Cryogenic helium valves deflection and relaxation in ESS linac cryogenic distribution system

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HR EXCELLENCE IN RESEARCH

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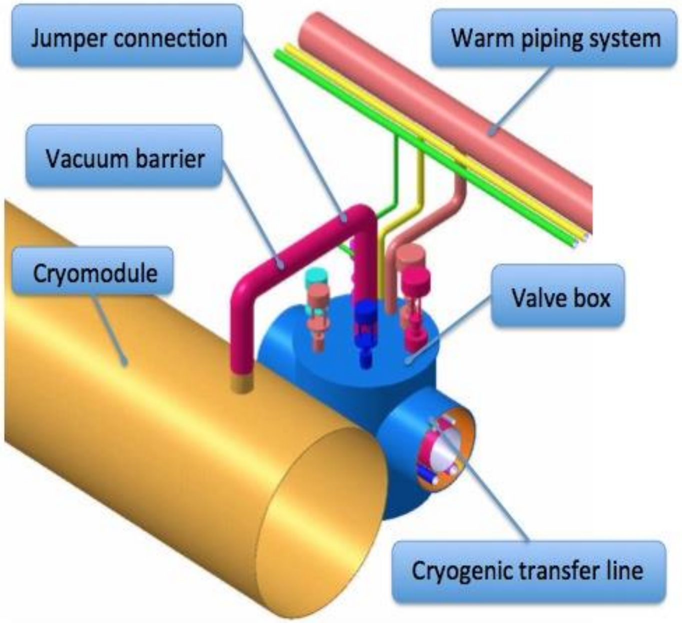
Content

- Valves in CDS – numbers and specific features
- Non inveasive measurement af the valve deflection
- Cryogenic valve relaxing with a minimu intervention to a cold box structure
- Mechanically allowable deformation of cryogenic valve
- Conclusions

Cryogenic Distribution System CDS

- Connects a cryoplant with cryomodules, magnets, helium innventory tanks
- Transfers helium in both directions
- Allows cool down, cryostating, warm up a machine
- Guarantees safe operation in all operating modes (including failure modes)
- Main components of CDS are: transfer lines, valve boxes, jumper connections, warm piping systems



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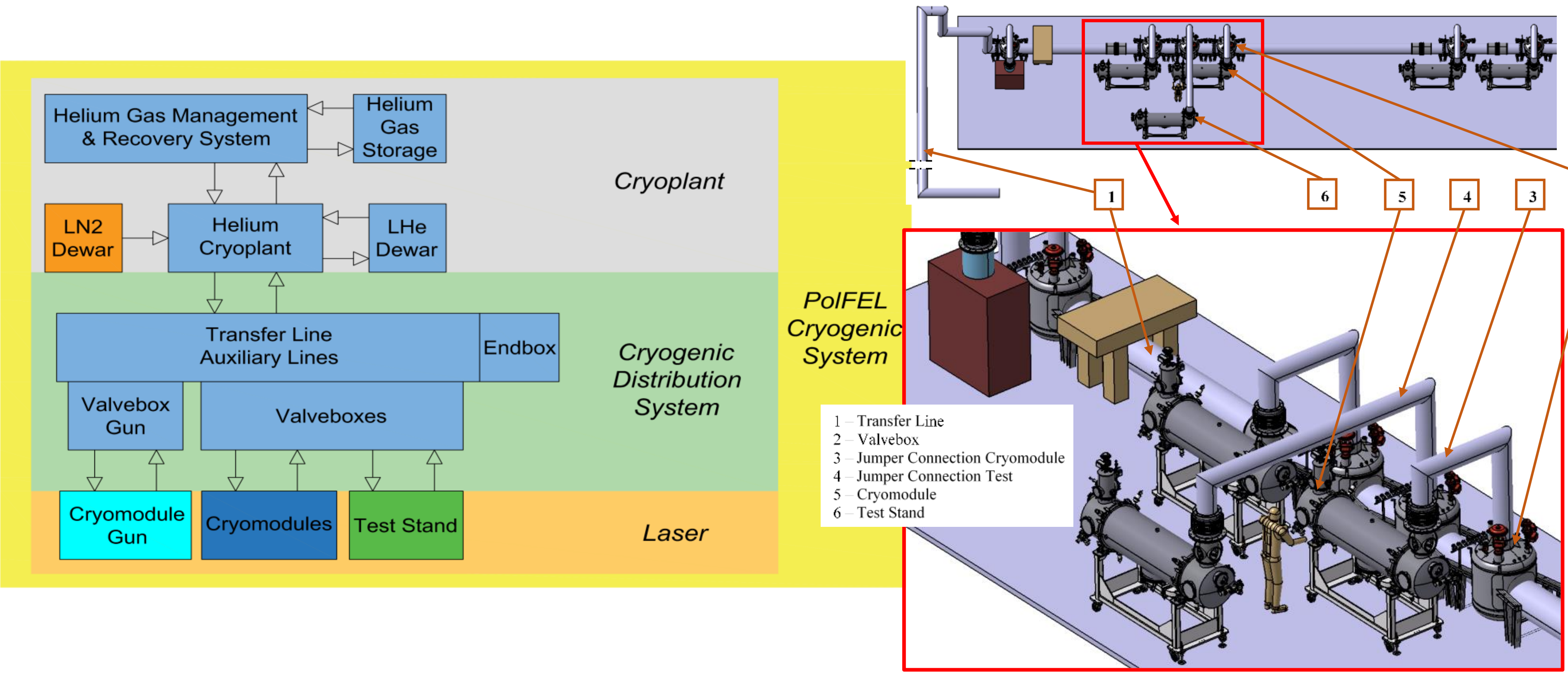
Exemplary Cryogenic Distribution System – POLFEL

PolFEL (Polish Free Electron Laser) will be the first Free Electron Laser (FEL) facility operating in Poland and Eastern Europe.



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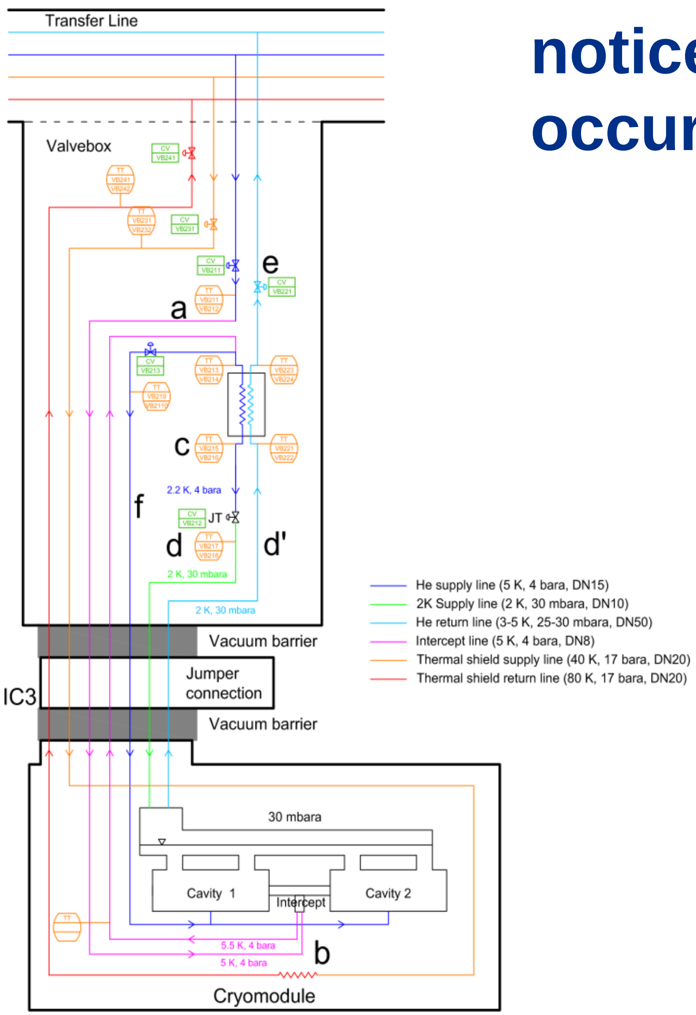
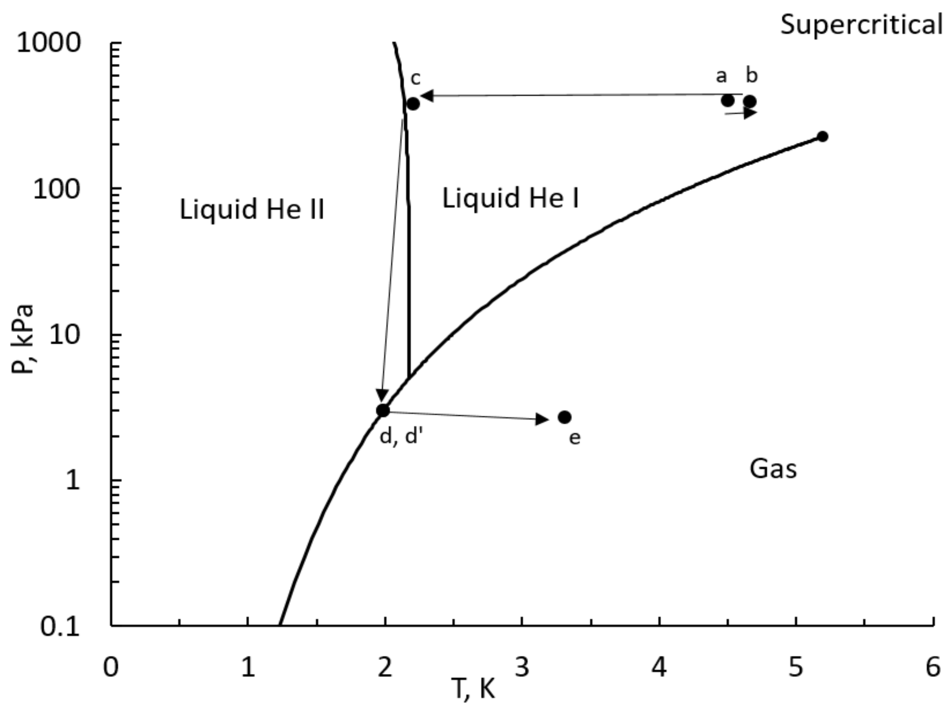
Simplified flow scheme of POLFEL Valve Box with corresponding T-s diagram Take notice of thermodynamic processes occuring in Valve Box/Cryomodule





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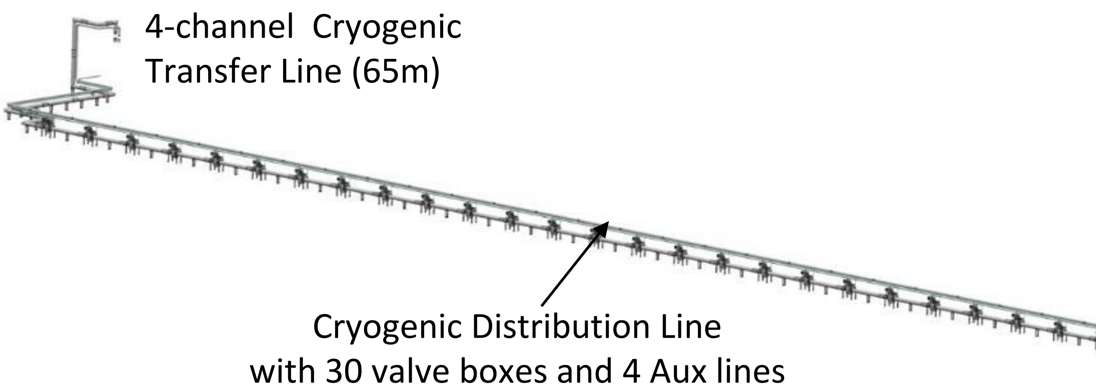
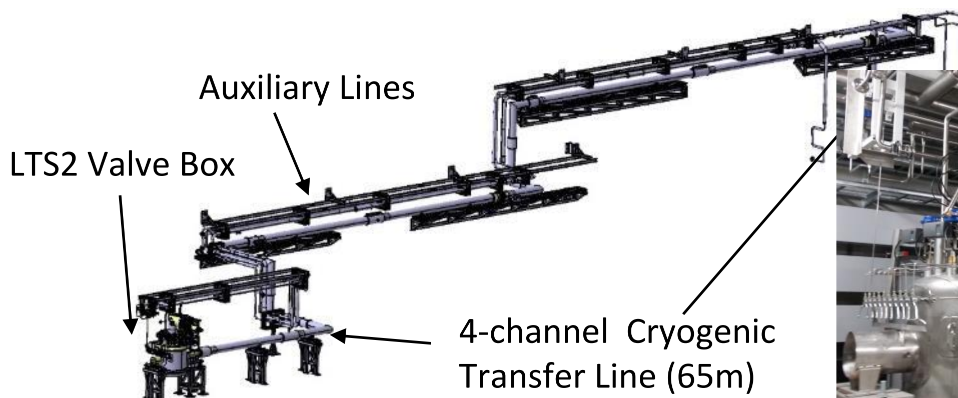
Cryogenic Distribution System in ESS

AIK 11.1 – Cryogenic Distribution for Elliptical Linac (CDS-EL)



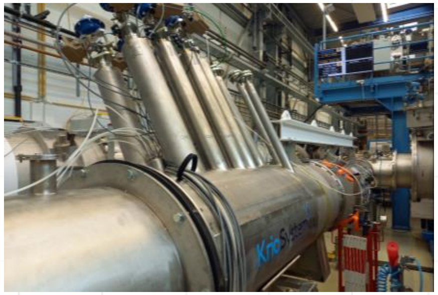
AIK 11.3 – Cryogenic Distribution for Lund Test Stand2 (CDS-LTS2)



Cryogenic control valves in CDS

The number of cryogenic control valves in cryogenic system mybe the order of thousands, the numer leaky valves may be of about 10 %.

Research facility	No of valves
European Spallation Source (ESS), Lund, Sweden	~360
PolFEL, Polish Free Electron Laser, Warsaw, Poland	~50
FAIR Super FRragment Separator (S-FRS), Darmstadt, Germany	~500



Why do cryogenic valves fail

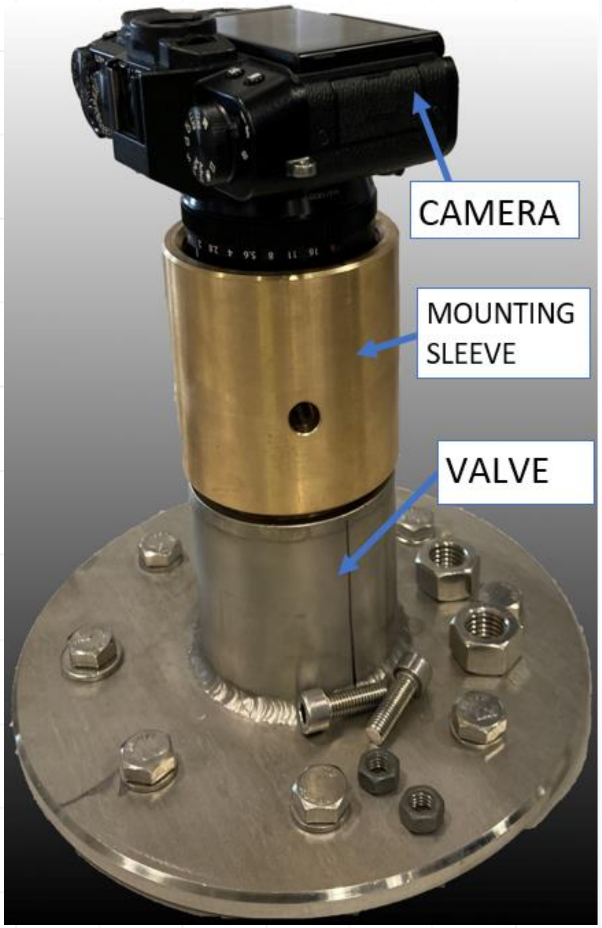
The valves should limit the heat transfer and remain mechanically stable

The valve deformations may result from:

- stresses produced during their manufacturing,
- improper transport,
- welding of the valve with valve box vessel
- process pipes loads
- cyclic thermal and pressure loads during the cool-down and warm up of cryogenic system.

Optical straightness measurement

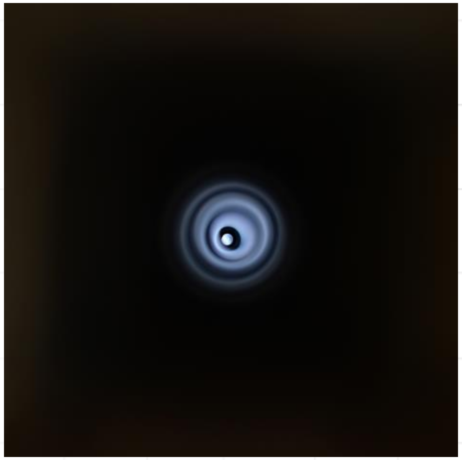
Valve straightness measurement using computer vision algorithms



- The hardware used to collect the photographs consists of a camera and a mounting sleeve
- Light emitting diode illuminate the bottom part of the valve, below the valve seat

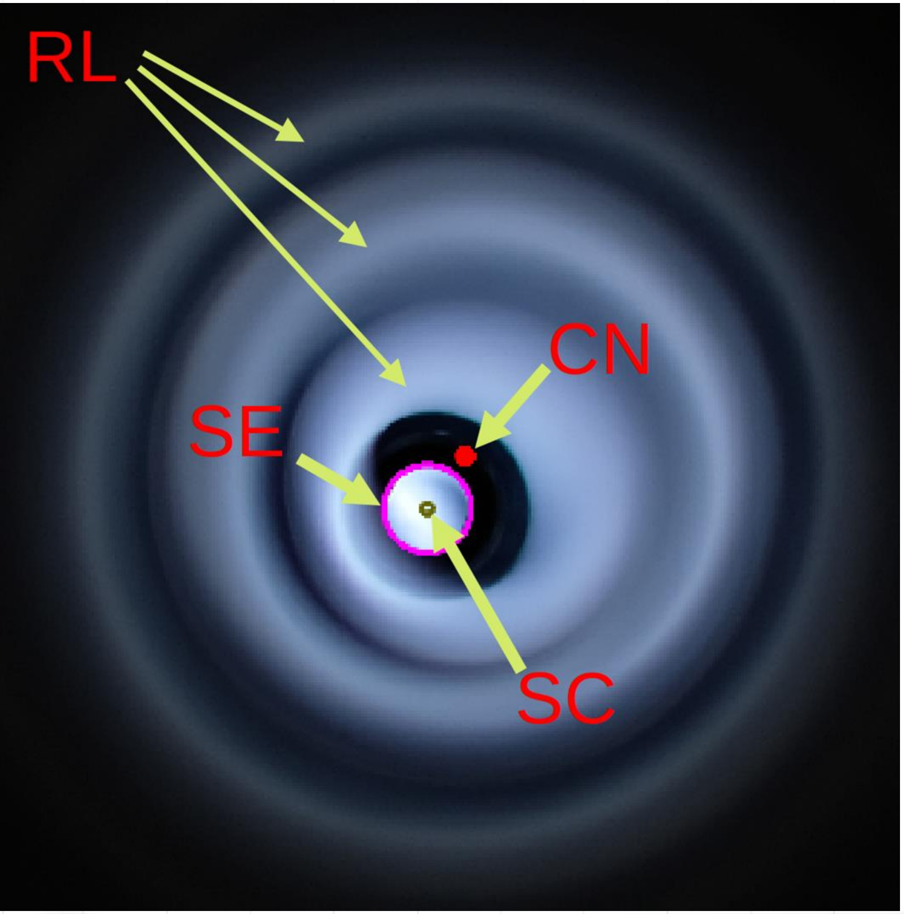
Optical straightness measurement

- The collected 269 photographs are used to estimate the valve deflection
- Computer vision algorithm (Hough transform for circles) detects valve seat edges and calculates position SC of the seat center
- By processing 269 photographs collected from 60 valves we statistically estimated nominal position CN of the valves' seat center
- Then, our deflection metric is calculated as the distance between the points CN and SC



Optical straightness measurement

Valve straightness measurement using computer vision algorithms



A valve interior photograph extended with detected seat edges.

CN – statistically estimated nominal (desired) position of valve seat center,

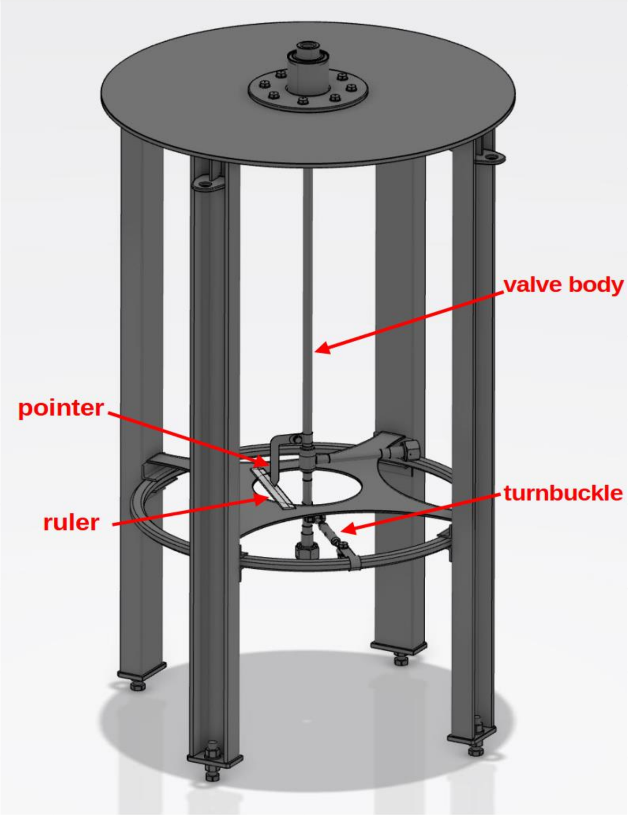
SC – estimated valve seat center,

SE – edge of valve seat,

RL – rings of light projected on the valve interior (irrelevant and undesired in the measurement process)

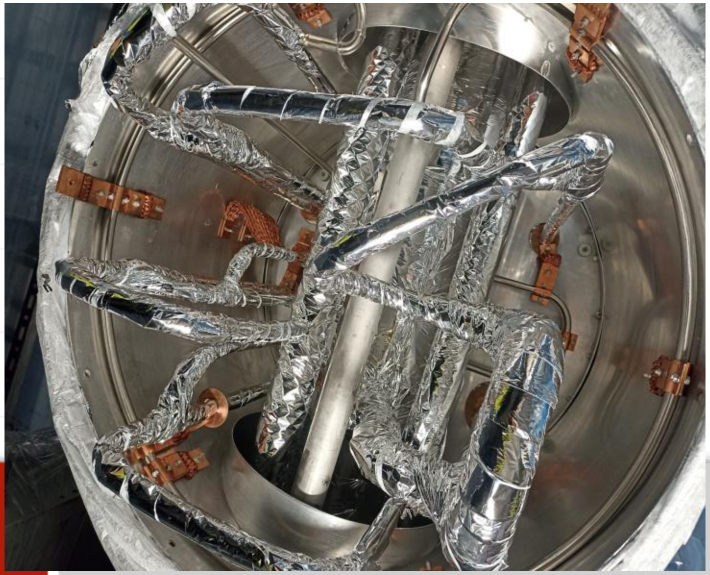
Valve straightness measurement using computer vision algorithms

- The method has been verified using special validation platform, where a valve is deflected in a controlled manner, to compare the computer vision results with ruler-based measurements.



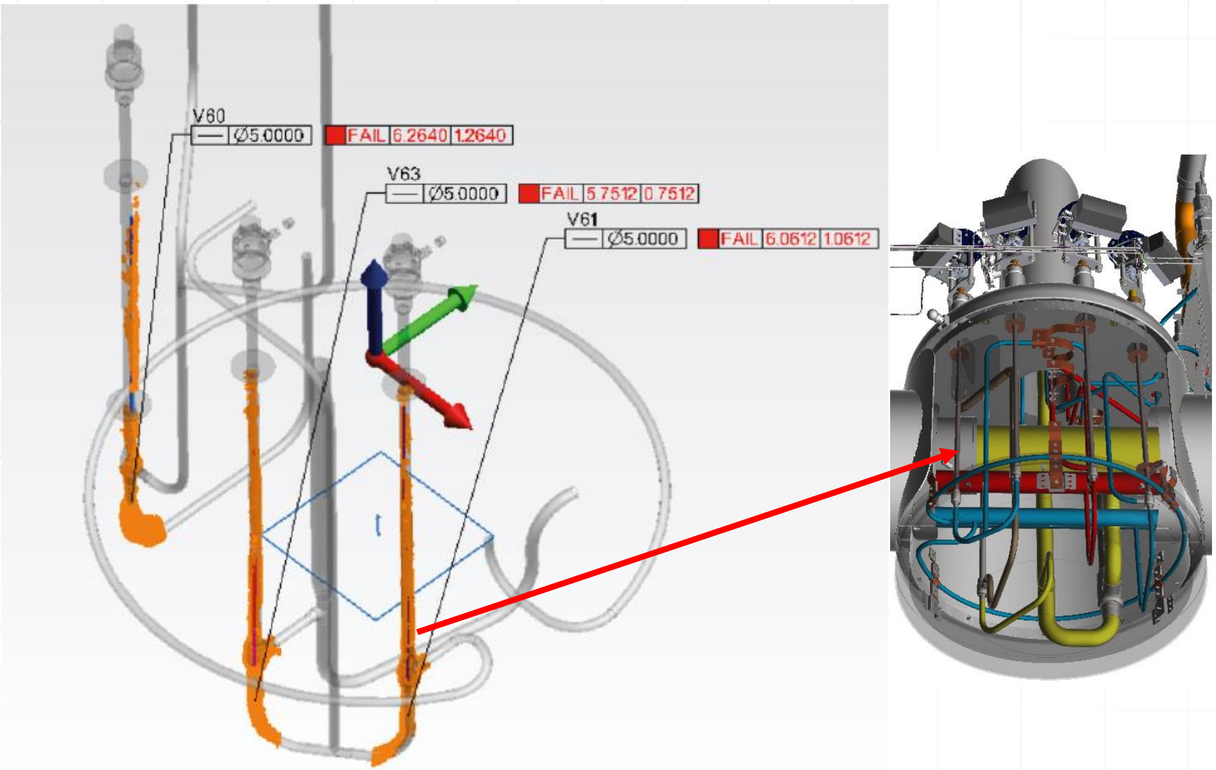
- <u>Uncertainty of measurement is no greater than 1.2 mm</u>

Valve Body Relaxation



- Some valves in the ESS CDS were deflected.
- These deflections necessitated repairs, during which the described optical method was used.
- The valve box with the deflected valve was opened from the bottom to assess the condition of the valves and pipes
- Visual inspection revealed relatively small deflections, allowing valves relaxations.

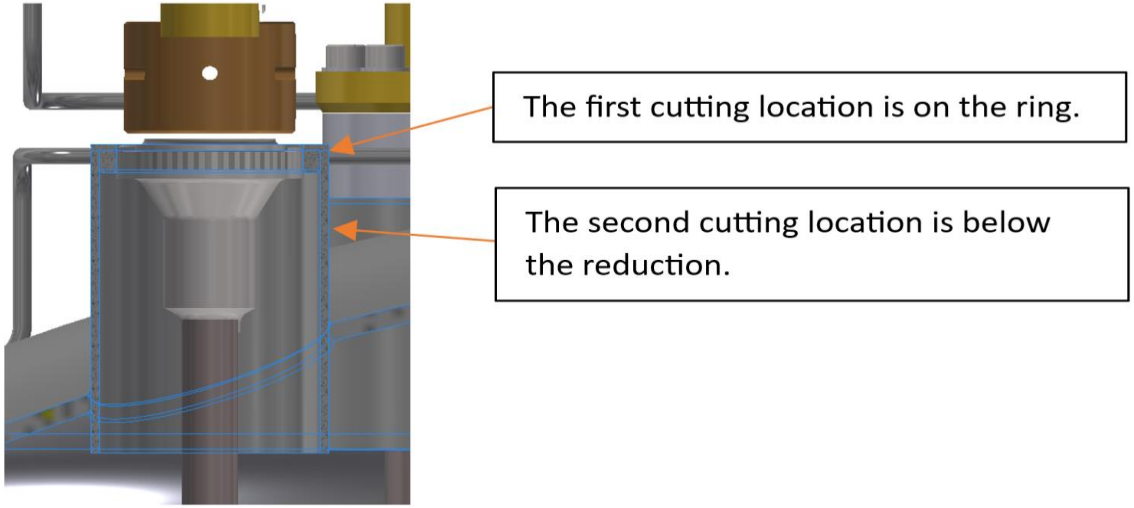
Valve Body Relaxation - 3D scanning and analysis

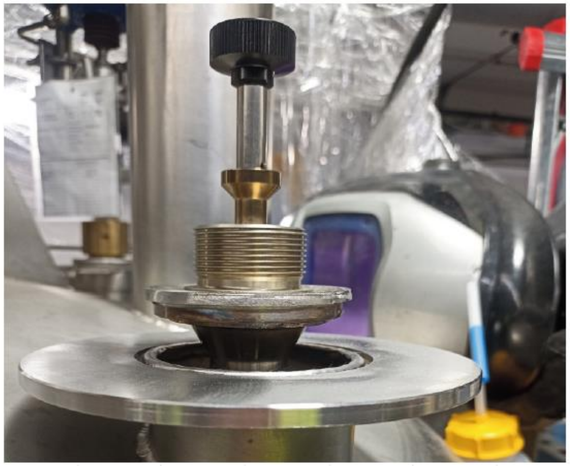


- A map of points derived from a 3D scan of the Valve Box overlaid onto its model, providing detailed information about any deviations.
- The scan allows for the observation of the shape of the valve deflections and the estimation of deviations from their nominal positions.

- Obtaining the 3D scan is challenging due to laser reflections from the Multi-Layer Insulation (MLI)

Valve Body Relaxation

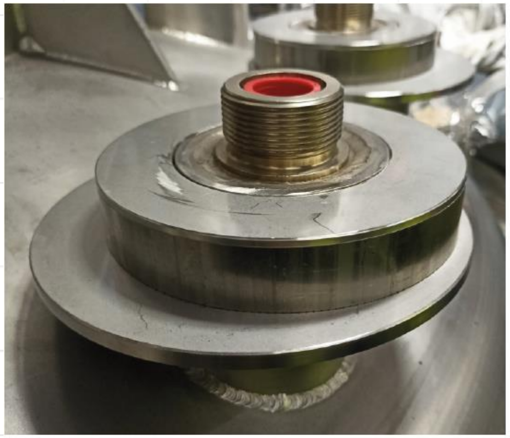




- To relax the stresses, the valve was cut dust-free in two places, allowing it to settle in all directions.
- The first cut was made on the ring, and the second below the reduction.
- Following the cutting process, the curvature of the valves was assessed using an optical method and the valve supplier's gauge.
  - It was confirmed that the valves were free from curvature after stress relaxation.

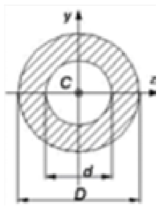
Valve Body Relaxation

Stress Relaxation Process



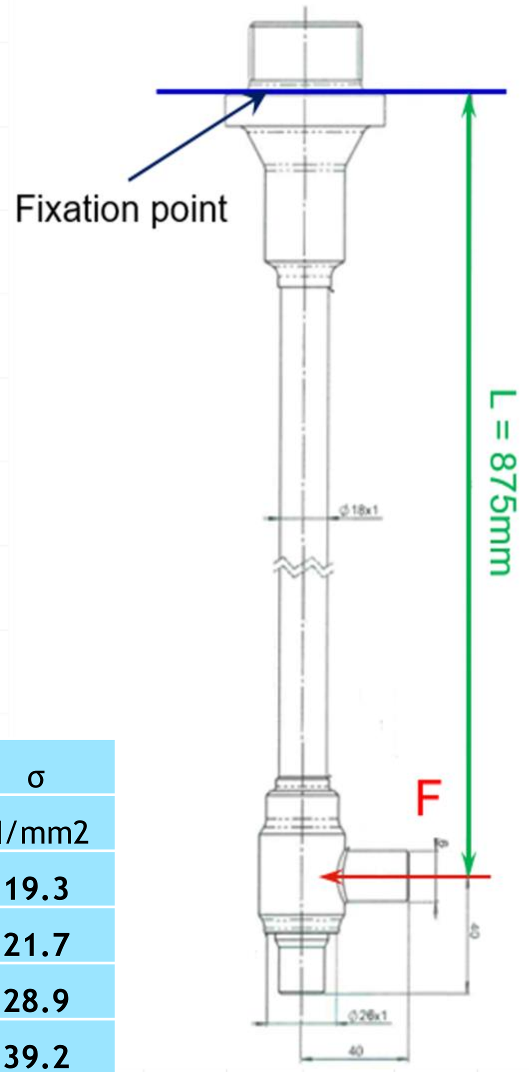
- After verifying that the valve returned to its nominal position, the fitting of the vacuum jacket adapters was checked and welded in a manner that did not introduce additional stresses on the valve.
- Throughout the welding process, the valve's position was continuously monitored using the valve supplier's gauge to ensure it remained stress-free.

Determination of stresses based on valve deflection

Cross section	J_z, mm^4	W_z, mm^3
	$\frac{\pi(D^4-d^4)}{64}$	$\frac{\pi(D^4-d^4)}{32D}$

$$F = \frac{3EJ_Zy}{L^3} \qquad \sigma = \frac{M}{W_Z}$$

$$M = FL$$



F- force acting on the vale [N]; E* = 205 000 [kN/mm^2];

y – deflection [mm]; L* = 875 [mm];

M - bending moment [Nmm] σ - maximum bending stresses [N/mm^2]

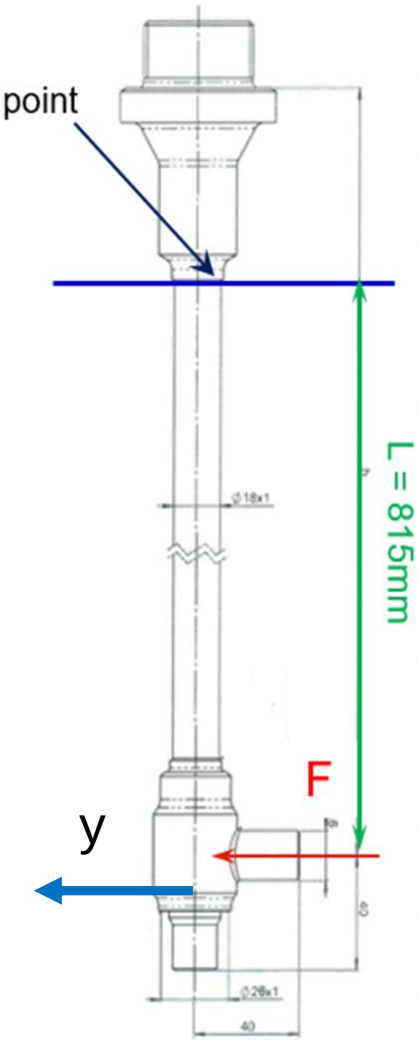
* Values given in WEKA_20080118_CryoValvesLoads&Bending_20100222

	D*	g*	y*	Jz	Wz	F	M	σ
	mm	mm	mm	mm4	mm3	N	Nmm	N/mm2
DN8	16	1	3.0	1331.2	166.4	**3.7 (4*)**	**3208**	**19.3**
DN10	18	1	**3,0**	1936.0	215.1	**5.3 (5*)**	**4665**	**21.7**
DN15	24	1	**3.0**	4787.0	398.9	**13.2 (13*)**	**11536**	**28.9**
DN20	32.5	1	**3.0**	12286.5	756.1	**33.8 (34*)**	**29608**	**39.2**

Determination of stresses based on valve deflection

Due to the significant stiffness of the upper part of the valve, it was assumed that only the pipe part was deformed, as a result, the force acting arm was shortened by 60 mm and the bending stresses increased.

$$\sigma = \frac{M}{W_Z} \qquad M = FL \qquad F = \frac{3EJ_Zy}{L^3}$$



F- force acting on the vale [N]; E* = 205 000 [kN/mm^2];

y – deflection [mm]; L = 815 [mm];

M - bending moment [Nmm] σ - maximum bending stresses [N/mm^2]

* Values given in WEKA_20080118_CryoValvesLoads&Bending_20100222

Stresses determined for different deflection values of the DN10 valve:

	D*	g*	y	Jz	Wz	F	M	σ
	mm	mm	**mm**	mm4	mm3	N	Nmm	**N/mm2**
DN10	18	1	**3.0**	1936.0	215.1	6.60	5378	**25.0**
DN10	18	1	**11.0**	1936.0	215.1	24.19	19718	**91.7**
DN10	18	1	**24.0**	1936.0	215.1	52.79	43020	**200.0**
DN10	18	1	**25.0**	1936.0	215.1	54.99	44813	**208.3**

Offset yield strength $R_{p0.2}$= 200 MPa, for steel 1.4404 of which the valve body tube is made

Conclusions

- A noninvasive optical method for the deflection of cryogenic valve measurement has been developed and verified.
- The limit of valve deflection allowing its relaxation has been estimated experimentally and verified numerically
- Cryogenic valve relaxing with a minimum intervention to a cold box structure has been proposed and implemented in several valves from ESS CDS,