Cryogenic Summary - Testing D2L104 in MAGCOOL, Part II (1/6 – 2/6/2003)

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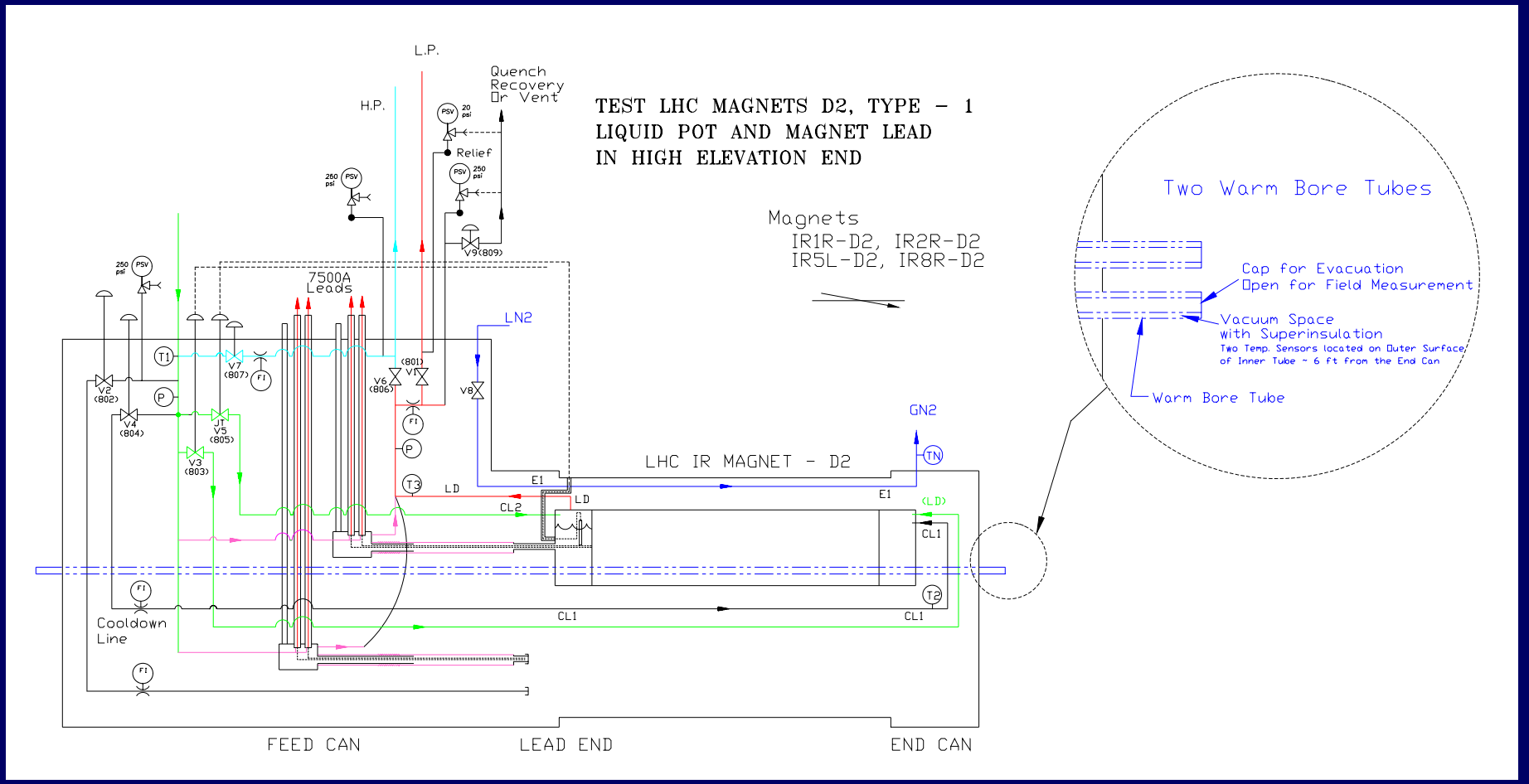
2/6/03

- General Description
- Operating Summary
- Tests Performed
- Detail Operation
- Test Conditions
- Summary

General Description - D2L104

- 0.28 % slope (slightly less than the 0.36 % slope in LHC IR8),
- Warm bore tubes inserted. Test have been performed with warm bore tubes evacuated and opened for field measurements.
- Information on the Warm Bore Tube and measuring device can be obtained from
  - A. Marone - andym@bnl.gov
  - G. Ganetis – ganetis1@bnl.gov
  - D. Sullivan – dans@bnl.gov

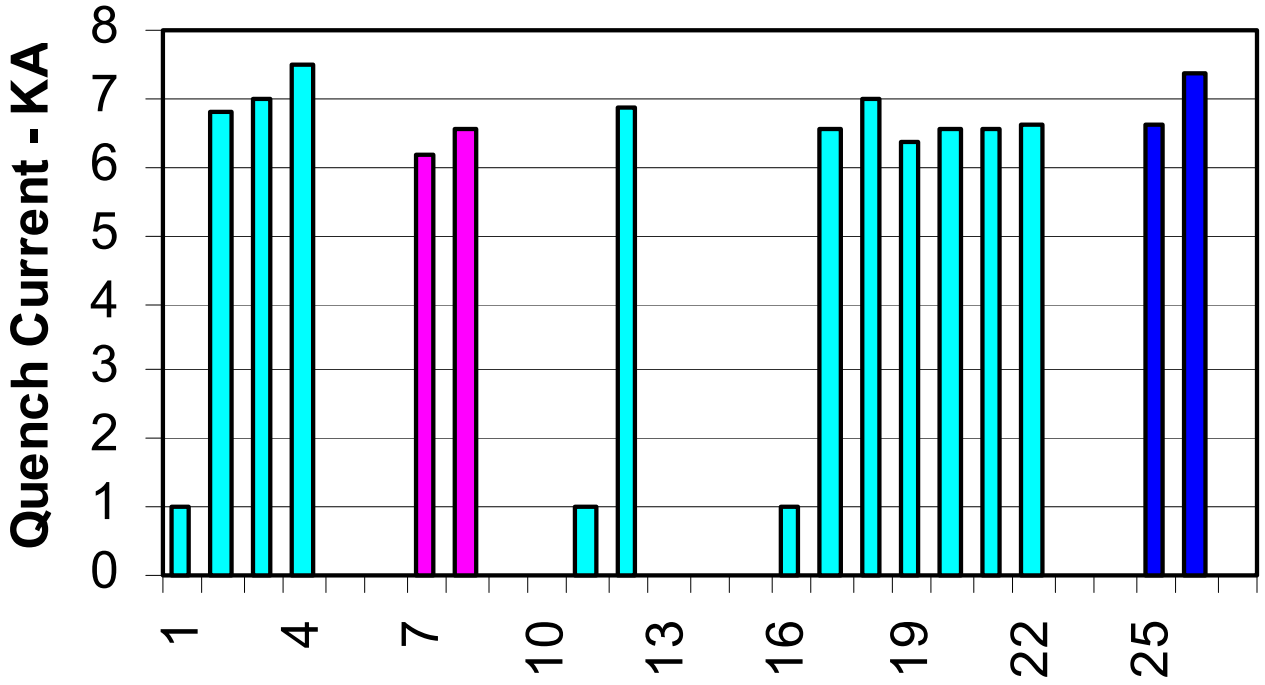
Flow diagram of D2L104 with Warm Bore Tubes – Capable of feeding liquid He from either high or low elevation ends



Tests Performed for D2L104 – Part II

- 4th test group (forced flow cooling ~ 4.65 K),
  - Shut off - 1000 A (1/9)
  - 1st quench – 6528 A (1/9)
  - 2nd quench – 6999 A (1/9)
  - 3rd quench - 6391 A (1/10)
  - 4th quench - 6579 A (1/10)
  - 5th quench - 6572 A (1/10)
  - 6th quench - 6618 A (1/11)
- 5th test group (forced flow with warm bore tube open D2 ~ 4.68 K, approximately 0.03 K higher than warm bore tubes evacuated),
  - 1st quench - 6642 A (1/14)
  - 2nd quench - 7359 A (1/14)
  - Perform field measurement AC cycle, DC loop and Fast Ramp to 6400 A (1/15-17, 1/21-24, 1/28 – 2/3)

Quench Performance of D2L104 with Warm Bore Tubes Evacuated (1000 A is Shut Off)



Quench - No. 1- 4 (Forced Flow), No. 7-8, (Liquid Cool)
No. 11 - 12, (Forced Flow after 1st Thermal Cycle)
No. 16 - 22 (Forced Flow after 2nd Thermal Cycle)
No. 25 - 26 (Forced Flow Warm Bore Open)

Operation (1/6 – 12)

- 1/6 – 1/8/03 — 4^{th} cooldown for D2L104. Takes ~ 40 hours to finish Cooldown I
- 1/8 – 9 — 100 – 5 K Cooldown ~ 20 hours using two expanders, E19 & E20.
- 1/9 — Reach test condition for forced flow, Cold check, 1000 A shut off, 6528 A, 6999 A quench.
- 1/10 — Keep cold overnight, 6391 A, 6579 A, 6572 A
- 1/11- 12 — 6618 A, switch to liquefaction mode D2 drifting through weekend

Operation (1/13 – 18)

- 1/13 D2 ~ 40 K, start 5 K Cooldown with warm bore tube open. Use two expanders, E19 & E20 to 8 K, and E19 only below 8 K.
- 1/14 Overnight, liquid accumulated in Subcooler but not Precooler. Start E20 to enhance cooldown. Insulating vacuum in warm bore is ~ 0.005 Torr using a turbo pump. Test D2 in forced flow. 6642 A, 7359 A quench.
- 1/15 - 17 Use E19 to keep D2 cold overnight. Perform AC cycle, DC loop to 6400 A.
- 1/18 Switch to liquefaction mode. Leave D2 drifting through weekend.

Operation (1/20 – 27)

- 1/20 D2 ~ 40 K, start 5 K Cooldown using two expanders, E19 & E20.
- 1/21 Overnight, liquid accumulated in Subcooler and Precooler. Shut E20.
- 1/21 - 24 Perform AC cycle, DC loop to 6400 A.
- 1/25 Switch to liquefaction mode. Leave D2 drifting through weekend.
- 1/27 D2 ~ 50 K. Start 5 K Cooldown.
  Found blockage in the two unused leads.
  Fortunately, not in the two 7500A leads.
  Believe will not prevent us from testing.
  Proceed cooldown using E19 & E20.

Operation (1/28)

- 1/28 Reach test condition in ~ 20 hours (from 50 K).
  Shut E19. Temperature is ~ 5.1 K at the bottom of two unused leads.
  Perform 1st AC cycle successfully. However, bus quenches unexpectedly at 4400A in the 1st DC loop.
  Hoping to use heat to remove plug, increase temperature setting to 150 F at the top of two unused leads. Unable to clear the blockage.
  Introduce flow, through vent valve on lead pot of the unused leads, to improve cooling to the bus.
  Resume AC cycle. Find voltage across the bus of the (+) line reached 0.002 V at 3600 A. Ramp down to avoid bus quenching.
  Slightly increase flow through vent valve.
  Able to perform AC cycle and DC loop to 6400A.

Operation (1/29 – 30)

- 1/29 Follow the same procedure established on 1/28, open vent valve to improve cooling to superconducting bus.
  Finish AC cycle and all DC loops.
- 1/30 Perform fast ramping measurement at 10 A/s.
  In the 1st ramping, the (+) superconducting bus quenched at ~ 5000A due to incorrect flow setting. With vent valves open (as 1/29) and Tare Flow set at 0.15 & 0.38 g/s above 10A (same as AC cycle at 10 A/s), D2L104 was ramped to 6400A. Stay at 6400A for 5 min. Ramp down to 4000A where a strip heater quench was issued. To keep warm end from freezing (slightly below 32 F, ~ 31.6 F), Tare Flow on the (+) lead was gradually reduced from 0.15 to 0.10 g/s once 6400A is reached.

Operation (1/31 – 2/6)

- 1/31 Repair measuring device, no test
- 2/1 Perform fast ramp test at 10 A/s and 5.5 A/s etc.
- 2/2 Keep D2 at test condition.
- 2/3 Complete fast ramp tests. Leave D2 drift.
- 2/4 Overnight D2 reaches ~ 35 K. Start warmup at 9 AM.
- 2/5 Warmup compressor tripped at 2 AM when D2 ~ 230 K (increase of ~ 200 K in 17 hours).
  Restart compressor at 8 AM.
  Blockages of the two unused leads disappeared when temperature exiting D2 ~ 200 K. The blockage could be caused by water since temperature of the blockage is slightly higher than that exiting D2.
- 2/6 Complete warmup at 6 AM. Total warmup time would be 38 hours if compressor did not trip.

Test Conditions

- Forced flow cooling - 12 atm, 4.6 K & 60 - 65 g/s
- Warm bore tube evacuated

  Pressure is 0.005 Torr in insulating vacuum of warm bore using a turbo pump

  Pressure is 0.170 Torr inside warm bore tube

  Temperatures are

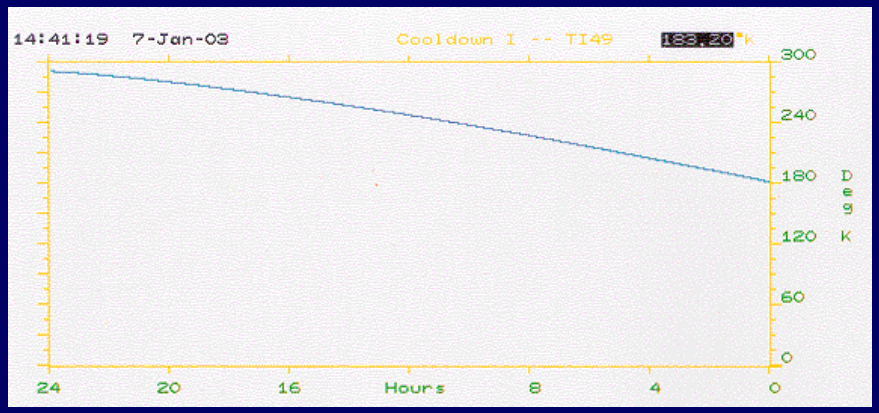
  -121 / -150 F in left aperture

  -58 / -77 F in right aperture
- Warm bore tube opened

  90 SCFH, 75 F nitrogen F flows through the warm bore tubes. An electric heater is used to control warm bore at 75 F.
- Temperature in D2L104 is approximately 0.03 K higher with warm bore tube open compared with evacuated.

Cooldown from 300 – 100 K for D2L104

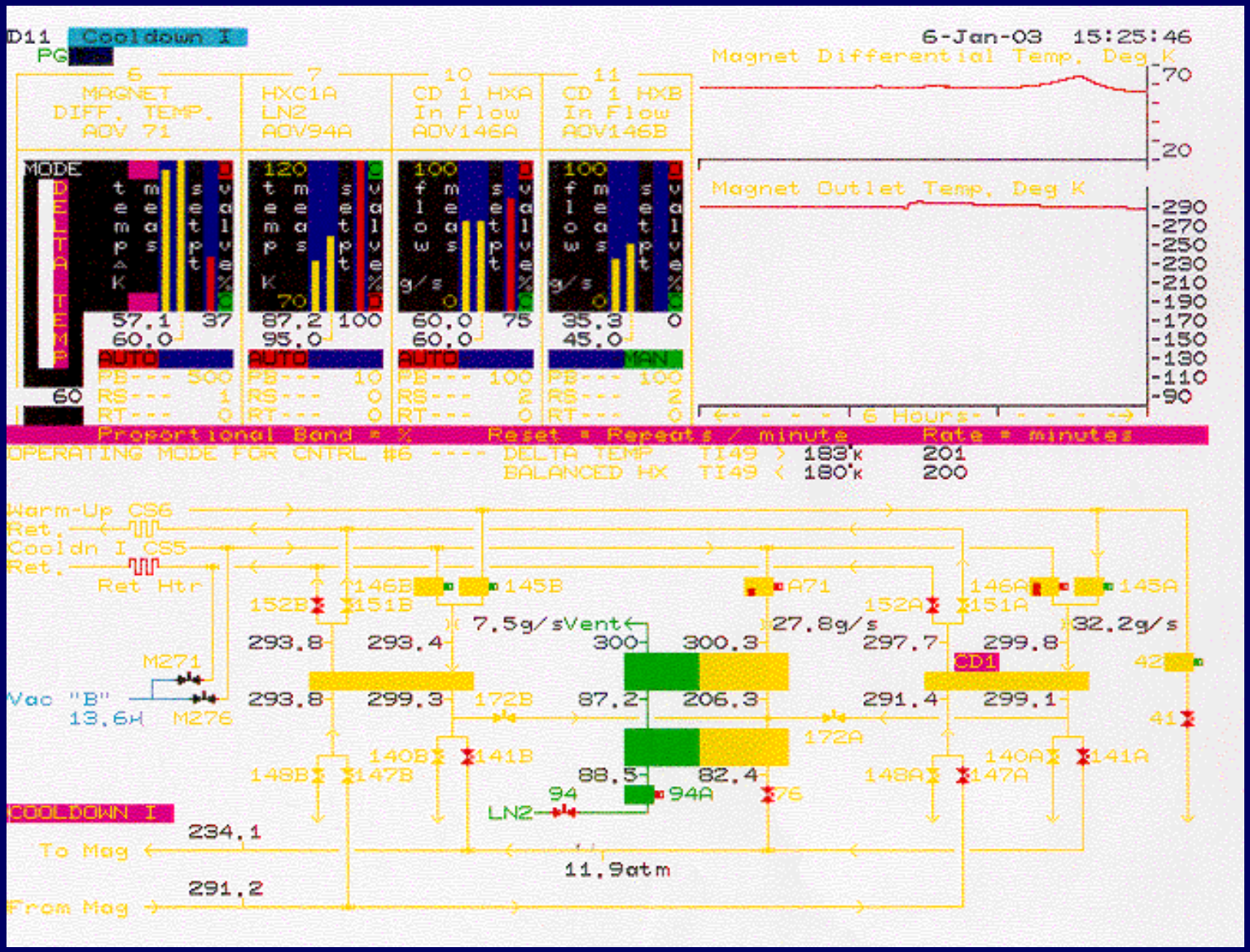
(1/6 - 1/8/03)



- 100 K Cooldown time ~ 40 hours
- Use 60 g/s of helium flow for MAGCOOL cooldown I.
- Cooldown rate ~ 5 K/hour above 200 K, ~ 8 K/hour between 200 and 100 K

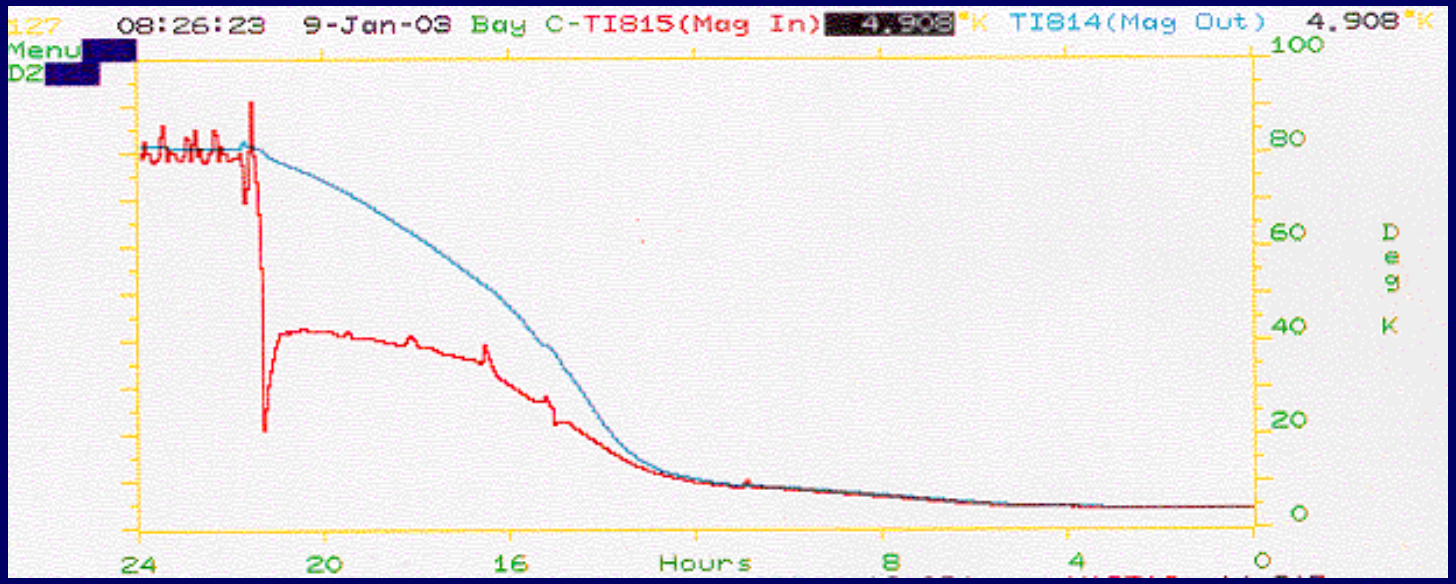
Operating Condition for 100 K Cooldown of D2L104

– 1/07/03



Cooldown from 100 – 6 K for D2L104

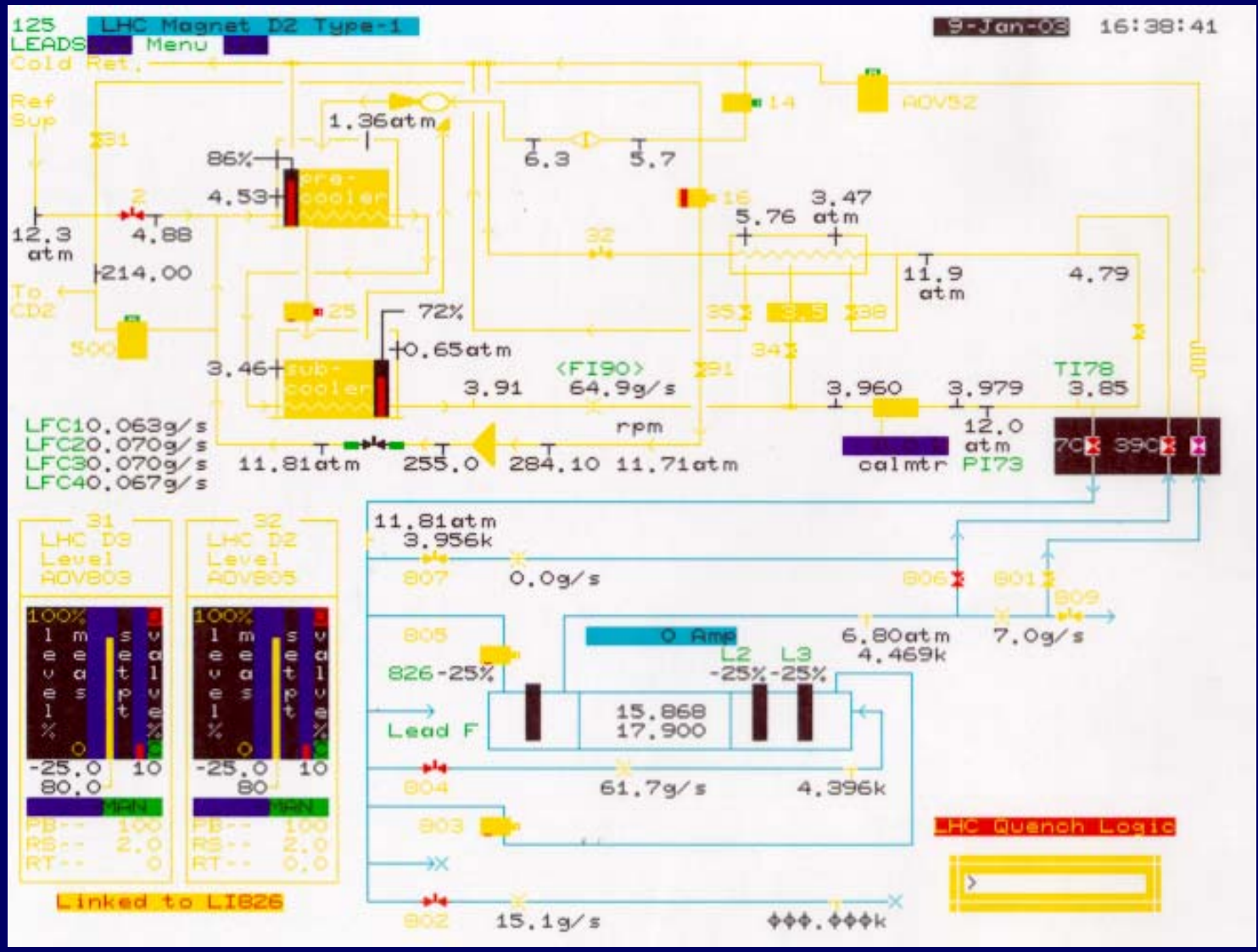
(1/8 – 1/9/03)



- Cooldown time (90 to 20 K) is 8 hours, ~ 9 K/hr using E19 & E20 (at ~190 rpm).
- Cooldown time (20 to 5 K) is ~ 14 hours, using E19 & E20 (at ~ 150 rpm).
- Total cooldown time from 90 K to test condition is ~ 24 Hours
- Cooldown rate is fast because the HEUB refrigerator is clean (pumped and purged after the New Year shut down).
- Temperatures at the inlet (red) and the exit (blue) of D2L104 are shown

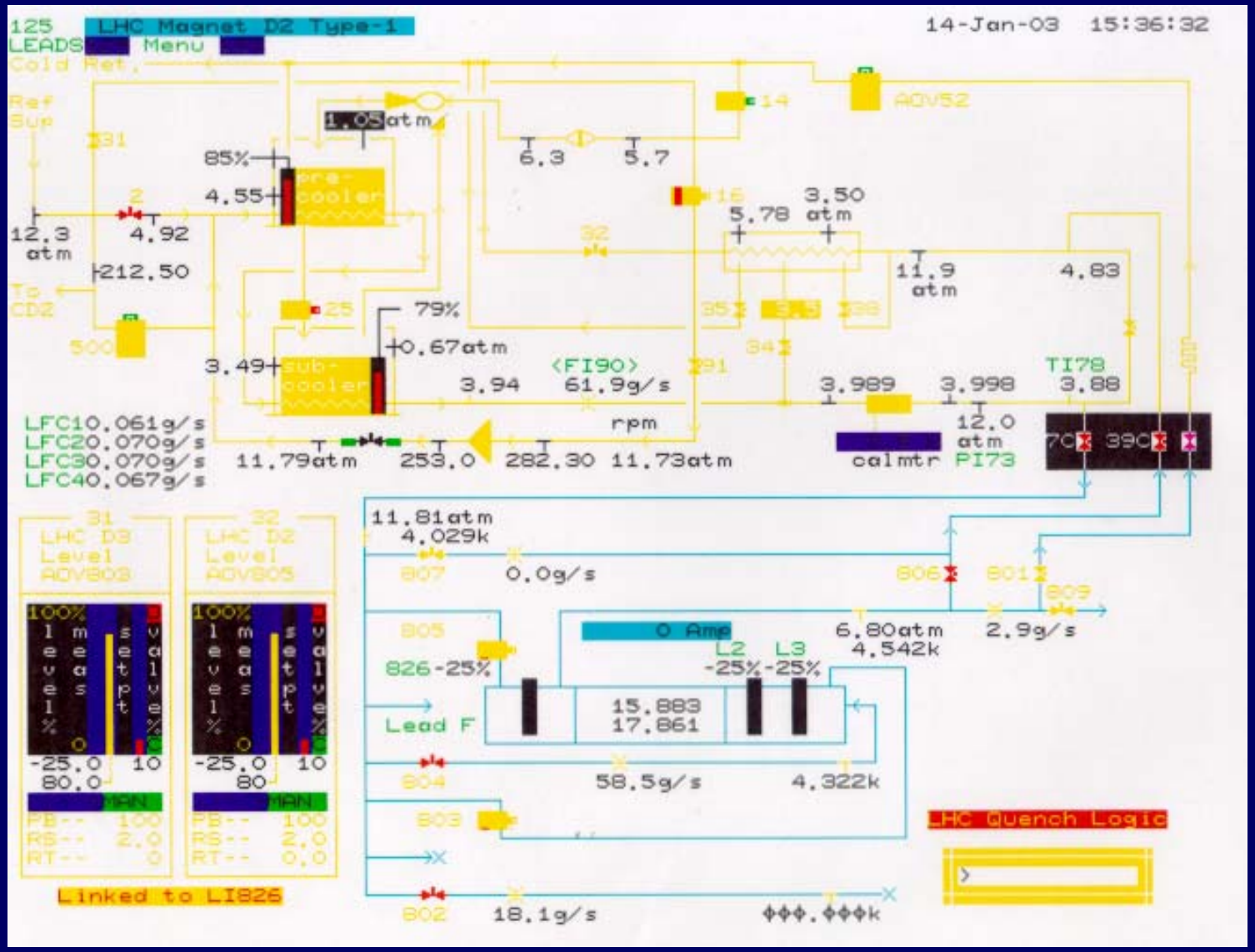
Forced Flow Cooling of D2L104 Prior to 6999 A Ramping

(Warm Bore Tube Evacuated with 0.170 Torr Pressure)



Forced Flow Cooling of D2L104 Prior to 7359 A Ramping

(Warm Bore Tube Open with 75 F Nitrogen Flow)

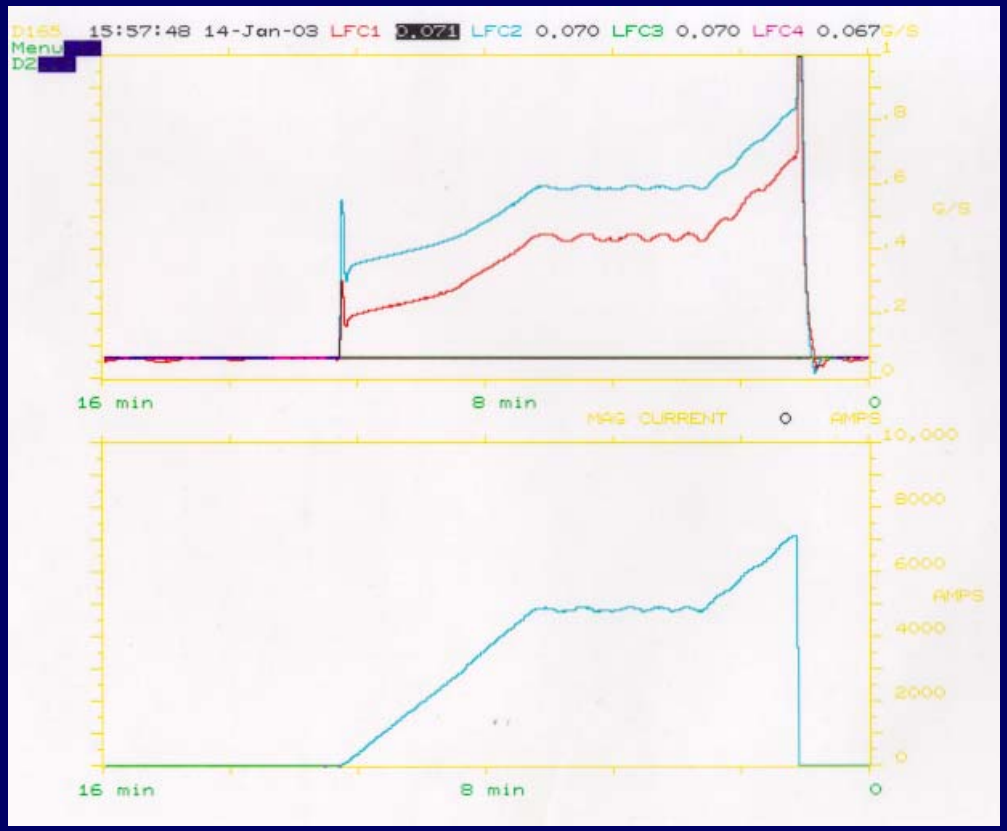


Lead Flow and Current During Ramping of D2L104

Ramp rate is 20 A/s. Below 10 A, Tare flow is 0.07 g/s. Above 10 A, Tare flow is 0.20 g/s for (+) lead & 0.35 g/s for (-) lead. Need to wait for voltage recovery of the (-) lead at 5000 A for about 3 min.

Upper Figure: Lead Flow – Blue for (-) Lead and Red for (+) Lead.

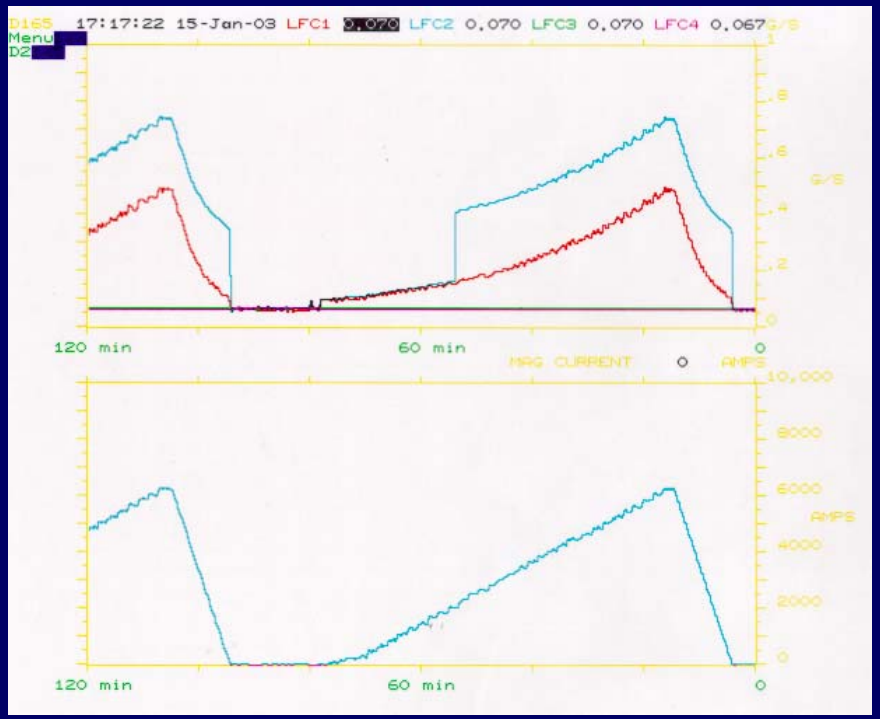
Lower Figure: Current as a Function of Time



Lead Flow and Current During DC Loop of D2L104

Upper Figure: Lead Flow – Blue for (-) Lead and Red for (+) Lead.
Lower Figure: Current as a Function of Time

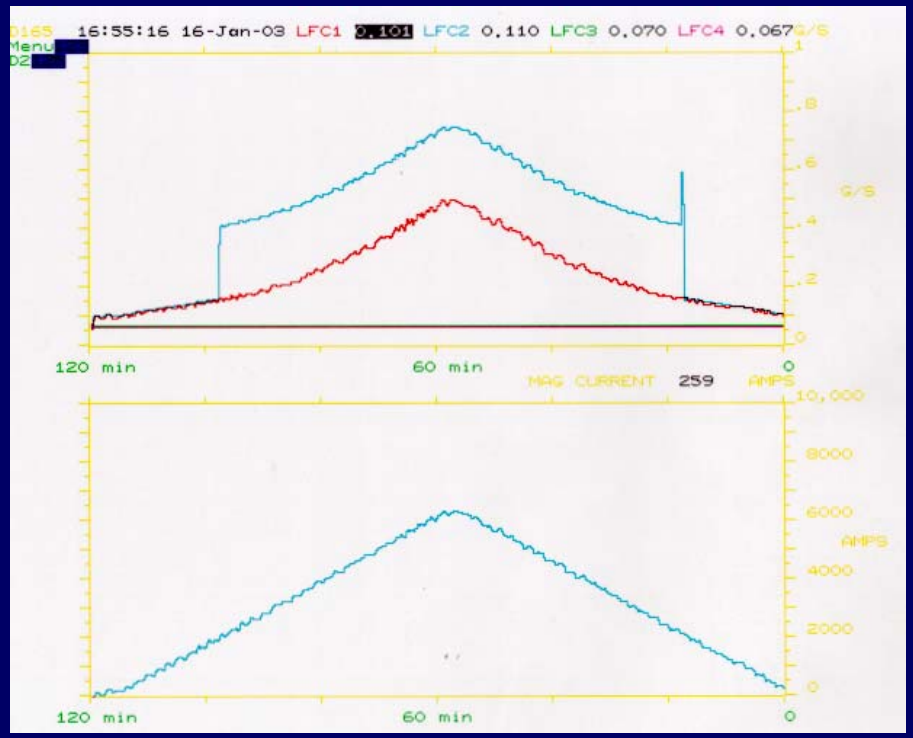
Ramp rate is 10 A/s. 80 seconds stop at several currents during ramp up. Ramp down at 10 A/s without stop.
It takes almost 60 min to reach 6400 A, there are time for the leads to be cooled.
The lead flow should approach design value as shown in the (+) lead. As we know, there is a defect in the (-) lead and requires more lead flow even through it takes 60 min to reach 6400 A.
Tare flow is set at 0.10 g/s for the (+) leads for all currents to 6400 A.
Tare flow for the (-) lead is set at 0.10 g/s below 2000 A and 0.35 g/s afterwards.



Lead Flow and Current During DC Loop of D2L104

Upper Figure: Lead Flow – Blue for (-) Lead and Red for (+) Lead.
Lower Figure: Current as a Function of Time

Ramp rate is 10 A/s. 80 seconds stop at several currents during ramp up.
Since it takes about 60 min to reach 6400 A, there are time for the leads to be cooled.
The lead flow should approach design value as shown in the (+) lead. As we know, there is a defect in the (-) lead and requires more lead flow even through it takes 60 min to reach 6400 A.
Tare flow is set at 0.10 g/s for the (+) leads for all currents to 6400 A and down.
Tare flow for the (-) lead is set at 0.10 g/s below 2000 A and 0.35 g/s between 2000 and 64000 A. Tare flow must be decreased to 0.10 g/s below 2000 A to avoid warm end of lead become too cold

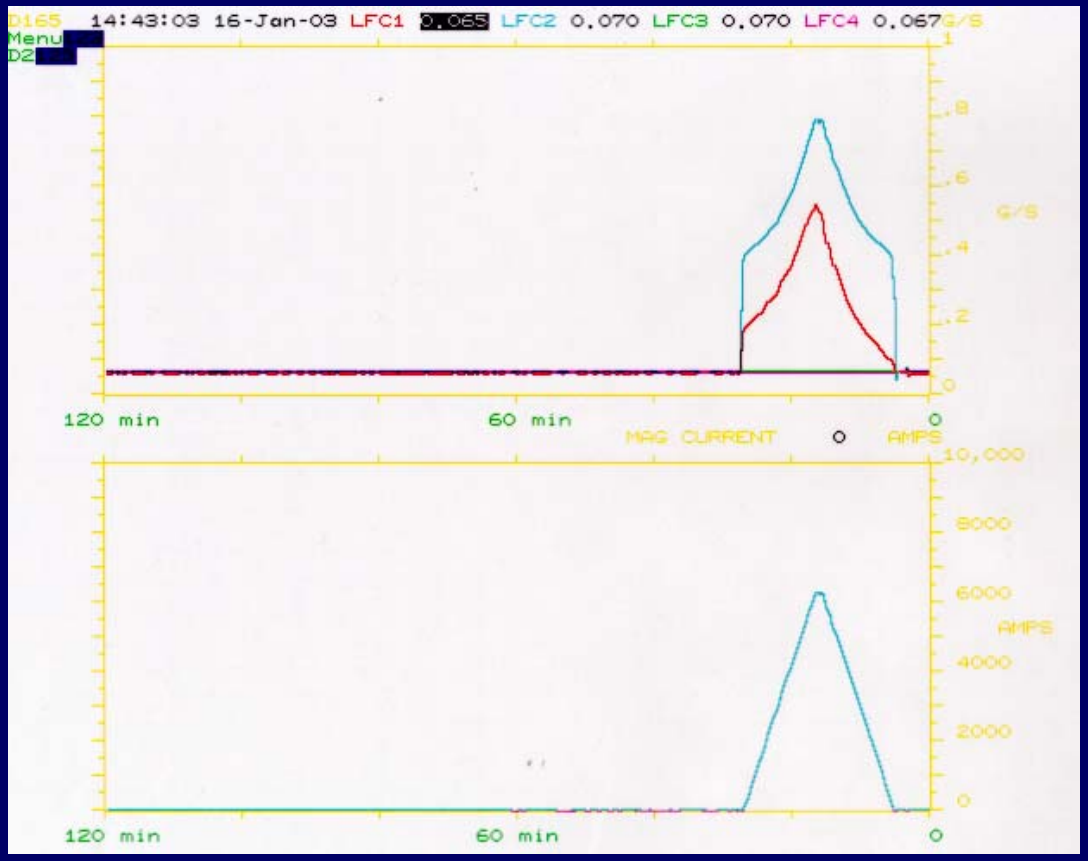


Lead Flow and Current During AC Cycle.

Upper Figure: Lead Flow – Blue for (-) Lead and Red for (+) Lead.

Lower Figure: Current as a Function of Time

Ramp rate is 10 A/s. For AC cycle, it is ramped directly to 6400 A and demands more lead flow especially the (-) lead.

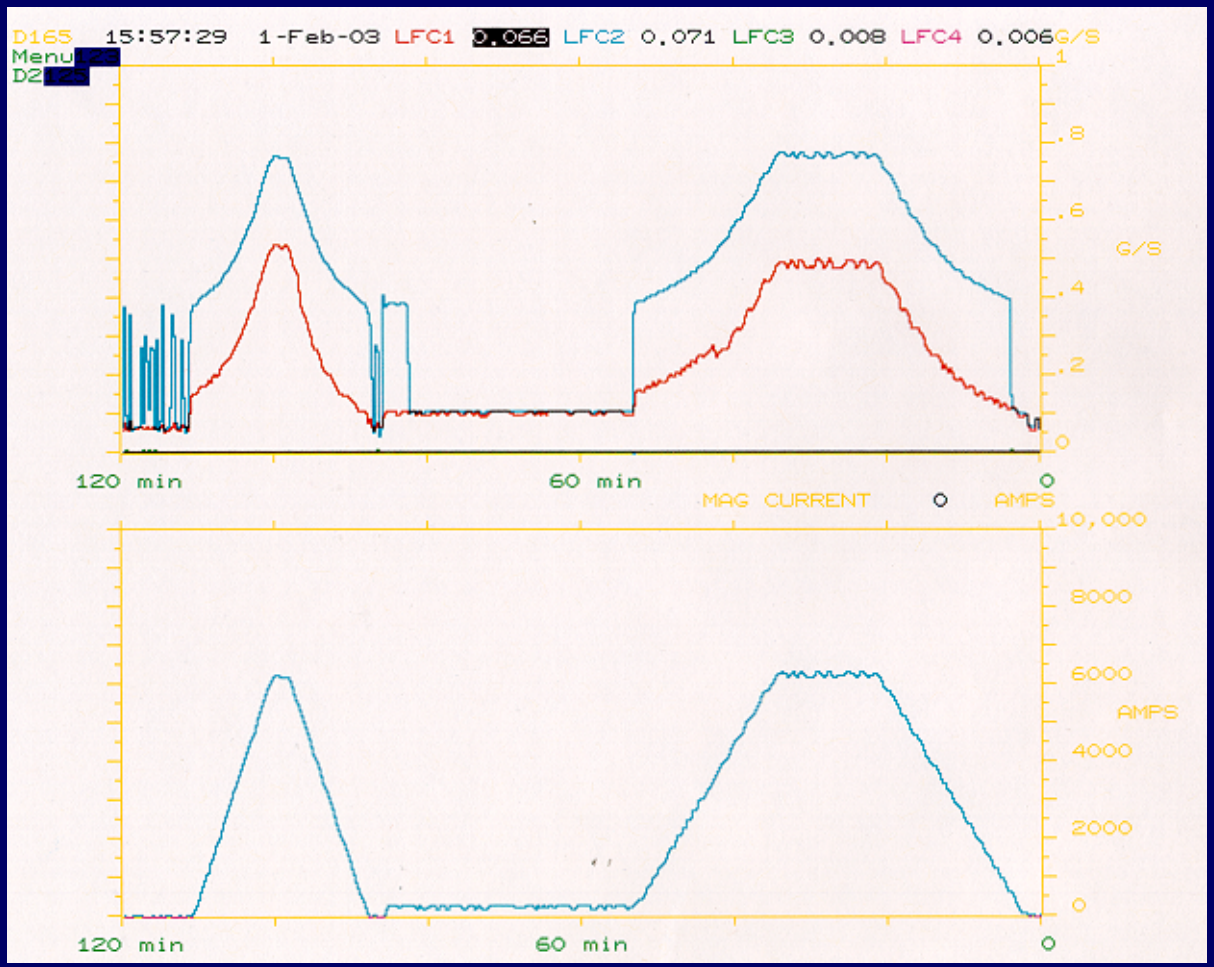


Examples of Lead Flow and Current During Fast Ramp

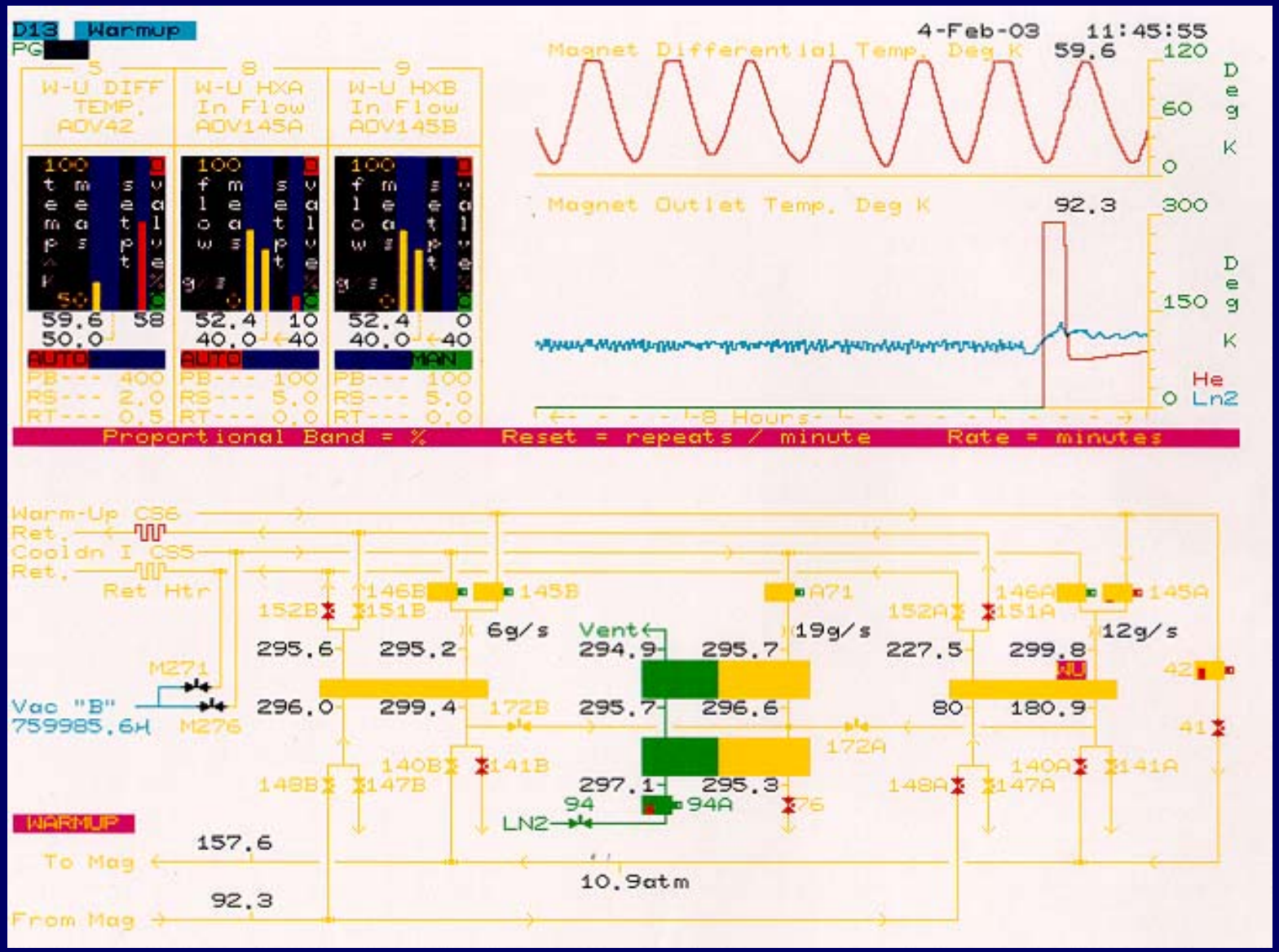
Upper Figure: Lead Flow – Blue for (-) Lead and Red for (+) Lead.

Lower Figure: Current as a Function of Time

(The following figure is for test with a 10 A/s AC cycle followed by 350 A, 5.5 A/s ramp to 6400 A, at 6400 A and ramp down)

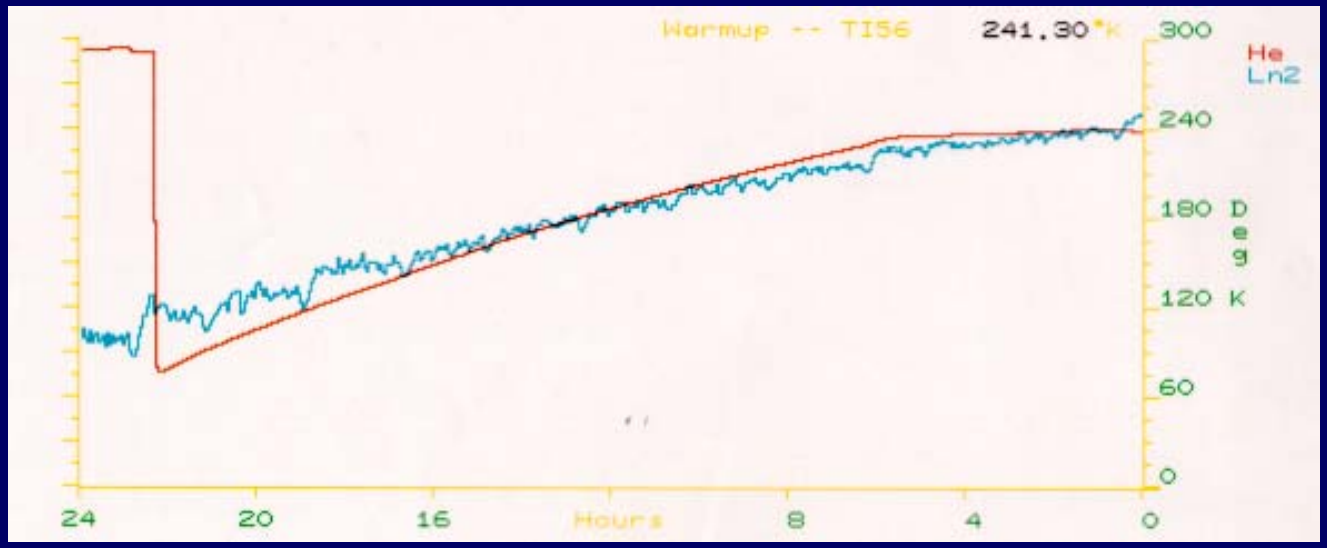


Process Control for Warmup D2L104 – 2/4/03

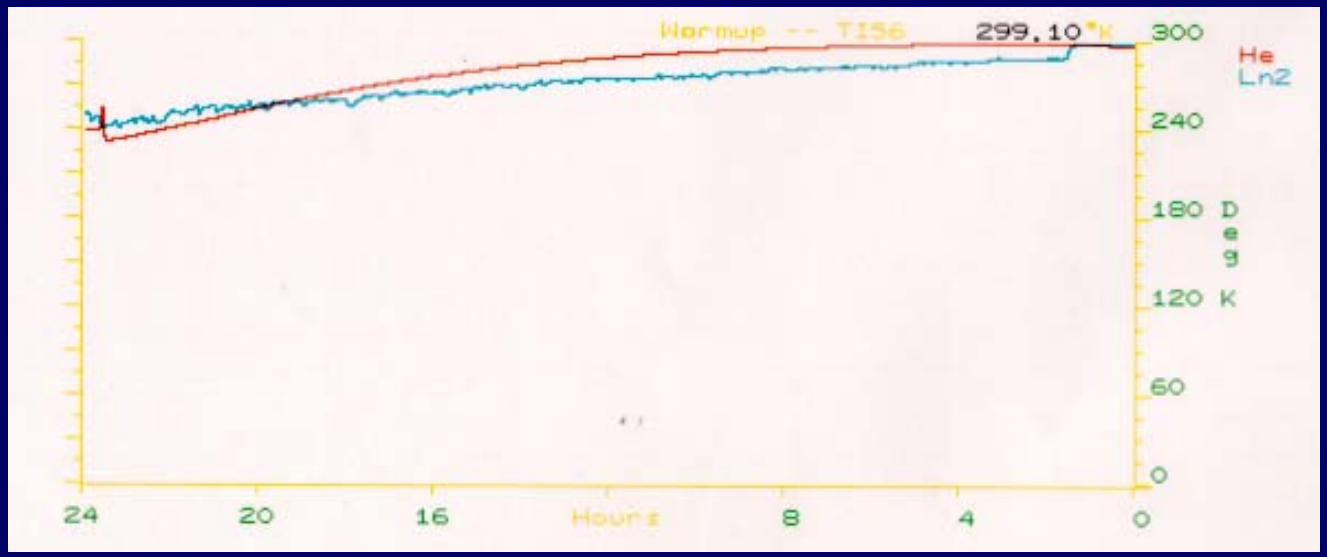


Warmup of D2L104 – from 35 to 300 K

Total time equals ~ 38 hours if warmup compressor did not trip.



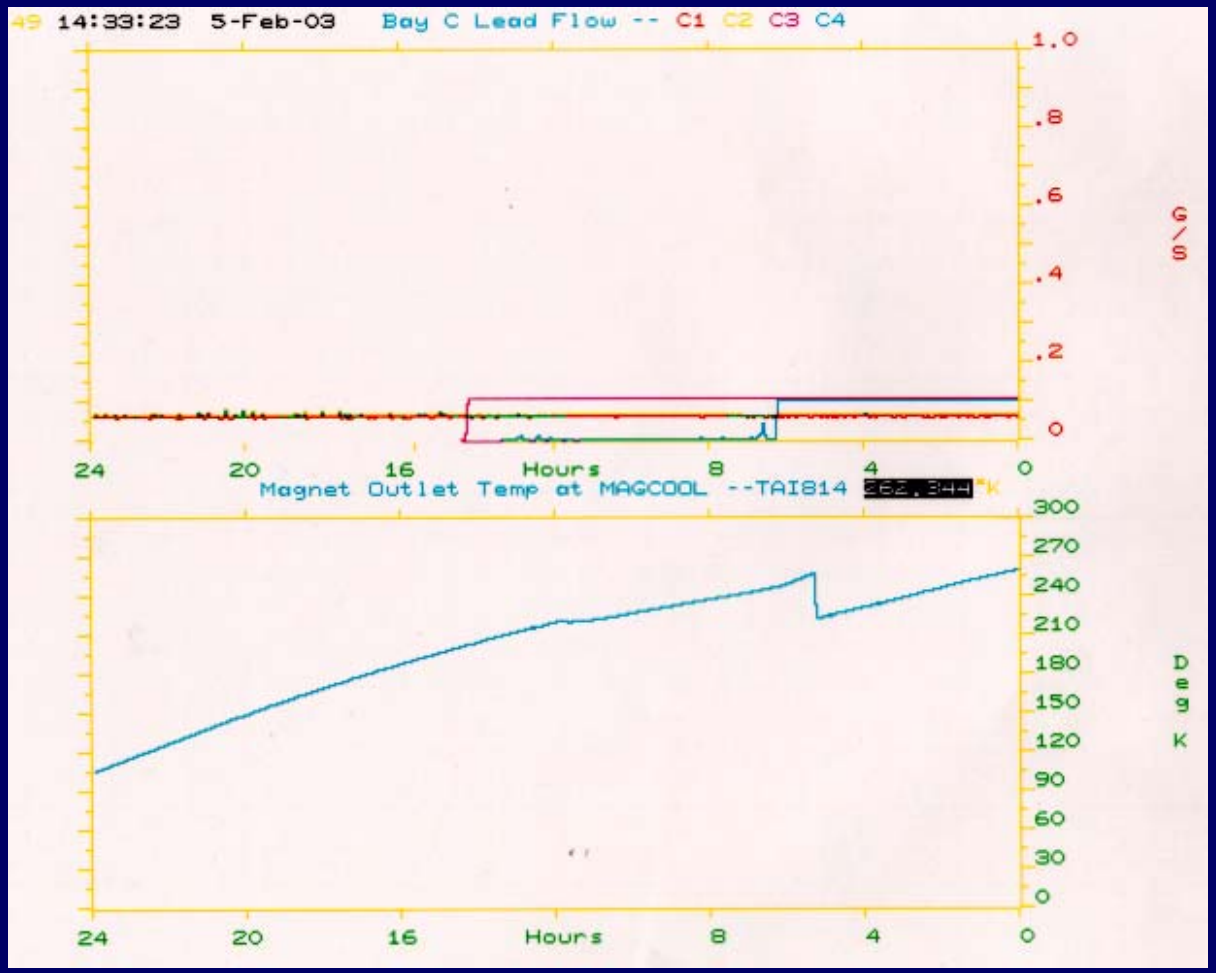
35 – 230 K
in 17 hours



230 – 300 K
in 21 hours
with
(290 - 300 K
in ~ 10 hours)

Blockage of Current Leads as Indicated by Lead Flow (upper curve) as a Function of Time. The corresponding temperature exiting D2L104 are given in the lower curve.

Blockage disappeared when temperature exiting D2 reached ~ 200 K. Blockage in lead 3 cleared a few hours before lead 4.



Current Leads

- Separate flow controllers for the 7500 A leads
- The (-) lead demands more flow than the (+) lead
  - For quench test at 20 A/s ramp rate,
    - The tare flow are 0.20 g/s for (+) lead and 0.35 g/s for (-) lead
    - Need to wait ~ 3 minutes at 5000 A for the (-) lead to recover the voltage developed before ramping current above 5000 A.
  - For AC cycle at 10 A/s ramp up directly to 6400 A (no wait at 5000 A),
    - Tare flow is ~ 0.15 g/s for (+) lead, (at 0.20 g/s, the warm end is cold)
    - Tare flow is ~ 0.38 g/s for (-) lead, (at 0.35 g/s, the lead voltage is on the high side. At 0.40 g/s, the warm end of the lead is slightly cold)
  - For DC loop at 10 A/s with 80 seconds stop at various pre-selected currents,
    - The tare flow is 0.10 g/s for (+) lead for all currents
    - The tare flow is 0.10 g/s below 2000 A and 0.35 g/s afterward, (or reduced back to 0.10 g/s below 2000 A with stop during ramp down)
- Unused leads are set at 0.070 g/s and 0.050 g/s.

Summary

- Field measurement for D2L104 have been successfully performed with two warm bore tubes.
- In initial quench tests, warm bore tubes are evacuated.
- In subsequent field measurement, warm bore tubes are open with 75 F nitrogen flowing through.
- Temperature increase due to opening of warm bore tube is insignificant. After two days of cooling, D2 is as cold as that when the warm bore tubes are evacuated.
- In the 1/25 weekend drift, the two unused leads plugged again mysteriously. Luckily, no blockage in the two operating leads. Impact on test is minor.
- Two bus quenches resulted from zero flow through unused leads. Bus quench was eliminated using a small flow through vent valves.
- Blockage of unused leads disappeared when temperature existing D2 reaches 200 K - probably due to water in the system.
- Complete field measurements.