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Seat leak tests and commissioning of control valves in the cryogenic distribution system of the ESS superconducting linac

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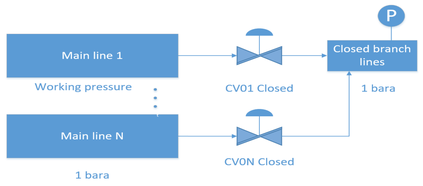
Abstract: The European Spallation Source (ESS) is a neutron-scattering facility which will use a pulsed 2.0 GeV proton beam generated in the linear accelerator (LINAC) for releasing high-energy neutrons in the ESS target station. The 2K superconducting linac comprises 13 spoke and 30 elliptical cryomodules. The cryogenic distribution system (CDS) connects the cryogenic plant with the 43 cryomodules through a 400 meters long cryogenic multi-transfer, 43 valve boxes and an endbox.

The CDS consists of 373 control valves in total. There are 8 and 10 control valves in each elliptical and spoke valve boxes, respectively, and 3 valves in the end box. The control valves are used for regulating or blocking the process helium flows. The seat tightness of the CDS valves is crucial especially for warming up individual cryomodules, which is required for potential short-term maintenance or repair activities in the cryomodule while keeping the others in cryogenic conditions. What is more, leaks over valve seats might cause moisture or ice formation on room temperature uninsulated pipes for warmup and cooldown valves or add heat load to the cryogenic system. Valve initialization and leak tightness tests were firstly performed with warm helium in the second half of 2022 before the first CDS cooldown. The tests revealed many leaks above the specified acceptable leak rate of 10-4 mbar·l/s with several of them reaching even 102 mbarl/s. The major bulk of those leaks were fixed before and after the 2nd CDS cooldown that followed in 2023. This paper describes the seat leak test method and results, as well as the possible causes of the observed leaks and the taken solutions for repairing the insufficiently tight valves.

Test method

- One of the main lines is pressurized to the working pressure while the other lines are 1 bara and all valves keep closed.
- Monitor the pressure different of the closed branch line to calculate the leak rate of the tested valves.
- The chosen acceptable leak rate for valve seat leak tightness is ≤ 10^{-2} mbar·l/s.



$$L = V * dP/t$$

- *L is the leak rate, mbar.l/s;*
- *V is the volume of closed branch lines, l;*
- *dP is the pressure difference for 24 hours, mbar;*
- *t is the test time, s*

Test Results

- In the first test campaign, 58 out of 344 valves were leaky, shown in table 1.
- With long time investigation and test, the causes and solutions for control valve seat leak are summarized in Table 2.
- After the test in November, 2023, there are 18 valves still leaky.

Table 1. A summary of seat leaky valves after 1st valves seat leak test campaign

Description	valve Tag	Size	Valve type	No. of LR > 10-2 mbar.l/s
4K inlet	CV03	DN10	Fail close	6
4K outlet	CV04	DN50	Fail open	4
3 bara HP to 4K circuit	CV05	DN10	Fail close	6
LP recovery to 4K circuit	CV06	DN15	Fail close	3
TS inlet	CV60	DN10	Fail close	6
TS outlet	CV61	DN10	Fail open	25
3 bara HP to TS circuit	CV62	DN10	Fail close	5
LP recovery to TS circuit	CV63	DN10	Fail close	3
Total No. of seat leaky valves				58

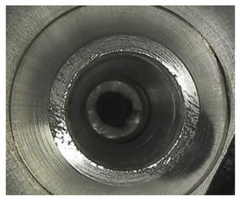
Table 2. A summary of causes and solutions for CDS control valve seat leak

No.	Causes	Solutions
1	Debris or dust on valve seat seal	Changing new seal or clean the seat seal
2	Preload and re-initialization	Adding preload and re-initializing the valve
3	IA leak	Tightening the IA pipe connection
4	Valve movement	Setting valve parameters, such as deadband
5	Valve misalignment	Changing short plug or rewelding the valve body
6	Valve seat surface damage	Grinding the surface with special tools and brushes

New valve seat seal replacement

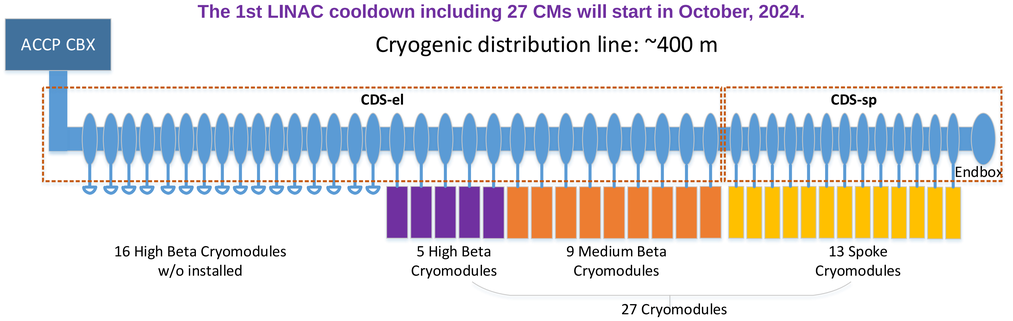
- Debris or dust was found on valve seat seal and some valve seats had scratches.
- After 2 times CDS commissioning, there are more than 40 leaky valves had new seal installed.
- Some valves showed that some valve seat started leaky after a period of cold commissioning, which means that the debris comes from installation or other parts of the system.

Debris on the valve seat seal

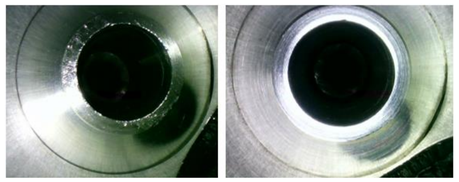


Scratched seat surface for one valve after 1st CDS commissioning

The 1st LINAC cooldown including 27 CMs will start in October, 2024.



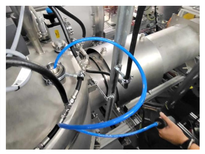
Valve seat grinding



The valve seat surface before (left) and after(right) seat grinding

Sand paper

Grind with drill

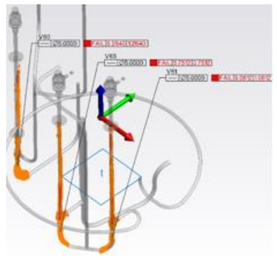


Vacuum debris

- Due to deep scratch on the valve seat surface, some control valves were still leaky after installing a new seat seal.
- ESS ordered the special valve seat surface grinding tool from WEKA and performed control valve surface grinding on 4 valves.
- All of the 4 grinded control valve were seat leak tight after leak test.

Valve misalignment and rewelding to relax the valve body

- 24 out of 30 Thermal Shield (TS) return valves CV61 in CDS-el were leaky with the leak rate between 10 and 100 mbar.l/s.
- The misalignment of CV61 and CV63 were investigated by ESS with caliper gauge and by WUST with an optical method by using camera to measure the valve deflection.
- All 30 CV61 in CDS-el were replaced with smaller digital on-off valve which has no regulating function, as a result, half of CV61 are not leaky any more.
- In HBL-200, 3 valves (CV60, CV61 and CV63) were rewelded on the top to relax the pipe.
- Another 3 high deflected leaky CV61 were performed with valve body rewelding on top flange as well.



A misalignment of 6 mm in the valve body showed in three valves

The top welding of the valve body was cut open to relax the pipe

Valve top was rewelded and checked straightness by caliper gauge

CDS cold Commissioning

- In the 1st CDS cooldown in 2022, the CDS was firstly cooled down to 6 K. There appeared Thermal Acoustic Oscillation(TAO) on 4K return valves in CDS-el and TAO on CDS 4K supply line safety valve connection pipe in Endbox.
- TAO on 4K return valves were solved by adding convection brakes on valve stems.
- The solution for TAO on safety valve connection pipe was to move the safety valve close to the Endbox top flange and to add a 100 litres damper vessel.
- In the 2nd CDS cooldown in 2023, the TAO on both 4K return valves and CDS 4K supply safety valve connection line were eliminated. With connecting 2 cryomodules, the measured CDS heat load was with 418 W and the cold compressors successfully pumped the big volume VLP line and 2 Cryomodules to 2K.

Cold spots due to valve seat leak from cold side to warm side

Update and plan

- The remaining 18 control valve seat leak have been fixed.
- The final CDS control valves seat leak test campaign will be performed in August, 2024.

Conclusion and lessons learnt

- After CDS installation, ESS had precious time to test control valve seat leak several times and checked the valve performance during CDS cold conditioning.
- Except for common ways to fix seat leak, such as valve initialization, adding valve preload and replacing new seat seal, ESS managed to perform seat surface grinding, changed short plug for small valve deflection and rewelded valve top body to relax pipe for big valve deflection, thanks to the mutual effort among ESS, WUST, Kriosystem and WEKA.
- It is easier to test control valve seat leak before the valve boxes installation in the tunnel and it costs less to fix the valve seat leak as well.
- The installation process requires a great quality control to avoid leaving debris in the CDS system which might cause valve seat leak. We also learned that during valve installation, keeping the valve seat surface clean or avoiding scratching the valve seat surface is very important for valve seat tightness.

Acknowledgments

The project co-financed by the program of the Ministry of Science and Higher Education of the Republic of Poland: "Support for the participation of Polish research teams in international research infrastructure projects" in accordance with contract No. 2023/WK/05 of July 17, 2023.