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REFINED STUDIES OF COOLDOWN AND WARMUP FOR THE LARGE HADRON COLLIDER

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Abstract

Compared with the previous study [1], this paper presents and improved mathematical model which takes into account the pressure evolution in the different headers of the cryogenic distribution line and the effect of the pressure drop across the valves during cooldown and warmup modes. The application of the improved model to the LHC sectors shows that the present processes of cooldown and warmup may take a longer time by about 5% than that predicted by using the previous model. Some issues found by using the latest model have also been presented and discussed.

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Compared with the previous study [1], this paper presents an improved mathematical model which takes into account the pressure evolution in the different headers of the cryogenic distribution line and the effect of the pressure drop across the valves during cooldown and warmup modes. The application of the improved model to the LHC sectors shows that the present processes of cooldown and warmup may take a longer time by about 5% than that predicted by using the previous model. Some issues found by using the latest model have also been presented and discussed.

INTRODUCTION

A study on thermal transient modes of LHC sectors [1] had been carried out from 2000 to 2001. The cooldown and warmup operations of a magnet, standard cell and LHC sector have been simulated numerically. In that study, to simplify the calculation, three supply headers, namely C, E and F, are treated as an equivalent supply path. Due to the complexity of the cooling circuits, this simplification leads to errors in the calculation of the cooldown and warmup times. This paper presents an improved model which takes into account the mass flow and pressure evolution in the different headers of the cryogenic distribution line as well as the effect of the pressure drop across the valves.

FLOW SCHEME

The general flow scheme for the cooldown and warmup of a LHC sector is shown in Figure 1. The refrigerator is hydraulically connected to each cell of the sector via cooling headers E, F, C and D (header B is not considered for its relative independence) and control valves. All LHC cells, which belong to regular arc, Dispersion Suppressor left and right (DSL/R) and the Long Straight Section left and right (LSSL/R) respectively, are cooled down and warmed up in parallel. During a "normal" cooldown and warmup, one refrigerator is used to supply one sector, while for a "fast" process, two neighboring refrigerators are coupled to one sector with twice the total mass flow rate and refrigeration capacity.

In Figure 1, the helium to the magnet cold mass is supplied via header C (ϕ104 mm) and returned via header D (ϕ154 mm). Headers C and F (ϕ84 mm) are interconnected using valves at the middle and at the end of the sector. This configuration enables to supply helium to header C from header F. Headers F and E (ϕ 84 mm) are interconnected using a valve at the end of the sector. Cooldown and fill valves (CFV) are installed between header C and the magnet cells to control the flow-rate, and the corresponding k_v-values vary from 5 m^3/h (stand alone magnets, SAM) to 32 m^3/h (standard cell in the arc). For all magnet cells in the LSS and a special cell in the arc, one valve serves one cell, while for the other standard cells in the arc and all cells in the DS, two neighboring cells are served by one valve. Quench valves (QV) are implemented between header D and most magnet cells (there is no valve for some cells in LSS), whose

k_V-values are always higher than 30 m^3/h.

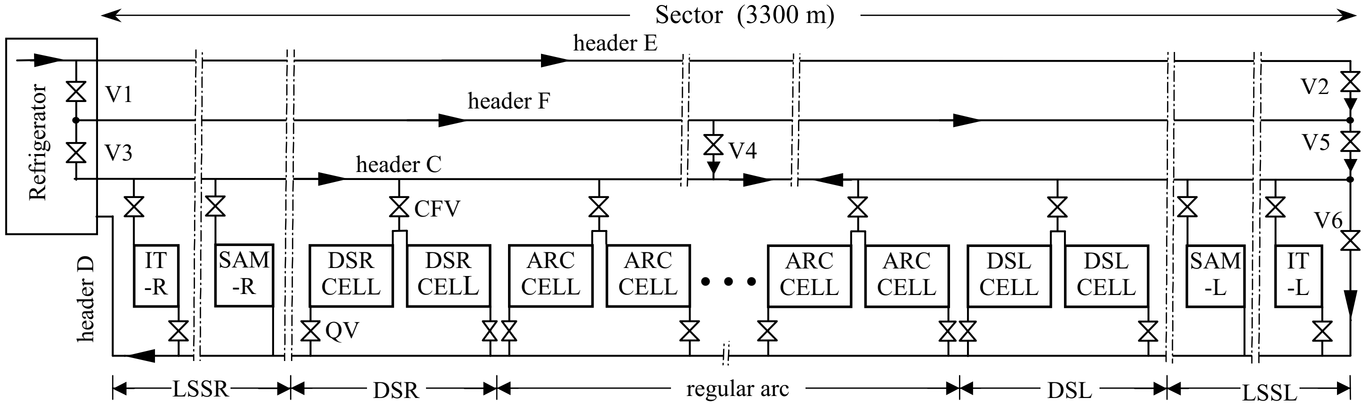

Figure 1 Flow-scheme for the cooldown and warmup of a LHC sector

CONSTRAINS FOR COOLDOWN AND WARMUP

Different flow-schemes of cooldown and warmup have been studied. The case presented in this paper corresponds to the flow-scheme schematically shown in Figure 1. The mass flow rate for normal cooldown/warmup is 770 g/s in total, where 450 g/s for header C, 135 g/s for header E and 185 g/s for header F. During a fast cooldown/warmup, the mass flow rates in the different headers will be doubled. The inlet pressure of header E is always set to 1.65 MPa and the inlet temperature of headers C, E and F are given according to the imposed cooldown/warmup constraints, such as the maximum ΔT across any magnet limited to 75 K. For the valves, all QVs, V2 and V4 are always fully opened, and all CFVs, V1, V3 and V5 are adjusted automatically to satisfy the calculated pressure drops and mass flow rates.

SIMULATION RESULTS AND DISCUSSION

Pressure profiles in headers

Figure 2 and Figure 3 give the pressure profiles of headers during a normal and a fast cooldown. From Figure 2 we can see that the inlet pressure of header E is higher than those of headers F and C due to pressure drop in V1 and V3. The trends of the pressure evolution of headers C and F change at the middle of the sector because of the flow from header F to header C. Flow limitation has been found at the beginning of a fast cooldown and the end of a fast warmup, where only 90% of the full flow (1440 g/s) can pass through the headers. The pressure profiles during a fast cooldown shown in Figure 3 correspond to this situation. The total cooldown / warmup time is not significantly affected by the short period of flow limitation of only 4 hours.

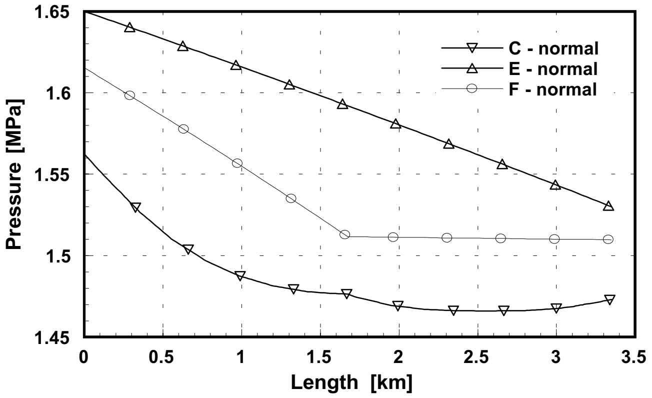

Figure 2 Pressure profiles of headers C, E and F at the beginning of a normal cooldown

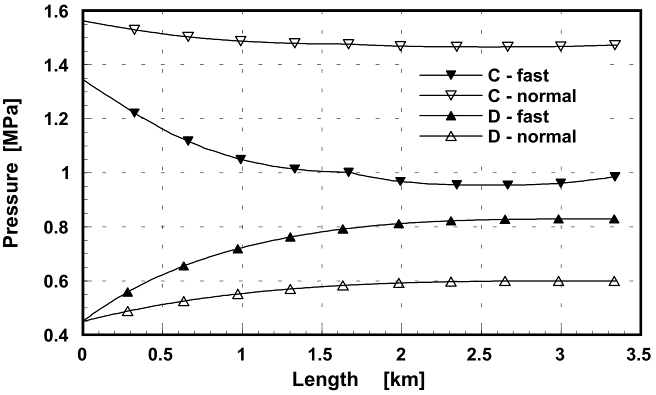

Figure 3 Pressure profiles of headers C and D at the beginning of a normal and a fast cooldown

Temperature profiles of headers

Figure 4 gives the temperature profiles of headers C, E and F during a normal and a fast cooldown after 12 hours, while Figure 5 gives the profiles of headers C and D after 4 hours. Figure 4 indicates that the highest temperature of header C occurs at 2.6 km away from the refrigerator, where the two flows from opposite directions converge (see Figure 1). This point is the last point cooled by the flow in header C, and its temperature is determined by the mixing of the two flows. Attention has been paid to avoid an unbalanced distribution of the flows. In Figure 4, we can also observe the impact on the temperature of the influx of two flows at the middle of sector as well as the three flows at the end of sector. Figure 5 compares the temperature profiles of the headers C and D during a fast and normal cooldown.

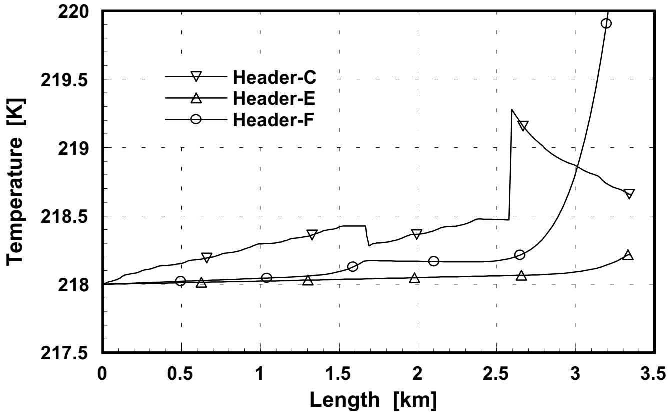

Figure 4 Temperature profiles of headers C, E and F during a normal cooldown after 12 hours

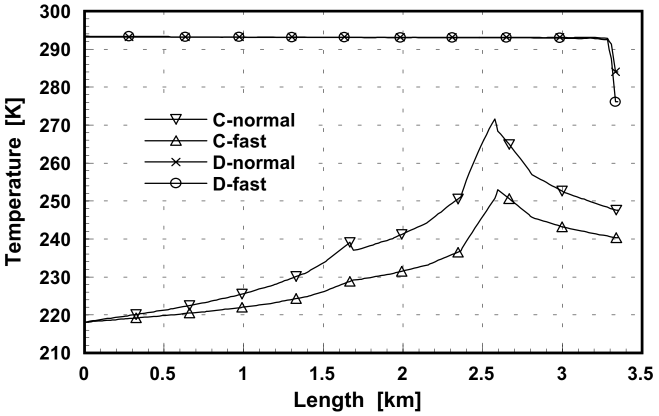

Figure 5 Temperature profiles of headers C and D during a normal and a fast cooldown after 4 hours

Temperature evolution of headers

The temperature evolution of headers C and D during a normal cooldown have been investigated and the corresponding results are shown in Figures 6 and 7. From these two figures one can see that the temperature profile of header C decreases uniformly with time, whereas that of header D shows a drop at the far end of the sector. This phenomenon is caused by the cooling flow from header C to header D via the sector end valve (V6 in Figure 1).

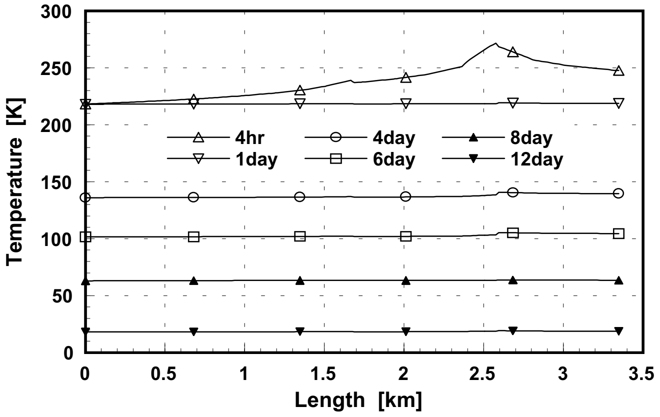

Figure 6 Temperature profiles of header C over time during a normal cooldown

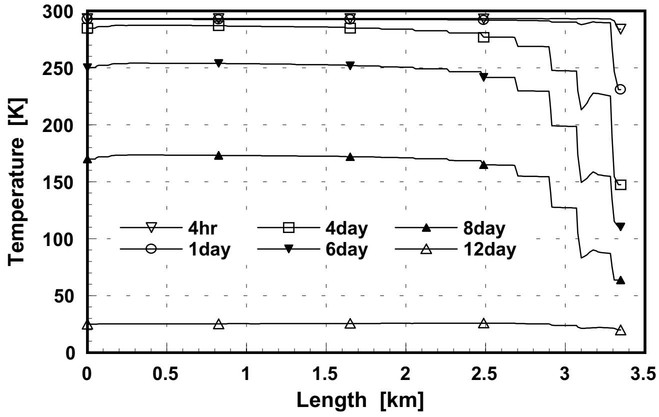

Figure 7 Temperature profiles of header D over time during a normal cooldown

Cooldown and warmup of a sector

The improved model has been used to estimate the cooldown and warmup processes of the LHC sectors. With the mass flow consideration used in [1], the normal cooldown of a typical sector of LHC, namely sector 8-1, takes about 12.5 days (Figure 8), the fast cooldown about 6.75 days (Figure 9), the normal warmup about 11.5 days (Figure 10), and the fast warmup about 6.25 days (Figure 11). Compared with the previous results, the average time used for these thermal transients has increased by an average of about 5%. In the improved model, the helium properties for temperatures below 20 K have been refined, which results in the extensions of the end period of the cooldown and the begnning period of the warmup and thus explains the 5% difference between the two models.

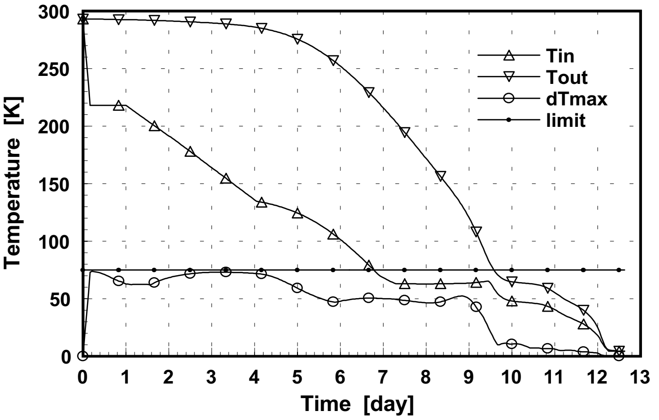

Figure 8 Normal cooldown of sector 8-1

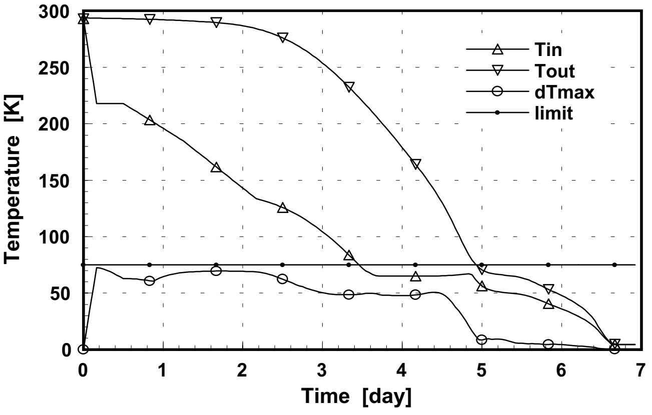

Figure 9 Fast cooldown of sector 8-1

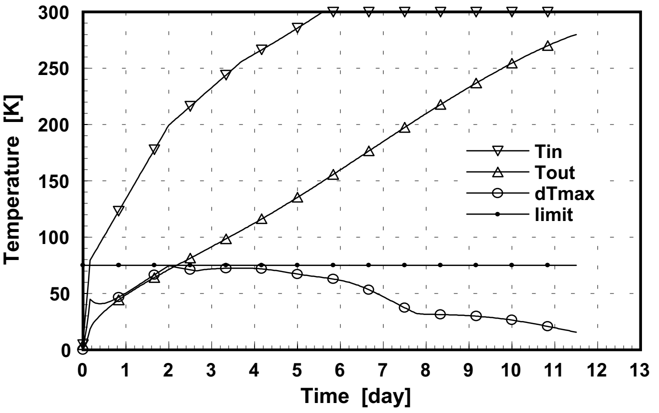

Figure 10 Normal warmup of sector 8-1

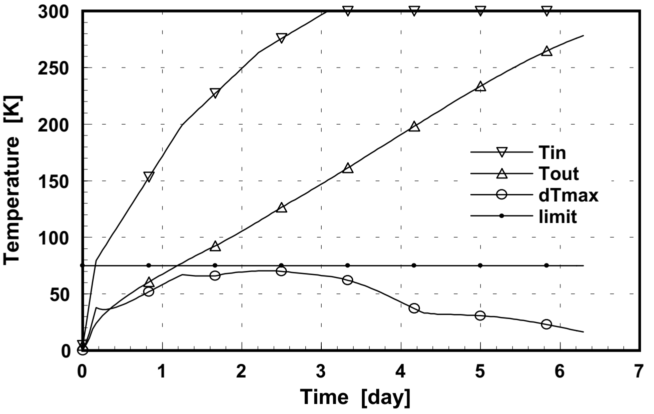

Figure 11 Fast warmup of sector 8-1

CONCLUSIONS

An improved mathematical model taking into account the pressure evolution in the different headers and the effect of the pressure drop across the valves has been developed to estimate the thermal transient modes of LHC sectors such as cooldown and warmup. Based on the results of the improved model and the layout presented in this paper, the cooldown and warmup take a longer time than that predicted by using the previous model by an average of about 5%. A flow limitation has been found at the beginning of a fast cooldown and the end of a fast warmup due to the very high pressure drops in the headers. The following work will consist in varying the input parameters (mass flows and inlet pressure in the supply headers) in order to prevent flow limitation during any cooldown and warmup modes.

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