

**Operation Methods** OM-PT9.01

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**Method For Measuring Residual Resistivity Ratio ( RRR ) on  
Standard C Bench using Keithley voltmeters**

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Operation Methods are used for testing the LHC Magnets in Cryogenic Conditions in building 2173 (SM18) and are the working documents produced for that purpose only. These Methods are produced by the Associates from DAE-India and the AB Division Operation Staff, carrying out the tests and working in collaboration, under the responsibility of AT Division for the LHC Project.

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# Method For Measuring Residual Resistivity Ratio ( RRR ) on Standard C Bench using Keithley voltmeters

## 1. Definition of Residual Resistivity Ratio ( RRR )

The RRR is the ratio between the resistance of the magnet coil at 293K and the resistance of the magnet coil just above the transition temperature (from super conducting to normal state).

For the Niobium – Titanium super conductors used in LHC magnets, the typical transition temperature from superconducting state to resistive state is 9.6 K.

## 2. Objective

To measure

- RRR for cables in each pole (D1\_L, D1\_U, D2\_L, D2\_U)
- RRR for cables in each aperture (D1, D2)

## 3. Principle of operation

### *3.1 Role of the Cryogenics team ( to be coordinated by SM18 Operation )*

**3.1.1 Case 1 :** When RRR measurements are carried out **after regular quench** at 6.5 KA as part of cold tests campaign

A Minimum Energy Quench is provoked in the magnet ( usually 6500 A ) using one Low Field Heater ( presently YT 112 ). The cooling down of the magnet is to be stopped after the quench with prior consultation and agreement of the Cryogenic Team. The temperature of the magnet has to be closely observed before and after the quench .Usually the temperature will reach a peak of 30 to 40 K ( immediately after the quench ) and will then stabilise at 9-10 K . As the cooling down of the magnet has been stopped the temperature of the magnet now begins to rise .It will cross the critical temperature ( approx . 9.6 K ) after 20 minutes .The temperature is allowed to rise up to 12 K or till resistive voltages have been recorded for each pole/aperture for about 30 minutes ( check tips for resistive voltages ) before the data acquisition is stopped .This will give a smooth transition from super conducting to normal state .

**3.1.2 Case 2 :** When RRR measurements are carried out **after the last quench** to warm up the magnets after cold test campaign

This is the case of RRR being carried out taking advantage of the quench to warm up the magnet. In this case an interaction with the cryo team becomes

even more important .Immediately after the quench , the cryo team should be requested to bring the temperature of magnet to about 9 K ( although this defeats the very purpose of warming up quench ).At this point the cooling should be definitely/immediately stopped and the temperature of the magnet should now be allowed to rise so as to eventually reach 300 K .Our region of interest still remains the same , from 9K to 12 K .

### 3.2 Graphical Illustrations of Temperature profiles after quench

**3.2.1 Discussion on Figure 1** : This is one of the best case scenarios where the temperature of the magnet goes below transition temperature ( cursor 1 ) and you are able to start recording of voltages from cursor 1 onwards .At cursor 1 the resistive voltages have not yet appeared . The recording of the voltages continue up to cursor 2 , during which the resistive transition sets in. After reaching cursor 2 the magnet should be simply cooled down to 1.9 K or 4.4 K as desired and the recording can be stopped at cursor 2 . .There is no point in warming up the magnet again ( like shown in the figure 1 ) up to cursor 3 since we have already completed the job at cursor 2.

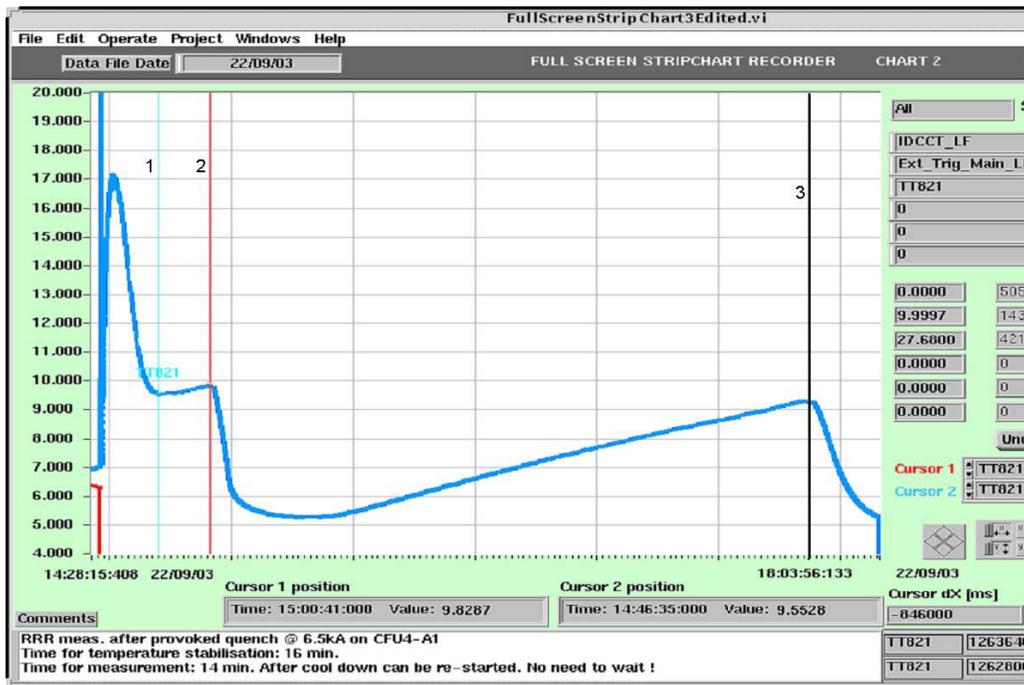


Figure 1 : The resistive transition has taken place some where between cursors 1 and 2 .No point in warming up the magnet again up to cursor 3 .

**3.2.2 Discussion on Figure 2** : Often we observe that by the time we begin recording the voltages, the temperature of magnet is either above the transition temperature or the temperature of the magnet has never gone below the transition temperature of 9.6 K . Figure 2 illustrates one such temperature profile after a 6.5 KA quench . In this case , we will observe resistive voltages as soon as we start recording at around cursor 1 . The transition voltages can now only be recorded during the cooling down of the magnet

.Hence the recording of resistive voltages is sufficient up to cursor 2 only ( approx . 30 minutes ) and after that the cryo team should be instructed to cool down the magnet .The recording of voltages should continue uninterrupted during cooling down up to a temperature of 8 K . There is no need to keep the magnet at around 12 K up to cursor 3 .

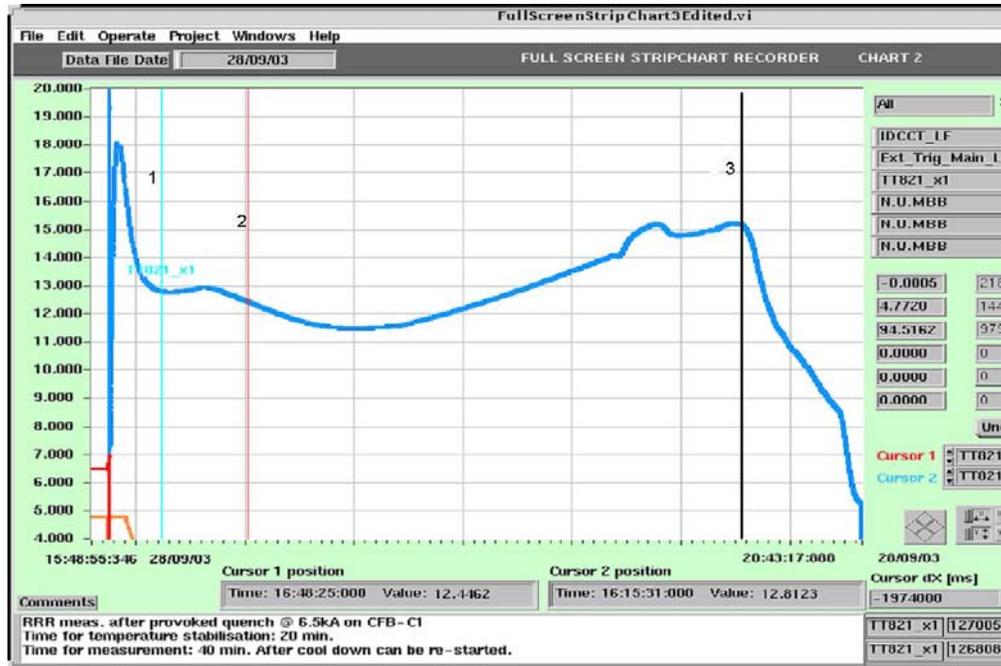


Figure 2 : Magnet temperature after a 6.5 KA quench . This curve emphasizes the futility of measurements between cursors 2 and 3 . Cursor 3 should be brought as close to Cursor 2 as possible i.e the magnet should start cooling down after reaching Cursor 2

### 3.3 Data Acquisition from Magnet Voltage taps

Immediately after the quench ,in addition to observing magnet temperature ,as explained above , a low frequency data acquisition from the magnet voltage taps has to be started .This will facilitate the recording of Poles and aperture voltages (from magnet voltage taps) at constant current of 18 A .Using these voltages we can easily estimate the resistance of the magnet windings , as the current transfers from super conductors to cu-matrix , as the temperature of the magnet crosses the transition temperature for Nb-Ti .

After the Quench a D.C current (18A) is passed through the magnet. The voltages are measured across 4 poles and 2 apertures using Kiethley meter’s interfaced to Sun workstation (sunmta19 on C1 and C2). The typical value of voltage per aperture after transition , becomes approximately around 260 mV per aperture at 18 A for RRR value of 200 ( check Tips at the end of this procedure ) . The acquired data is saved on the Sun workstation sunmta19 for C Benches ( please check the corresponding machine for E Benches ) . The detailed operational procedure is given below.

#### 4. RRR Measurement : ( with Kiethley's ) – Sequence of Operations

1. Make the connections , as shown below , to get differential signals from Voltage taps on Patch Panel ( just below keithley 's ) and connect to Keithley multimeters as per the following table. *Check the polarity of magnet. Make sure to take the V-taps from the QCD and RRR panel .*

##### For Right Magnet

Keithley No.	GPIB Address Keithley DMM	Signal Name	Direct V-taps Points on Patch Panel	
			Positive	Negative
1	16	D1_Lower	111	119
2	15	D1_Upper	119	113
3	14	D2_Lower	219	212
4	13	D2_Upper	211	219
5	12	D1	111	113
6	11	D2	211	212

##### For Left Magnet

Keithley No.	GPIB Address Keithley DMM	Signal Name	Direct V-taps Points on Patch Panel	
			Positive	Negative
1	16	D1_Lower	119	111
2	15	D1_Upper	113	119
3	14	D2_Lower	212	219
4	13	D2_Upper	219	211
5	12	D1	113	111
6	11	D2	212	211

2. Open a new X-term window on Sun Workstation (Sunmta19 for TBC1 and TBC2) where RRR measurement is to be performed and type **DVM\_DAQ** ( check the latest program with the test coordinator ) and press “Enter” to configure the acquisition software.

3. In Acqui\_hall.vi window click the “**Acquisition setting**” button. A window will appear and in that click “**Change Path**” button. Then select the required path and write the file name in which data is to be stored and click “OK” button .**The selection of correct destination for the file to be stored is of utmost importance for future data treatment .**

The RRR measurement data file (\*.dat) for TBC1 and TBC2 is normally stored in the sunmta19 workstation at path “ \ incaa \ database \ DVM\_DAQ \ RRR \ magnet\_name ” ( Example for magnet name MBB3041 ) .**The default file name is test.dat . Change this file as per the following :**

- a. Under the above directory make the RRR data file with the following name  
RRR\_dd-mm-yy.dat
- b. If there are more than one RRR measurements file for the same magnet then store all of them under the magnet name folder ( as above mentioned example) and name them as per their corresponding dates.
- c. If there are more than one RRR measurements on the same day for the same magnet then store all of them under the magnet name folder ( as above mentioned example) and name them as per their corresponding dates and time for example  
RRR\_dd-mm-yy.dat ( for the first file on a given date )  
RRR\_dd-mm-yy\_hh-tt.dat ( for the second file on the same day at hh-tt hrs and mins.)

For Example **RRR\_22-08-03\_18-30.dat** for the second file created on 22.8.03 at 18 hrs and 30 minutes

4. Check whether the selected path is displayed correctly.
5. Set the “Integration Time” to Maximum .
6. Set the “Sample Time” to 300 ms.
7. Set the “Measurement Time” to 15000 Seconds.
8. click the “OK” button to save your acquisition settings.
9. Now the channel setting button will highlight.
10. Click the “Channel setting” button, a window will appear and by default there will be two channels ( for ex. keithley 1 and keithley 2 )already loaded .Delete these two channels using “delete channel” option .Then set the channels as per following table .Use load channel button for setting up the channels . **Pick the channels only from \incaa\config\DVM\_DAQ\user\RRR and verify all the settings for each channel . The order of the channel setting must be respected and to be done as listed below.** After setting up all the six channels click “OK” button .

### Channel Settings Panel

Channel No.	GPIB Address	Channel Name	Range	Unit	Gain	Offset	Offset Reference	Channel Resistance
1	16	D1_Lower	200 mV	V	1.0	0	OFF	-
2	15	D1_Upper	200 mV	V	1.0	0	OFF	-
3	14	D2_Lower	200 mV	V	1.0	0	OFF	-
4	13	D2_Upper	200 mV	V	1.0	0	OFF	-
5	12	D1	2.0 V	V	1.0	0	OFF	-
6	11	D2	2.0 V	V	1.0	0	OFF	-

11. Click “START acquisition” button and see whether all the Keithely DMMs are initialized properly. (Just for checking the setup).
12. Click “STOP acquisition” button and allow to save the data.
13. Now once again click the “Acquisition setting” button and “OK” button. Then click the “Channel setting” button and “OK” button. Now the acquisition is Poised to start.
14. Keep the Programmable Power supply (18V/20A) ready to connect to the main current leads after the quench.
15. Set the voltage to 12.0V ( press “VOLTS” button and enter “12.00” and press “CONFIRM” button) and set current to 18.00A ( press “AMPS” button and enter “18.00” and press “CONFIRM” button).
16. Now inform the Cryogenics Operators that RRR measurement is going to be performed after the next quench on C bench , so that cryogenic procedure ( to warm up the magnet after quench ) for RRR measurement will be launched after the quench.
17. Now perform a provoked quench (Minimum energy) at 6.5 KA (refer procedure for Provoked Quench - Minimum Energy ). Remember to disable fast power abort for the above quench .
18. After the quench check on SUNMTA23 that the file is saved and both HF and LF acquisition are re-armed .This will take about five minutes .
19. Switch off the HF and LF acquisition ( Don’t exit the application )

20. Now put the Rotary switch for TBC Bench in CC position .
21. Connect the DC Current cable hanging on top to the respective leads - check polarity
22. Connect the Programmable Power supply to DC inputs provided for the bench ( C1 or C2 – whichever applicable ) and enable the output by pressing the “OUTPUT” button. Check whether the supply is in current source mode and the current displayed is 18 A.
23. From Tema launch the test *RRR@cold\_with kiethley's\_C\*.tst*. This test can be found in the test sequence Standard\_power\_tests\_C\*.seq ( replace \* with 1 or 2 when selecting the test on the corresponding bench ).
24. The selection of the above test will switch the interconnection box to QCD\_X1 ( or QCD\_X2 as selected by test on step no. 23 )
25. Click “Start Acquisition” button on SUNMTA19 and check whether all the Keithley DMMs are initialized properly and the voltages are read properly .the voltages will be nearly zero if the magnet is below 9 K .
26. After the magnet crosses the transition temperature check whether all the voltages are positive and  $D1 = D1\_L + D1\_U$  and  $D2 = D2\_L + D2\_U$  .
27. Allow the acquisition to continue till the magnet reaches temperature 12K (TT821) which covers the transition of magnet from superconducting to resistive state. In between as the magnet temperature is around 7K to 8K check the health of power supply, Keithely meters and DVM\_Daq. In case of any problems first refer to troubleshooting procedure or immediately contact technical support.
28. After the magnet reaches 12 K ( and you get to see stable voltages between 100 mv to 400 mv in the two apertures in the Keithley’s) the acquisition can be stopped .
29. Stop the acquisition by clicking the “Stop acquisition” button ( SUNMTA19 ). Let the data be saved in the same file name (select replace if prompted ) . To check the measured data click “Result Visualization”. Then select measurement data file by clicking “Select Data file” , select the pens (measured signals) and click “Go”. Check the signals for the transition from superconducting state to resistive state. Note down the resistive transition voltages for both apertures D1 and D2 . this will be useful later to calculate the RRR .Inform supervisor in case of any problems. Exit the viewer by clicking “EXIT” button. Close the DVM\_Daq application by clicking “Quit” button.
30. Disable the Power supply output by pressing “OUTPUT” button. Switch off the power supply and disconnect from main current leads.
31. From Tema switch off the LF acquisition .

32. Put the Rotary switch back to corresponding test bench position.
33. Inform the Cryogenics operator that RRR measurement is finished so that further action can be taken. **TEST OVER.**
34. Inform the concerned person responsible for the analysis of RRR data about the RRR measurement performed (Sun workstation name, path, Magnet name, RRR measurement file name).

## **5. Entering RRR value in Quench Table (cell R2 ) - Brief Calculation Method**

The steps given below should be followed after **each** RRR measurements by **every** team . This will give an approximate value of RRR for **entering** in the quench table .The detailed analysis of RRR should be left to the concerned person responsible for this analysis.

### **Step 1 : To Calculate Cold Resistance after transition to normal state**

Get the Cold voltages of D1 and D2 (  $V_{\text{cold\_D1}}$  and  $V_{\text{cold\_D2}}$  ) from Keithleys Multimeters ( keithley numbers 5 and 6 respectively ) at temperature around 11-12 K .These are the resistive transition voltages you had taken down at step 29 in the sequence of operations . The voltages will approximately be as per the table given below :

#### **Approximate voltages/aperture at 12 K for each magnet manufacturer**

**(IMP. These values are based on the magnets tested till date.Actual values may vary with the cables used by each manufacturer )**

<b>S.No.</b>	<b>Manufacturer</b>	<b>Aperture voltages (V) @ 12 Kelvin , 18 A</b>
1	Alstom	0.216 - 0.225
2	Ansaldo	0.25 - 0.26
3	Noell	0.31 – 0.32

Divide these voltages by Current ( 18 A ) to get  $R_{\text{coldD1}}$  and  $R_{\text{coldD2}}$  .These are the cold resistances for each aperture.

### **Step 2 : Fetch Warm resistances of the magnet from IAP( IAP @ Warm initial )**

From IAP results get the warm voltages in each aperture ,  $V_{\text{warm\_D1}}$  and  $V_{\text{warm\_D2}}$  .

Divide these Voltages by D.C Current ( 2.5 A or 2 A as the case may be ) to get the warm resistances  $R_{\text{warmD1}}$  and  $R_{\text{warmD2}}$  for each aperture . The resistance of each aperture should be roughly 2.88 ohms at 300K.

**Step 3 : Calculate the RRR value for each aperture and the whole magnet**

$$\mathbf{RRR\_D1} = R_{\text{warmD1}} / R_{\text{coldD1}} \quad \text{----- (1)}$$

$$\mathbf{RRR\_D2} = R_{\text{warmD2}} / R_{\text{coldD2}} \quad \text{----- (2)}$$

RRR for the whole magnet is the arithmetic mean of the RRR for the two apertures as shown below

$$\mathbf{RRR} = ( \mathbf{RRR\_D1} + \mathbf{RRR\_D2} ) * 0.5 \quad \text{----- (3)}$$

**Step 4 : Fill this value of RRR obtained from (3) above into cell R2 of the quench table for the corresponding magnet .**

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