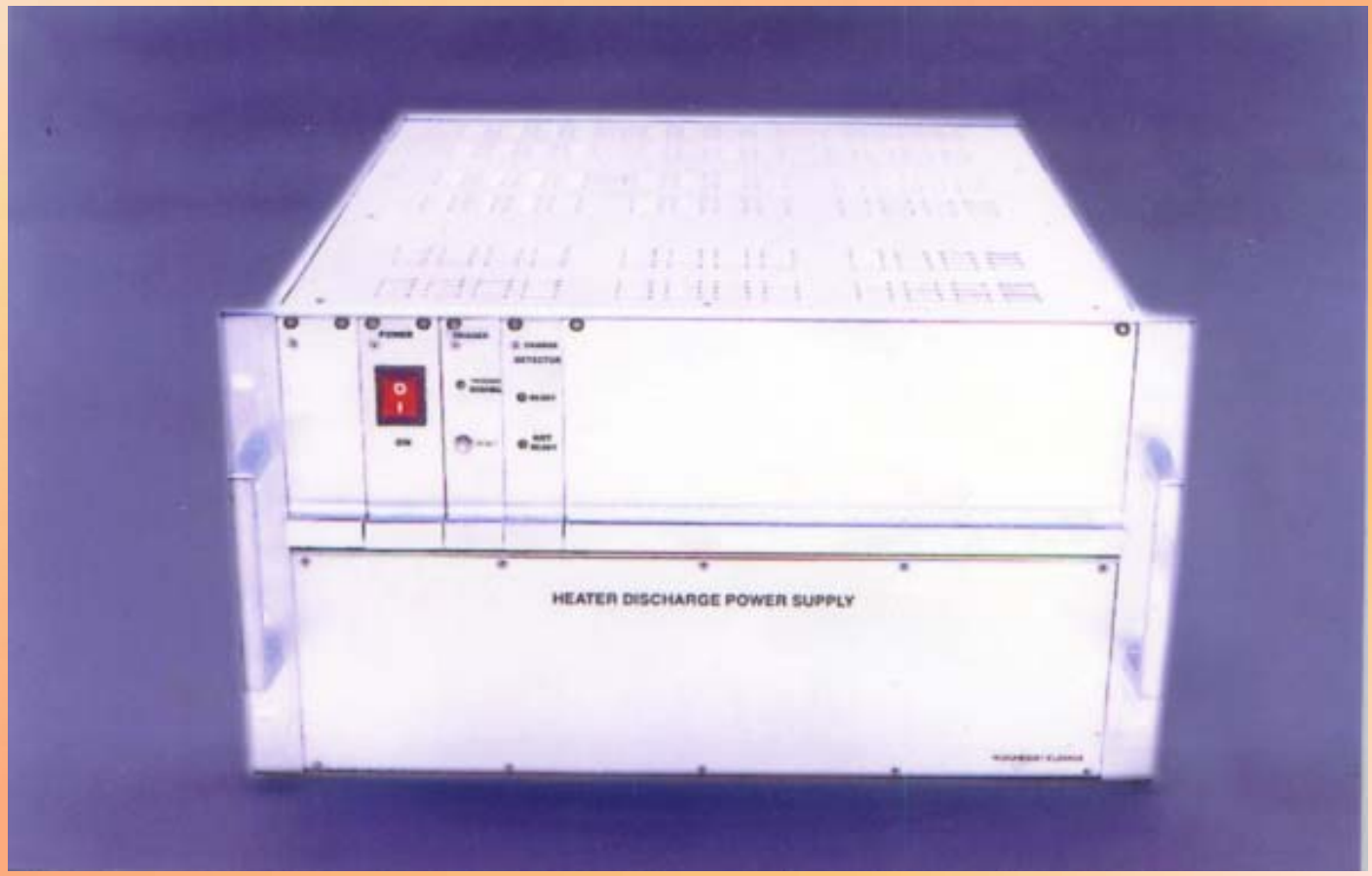
ROTARY PUMP

BELLOW

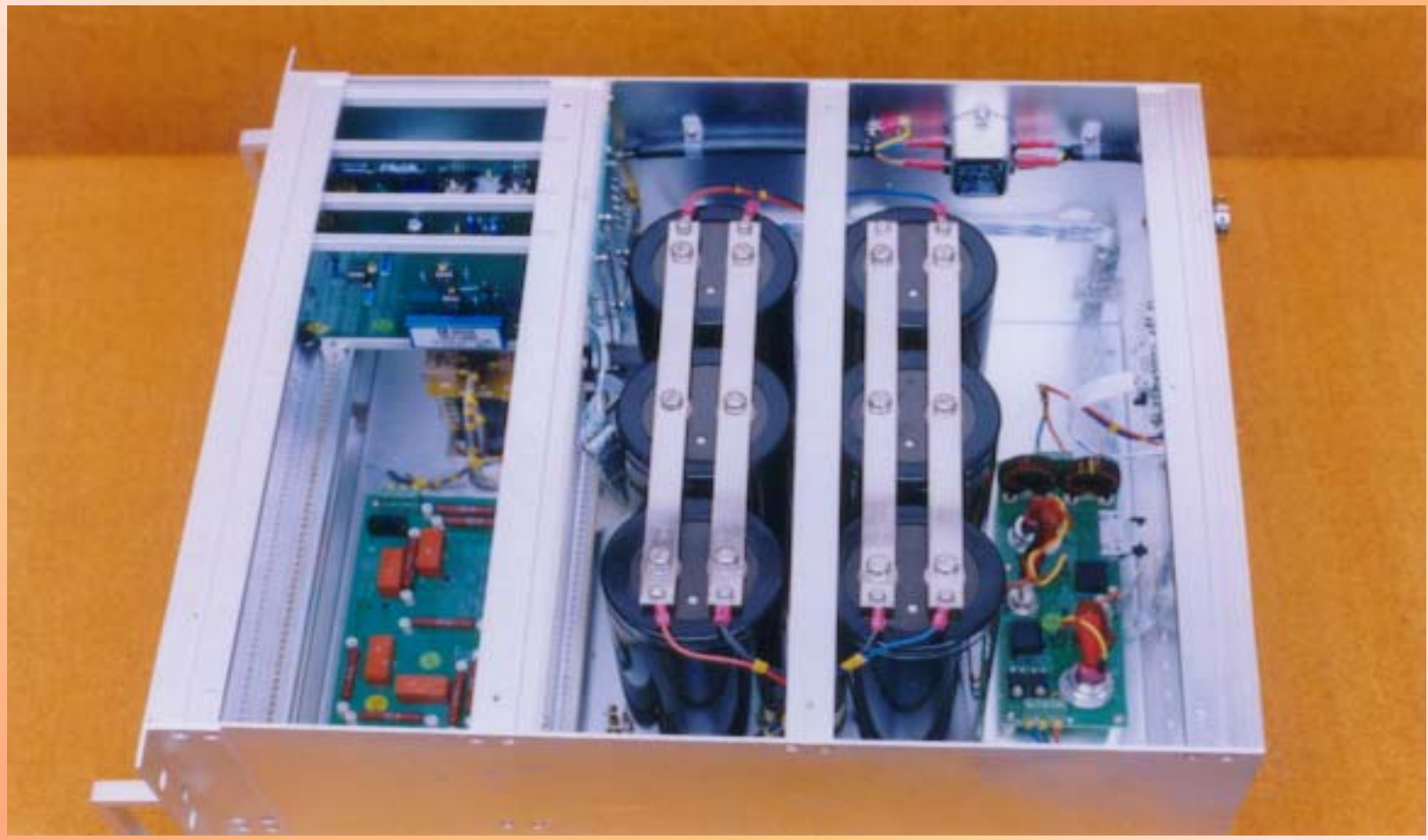
L.H.C. BEAM DUMP LINE

DRG. No.:-CAT/LHC/BD/001

DRN.:- M.S.Bhavsar



Prototype Quench Protection System Power Supply unit (QPS P/S)



Internal details of QPS P/S

Pre-Series QPS P/S
made by ECIL

Pre-Series of control electronics for circuit breaker
(energy extraction system)

Software Development

C.1 GEODE and JMT-1

Database for Survey and Job Management Toolkit for Workshops

C.2 JMT-2

Advanced version of JMT-1 with Client node interface through Oracle forms and reports and Web interface

C.3 Industrial System control

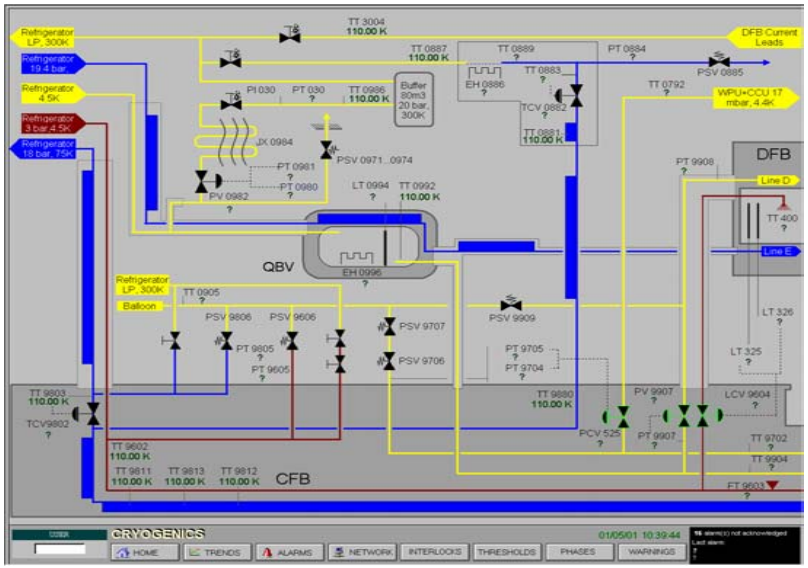
Supervisory Control and Data Acquisition (SCADA) s/w for systems like Cryogenics,Vacuum,Power Converters Magnet Protection, Energy extraction system of LHC magnets

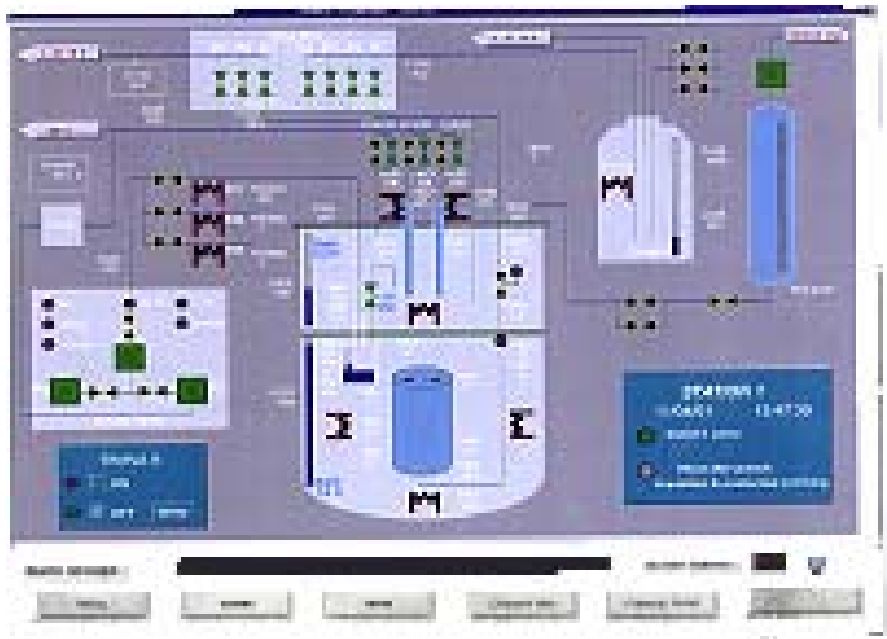
C.4 Magnetic Measurement(MM) Data Analysis Project(DAP).

Deployment of Data Analysis Tools on Web- which includes storing (insertion), retrieval, Cataloging of MM data with data security features.

C.X LHC Machine Control Software….is being launched now

SCADA software for LHC String-2 and Magnet Test Stations





Magnet Test and Measurement Technical Documentation

Magnetic Measurements (MM)	Power tests (PT)	Other test and Measurements
MM of main MB (TRU)	PT pre-series MB	Insulation test
MM of SSS, (Chaconsa)	PT of Series MB	AC Transfer function
Long shaft calibration	PT of SSS	T-Coil measurements
Warm mole for MB		Field advance measurements
Cold Mole for MB		RRR measurements
Single stretched Wire		Joint resistance measurements
		Loss and inductance measurements

Magnetic Measurement and Calibration

1.User Manual for Warm Mole System

2.Measurement of Magnetic axis and Field Harmonics of Main Dipole with Warm Mole.

3.Operational Procedure of Warm Mole LHC.

4.User Manual for Long rotating coils and TRU for main Dipole

5.Magnetic measurement of main Dipole at MB test station with TRU.

6. Long shaft calibration using standard magnet and dedicated bench.

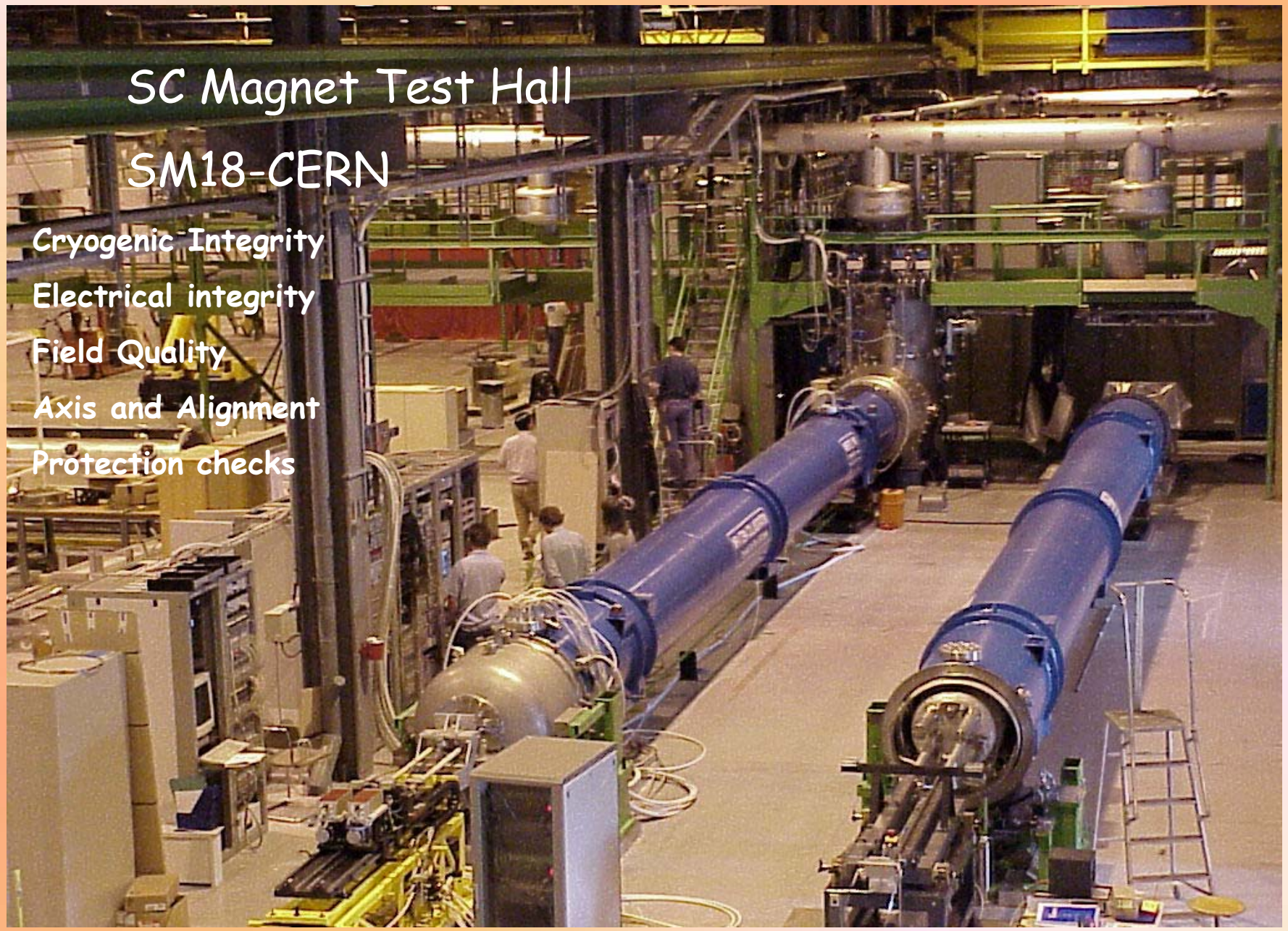
7.Calibration procedure for 15 M dipole long coil shaft.

8.Technical Reference Manuals for TRU

Power Tests

1.User Manual for Power Tests of Pre-series Main Dipole (MB) magnets at SM18 hall

2. Technical Reference manual for Power Test (pre-series)


SC Magnet Test Hall
SM18-CERN
Cryogenic Integrity
Electrical integrity
Field Quality
Axis and Alignment
Protection checks

S t a t u s

- **Items valued more than 30M Swiss Francs finalised-reaching close to the target of the original Protocol**
- **Pre-series phase completed with acceptance (as per LHC specs-CERN) of all major items of contribution**
- **Series production and testing of SC magnets and PMPS jacks well on its way in Indian Industries: 1000MCS-MCDO and 900 PMPS Jacks delivered to CERN.**
- **Indian team contributing substantially to LHC cryomagnet tests and measurements at SM18 hall CERN**
- **Cooperation agreement with CERN extended for further ten yrs period,contributions enhanced in LHC**
- **INDIA is now an "Observer State" in the governing council of CERN..**
  EC,Israel,Japan,Turkey,USA,UNESCO being other observers


Thank you
for
your patient listening
DST-LC meet 10-11 Nov'03 N Delhi

LHC Progress Dashboard

Dipole cold masses