Commissioning of the cryogenic distribution system of the ESS accelerator

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Introduction

At the European Spallation Source (ESS), a 2.0 GeV proton accelerator is being built, comprising an superconducting part with 43 cryomodules (CMs) that operate at 2K.

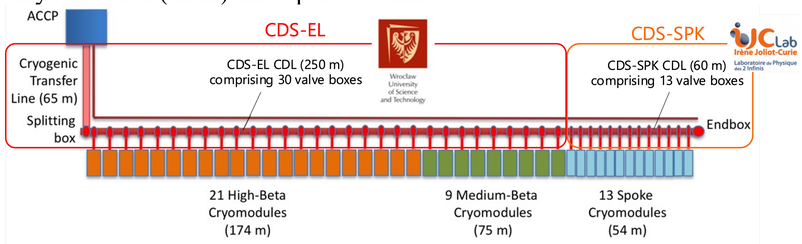


Figure 1: Simplified CDS indicating supply of different ESS in-kind partners

The cryogenic distribution system (CDS, figure 1) connecting the CMs and the cryoplant (ACCP) via warm and cryogenic multi-transfer lines, 43 valveboxes (VBXs) and an endbox has been tested in a first cooldown in December 2022.

Test setup

Heat load testing was carried out by short circuiting supply and return tubes of every VBX, feed the supply flow at a temperature of 8K and modulate the mass flow via the endbox for a series of tests and statistics to reduce the impact of systematic measurement errors. Figure 2 shows a simplified test scheme of the cryogenic part of the assembly.

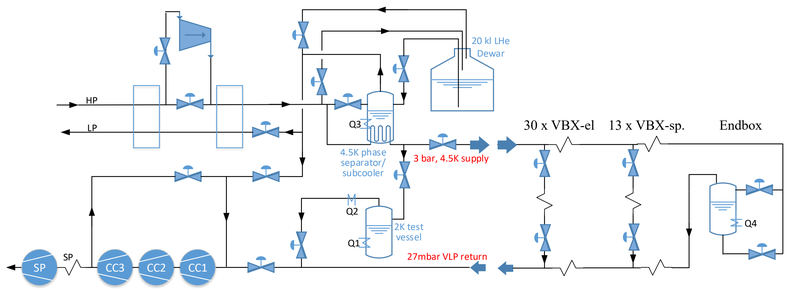


Figure 2: Simplified schematic of refrigerator cold and and CDS 4.5K loops

Thanks to the built-in test equipment of the ACCP, operation is possible at much reduced load with no or only a few CMs connected. The first cooldown revealed a number of shortcomings, particularly thermo-acoustic oscillations (TAO) on the 4K return valves, TAO on the endbox, leakage on safety valves (SVs), leakage over valve seats and instrumentation problems (level and temperature measurements).

Operating with 6K supply temperature for cold compressor (CC) operation without phase change was difficult and limited cold compressor control functionality. Operating as designed with 4.5K supply temperature triggered TAO in the endbox, making CC operation unfeasible.

TAO on valves

TAO appeared on all CDS-EL 4K vapor (VLP) return valves due to a high temperature gradient along the valve stem and TAO-ideal gap size between valve insert and body. The valve body is not thermally anchored. The impact of TAO on these return valves could be regulated by reducing the valve opening of the respective 4.5K supply valves as illustrated in figure 3.

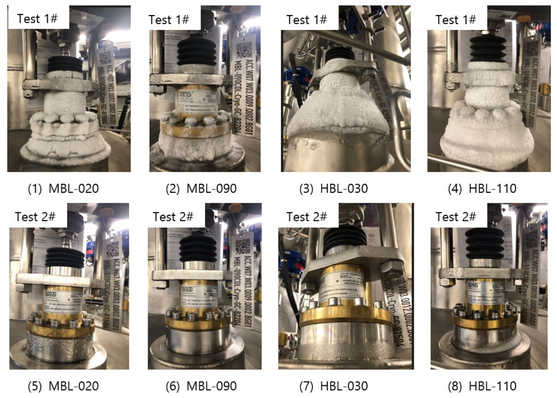


Figure 3: Ice formation on CDS-EL VLP return valves at 20% open 4.5K supply valves (Test 1#) and at 3% open 4K supply valves (Test 2#). Other operation conditions as valve openings, temperature and pressure have been kept stable, indicating that the ice forming is connected to flow conditions rather than heat conduction.

In order to eliminate TAO on the valves, all inserts were dismounted, equipped with wipers and steel rings to keep them in place as shown for one valve in figure 4.

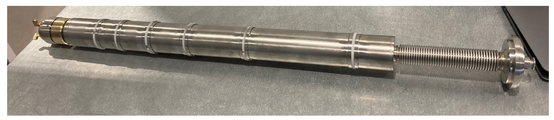
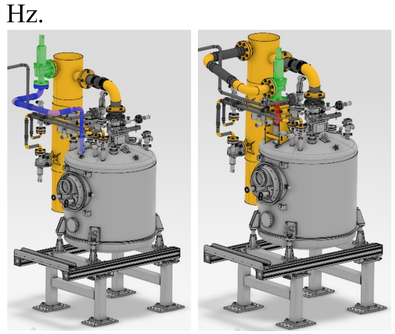


Figure 4: VLP return valve insert with wipers as convection brakes against TAO

TAO on endbox

The appearance of TAO is directly linked to reducing the 4.5K supply temperature and not to other system variables like liquid helium level in the endbox phase separator, tank temperature, valve openings or alike. No pressure oscillations have been observed in the previous operation phases. The dominant detected oscillation frequency was 0.2 Hz.



Figures 5 and 6: 3 D model of the endbox before (left) and after (right) the modification of 4.5K supply safety valve (SV) position (green) and thus reducing warm inlet pipe length (blue). This pipe was covered in ice during operation at design temperature, indicating a large heat transport there.

Using electro-acoustic analogy three elements of an "RLC" system were added to detune the acoustic resonator and damp TAO: a fine control needle valve as resistor (R), a flexible hose as inductor (L) and a warm damper vessel as capacitor (C), see figure 7.

Figure 7: RLC elements added to the endbox to dampen TAO

Preliminary results and outlook

The 2nd cooldown started in June 2023 with the main objectives to show successful elimination of TAO on the VLP return valves and on the endbox, meaningful operation of the ACCP CCs including the two pilot cryomodules that have now been installed and more. Operations are still ongoing but some conclusions can already be carefully drawn.

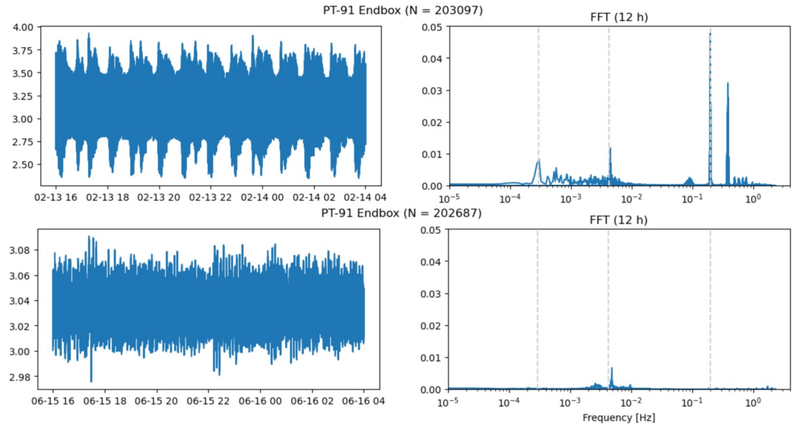


Figure 8: 4.5K supply pressure before (top), after after TAO damping (bottom) with pressure oscillations (left) and Fast Fourier Transform (FFT) (right)

CCs pump down and operate reliably over a large load range as illustrated in figure 9.

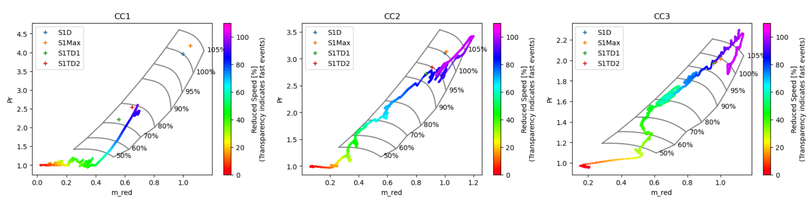


Figure 9: Pump down and operation trace in the CC operation fields

Dampened TAO on the VLP return valves can be assumed but need further confirmation as well as the outstanding heat load testing. The primary goals have been achieved and the system is in a satisfactory state to allow series CM installation.