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Effect of a thermal fluctuation caused by a proton beam injection on the ESS large-scale 20 K helium refrigeration system

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Abstract

In the European Spallation Source (ESS), a large-scale 20 K helium refrigeration system with the cooling capacity of 30.2 kW at 15 K, which is called Target Moderator CryoPlant (TMCP), has been installed in the summer of 2022. The purpose of it is to cool the cryogenic moderator system (CMS) that provides subcooled liquid hydrogen with a temperature of 17.5 K to two hydrogen moderators (to be increased to four in the future) and remove nuclear heating generated of 6.7 kW and 17.2 kW for two and four moderators at the proton beam power of 5 MW. In this paper, we studied a stability of the TMCP operation when the heat load of 5.92 kW and 17.5 kW was rapidly applied and how to mitigate the propagation of the temperature fluctuation in order not to affect the CMS supply temperature

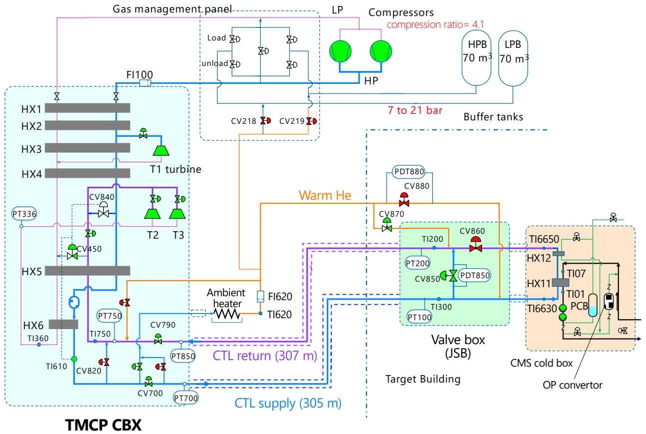
1. Introduction

At the ESS target, high energy spallation neutrons are produced by impinging 5 MW proton beam on tungsten (repetition of 14 Hz and a pulse length of 2.86 ms.)

- Nuclear heating at two hydrogen moderators is estimated to be 6.7 kW for the 5-MW proton beam power.

(For four (two above and two below the target wheel, respectively) in the future where the nuclear heating: 17.2 kW.)

- 6.7 kW (17.2 kW) of heat load will be suddnely applied or removed when the proton beam with the power of 2 MW (5 MW) is on or tripped.
- TMCP hawillcompensate the rapid heat load chage by changing the cooling power to the CMS at the JSB without changing that of the TMCP CBX, because the CMS has no thermal compensation function.



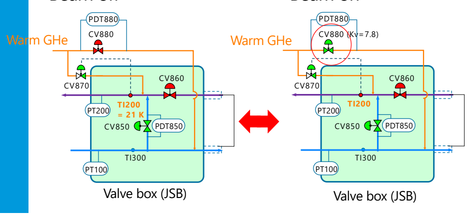
The CTL and JSB has been installed in the summer of 2022 and the TMCP commissioning without connecting the CMS has been completed in December 2022.

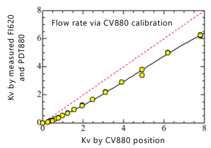
In this study, we studied a stability of the TMCP operation when the heat load of 5.92 kW and 17.5 kW for the two and four moderatos was rapidly applied and how to mitigate the propagation of the temperature fluctuation in order not to affect the CMS supply temperature.

2. Transient heat load tests

Transient heat loads, Q_c, of 5.92 kW and 17.5 kW, were applied or removed.

- CTL return temperature is kept at 21 K by the PID control of the TI200 controller.
- Sudden heat load change caused by the CMS was simulated using CV880.





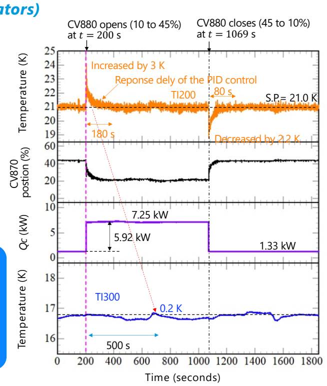
In advance, the flow rate via CV880 ($\dot{m}_{in}$) has been calibrated using CV880 position, PDT880 and FI620.

The heat load of Q_c was estimated by $\dot{m}_{in}(h_{620} - h_{300})$ where h_{620} and h_{300} were the enthalpies at TI620 and TI300.

2.1 Transient heat load test for Q_c=5.92 kW

(4.4 MW proton beam for two moderators)

- **Operational conditions**
  - One compressor, T1 and T2 turbines
  - HP=11.8 bar
  - TI300= 16.8 K
  - TI200= 21.0 K
  - CTL flow rate = 315 g/s
  - CV880 position: 10% to 45% for 1 sec (5.92 kW), which correspons to ΔT=3.2 K
  - TI200 temperature controller: ON SP=21.0 K



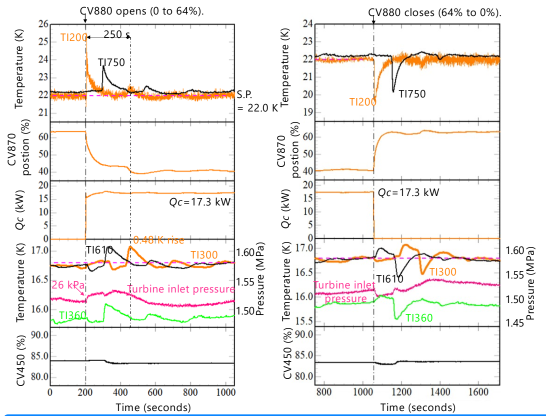
- The temperature fluctuation of 0.2 K is acceptable because the CMS supply temperature (TI6630) controlled by CV880 will have a margin of 0.4 K.
- For the two-moderator arrangement, the temperature fluctuation would be able to be mitigated by only the PID control for TI200 by CV870.

2.2 Transient heat load test for Q_c=17.3 kW

(5 MW proton beam for four moderators)

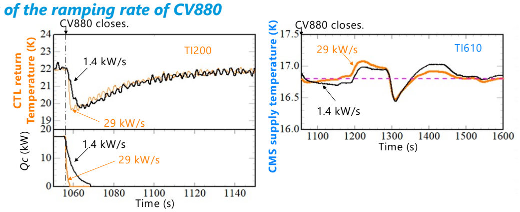
2.2.1 CTL return temperature controlled by a PID control.

- **Operational conditions**
  - Two compressors, T1, T2 and T3 turbines
  - HP=15.4 bar
  - TI300= 16.9 K, TI200= 22.0 K (24 kW was applied by CV870 during beam off)
  - CTL flow rate = 761 g/s
  - CV880 position: 0% to 64% at 29%/s, which correspons to ΔT=3.8 K
  - TI200 temperature controller: ON (SP=21.0 K)



The temperatures were increased by 0.48 K at the cold end and the JSB, which was higher than the margin of 0.4 K for the TI6630 control.

Effect of the ramping rate of CV880



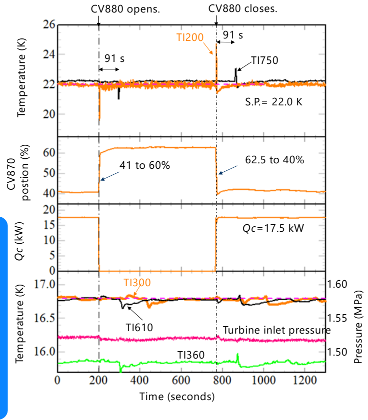
- Temperature reduction of TI200 became larger for faster ramping speed.
- However, the time required for TI200 getting back to the set point and TI610 reduction seemed to be little affected by the ramping speed of the heat input.

2.2.2 CTL return temperature controlled by a combination of feed forward and PID control.

- **Operational conditions**
  - Two compressors, T1, T2 and T3 turbines.
  - HP=15.4 bar
  - TI300= 16.9 K, TI200= 22.0 K (24 kW was applied by CV870 during beam off)
  - CTL flow rate = 761 g/s

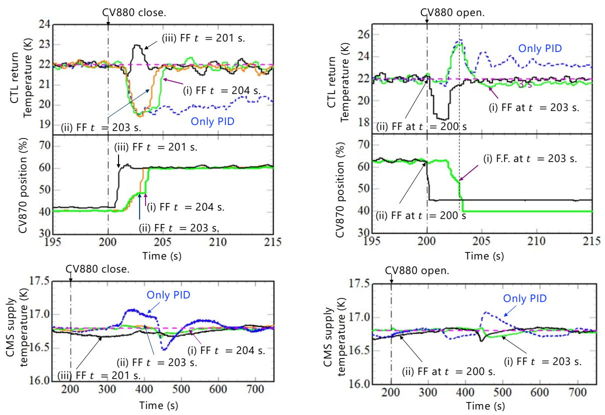
TI200 temperature control

- CV880 position change corresponding to 17.5 kW for the feed forward control = 41 to 60% for 1 s. When TI200 is increased/decreased by 1 K.
- TI200 temperature controller: ON (SP=21.0 K)



- Temperature change of around 2 K appeared during a short duration before the feed forward control executed.
- Fluctuations of the temperature and the pressure became much smaller than those for only the PID control.
- Although the temperature fluctuation propagated to the CTL supply side, it was below 0.1 K
- The combination would be effective to mitigate the pressure and temperature fluctuations. Optimizing the timing for starting the feedforward control is needed.

Effect of the timing for the starting the feedforward control



- Based on the experimental results, it turns out that the combination with the feedforward and the PID control can mitigate the temperature fluctuation caused by the transient heat load change of 17.5 kW and the CMS supply tempeature can be reduced below 0.1 K.
- The feedforward control should be executed just before the CTL return temperature starts to decrease.

3. Conclusions

- The behaviors of the temperature fluctuations caused by the transient heat load of 5.92 kW and 17.5 kW, which corresponded to the nuclear heating for the two and four-moderator, have been studied.
- For the transient heat load of 5.92 kW, the fluctuation of the CMS supply tempeature was able to be mitigated within the allowable one of 0.4 K.
- After the final installation of the transfer lines between the JSB and CMS cold box, we will plan to further study to optimum the timing for executing the feedforward control and the ramping speed of CV870 using a temperature sensor located at the outlet of the HX11(TI6650), considering the response speed of CV870 and the traveling time of the return helium stream from the CMS cold box to the JSB.