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NUMERICAL ANALYSIS OF THE RECOOLING OF A LHC SECTOR FROM 30 K TO 1.9 K FOLLOWING RESISTIVE TRANSITION OF A MAGNET STRING

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Abstract

To analyze the recovery process from a resistive transition of a magnet string of a LHC sector, a mathematical model is established based on the existing models describing the cooldown from 300 K to 1.9 K. In the new model, the number of magnet strings which undergo a resistive transition, as well as their location are considered. According to the analysis, the recovery process is optimized as well as the temperature evolution in the magnet cold-mass, the pressure profile in the very low pressure header during the recool-down process and the time used for the recool-down are presented.

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Numerical analysis of the recooling of a LHC sector from 30 K to 1.9 K following resistive transition of a magnet string

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INTRODUCTION

During the normal operation of a LHC sector, a resistive transition may occur in some superconducting magnet strings (so-called cells, 107 m each). The influence of the resistive transition of some cells on the other cells and on process headers, as well as the re-cool down time is essential for the operation of the sector. Previous studies were devoted to the cooldown of a whole 3.3-km sector from 300 K to 4.5 K, the helium filling operation at 4.5 K and the further cool-down from 4.5 K to 1.9 K [1][2]. By using these models, the recovery operations from the resistive transitions of 1 to 3 cells and from fast current ramp-down (FCRD) are simulated and optimized.

FLOW SCHEME AND CONSTRAINT CONDITIONS

The simplified flow-scheme for the recovery process after a resistive transition of a typical LHC sector (sector 7-8) is shown in Figure 1. The refrigerator is hydraulically connected to each cell of the sector via the cooling headers B, C and D and different control valves. All LHC cells, which belong to the regular arc, Dispersion Suppressor next to and opposite to the refrigerator (DSN/O) and the Long Straight Section next to and opposite to the refrigerator (LSSN/O, which consists of Inner Triplets, IT and stand-alone magnets, SAM) respectively, are filled and cooled down in parallel. There are four phases for the recovery process, which are recool-down from 30 K to 5 K, filling from 0 to 67 %, filling from 67 to 100 % and recool-down from 4.5 K to 1.9 K. During the 1st and 2nd phases, the helium is supplied to the cold-mass of magnet via CV920 and header C, and returned via QV and header D. However, during the 3rd and 4th phases, the helium from header C is supplied to the magnet cold-mass via CV920, and to the 1.8 K heat exchanger (HX) after passing through a subcooling heat exchanger (HR) and CV910. The liquid helium flowing inside the 1.8 K heat exchanger is heated by the helium at 0.13 MPa in the cold-mass, and the vaporized flow is returned to header B at about 1.6 kPa.

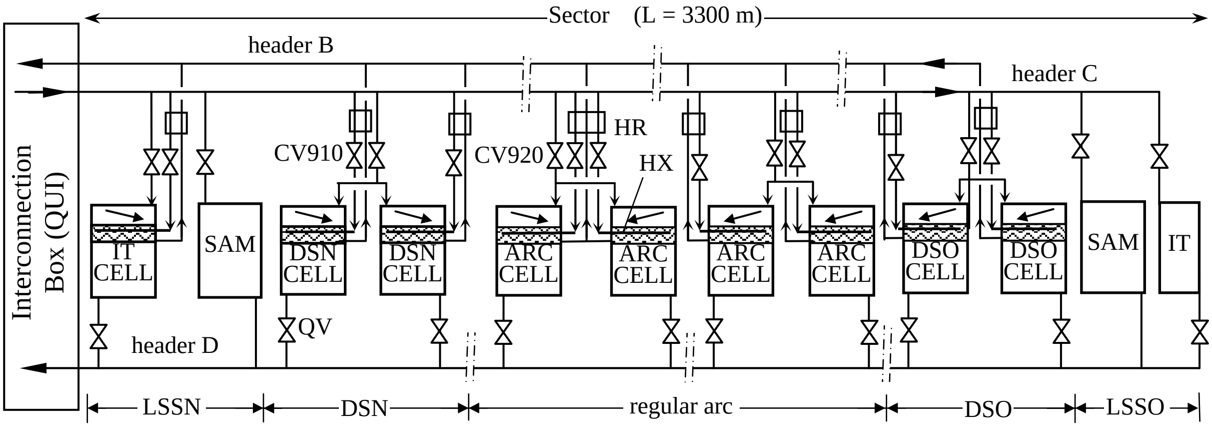

Figure 1 Simplified flow scheme for recool down of a LHC sector after a resistive transition

Based on the flow-scheme in Figure 1 and the models we developed in [1] and [2], the recovery process has been studied. In this study, the main boundary conditions are: 1) mass-flow rate of header C ≤ 225 g/s; 2) mass-flow rate of header B ≤ 125 g/s; 3) temperature at the inlet of header C = 4.6 K; 4) pressure at the inlet of header C = 0.3 MPa; 5) pressure at the outlet of header B = 1.6 kPa; 6) pressure of helium inside all magnet strings = 0.13 MPa.

SIMULATION RESULTS AND DISCUSSIONS

Fast current ramp-down

In the case of FCRD, all magnets are heated to the temperature below the lambda line T_λ (no magnet resistive transition occurs). To reduce the recool-down time of all the magnets from T_λ to 1.9 K, the distribution of the available cold helium to the different cells should be optimized to recool down the different cells simultaneously. Figure 2 shows this optimized distribution scheme.

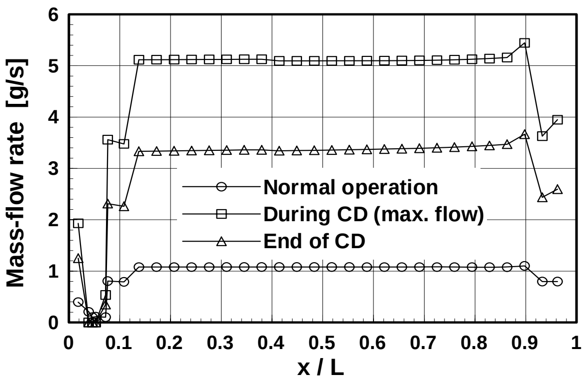

Figure 2 Mass-flow rate of cells during recool-down after a FCRD

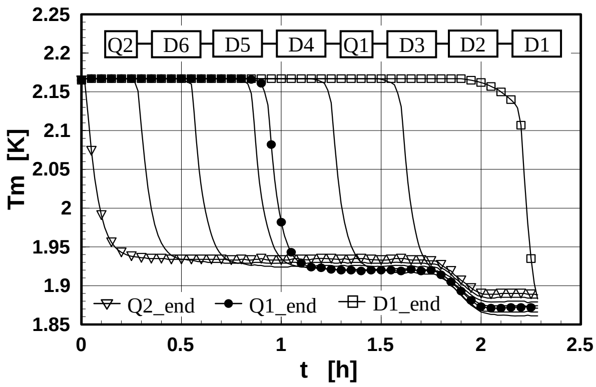

Figure 3 Magnet temperatures of a cell during recool-down after a FCRD

Figure 3 shows the evolution of the magnet (e.g. magnets Q2, Q1 and D1) temperatures of one cell after FCRD following this optimized scheme. In this case the recool-down of a cell, namely the whole sector, will take about 2.3 hours.

Resistive transition of 1 cell

The recovery process after the resistive transition of 1 cell and the impact of its location of on the recool down have been studied. Figures 4 and 5 give the mass-flow rate and pressure profiles of header B respectively. For comparison, the recovery processes of a cell close to QUI and a cell far away from QUI after a resistive transition have been analyzed. As the helium mass-flow rate is much higher for the cell which underwent a resistive transition than for other cells, the mass-flow rate and pressure distributions in header B change profile at the location of this cell (e.g. x/L ≈ 0.205 and 0.825).

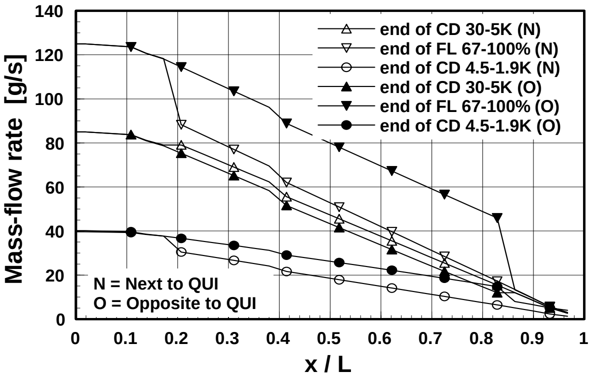

Figure 4 Mass-flow rate of header B during recovery after a transition of 1 cell

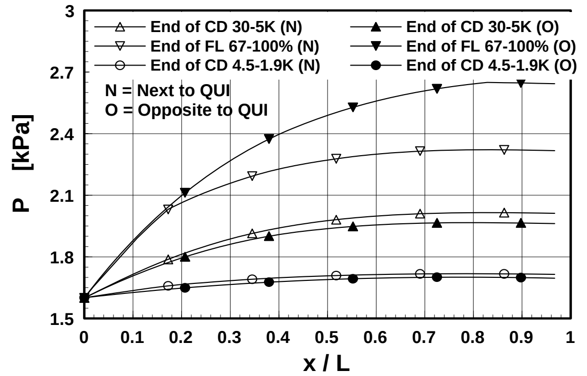

Figure 5 Pressure of header B during recovery after a transition of 1 cell

The recovery time of the final re-filling and final recool-down is shorter (by about 9 minutes) for the cell close to QUI than that for the cell far away from QUI (see Figure 6). Considering the corresponding time difference for the re-cool down from 30 to 5 K and re-filling from 0 to 67 %, the total time difference is 12 minutes (representing 4.2 % of the total time). The mass-flow rate is the same for the two cases, but the cooling capacity of the helium is lower for the cell far away from QUI (higher supply temperature and down-stream pressure) and this may explain the difference in the recool-down time.

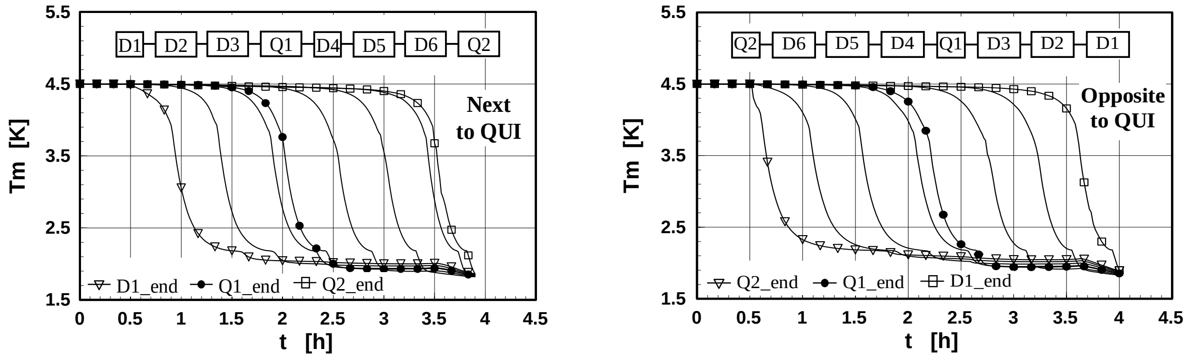

Figure 6 Magnet temperatures during 4.5–1.9 K recool-down after the resistive transition of the corresponding cell

Resistive transition of 2 and 3 cells

The recovery processes after the resistive transition of 2 and 3 cells have also been studied. As illustrated in Figure 7, the recool-down from 30 to 5 K after the resistive transition of 2 cells takes about 50 min. As shown in Figure 8 the processes of re-filling from 67 to 100 % and recool-down from 4.5 to 1.9 K after the resistive transition of 3 cells take about 4.3 hours.

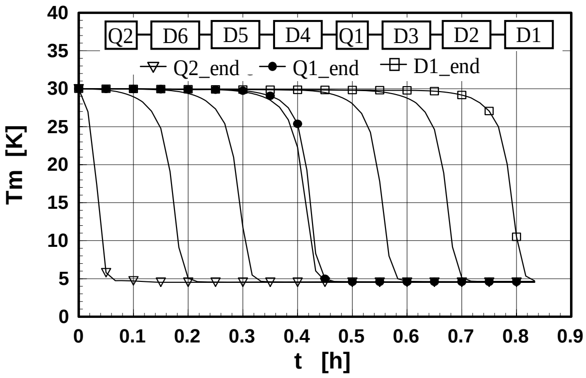

Figure 7 Magnet temperatures of a cell during 30-5 K recool-down (resistive transition of 2 cells)

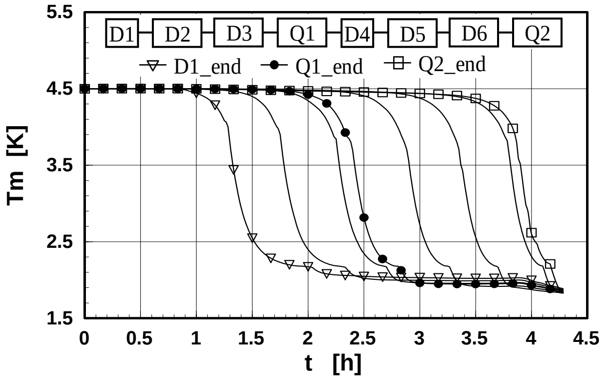

Figure 8 Magnet temperature of a cell during 4.5-1.9 K recool-down (resistive transition of 3 cells)

Optimized flow distributions

The optimized distributions of the total helium mass-flow rate to the different cells in the case of FCRD and resistive transition of 1 to 3 cells are shown in Figure 9. From this figure we can notice that during the recool-down from 30 to 5 K and re-filling from 0 to 67 %, due to no constraint for the flow-rate of header B, all the available mass-flow rate of 225 g/s (supplied by header C) can be used and the main part of the helium is supplied to the cell(s) which underwent a resistive transition to accelerate the recovery process. However, during the re-filling from 67 to 100 % and recool-down from 4.5 to 1.9 K, more and more helium returns to header B, and its mass-flow rate is limited to 125 g/s. Consequently, the total supply flow and the mass-flow rates for the cell(s) which underwent a resistive transition have to be decreased.

Summary of recovery time

The optimized times of each phase of the recovery after all resistive transition cases and FCRD are given in Figure 10. The recovery from FCDR will take 2.28 hours, the recovery from the transition of 1 cell close to and far away from QUI will take 4.67 and 4.87 hours (the difference rate is 4.2 %) respectively, and the recovery from the transition of 2 and 3 cells will take about 5.6 and 6.5 hours, respectively.

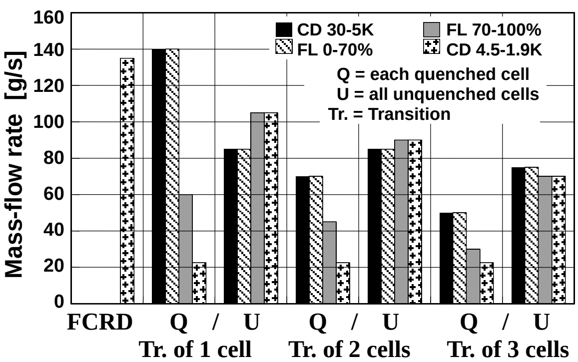

Figure 9 Mass-flow rate distribution of header C

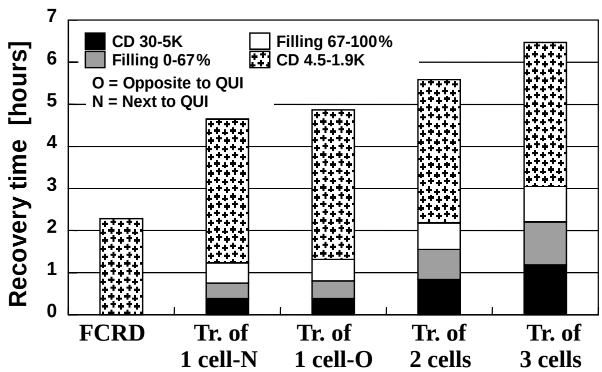

Figure 10 Recovery time for the different study cases

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2. Riddone, G., Liu, L. and Tavian L., Numerical Study of the Final Cooldown from 4.5 K to 1.9 K of the LHC, in Proc. of International Cryogenic Engineering Conference 20, Beijing (2004) 1007-1010