Appendix

A1 - ESA SOW Report

Annex 1: Preliminary Functional Specification

A.1 End Product (System) Definition and Breakdown

The Heat Switch shall consist of:

a. Hot mounting interface
b. Cold mounting interface
c. Switching device to vary the thermal conductance between the hot and cold interfaces

The heat switch shall be a stand alone item ready to be mounted between a unit and radiator

A.2 Requirements

A.2.1 Functional & Performance Requirements

Spec Reference	Description
FPR1	The Heat Switch shall have a peak conductance value greater than 1 W/K
FPR2	The Heat Switch shall have an ON/OFF ratio greater than 100
FPR3	The Heat Switch shall operate in vacuum and in 10mbar of CO_2
FPR4	The variable conductivity range of the Heat Switch shall be between 15°C to 25°C of the hot interface
FPR5	The Heat Switch shall be designed to transport 1W to 10W in closed/ON mode with a maximum delta temperature of 10K
FPR6	The Heat Switch shall have a temperature stability of +/- 1°C with a constant power input and constant sink temperature
FPR7	In a redundant configuration, it shall be possible to mount two separate and identical Heat Switches in parallel between the radiator and the heat source without any individual performance degradation

A.2.2 Interface Requirements

Spec Reference	Description
IR1	The Heat Switch shall have a flat mechanical interface on the Hot and Cold side for mounting onto the dissipating component and to temperature sink
IR2	The Heat Switch shall have a hot mounting surface area of roughly 16 cm^2 (TBC)
IR3	The Heat Switch shall meet the requirements with cold interface temperatures between -125°C and 50°C and with hot interface temperatures between -55°C and 60°C

A.2.3 Environmental Requirements

The product shall be designed and manufactured to withstand the following environmental conditions:

Spec Reference	Description
ER1	The qualification temperatures for the Heat Switch are the temperature listed in IR3 with margin of 10K

<table>
<tr><td>ER2</td><td>
The Heat Switch (at the evaporator level) shall sustain the following mechanical environment in each of the 3 orthogonal axes :
- Sinus (from AD4):
<table>
<tr><th>Freq (Hz)</th><th>Level</th></tr>
<tr><td>5 - 21</td><td>11mm</td></tr>
<tr><td>21 - 60</td><td>20g</td></tr>
<tr><td>60 - 100</td><td>6g</td></tr>
<tr><td>Sweep Rate</td><td>2 octaves/minute, 1 sweep up</td></tr>
</table>
- Random (from AD4):
<table>
<tr><th>Freq (Hz)</th><th>Level</th></tr>
<tr><td>20-100</td><td>+3 dB/oct.</td></tr>
<tr><td>100-300</td><td>0.94 g^2/Hz</td></tr>
<tr><td>300-2000</td><td>-5 dB/oct.</td></tr>
<tr><td>Composite</td><td>23.3 g rms</td></tr>
</table>
</td></tr>
<tr><td>ER3</td><td>
The Heat Switch shall not be affected by a radiation environment of 30kRad accumulated over its life.
Note: In order to cover a larger range of applications, the Heat Switch should be insensitive to the radiation environment since possible future missions could be subject to 30kRad/day
</td></tr>
<tr><td>ER4</td><td>The Heat Switch shall be able to work in every position with respect to gravity acceleration and in 0g.</td></tr>
</table>

A.2.4 Physical & Resource Requirements

The product shall comply with the following constraints:

Spec Reference	Description
PRR1	The Heat Switch shall have a mass lower than 60 grams

A.2.5 Operational Requirements

Spec Reference	Description
OR1	The Heat Switch shall have an operational life greater than 7 years

A.2.6 Human Factors Requirements

N.A.

A.2.7 Logistics Support Requirements

N.A.

A.2.8 Product Assurance Requirements

Spec Reference	Description
PA1	The Heat Switch shall comply with product safety requirements stated in AD4
PR2	The materials and processes shall comply to the requirements of AD5
PR3	The contractor shall be compliant with AD6 chapter 5.6

A.2.9 Configuration & Implementation Requirements

N.A.

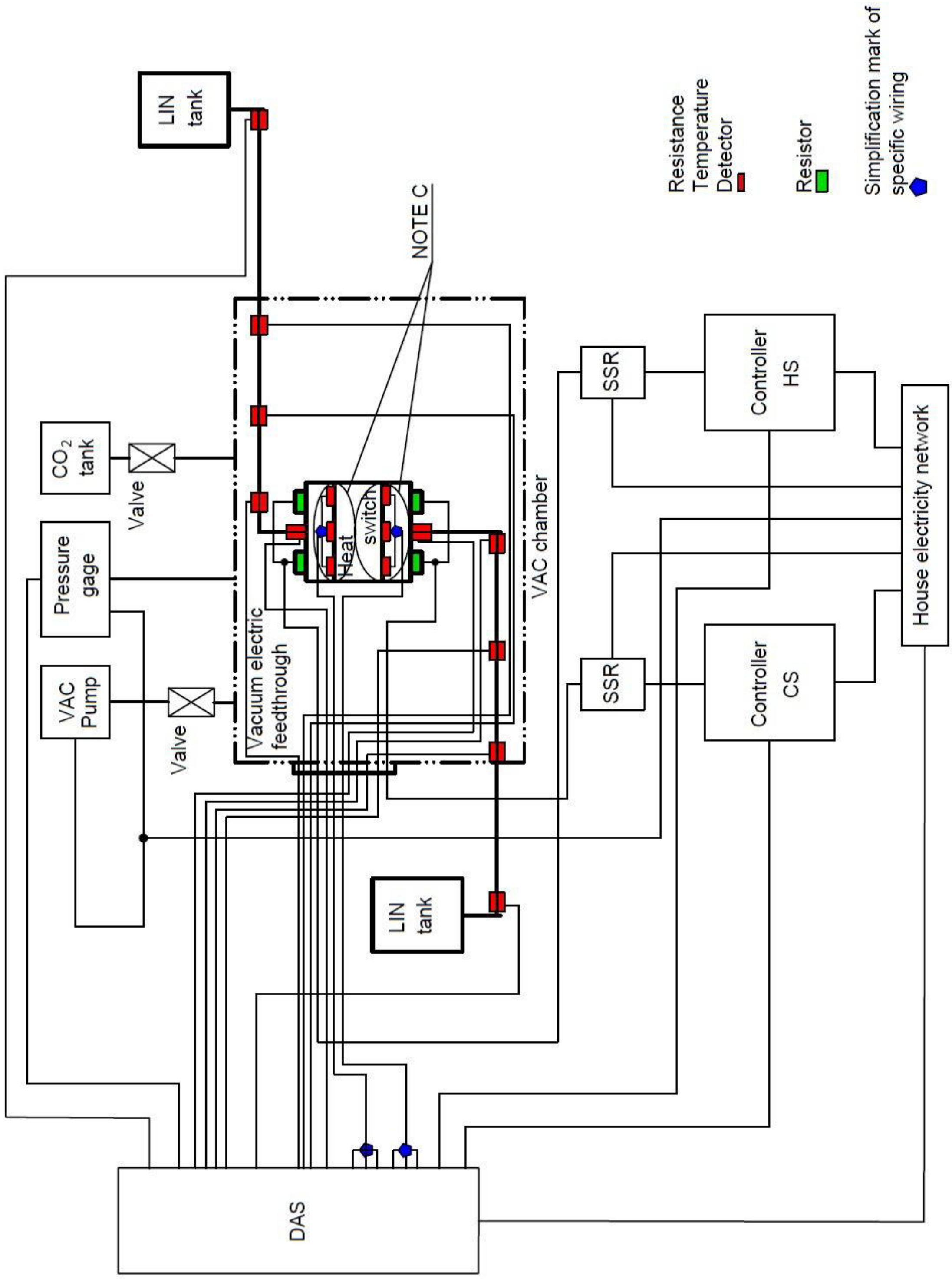
A.2.10 Design Requirements

Spec Reference	Description
DR1	The heat switch design should allow the set-point to be changed
DR2	Fatigue life demonstration shall be performed in conformance with AD2
DR3	The prevention and control effects of the corrosion shall be in accordance with AD2
DR4	The requirements on material section, material design allowable and characterisation shall be in conformance with AD2
DR5	The Heat Switch shall fail open, meaning that in all failure cases the heat switch shall remain OFF.
DR6	The Heat Switch design shall be capable to be sterilized with Dry Heat Microbial Reduction process at +125°C for 30 hours
DR7	The Heat Switch shall be designed to sustain 100000 open and close cycles (TBC)

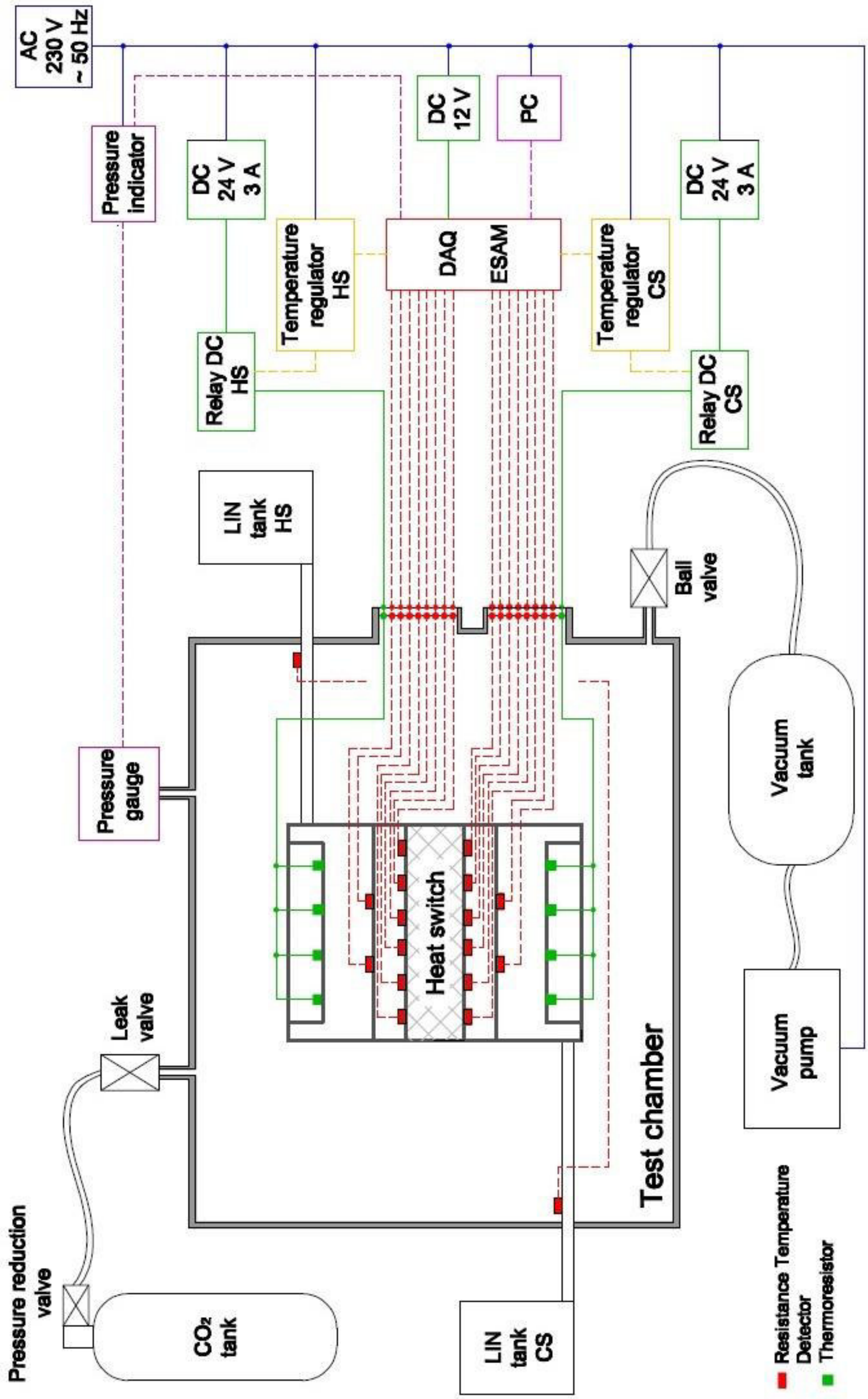
A.2.11 Verification & Testing Requirements

Spec Reference	Description
VTR1	The Heat Switch shall be subject to 8 thermal cycles over the temperature range specified in IR3 with a hold-time of 1hour at each temperature extreme.
VTR2	The Heat Switch shall be subject to sinusoidal tests for all axes with 1 sweep-up at 2 octaves per minute
VTR3	The Heat Switch shall be subject to random vibration for the duration of 2.5 minutes per axis
VTR4	The thermal performance of the Heat Switch shall be measured
VTR5	The simulation of large heat load variations shall be performed (i.e. by increasing and decreasing the applied heat load)

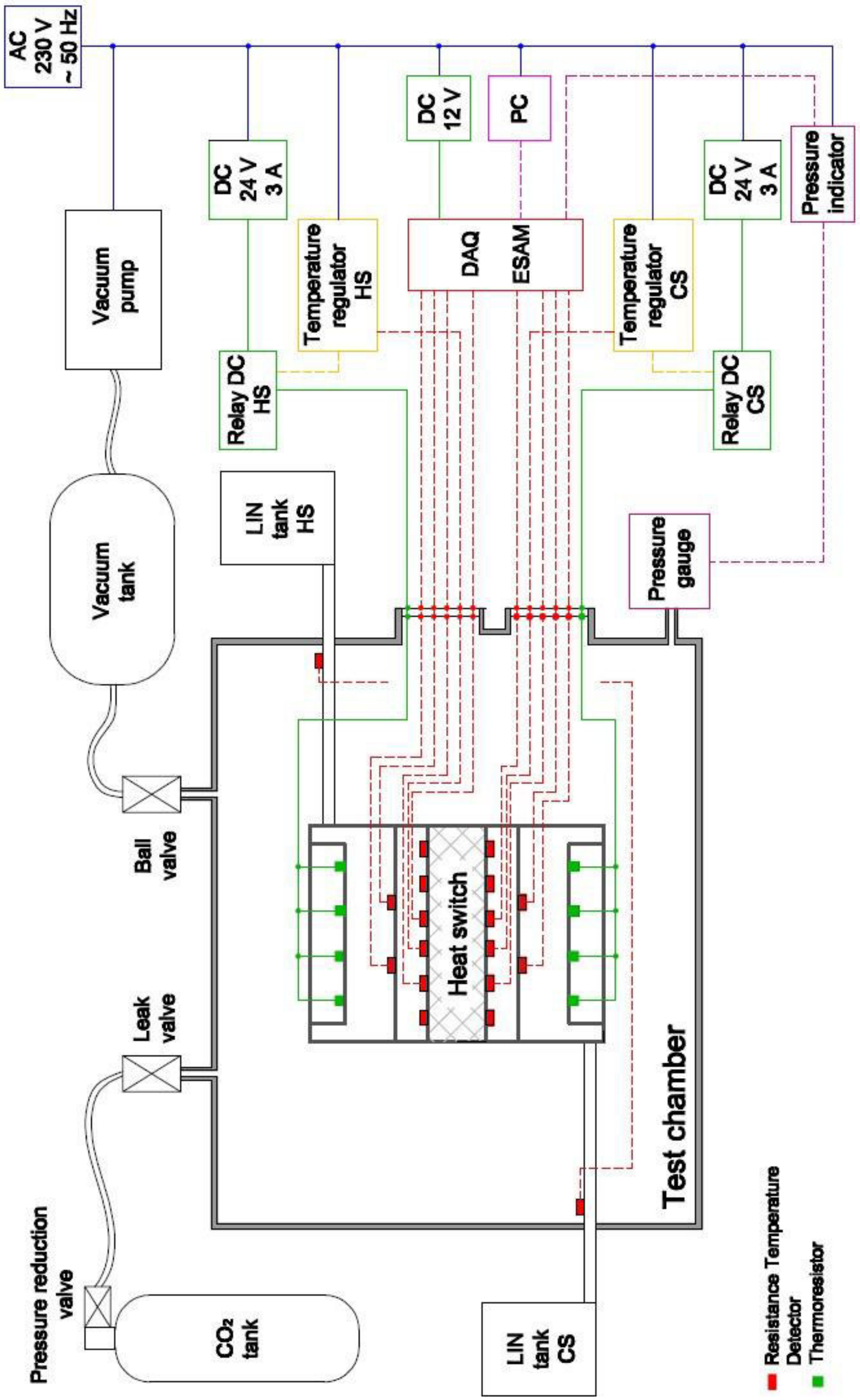
A2 - Version 0: System scheme



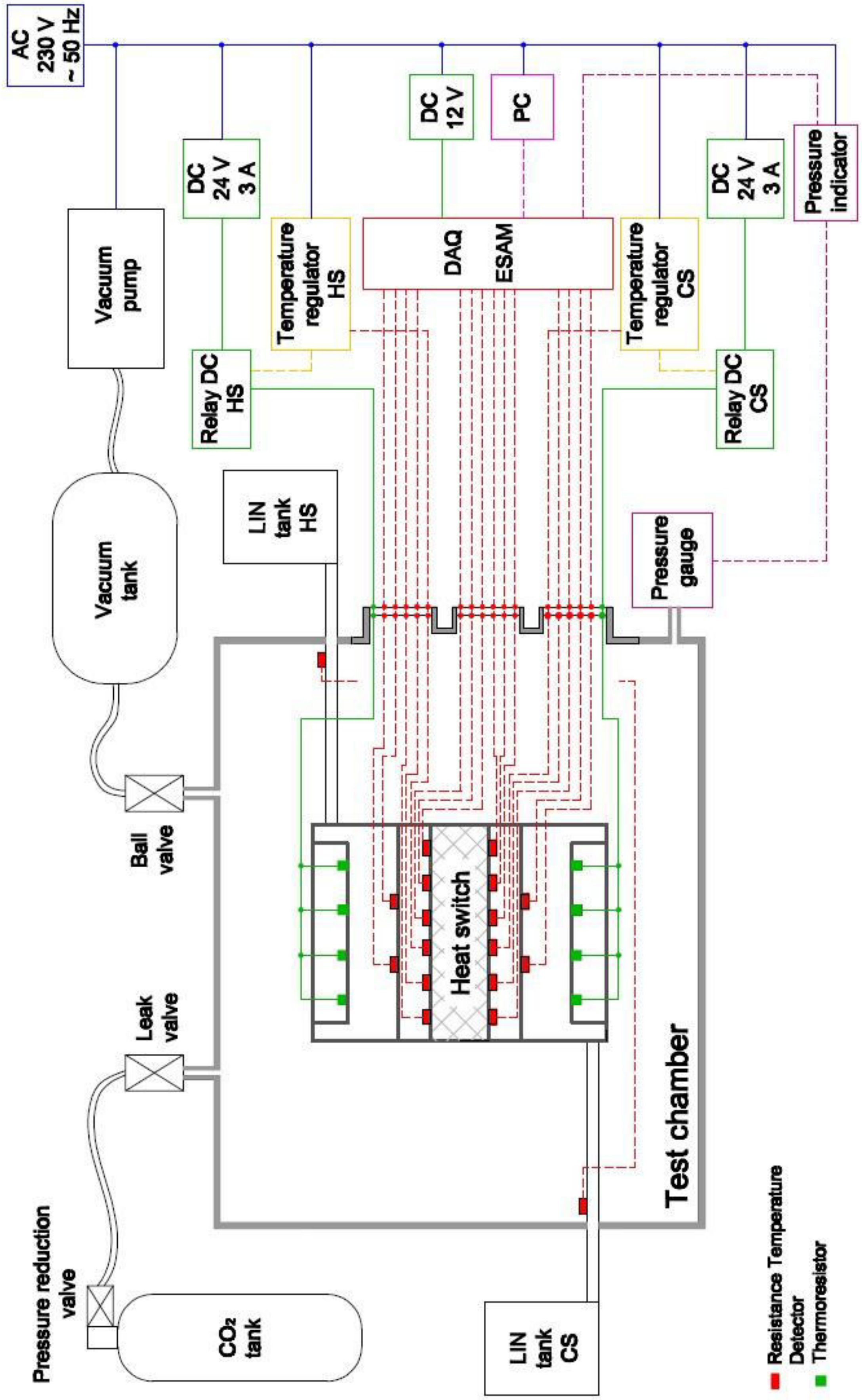
A3 - Version 2 – Initial: System scheme



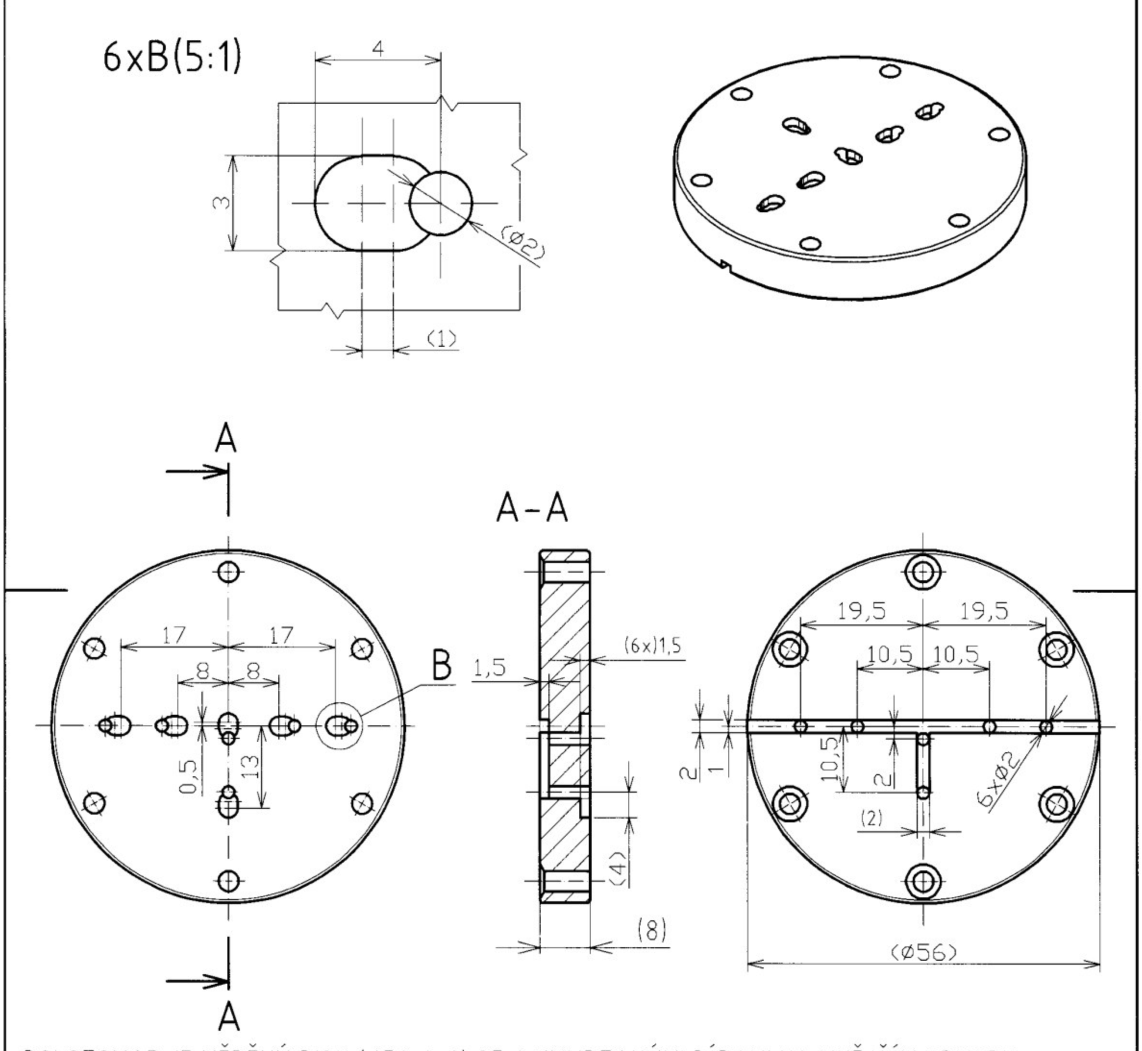
A4 - Version 2 – Advanced: System scheme



A5 - Version 3: System scheme



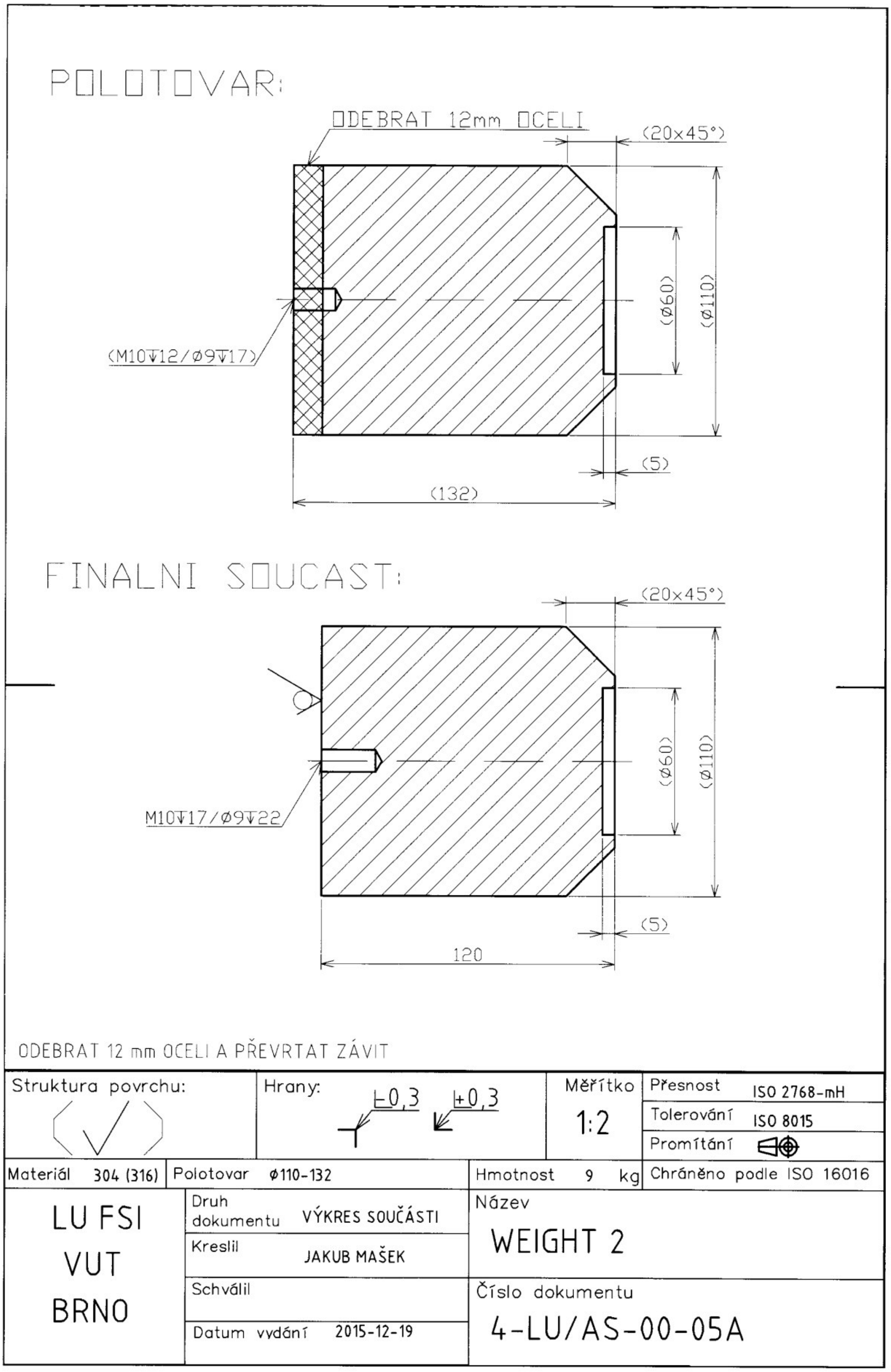
A6 - Version 2 – Initial: Copper plate drawing



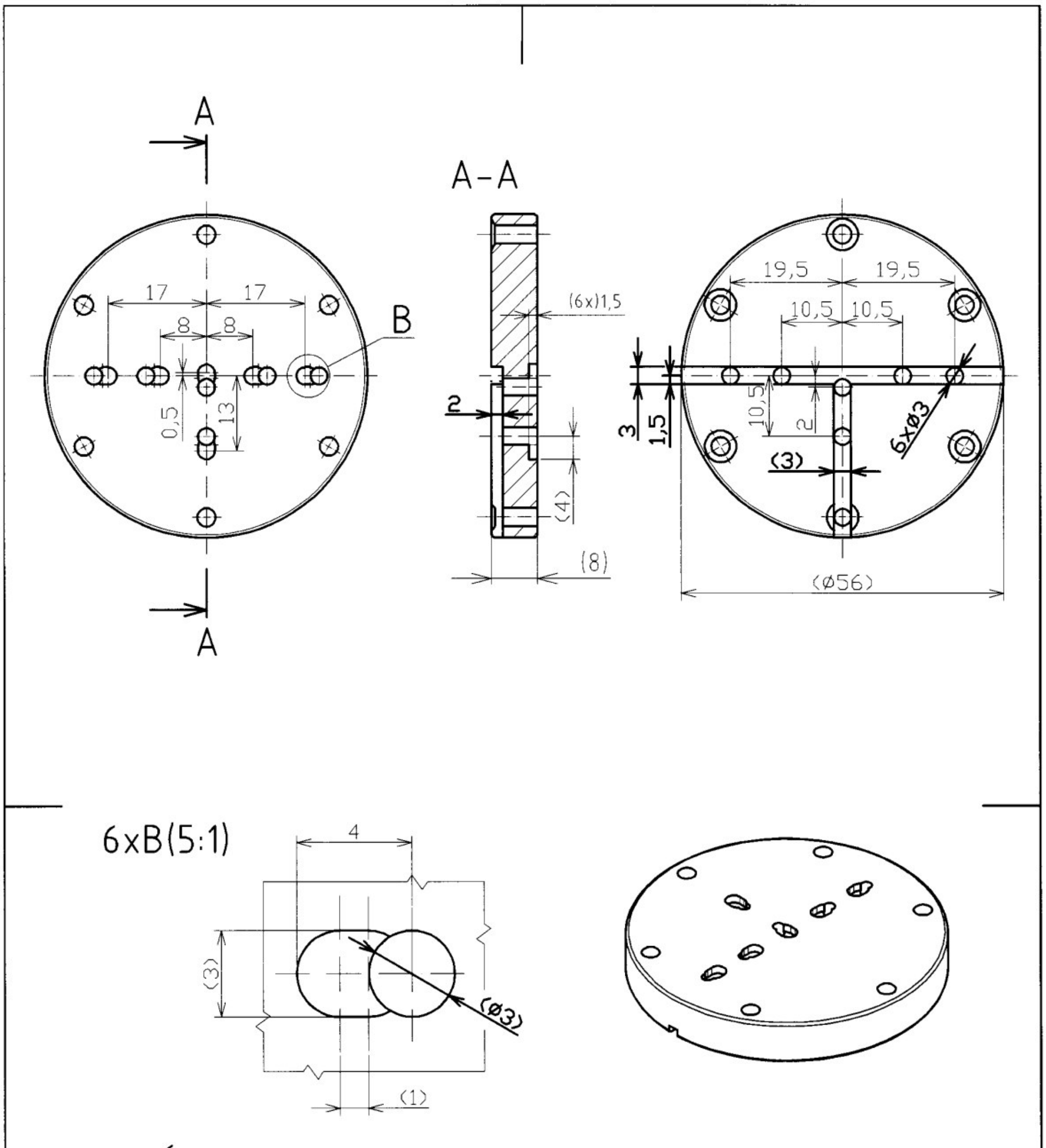
POLOTOVAR JE MĚDĚNÝ DISK (Ø56, t=8) SE 6 VYVRTANÝMI DÍRAMI NA VNĚJŠÍM OBVODU

Struktura povrchu: Ra 3,2	Hrany: -0,3 +0,3	Měřítko 1:1	Přesnost ISO 2768-mH Tolerování ISO 8015 Promítání
Materiál Cu	Polotovar Ø56, t=8	Hmotnost - kg	Chráněno podle ISO 16016
LU FSI VUT BRNO	Druh dokumentu VÝKRES SOUČÁSTI Kreslil JAKUB MAŠEK Schválil Datum vydání 2015-12-19	Název COPPER PLATE Číslo dokumentu 3-LU/AS-01-02A	List /

A7 - Version 2 – Initial: Weight 2 drawing



A8 - Version 2 – Advanced: Copper plate drawing

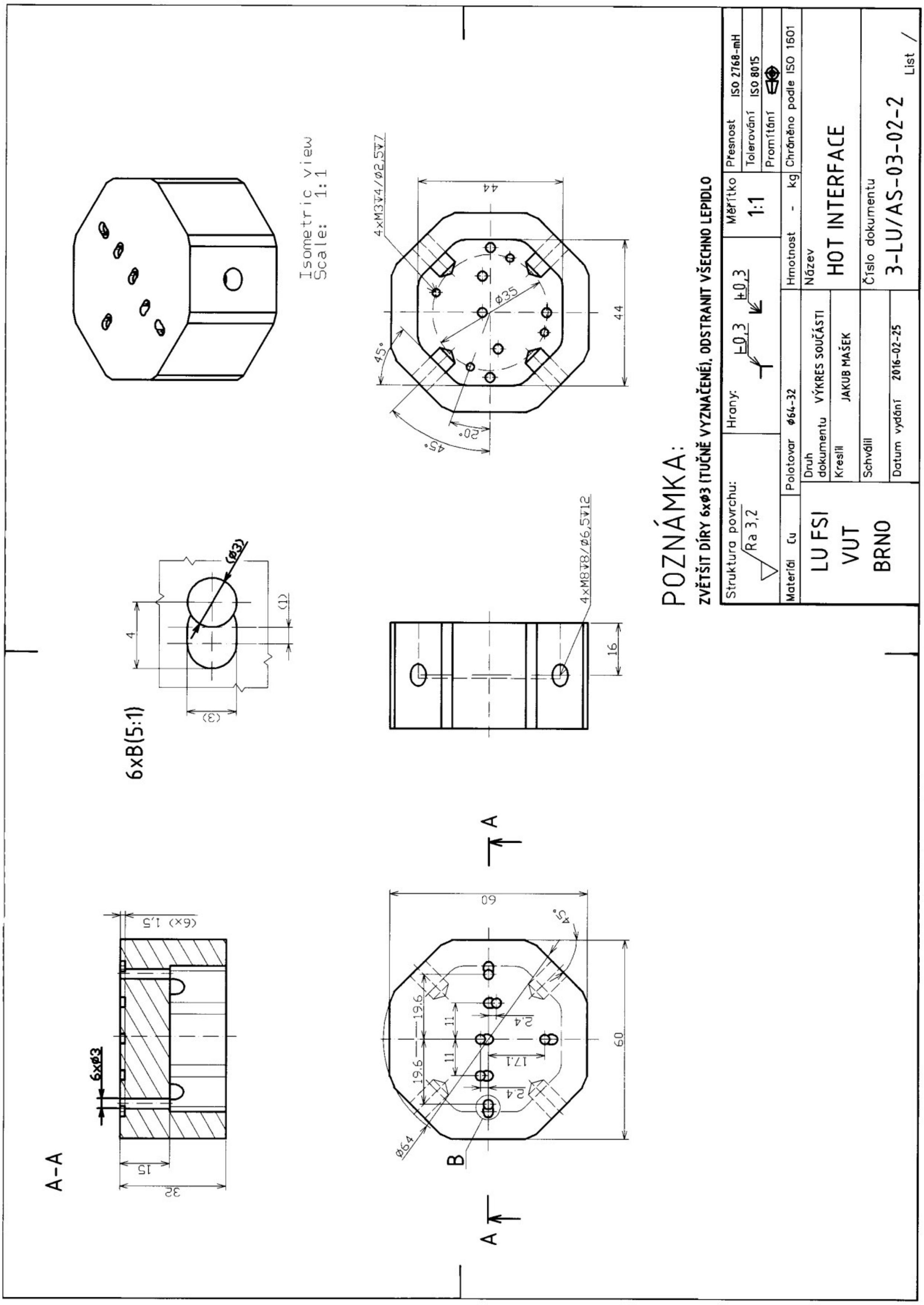


POZNÁMKA:

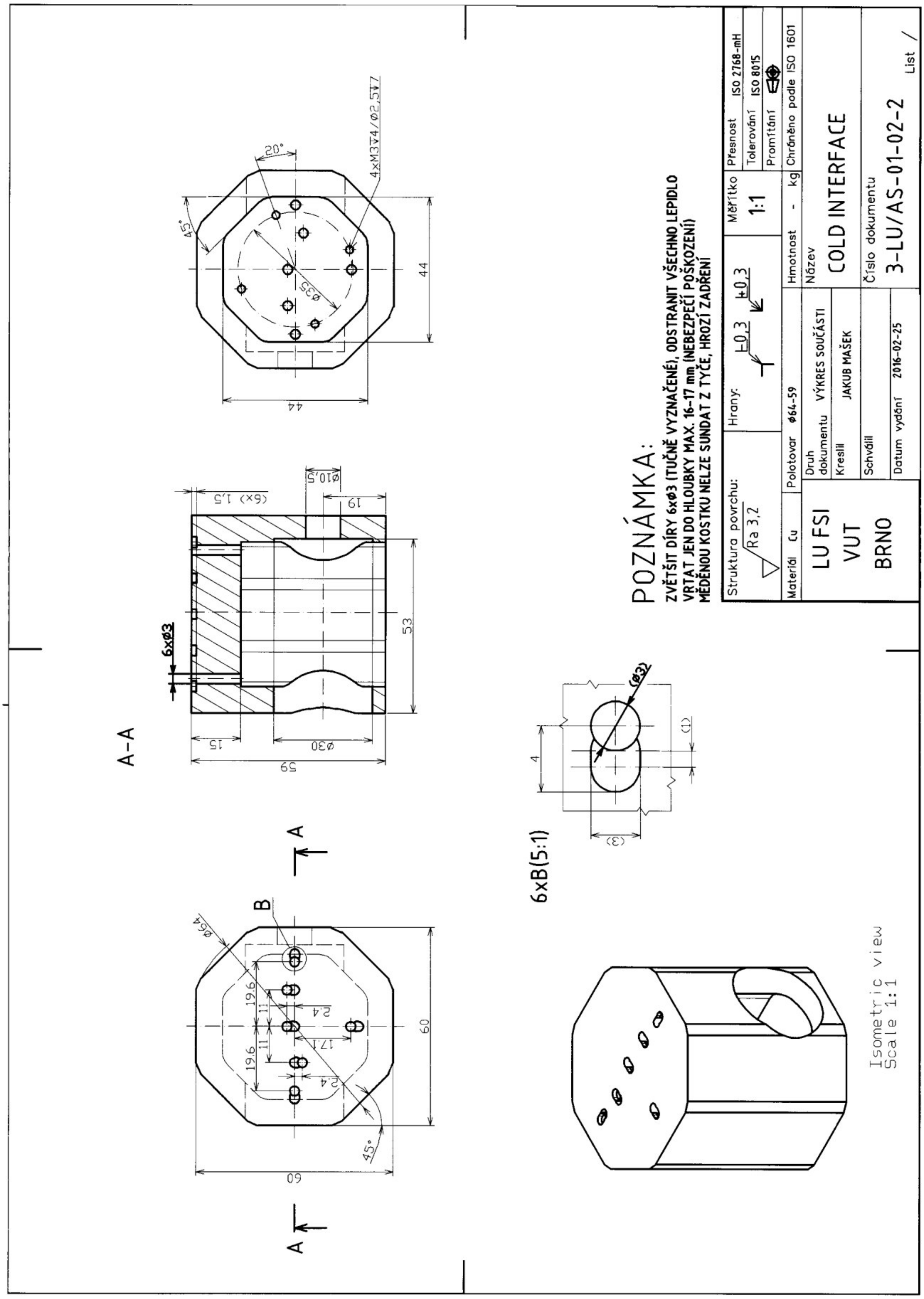
ZVĚTŠIT DÍRY 6xØ3 A DRÁŽKY 3x2 (TUČNĚ VYZNAČENÉ), ODSTRANIT VŠECHNO LEPIDLO

Struktura povrchu: Ra 3,2	Hrany: -0,3 +0,3	Měřítko 1:1	Přesnost ISO 2768-mH
			Tolerování ISO 8015
			Promítání
Materiál Cu	Polotovar Ø56, t=8	Hmotnost - kg	Chráněno podle ISO 16016
LU FSI VUT BRNO	Druh dokumentu VÝKRES SOUČÁSTI	Název COPPER PLATE	
	Kreslil JAKUB MAŠEK		
	Schválil	Číslo dokumentu 3-LU/AS-01-02B	
	Datum vydání 2016-2-25		

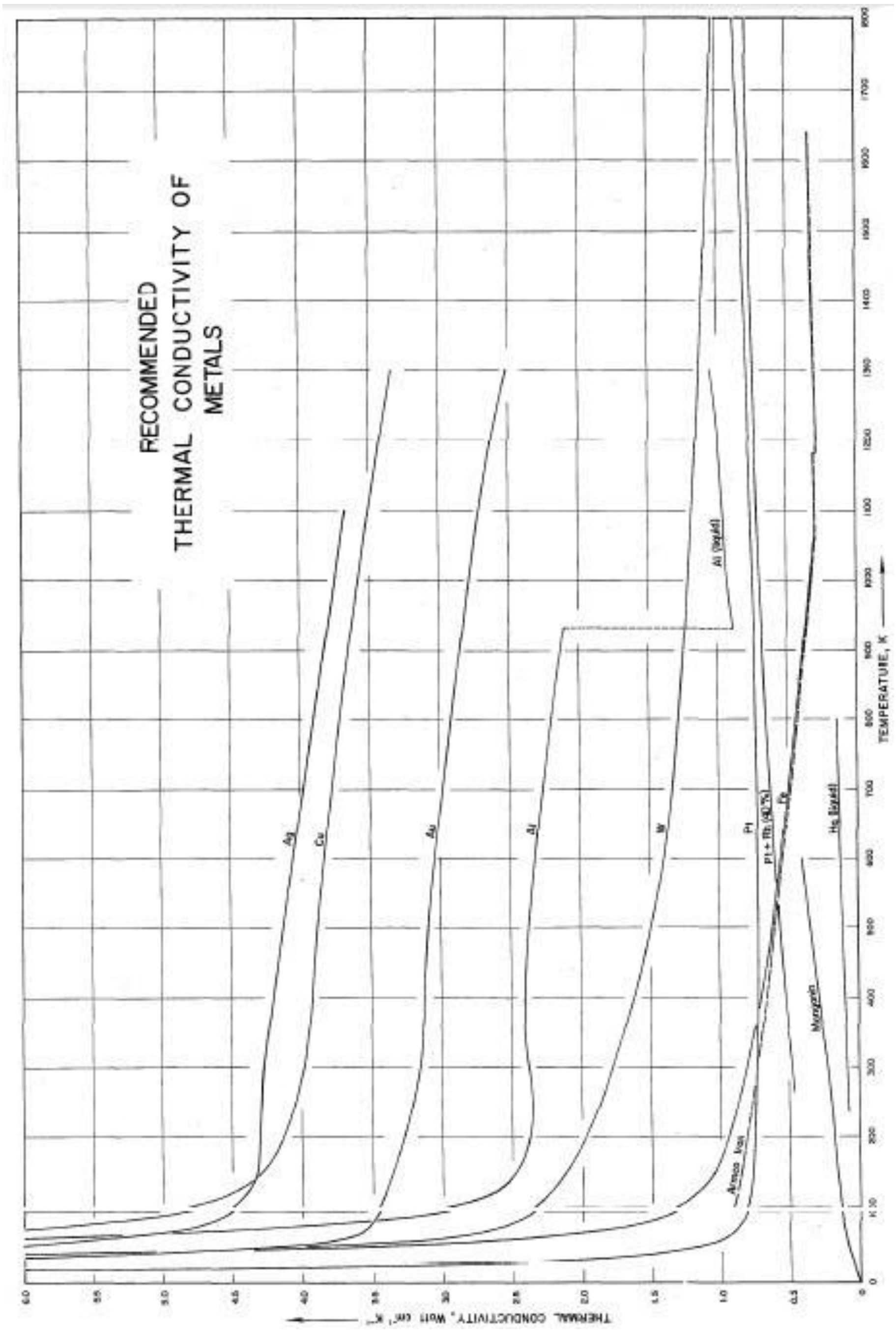
A9 - Version 2 – Advanced: Hot Interface drawing



A10 - Version 2 – Advanced: Cold Interface drawing



A11 - Copper conductance temperature dependency



T, K	Aluminum	Copper	Gold	Iron (Armco)
100	3.0	4.83	3.45	0.913
150	2.47	4.28	3.35	0.854
200	2.37	4.13	3.27	0.804
250	2.35	4.04	3.20	0.764
273	2.36	4.01	3.18	0.747
300	2.37	3.98	3.15	0.727
350	2.40	3.94	3.13	0.691
400	2.40	3.92	3.12	0.657
500	2.37	3.88	3.09	0.593
600	2.32	3.83	3.04	0.531
700	2.26	3.77	2.98	0.473
800	2.20	3.71	2.92	0.422
900	2.13	3.64	2.85	0.372

A12 - Version 0: Figures of 3D model

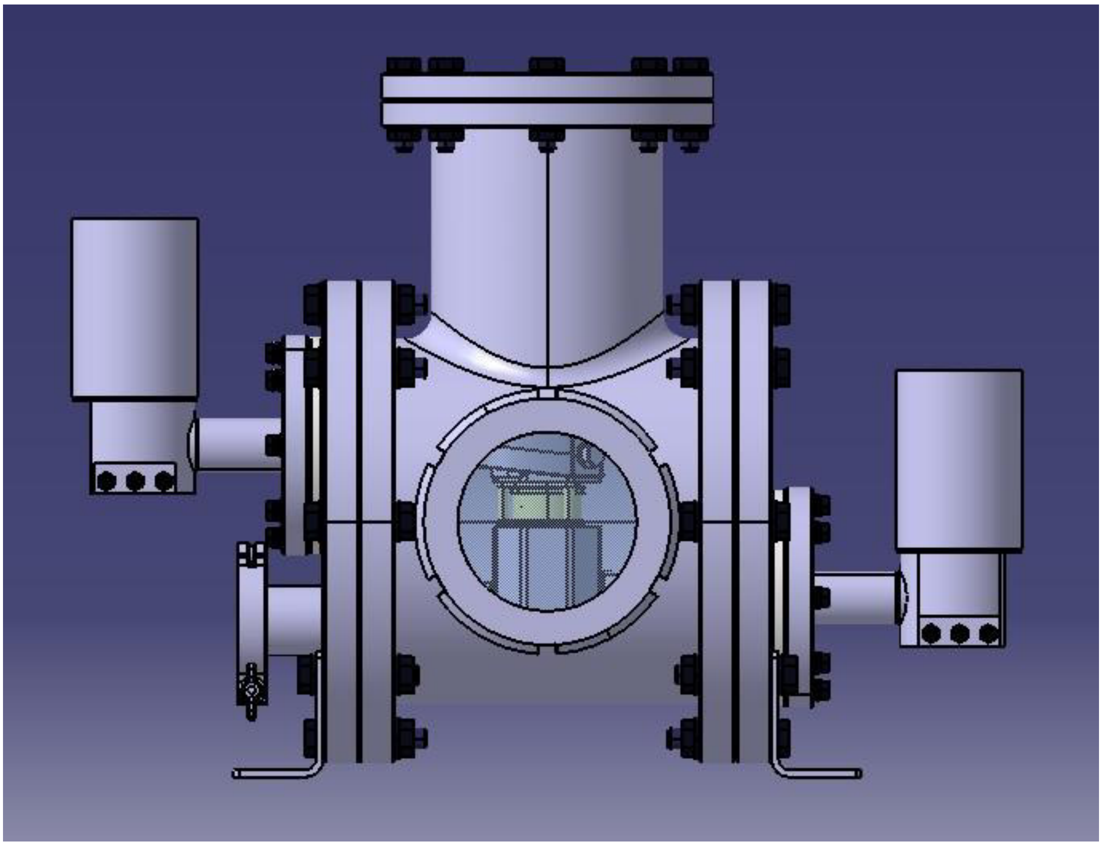


Figure 16.1: *Version 0 front view: Chamber initial design (systems had not been designed yet).*

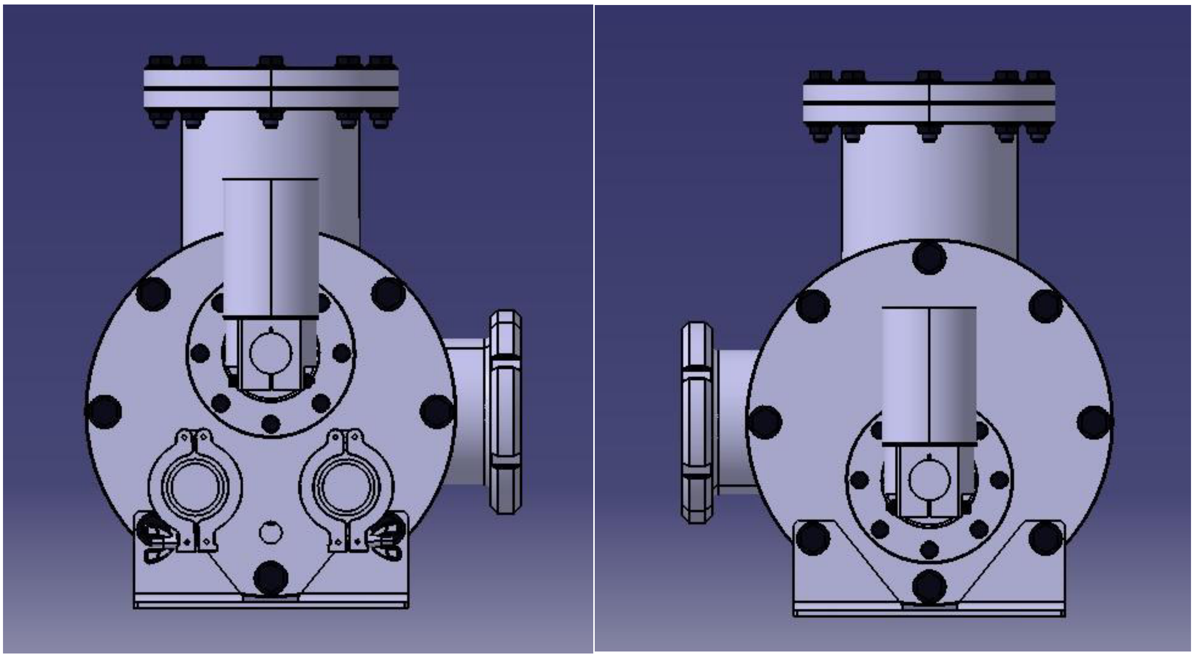


Figure 16.2: *Version 0 side views: HST Chamber initial design.*

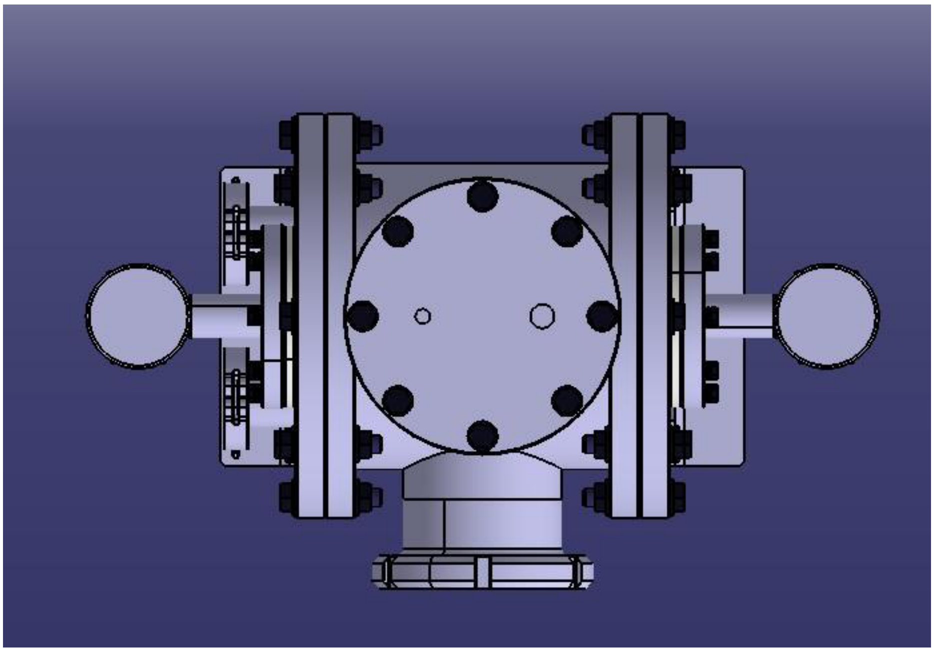


Figure 16.3: *Version 0 top view: HST Chamber initial design.*

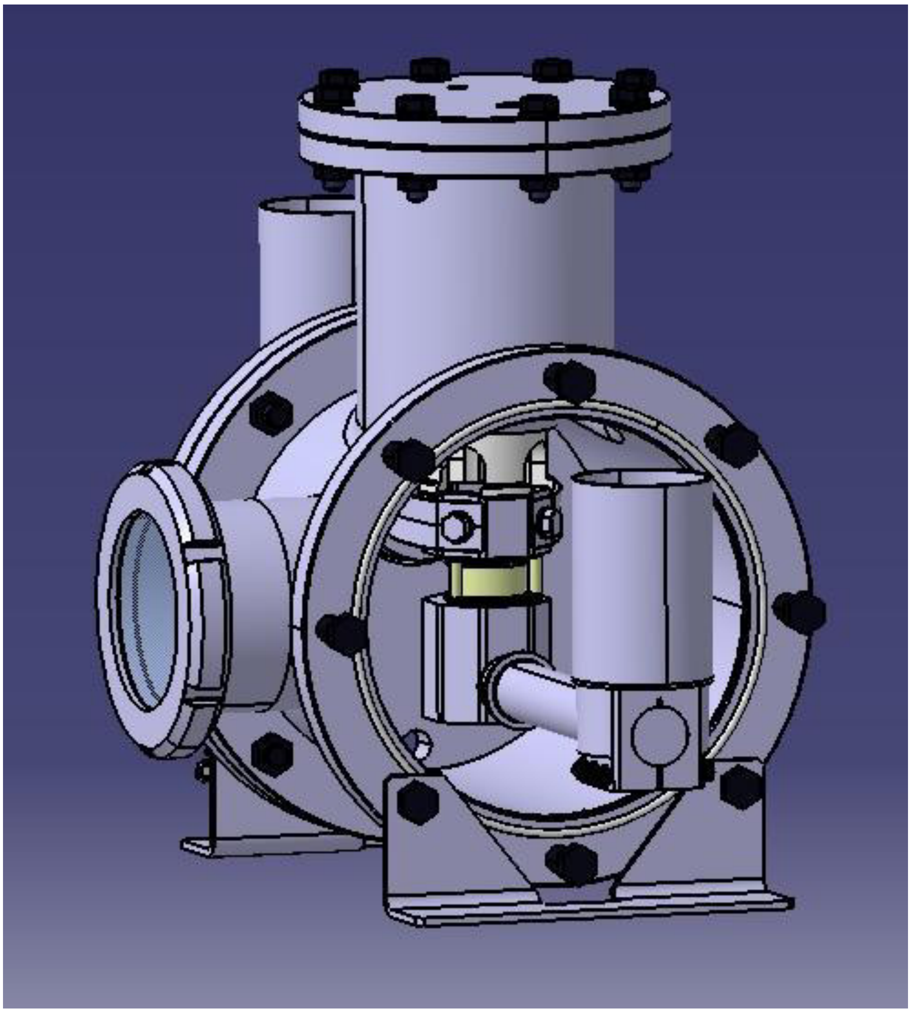


Figure 16.4: *Version 0: HST Chamber inner design (components Flange 200 and Flange joint steel are hidden).*

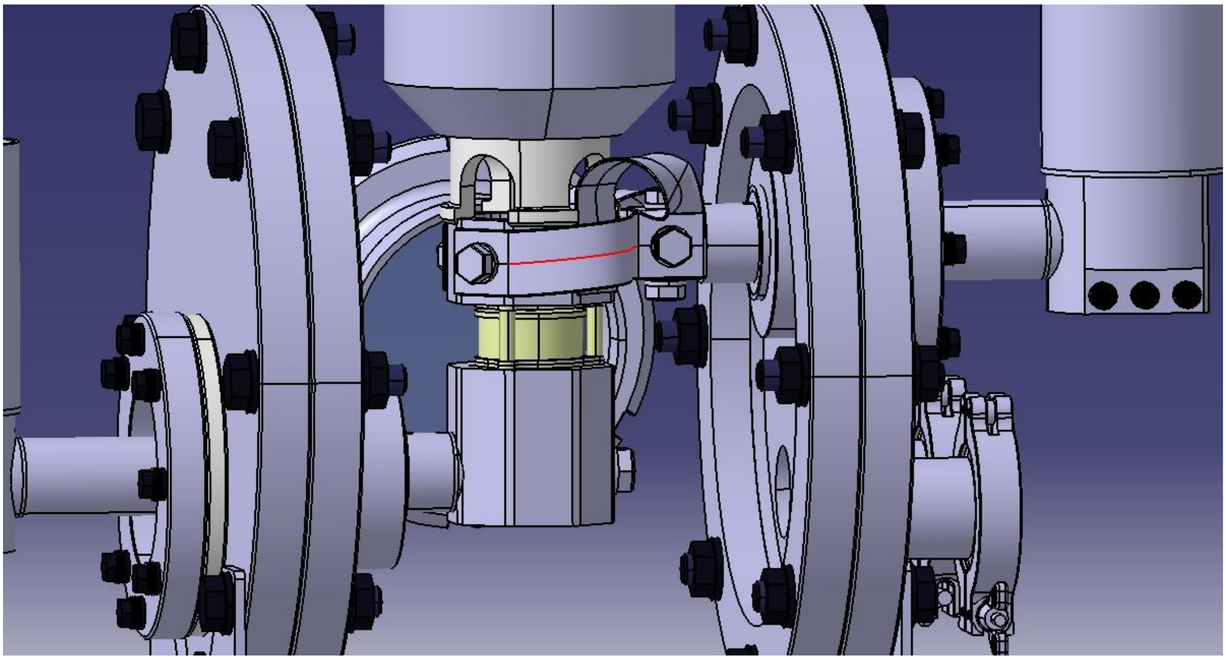


Figure 16.5: *Version 0: HST Chamber inner design (component "T" chamber body is hidden).*

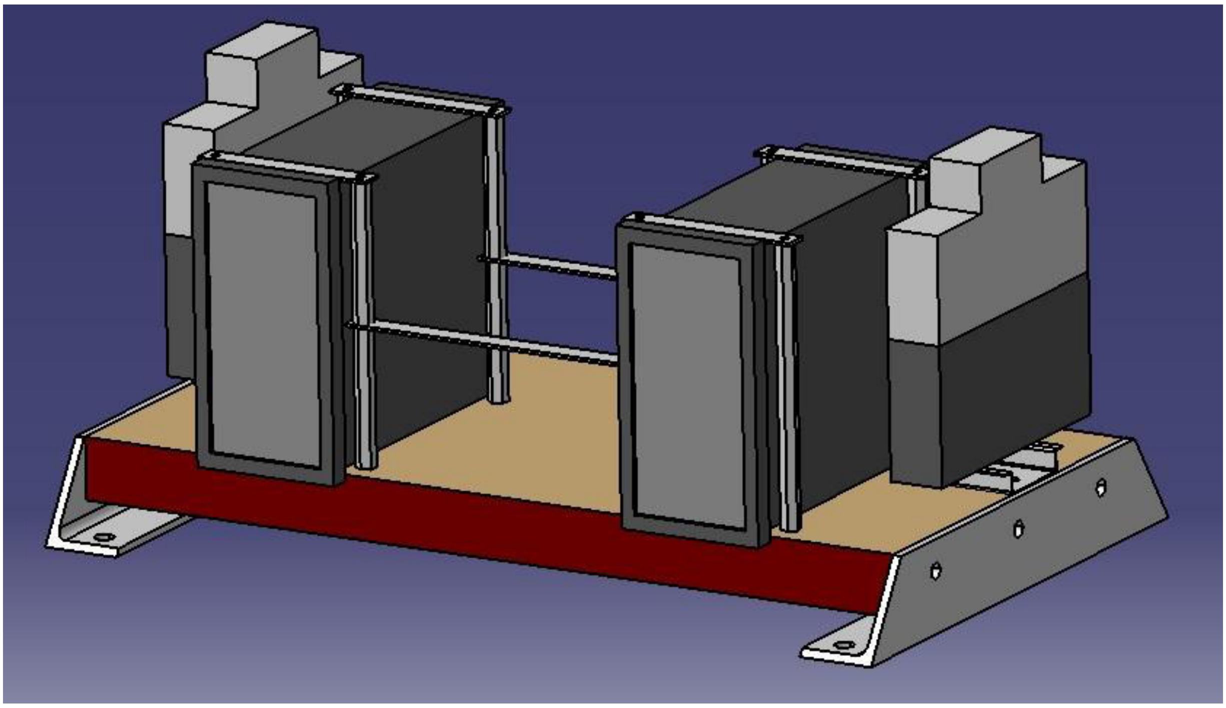


Figure 16.6: *Version 0: Control panel (Temperature Controllers and AC solid state relay).*

A13 - Version 1: Figures of 3D model

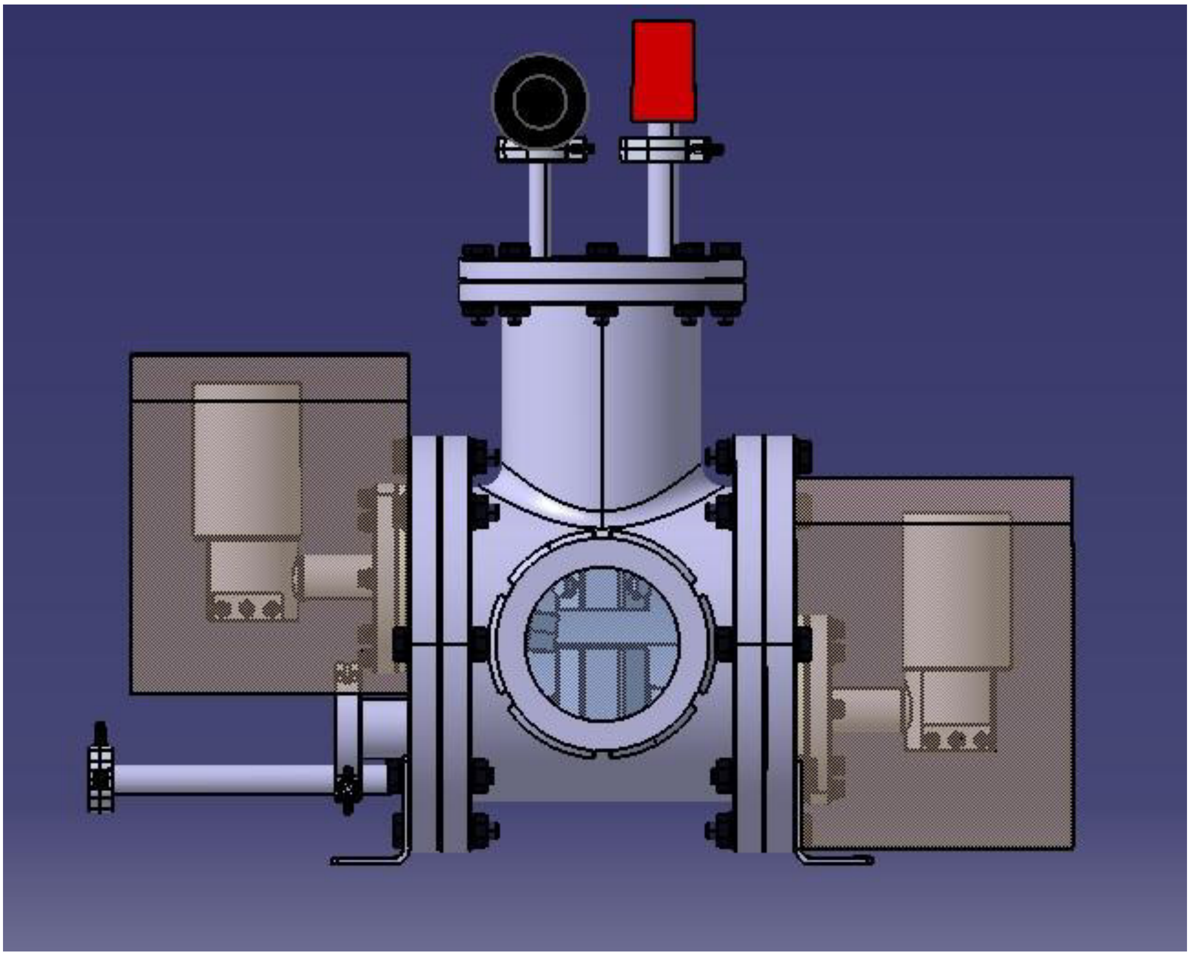


Figure 16.7: *Version 1 front view: HST Chamber design with insulation of cold parts + pressure control system.*

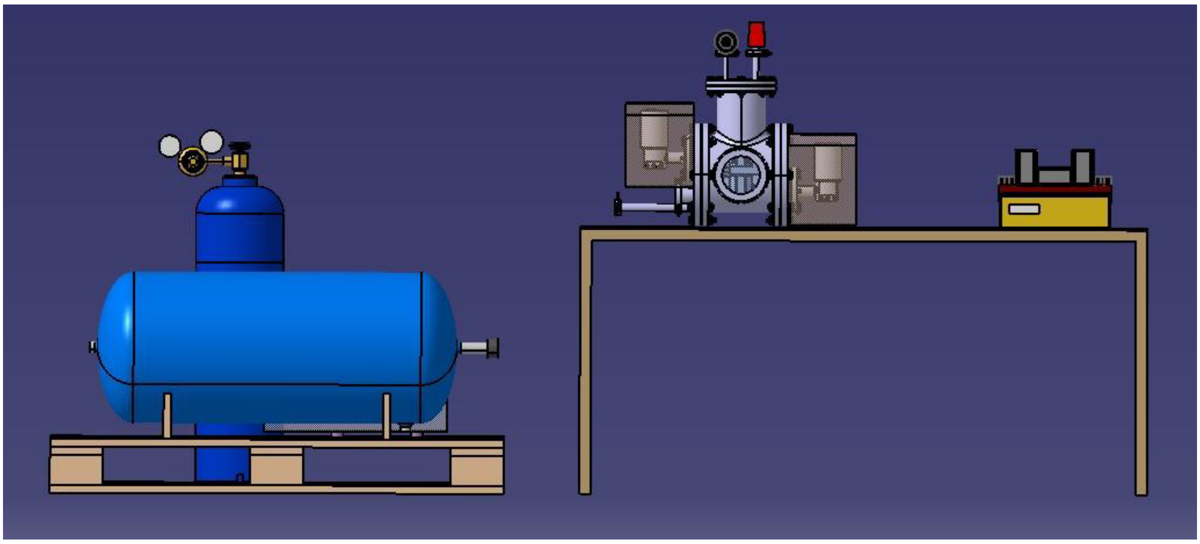


Figure 16.8: *Version 1: HST Chamber with Control panel, DAS unit and pressure control system (Vacuum pump, Vacuum tank and* CO_2 *tank).*

A14 - Version 2 – Initial: Figures of 3D model

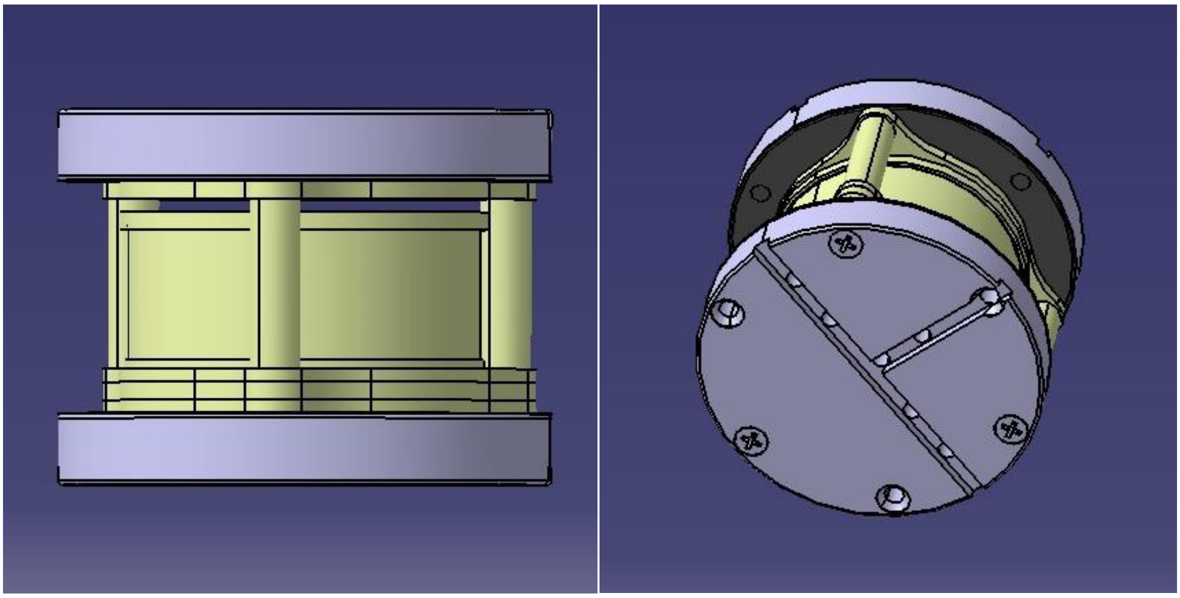


Figure 16.9: *Version 2 - Initial: Miniaturized heat switch between additional copper plates + graphite foils on the contact surfaces.*

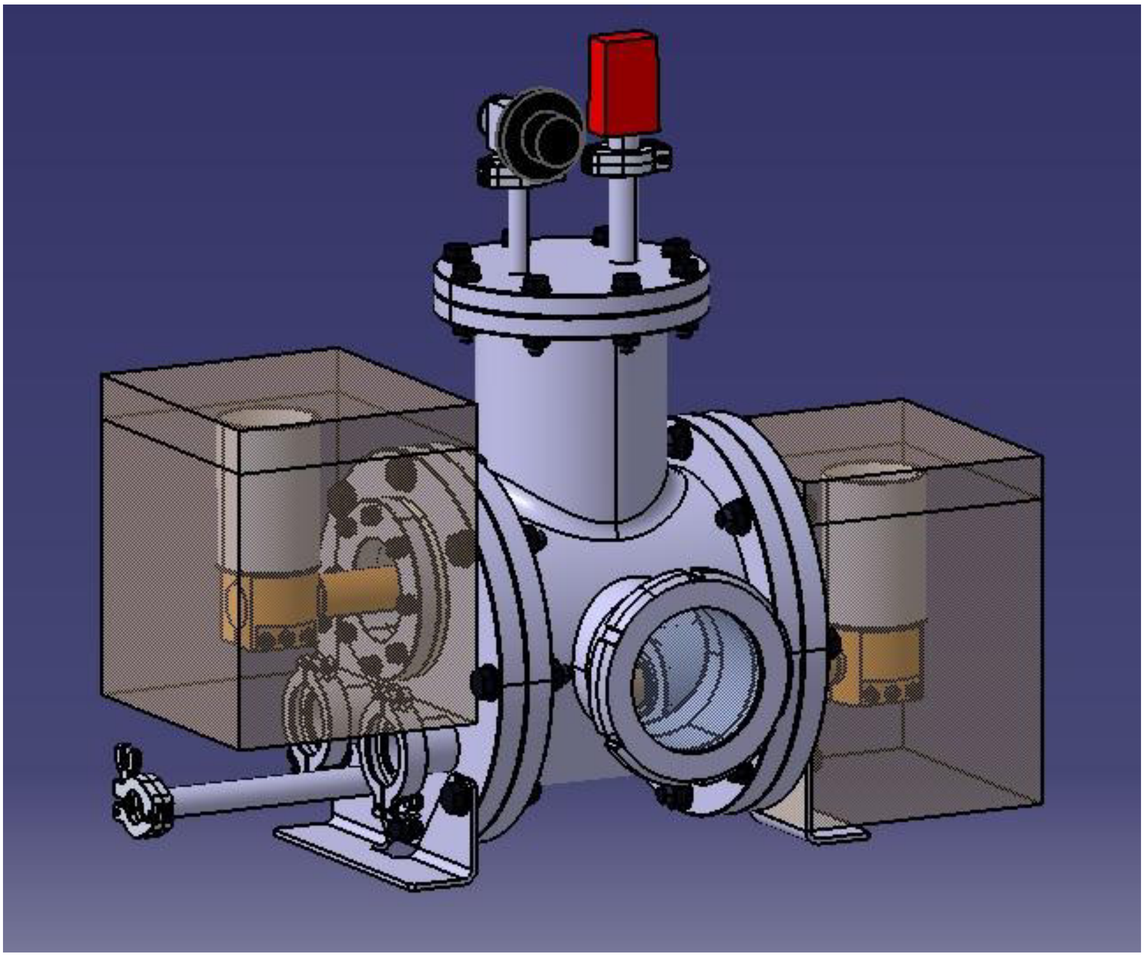


Figure 16.10: *Version 2 - Initial isometric view: HST Chamber design.*

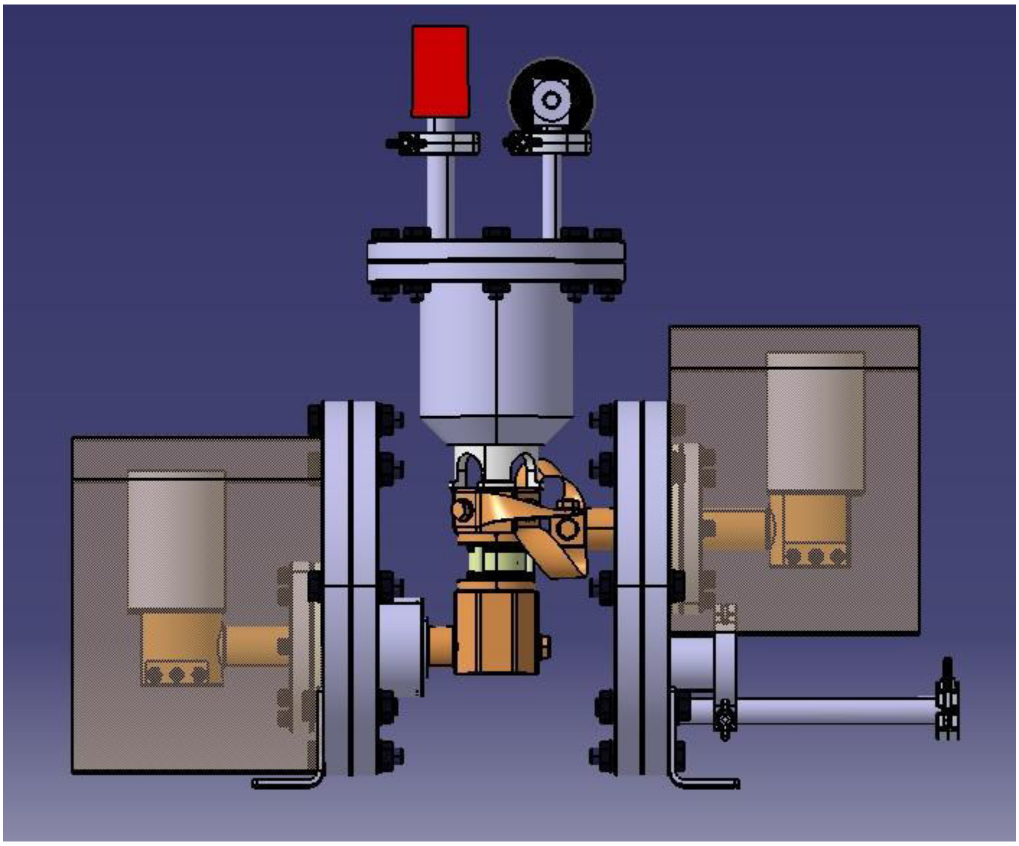


Figure 16.11: *Version 2 - Initial: HST Chamber inner design; copper Belts included (component "T" chamber body is hidden).*

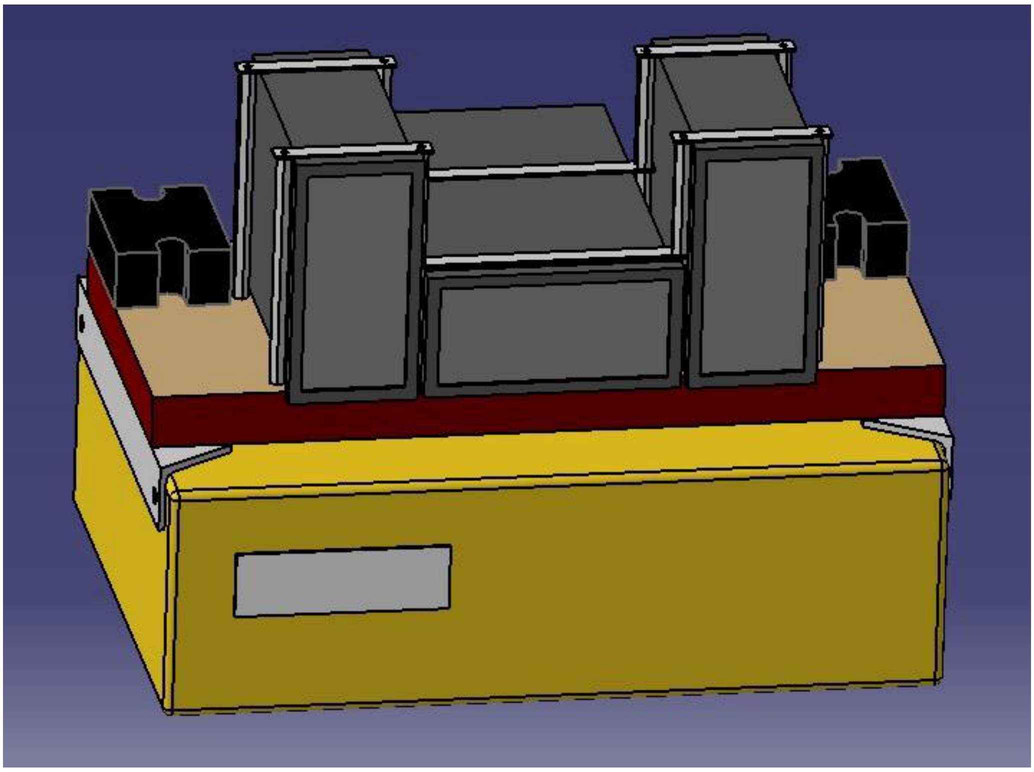


Figure 16.12: *Version 2 - Initial: Controller panel (Temperature Controllers, DC solid state relay, Active Digital Controller and DAS unit).*

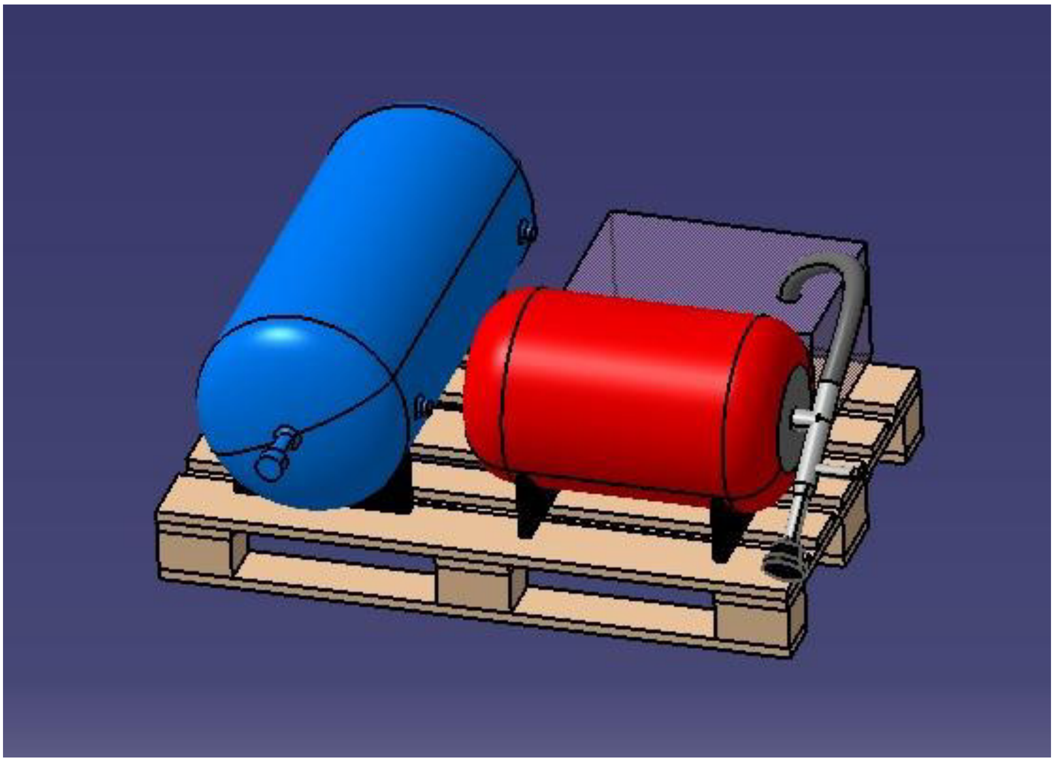


Figure 16.13: *Version 2 – Initial: Vacuum pump imitation and Vacuum tank.*

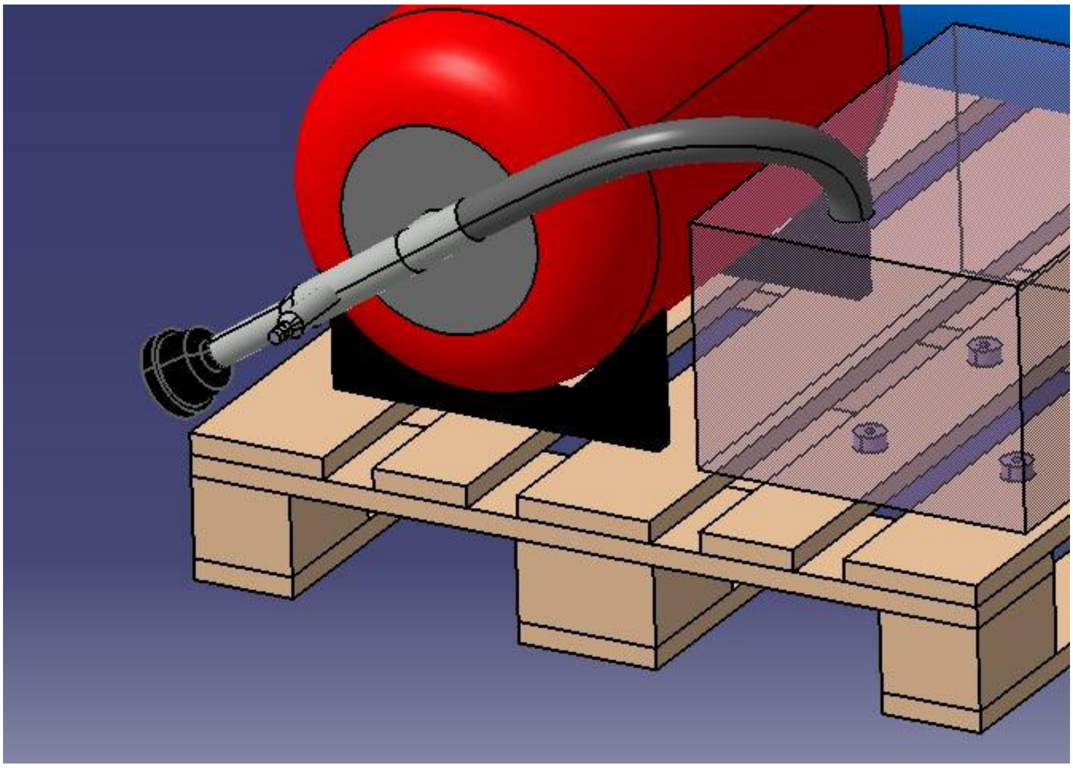


Figure 16.14: *Version 2 – Initial: Detail of Vacuum pump imitation and Vacuum tank + Air filter.*

A15 - Version 2 – Advanced: Figures of 3D model

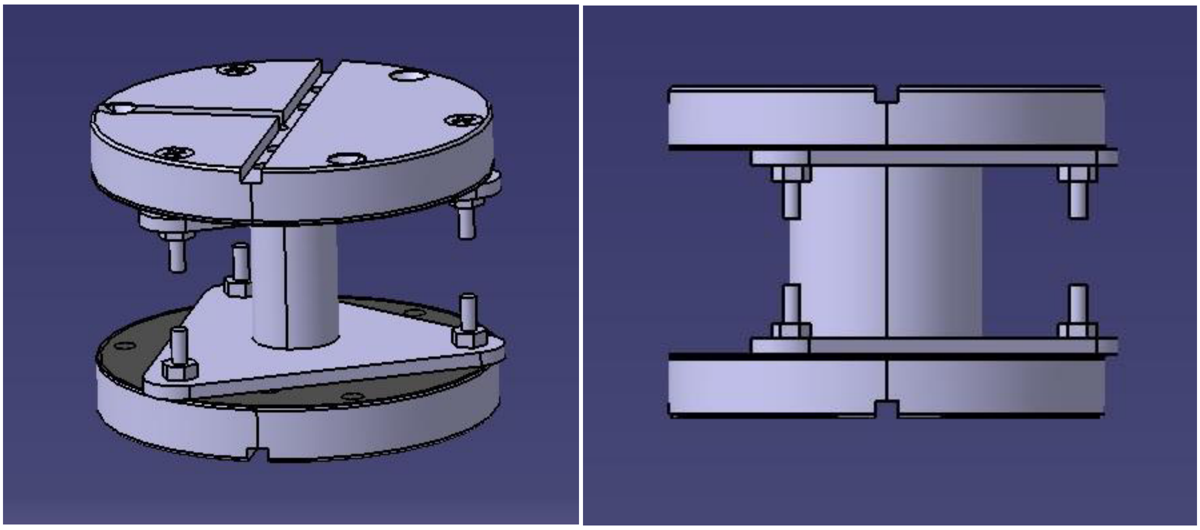


Figure 16.15: *Version 2 - Advanced: Dummies I generation; copper plates and graphite foils included (Left: Dummy 1 imitating opened position of MHS, Right: Dummy 2 imitating closed position of MHS).*

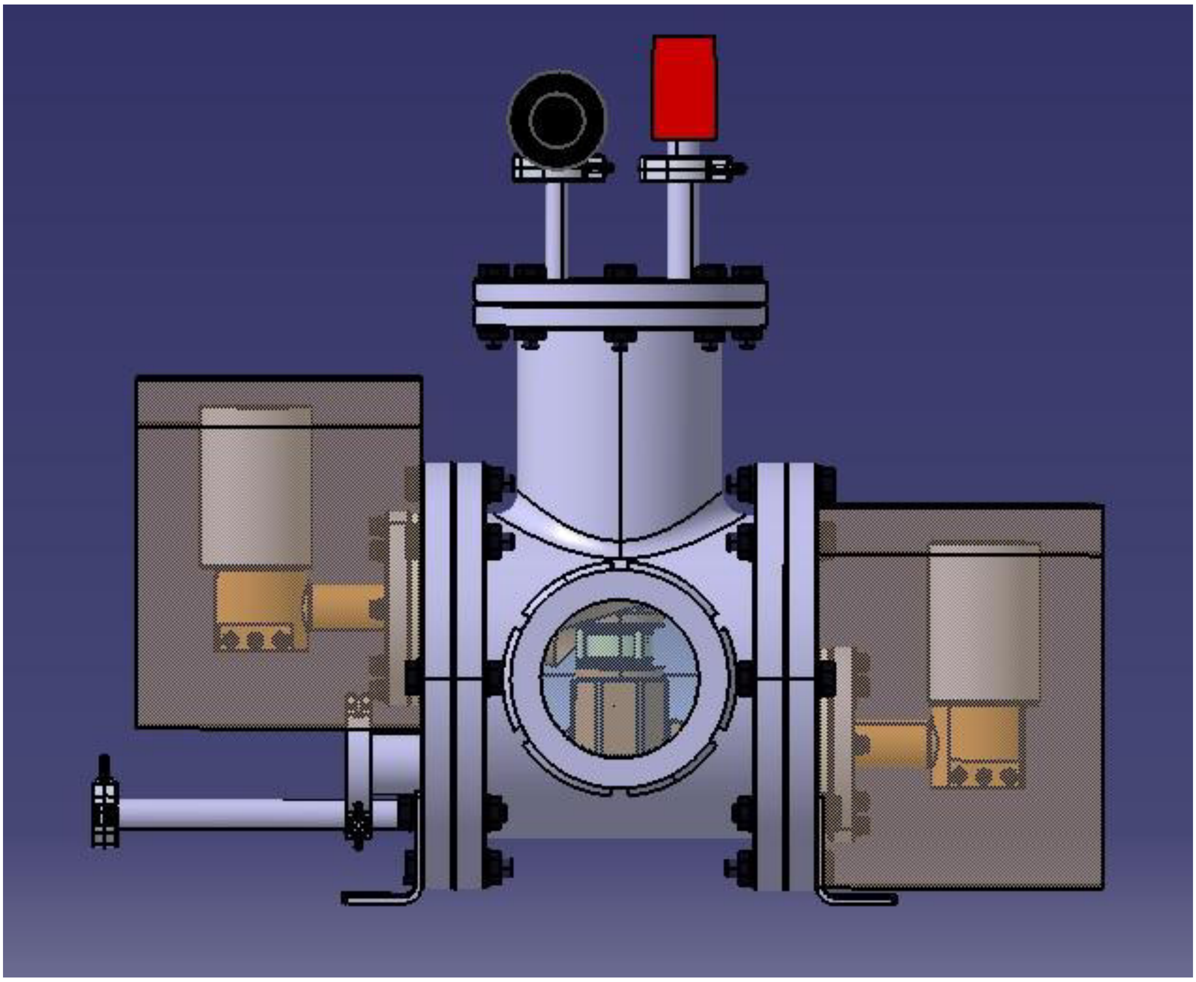


Figure 16.16: *Version 2 - Advanced front view: HST Chamber design; all components and systems included.*

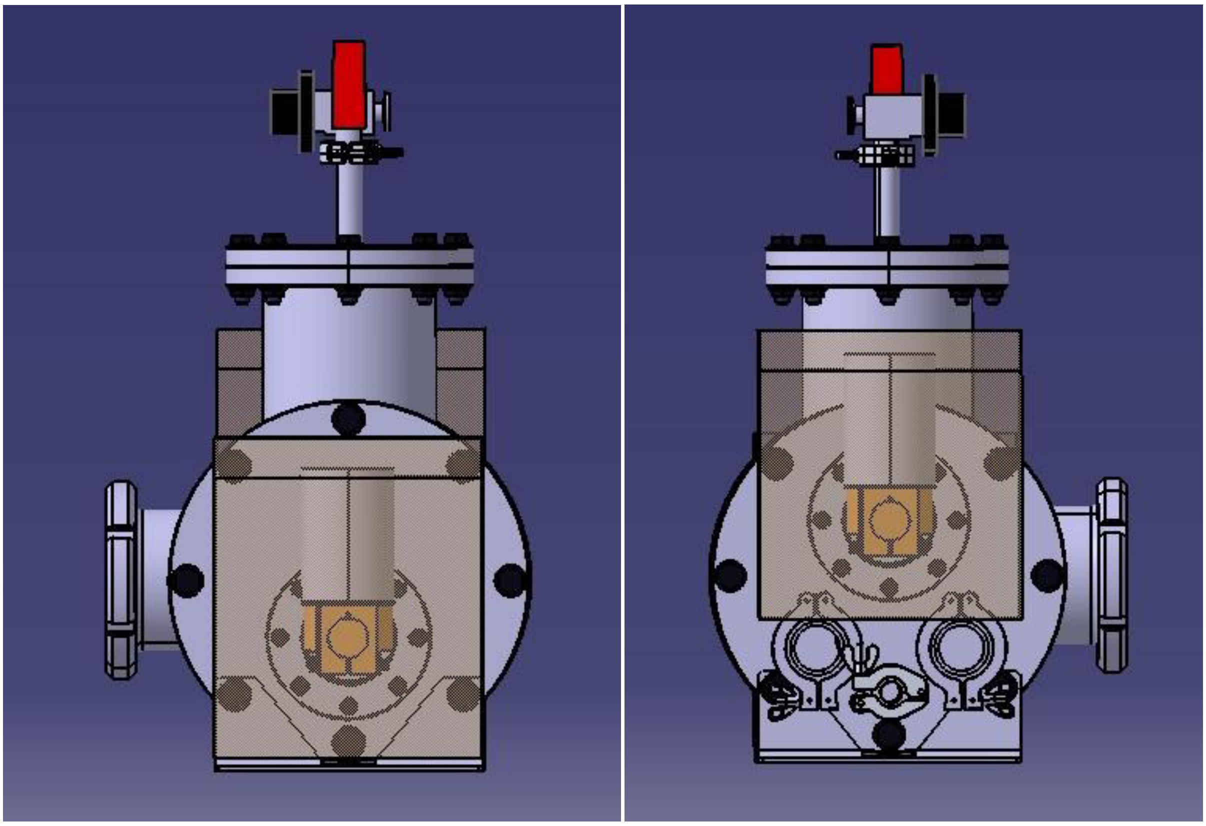


Figure 16.17: *Version 2 - Advanced side views: HST Chamber design.*

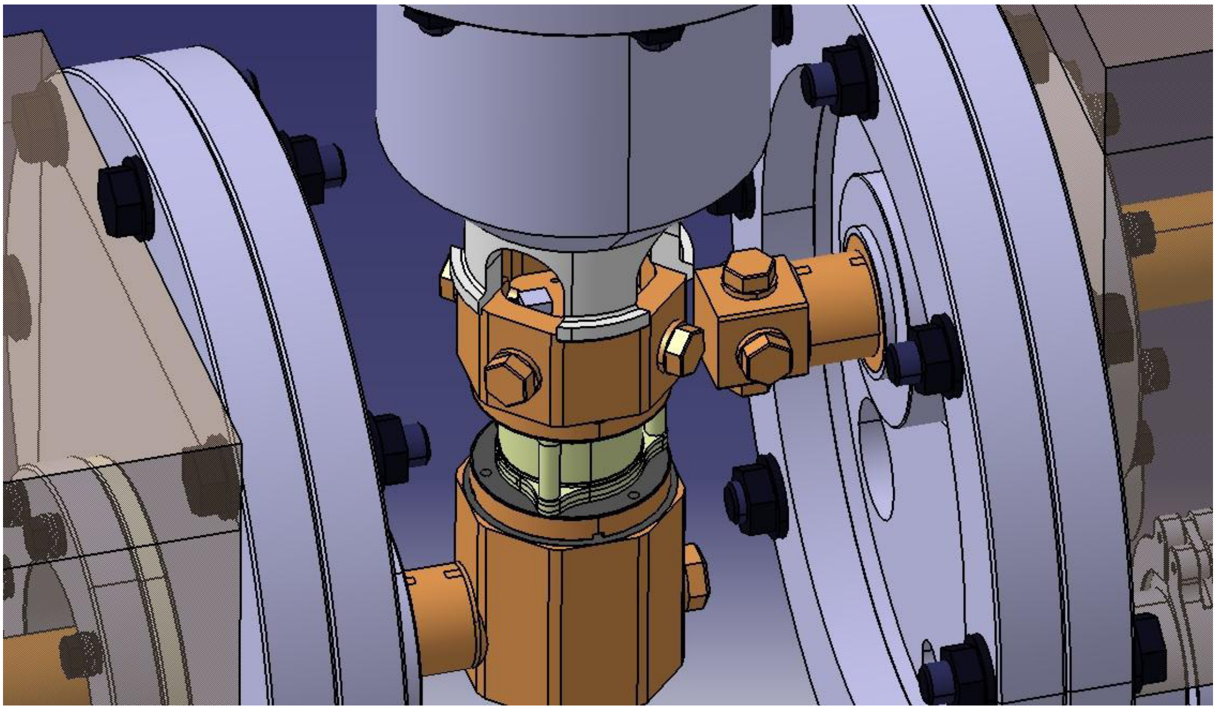


Figure 16.18: *Version 2 - Advanced: HST Chamber inner design without copper Belts (component "T" chamber body is hidden).*

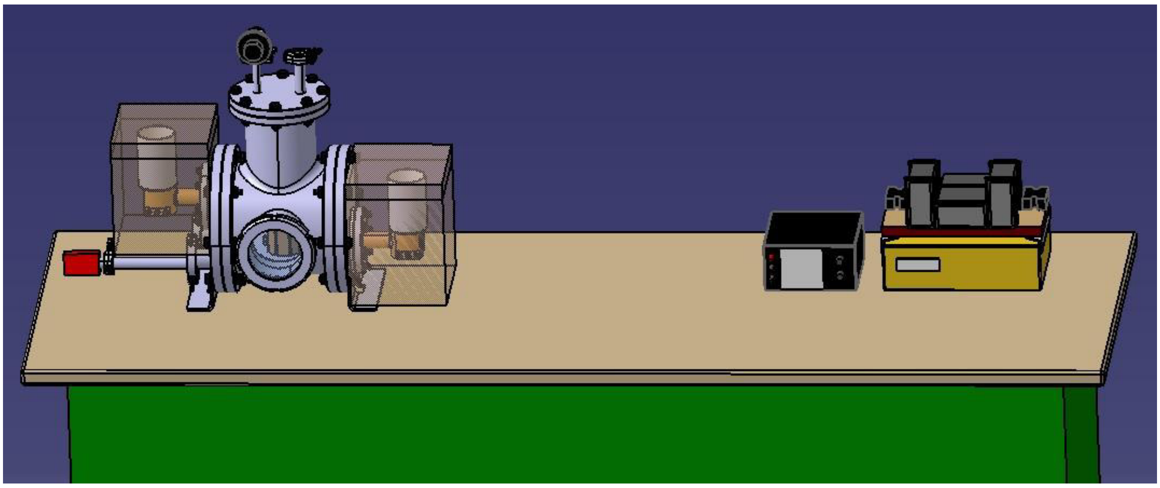


Figure 16.19: *Version2 - Advanced: Facility layout - HST Chamber (pressure gauge exchanged with the vacuum system Ball valve), Control panel, DC power supply, DAS unit.*

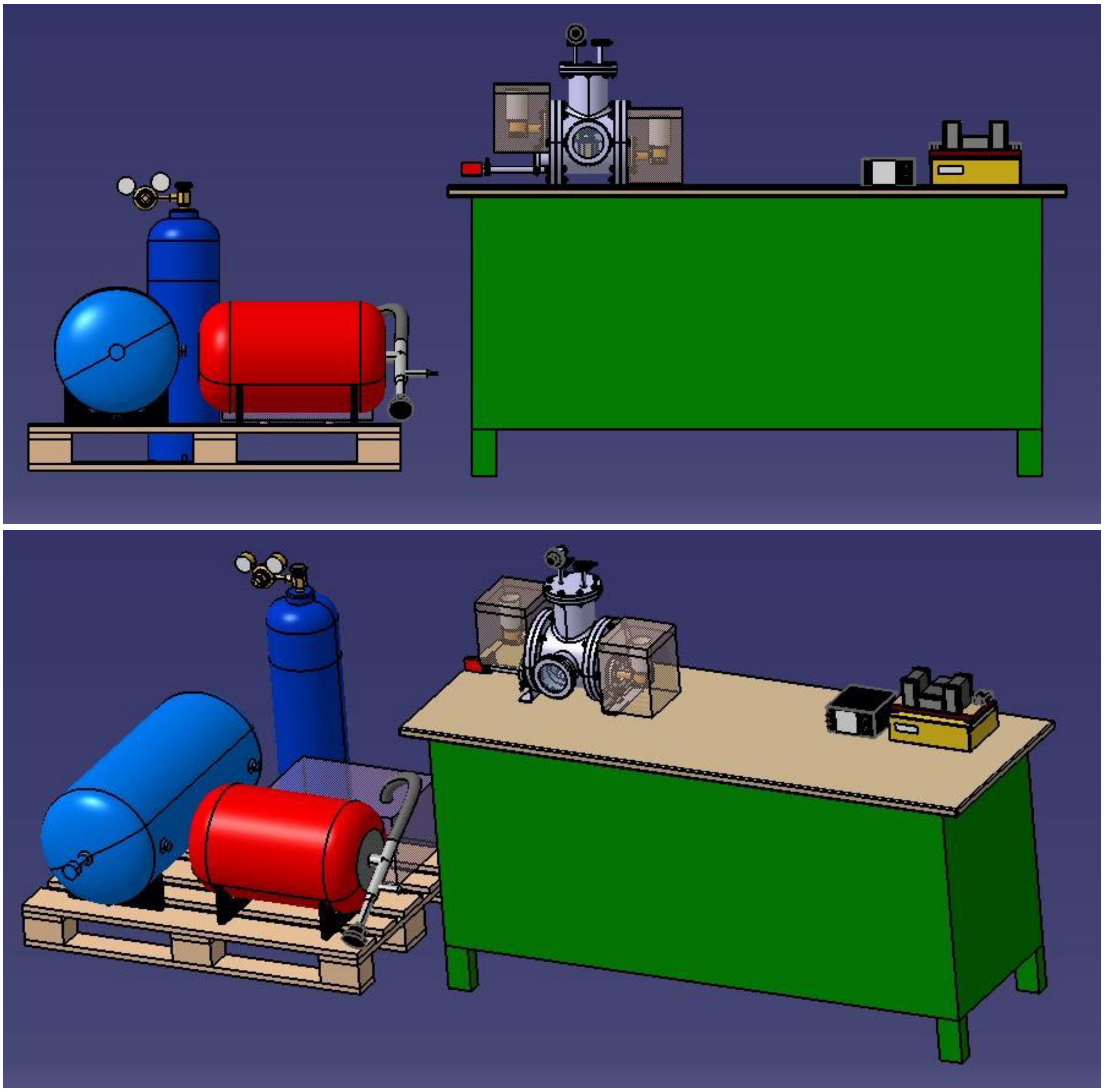


Figure 16.20: *Version 2 - Advanced: HST Chamber with all systems: Control panel, DC power supply,DAS unit and pressure control system (Vacuum pump, Vacuum tank, CO_2 tank).*

A16 - Version 3: Figures of 3D model

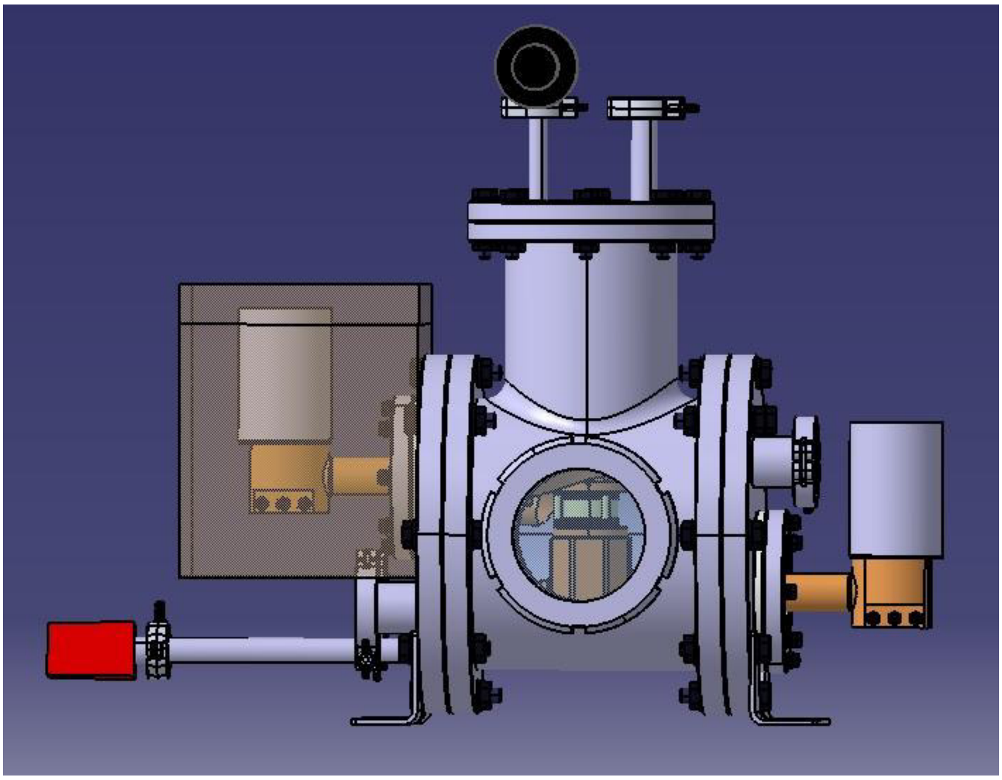


Figure 16.21: *Version 3 front view: HST Chamber design with the third additional electrical vacuum feed-through.*

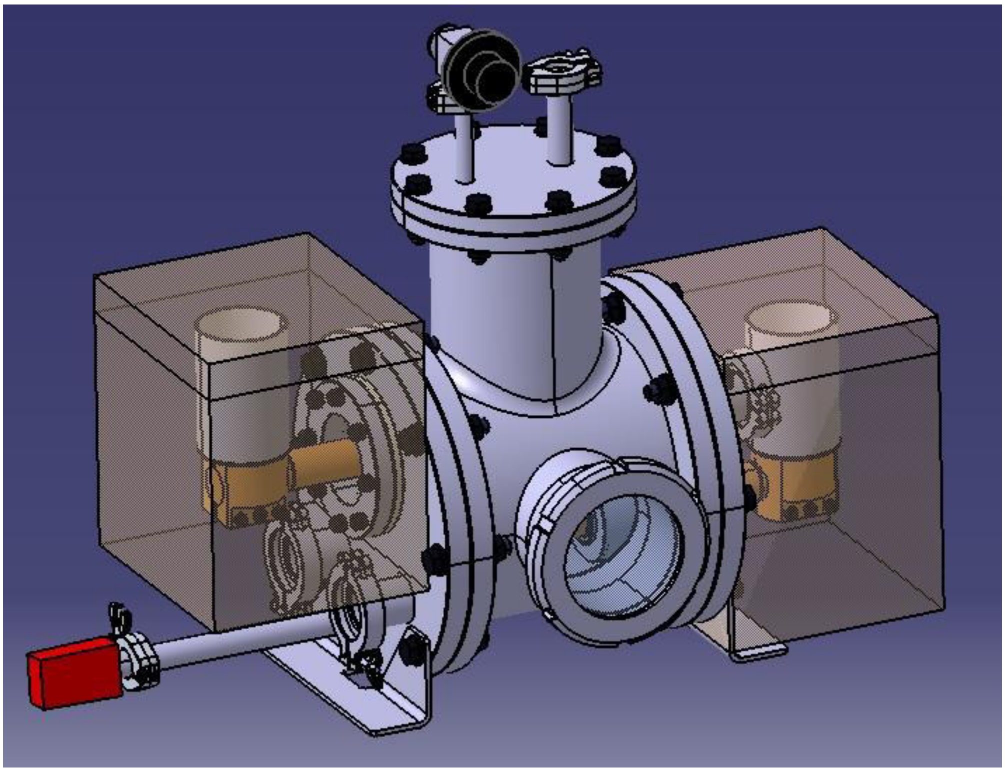


Figure 16.22: *Version 3 isometric view: HST Chamber design; all components and systems included.*

A17 - Photo gallery: Heat switch test chamber assembly procedure

Figure 16.23: *Heat switch test chamber components.*

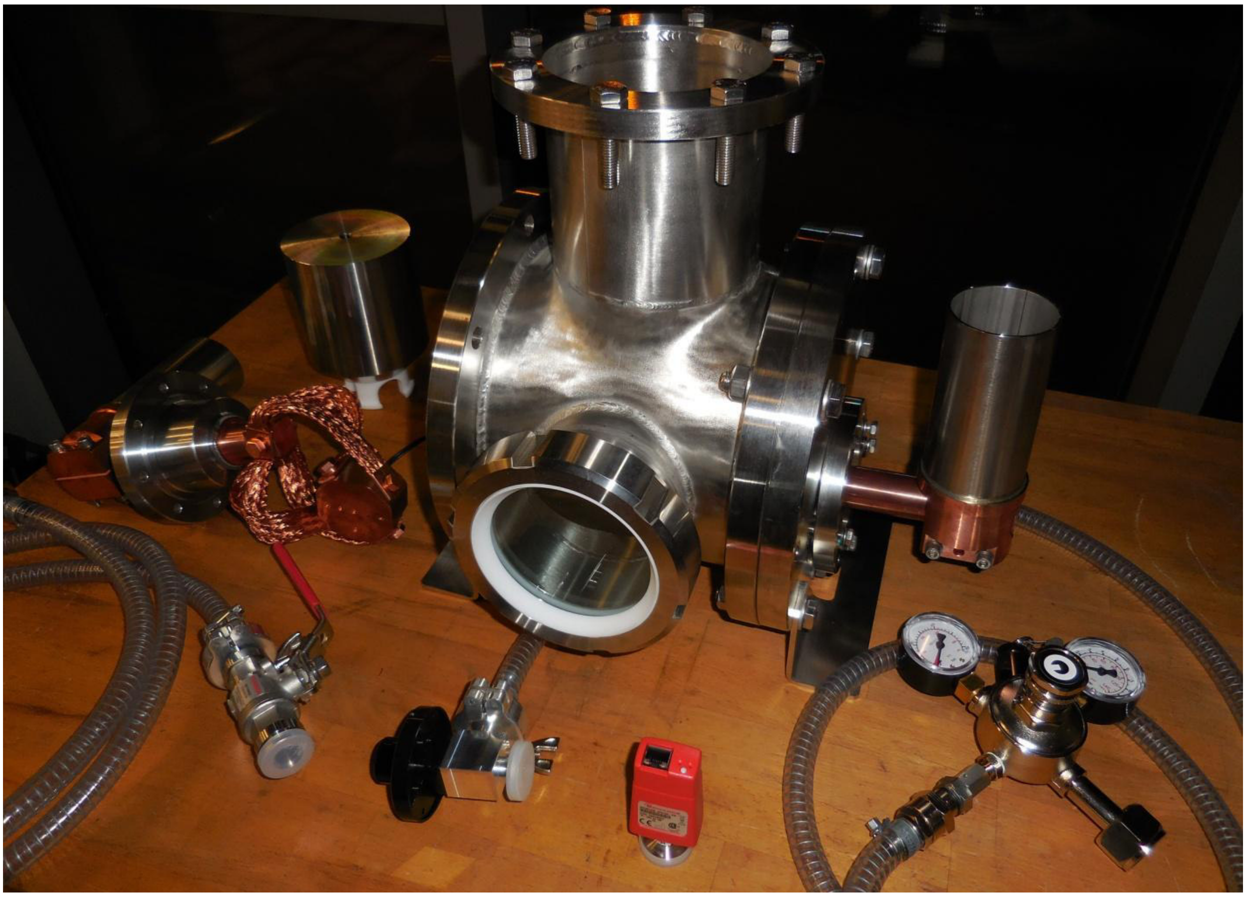


Figure 16.24: *Heat switch test chamber and systems components.*

Figure 16.25: *Resistors mounted on the Hot Interface.*

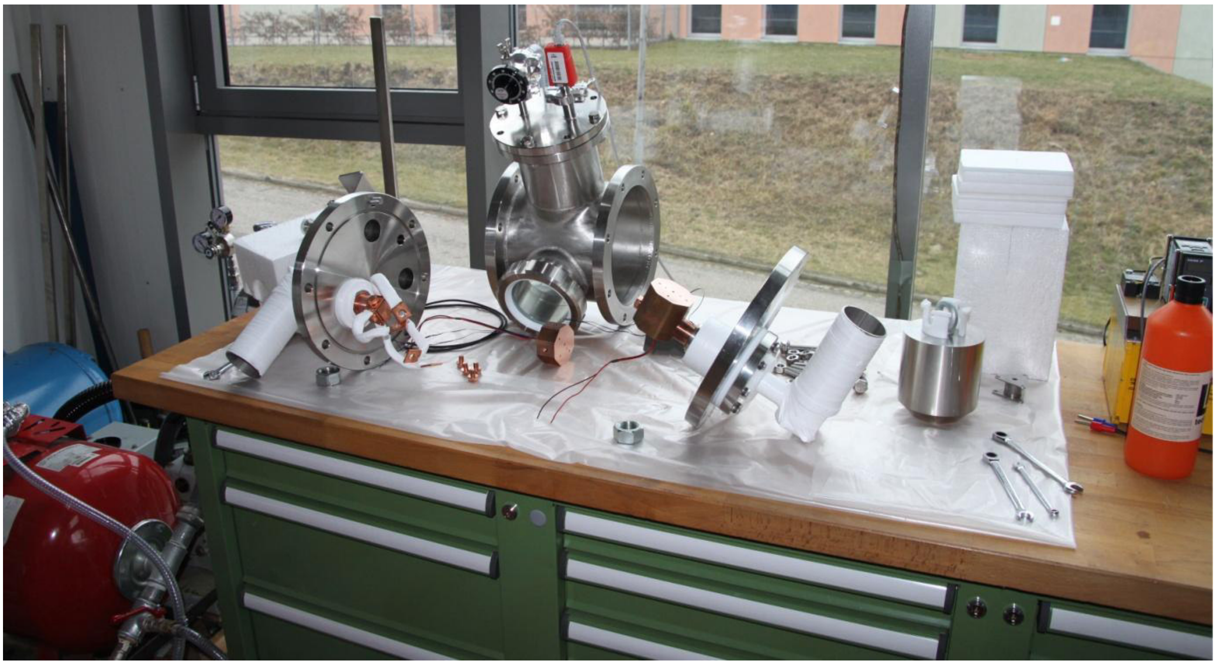


Figure 16.26: *HST chamber components assembly process including heat loaded parts covering by the PTFE ribbon.*

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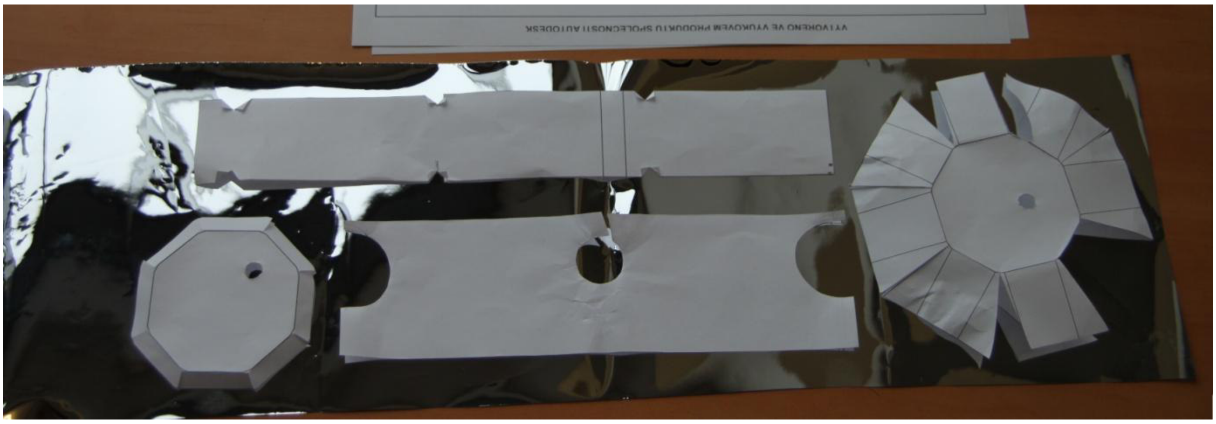

Figure 16.27: *Preparation works to cover the heat loaded parts by Mylar and Upilex foil.*

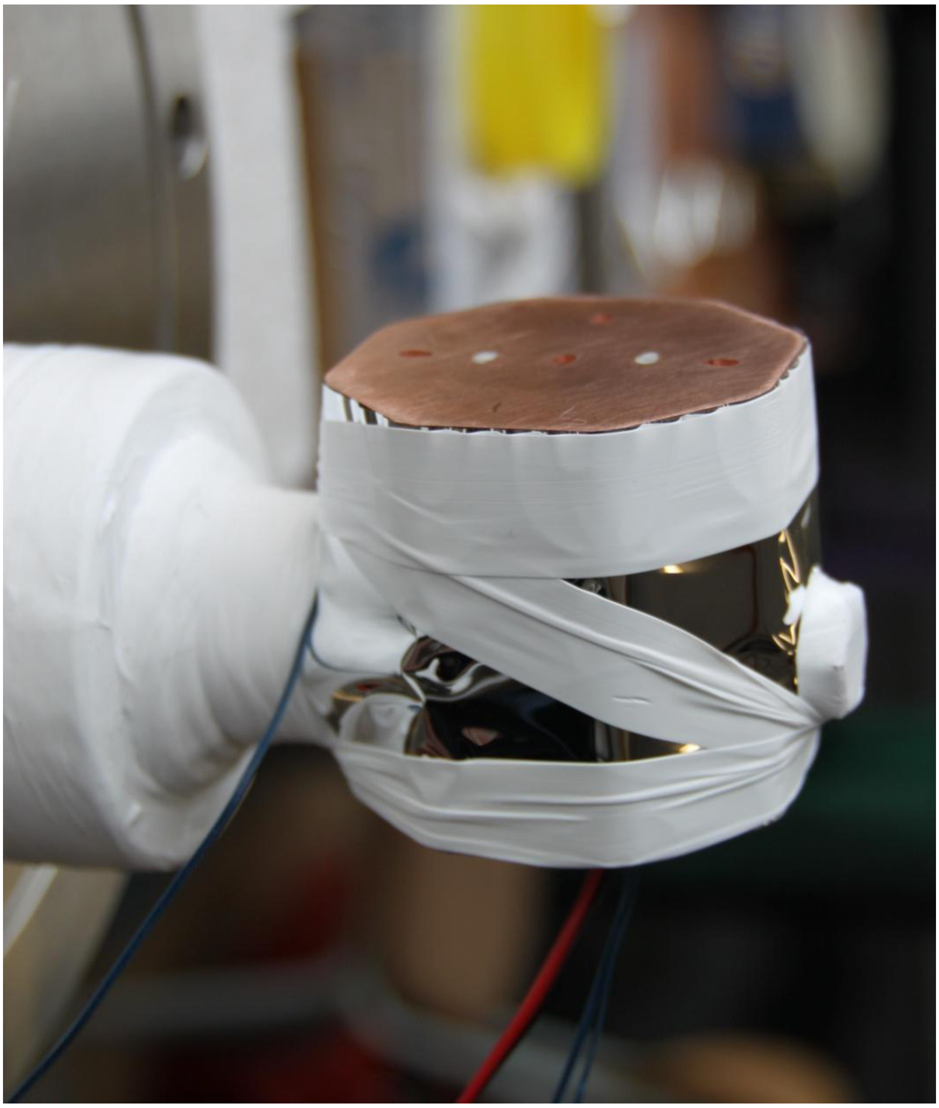

Figure 16.28: *Covering the Cold Interface by Mylar foil, Upilex foil and PTFE ribbon.*

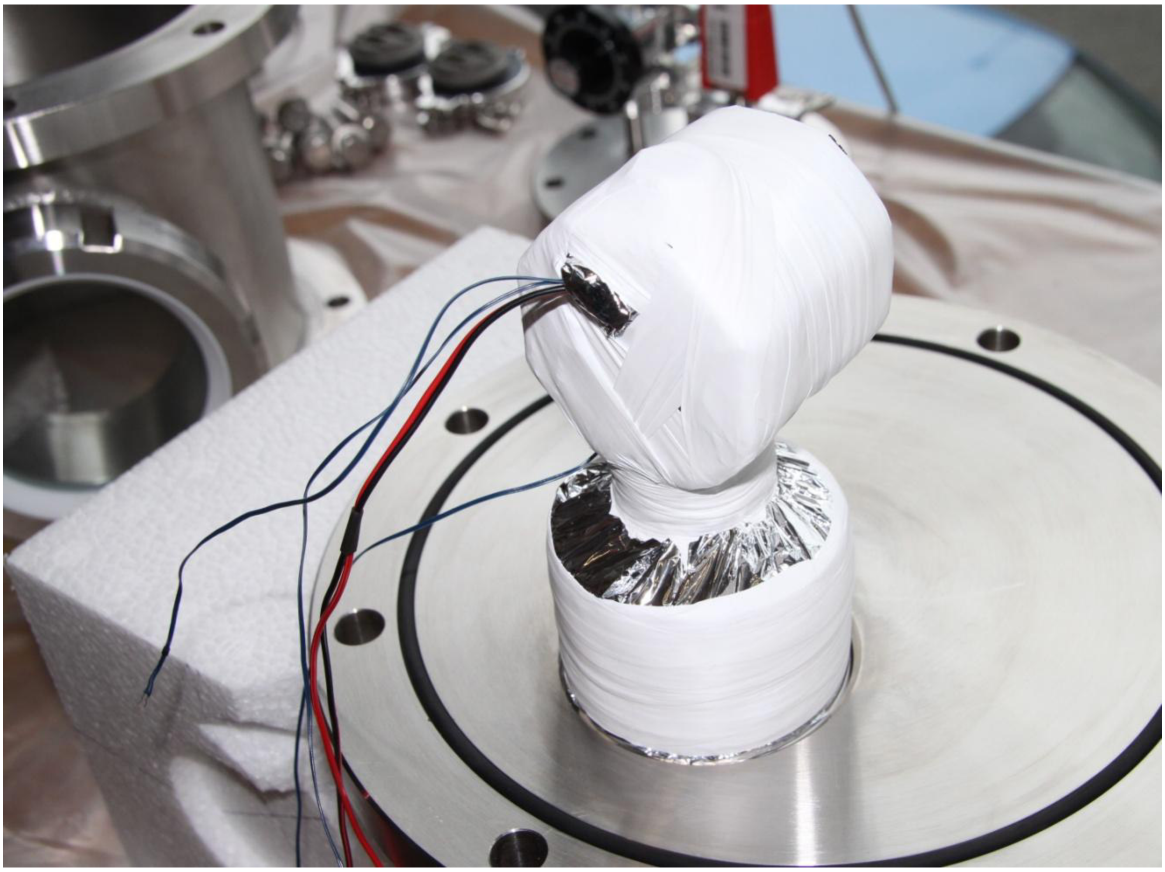

Figure 16.29: *Cold Interface covered by Mylar foil, Upilex foil and PTFE ribbon, prepared for final chamber assembly.*

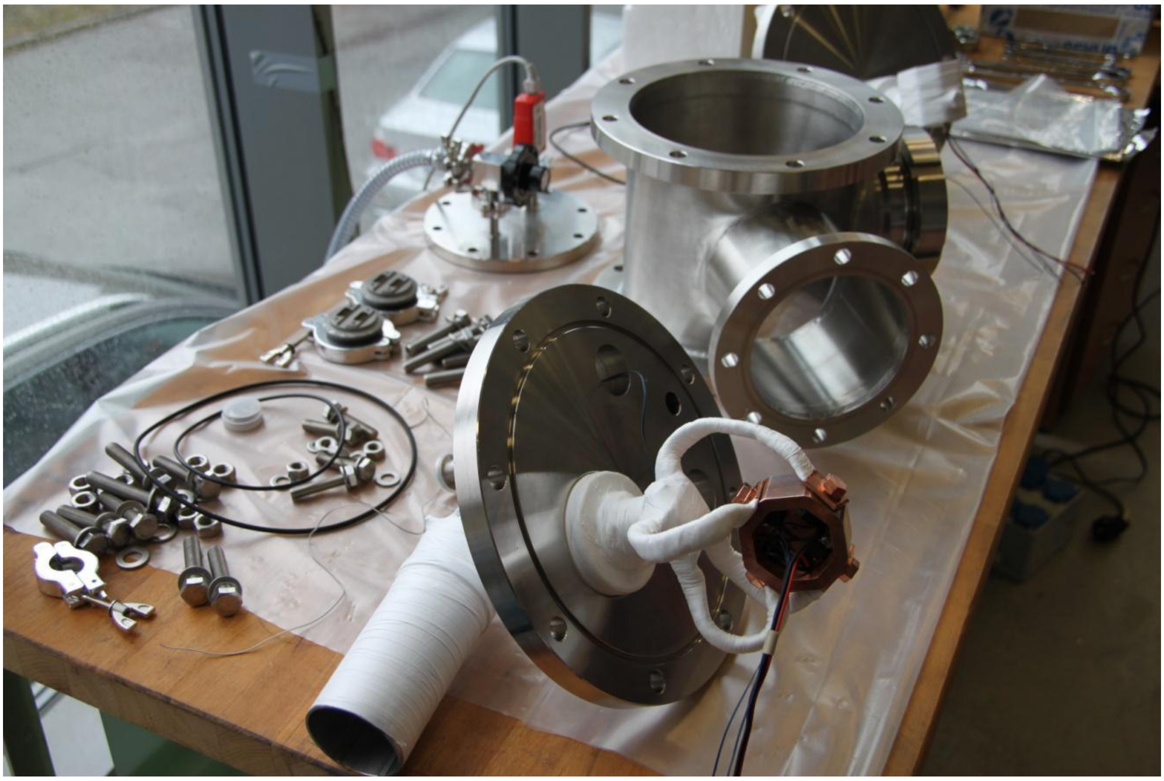

Figure 16.30: *Hot Interface assembly process included insulation layers application to prohibit radiation leakages.*

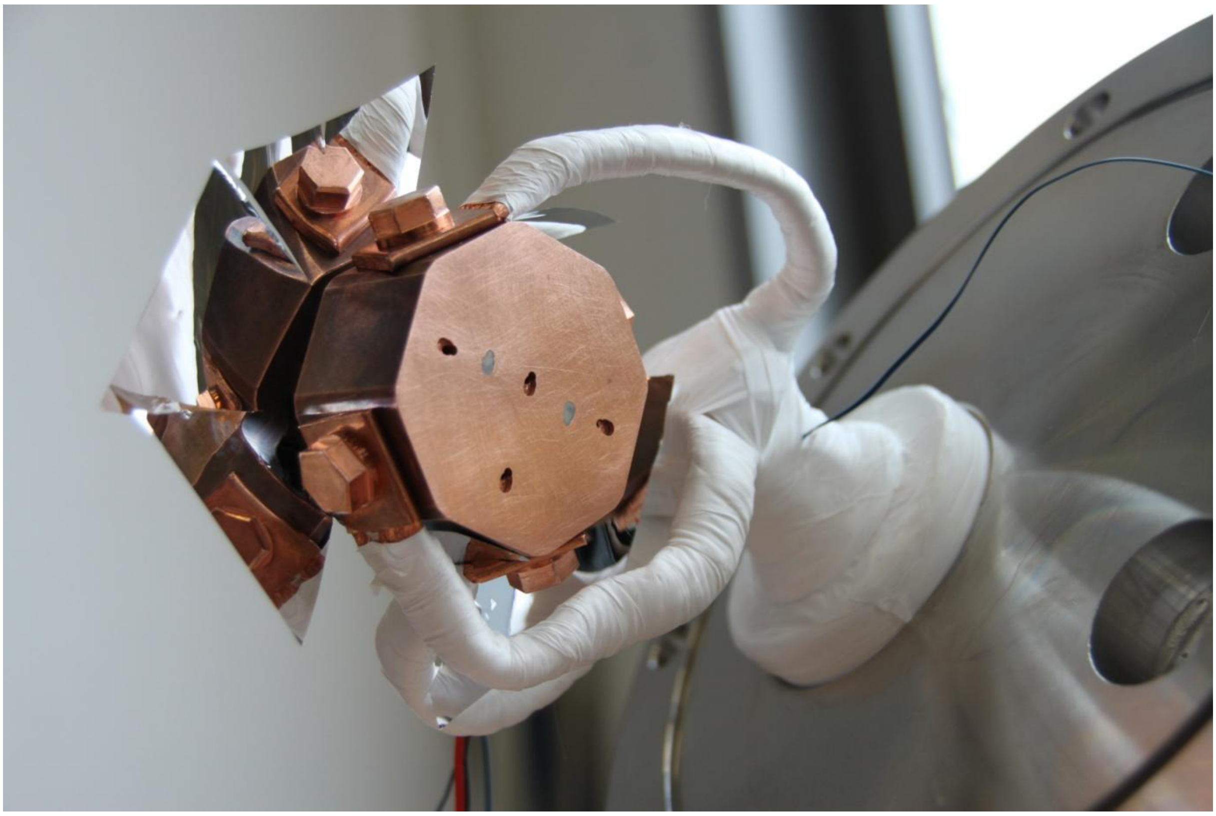

Figure 16.31: *Hot Interface covering by Mylar foil.*

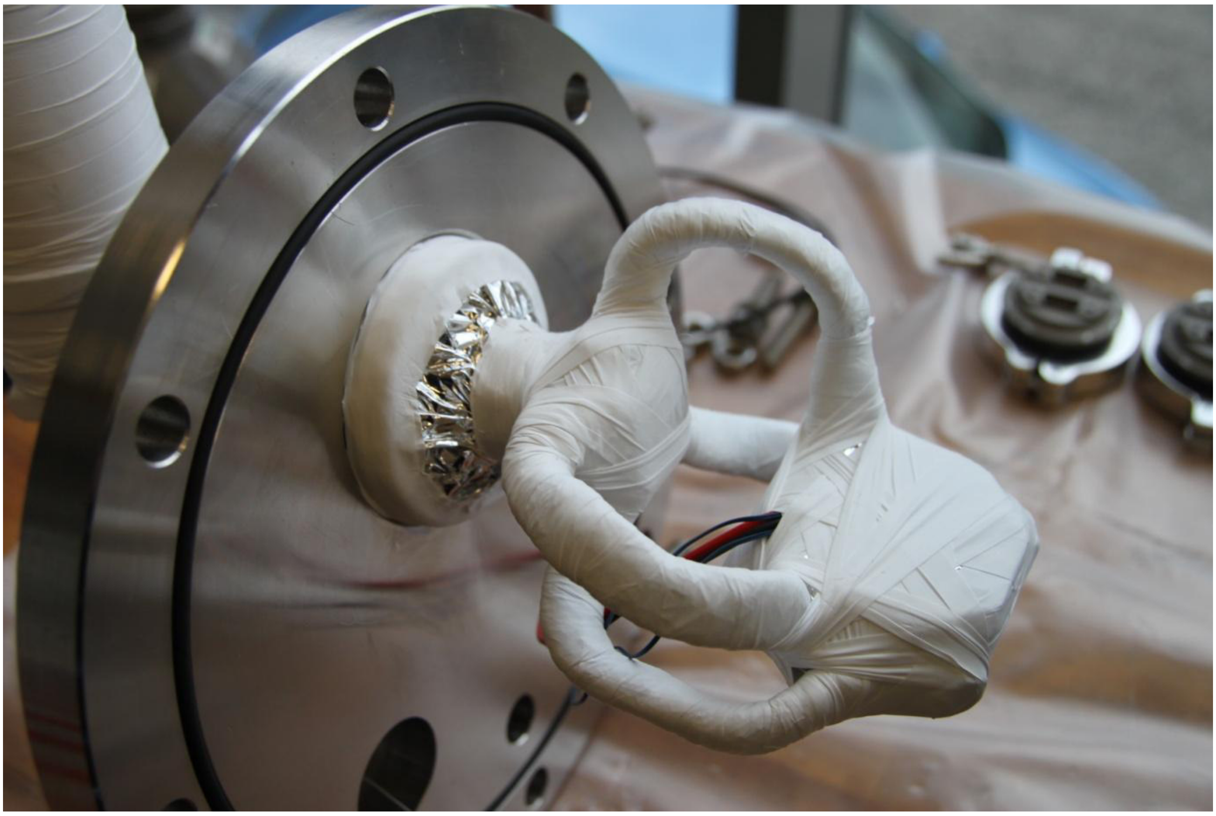

Figure 16.32: *Hot Interface covered by Mylar foil, Upilex foil and PTFE ribbon, prepared for final chamber assembly.*

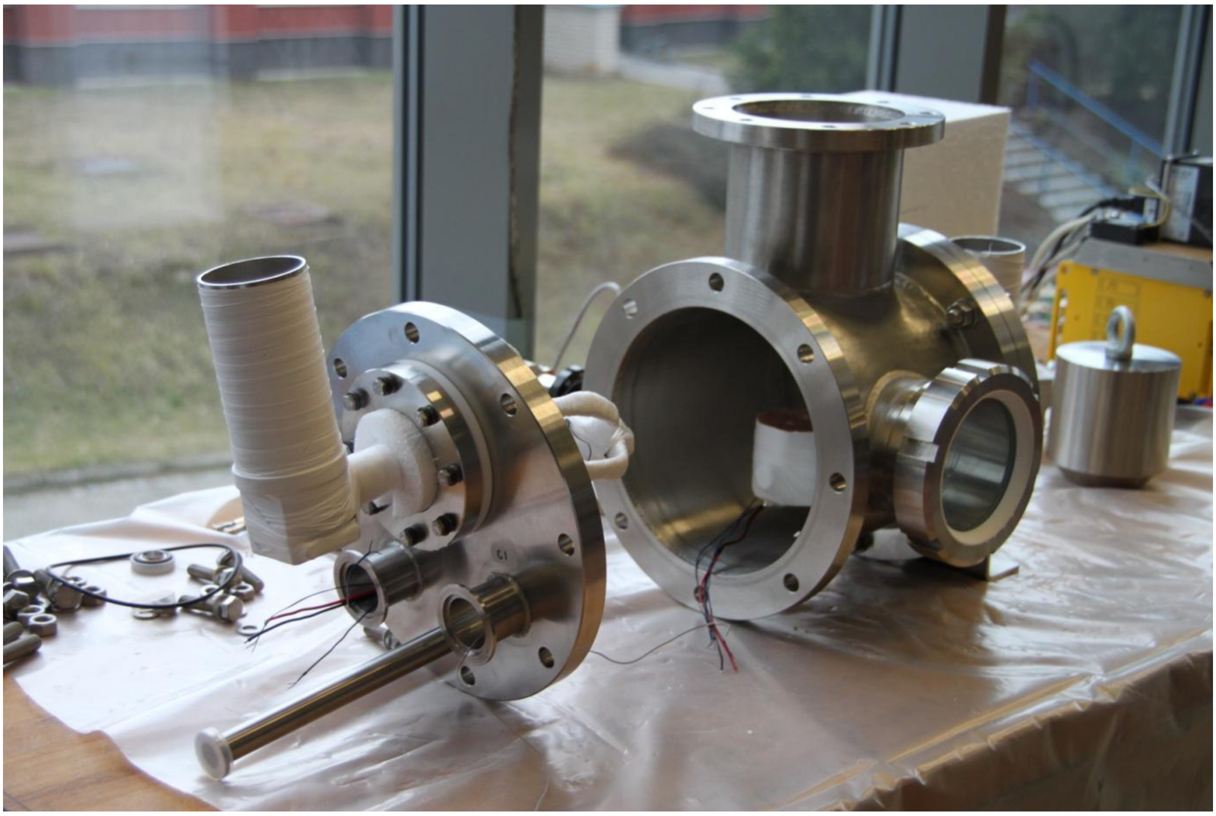

Figure 16.33: *Final CI and HI flange mounting.*

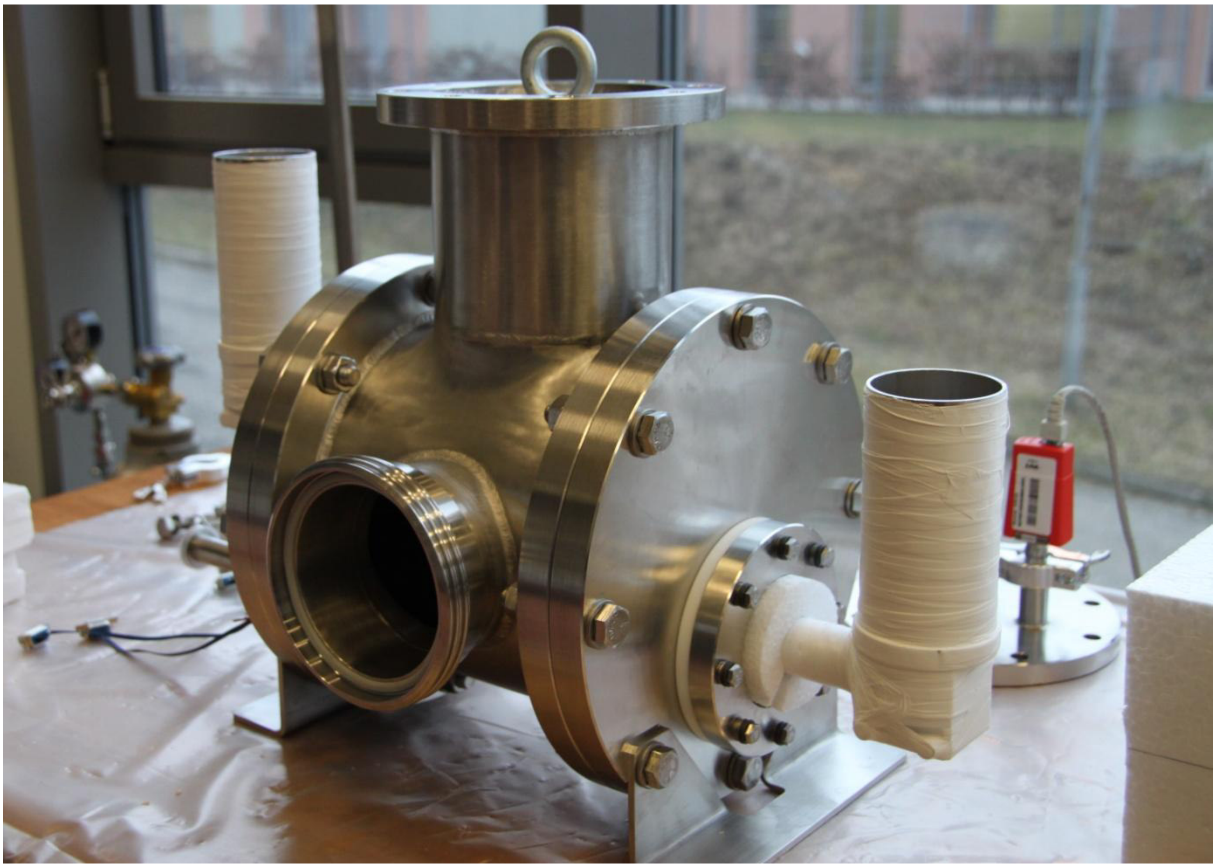

Figure 16.34: *CI and HI flange mounted, specimen placed inside of the HST chamber and the Weight placed up on the Hot Interface.*

Figure 16.35: *Electric vacuum feed-throughs.*

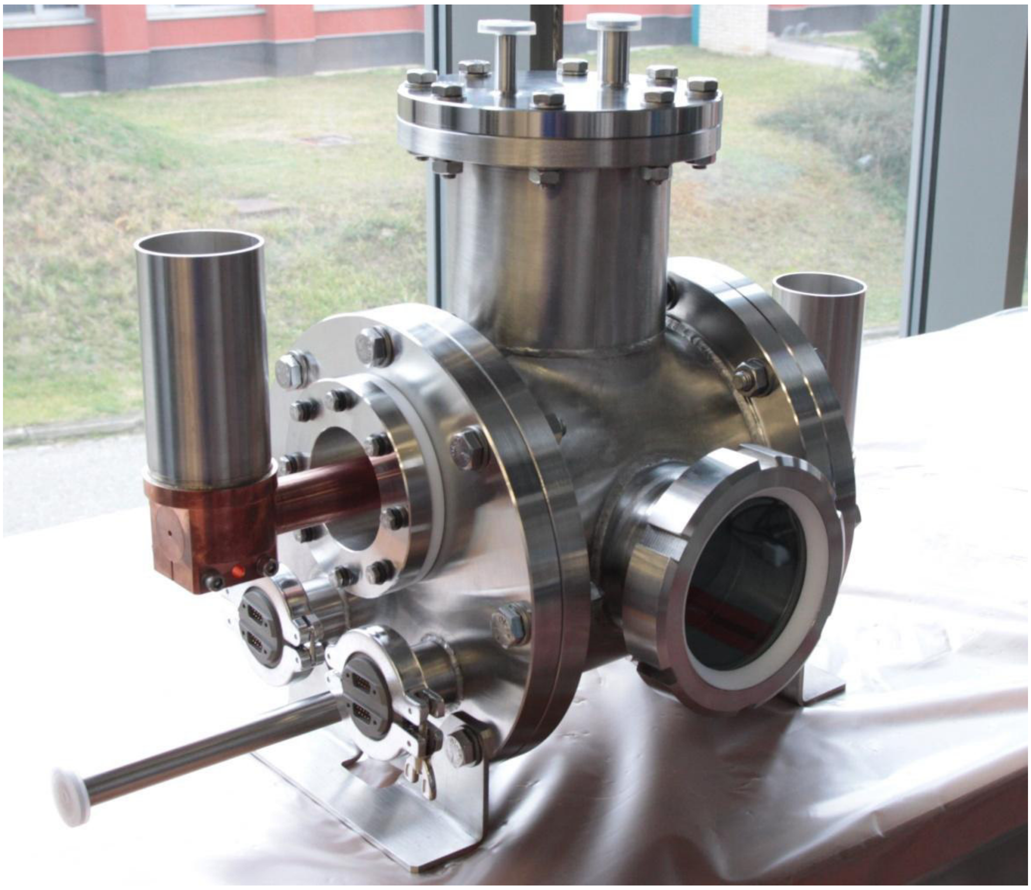

Figure 16.36: *Final HST chamber assembly without pressure control system components.*

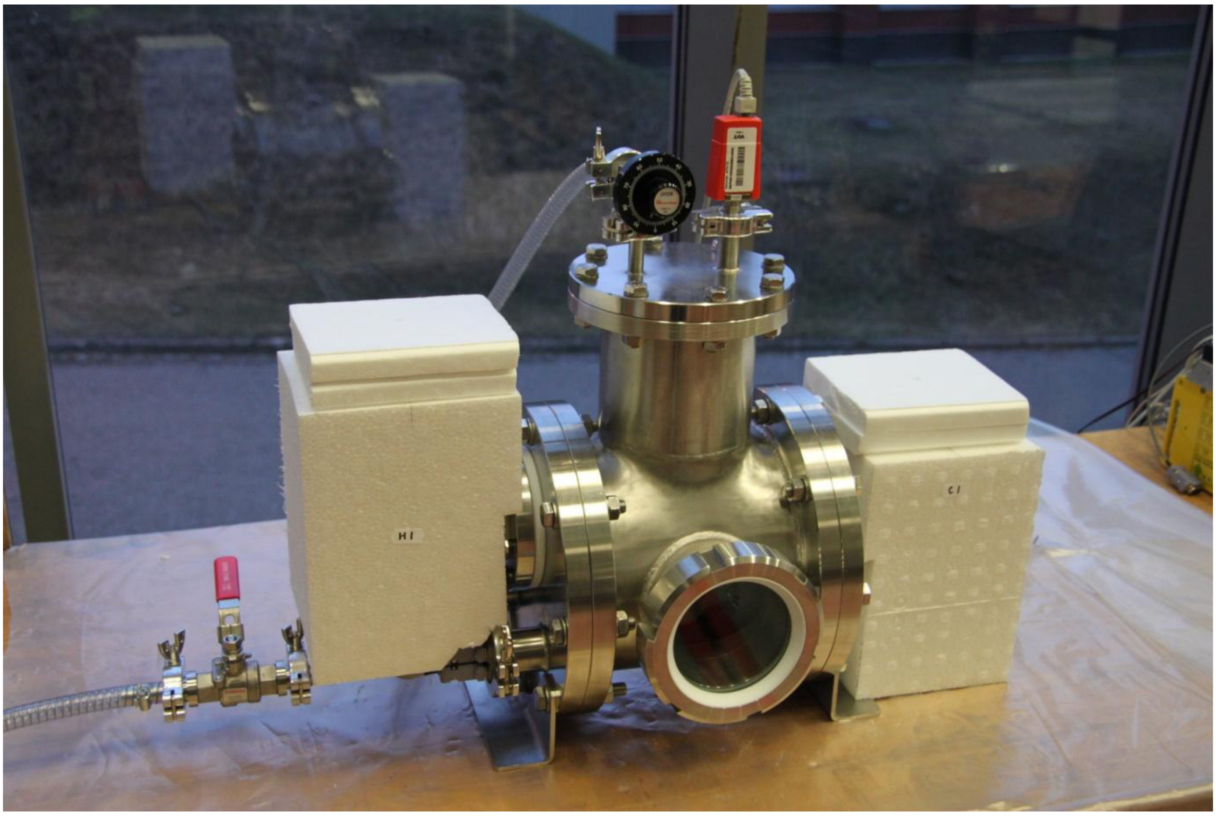

Figure 16.37: *Final HST chamber assembly with pressure control system connection.*

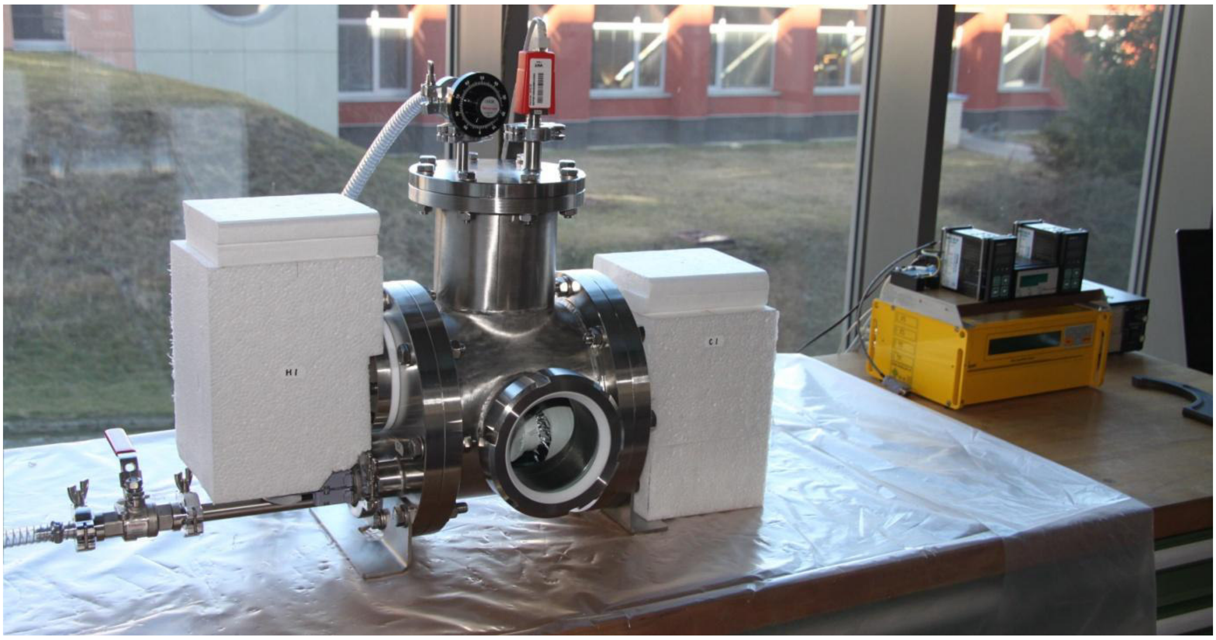

Figure 16.38: *Final HST chamber assembly, Control panel and DAS unit.*

Figure 16.39: *Cold Interface cooling by adding the liquid nitrogen into CI tank.*

Figure 16.40: *Control panel (Ht40P Controllers, Active Digital Controller and DC relay) and DAS unit (ESAM Traveller).*

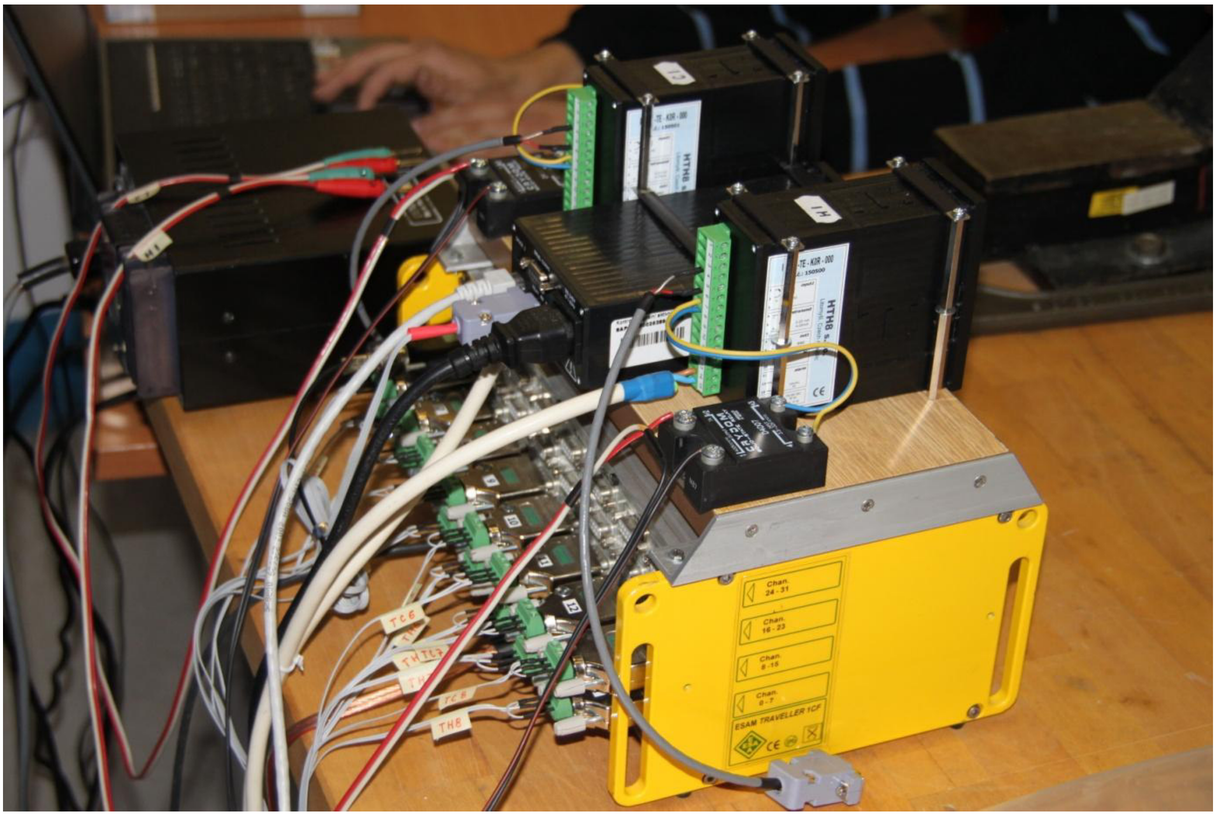

Figure 16.41: *Wire connection between the chamber, Control panel (Ht40P Controllers, Active Digital Controller and DC relay) and DAS unit (ESAM Traveller).*

Figure 16.42: *Pressure control system: Vacuum pump, Vacuum tank, CO_2 tank with Reduction valve and in forward tank for LIN storage.*

A18 - Photo gallery: Specimens

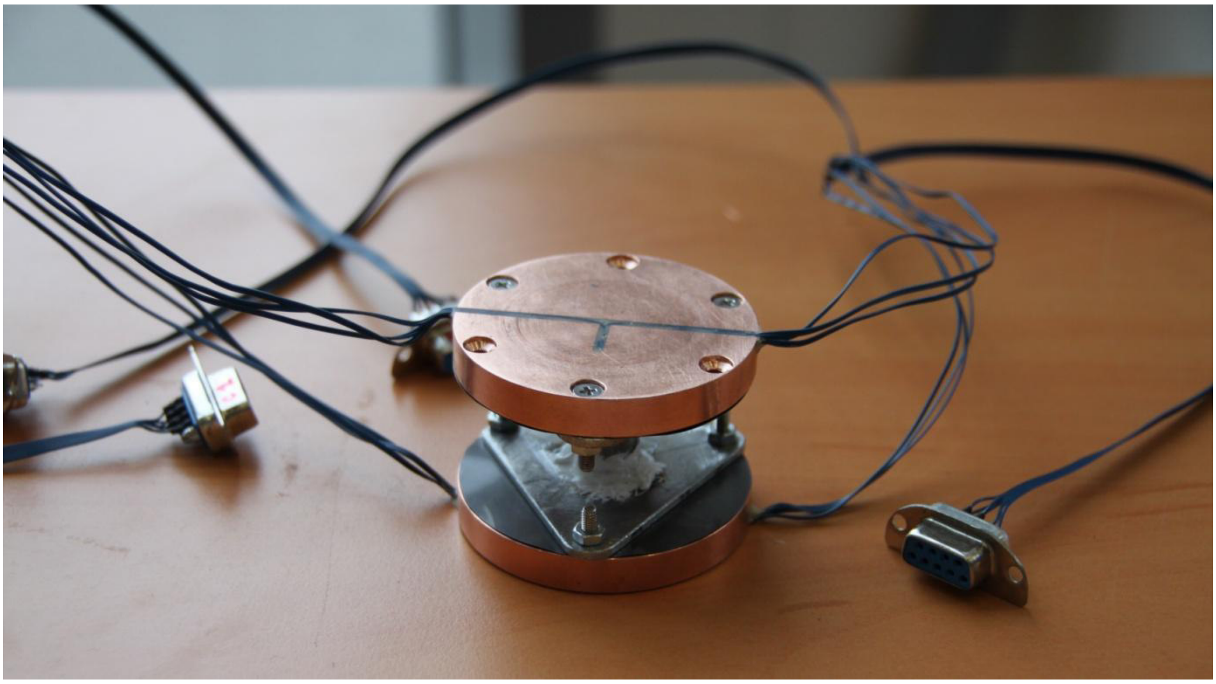

Figure 16.43: *Dummy I. generation, imitating opened position of the Miniaturized heat switch. Specimen placed between the additional copper plates and graphite foils.*

Figure 16.44: *Dummy II. generation, imitating opened (left) and closed (right) position of the Miniaturized heat switch.*

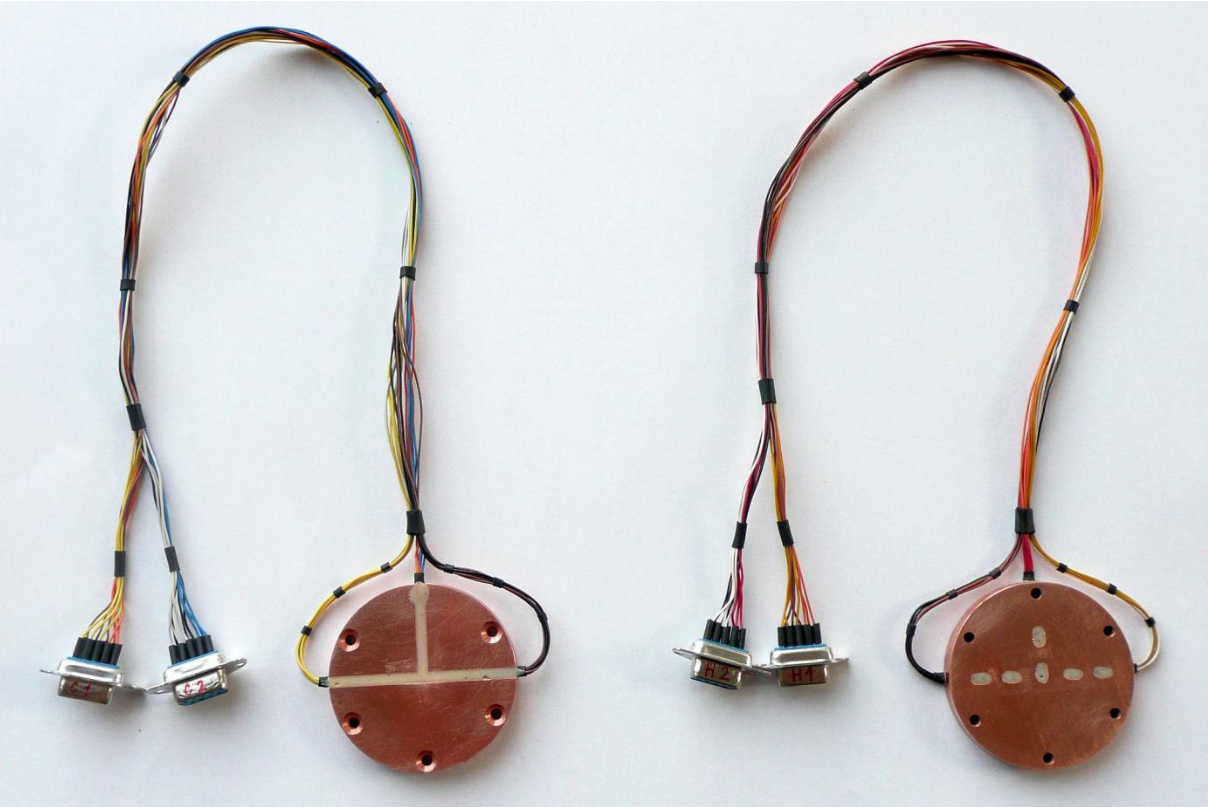

Figure 16.45: *Additional copper plates with glued thermocouples, 6 in each plate.*

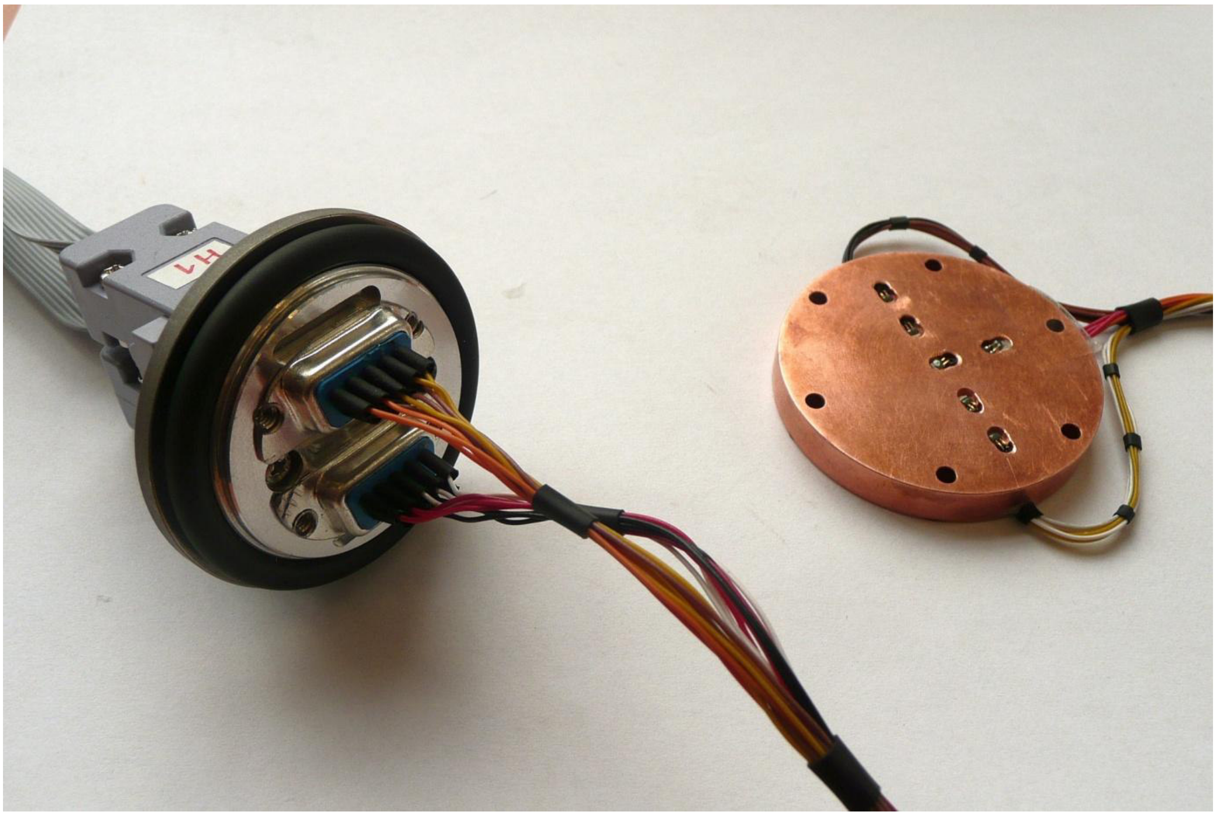

Figure 16.46: *Additional copper plate with 6 thermocouples in holes before glue process and electric vacuum feed-through with inserted wire connectors.*