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МУЛЬТИПРОФИЛЬНАЯ ЛАБОРАТОРИЯ
ARCOLAB

TPC and ECAL cooling system: status

XV Collaboration Meeting of the MPD Experiment at NICA

April 16, 2025

Speaker: Alexander Fedotov

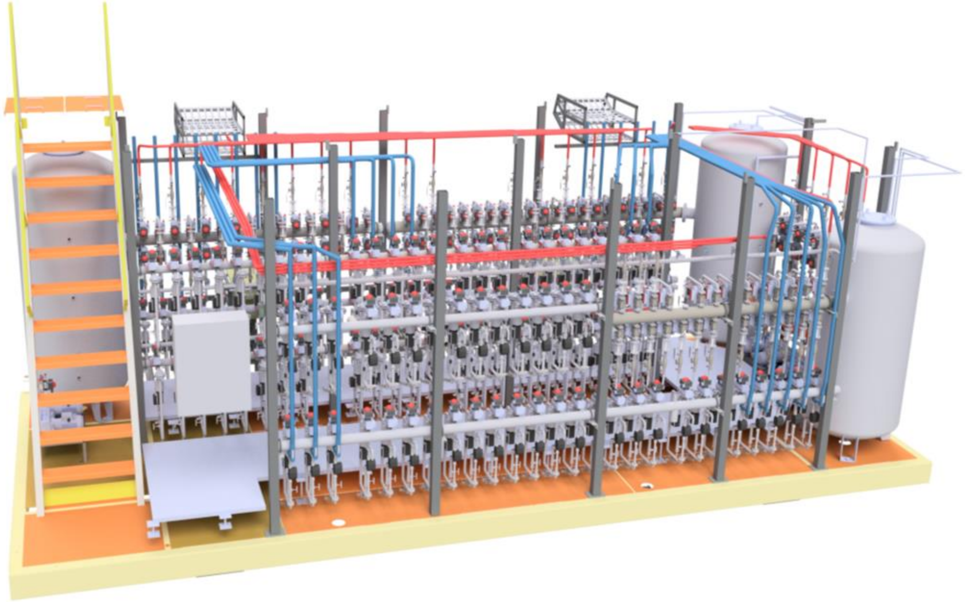
The outline

1. Installation status;
2. Test run;
3. High-precision thermometry;
4. Research stand status.

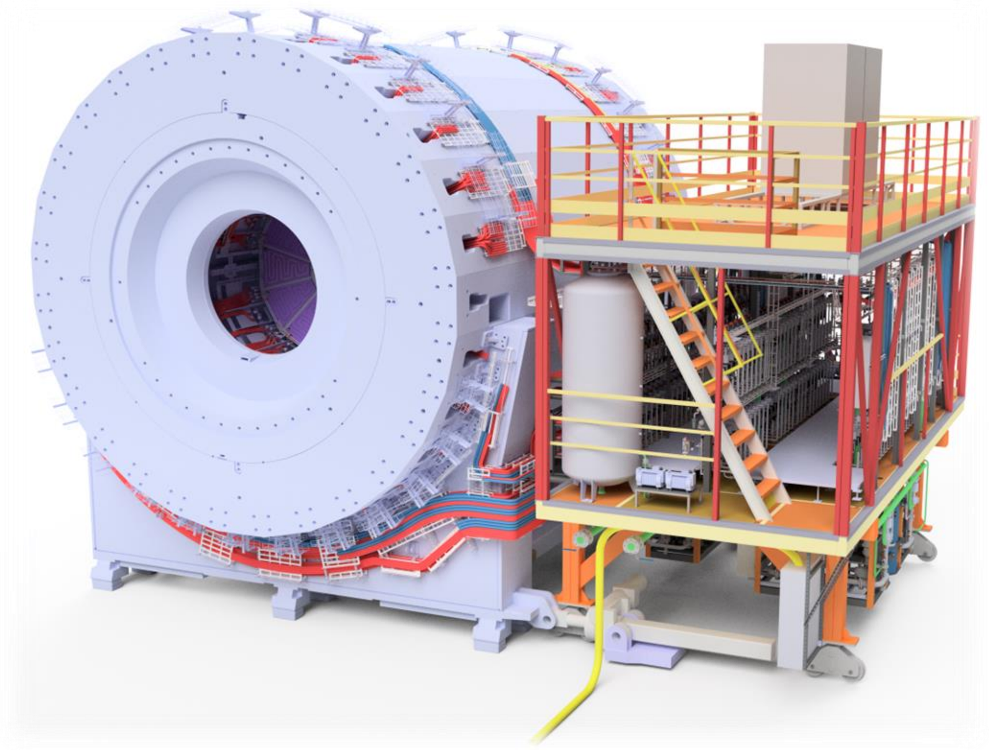
Installation status

Installation

1^{st} Floor: manifolds, sensors, vacuum tanks



2^{nd} Floor



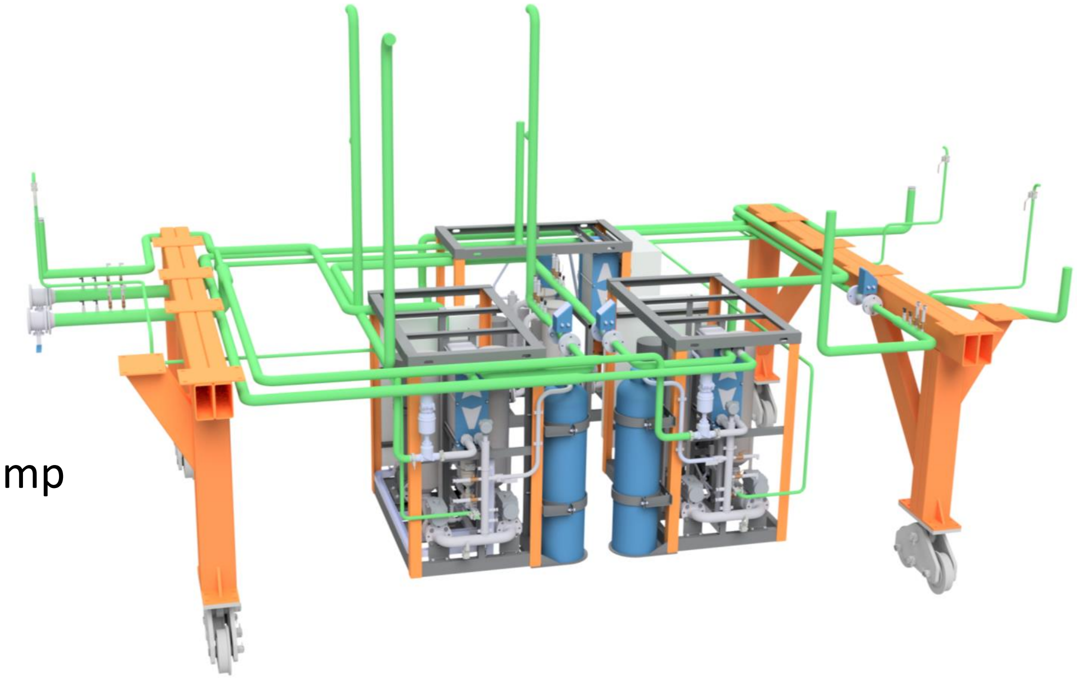
1^{st} Floor

0 Floor

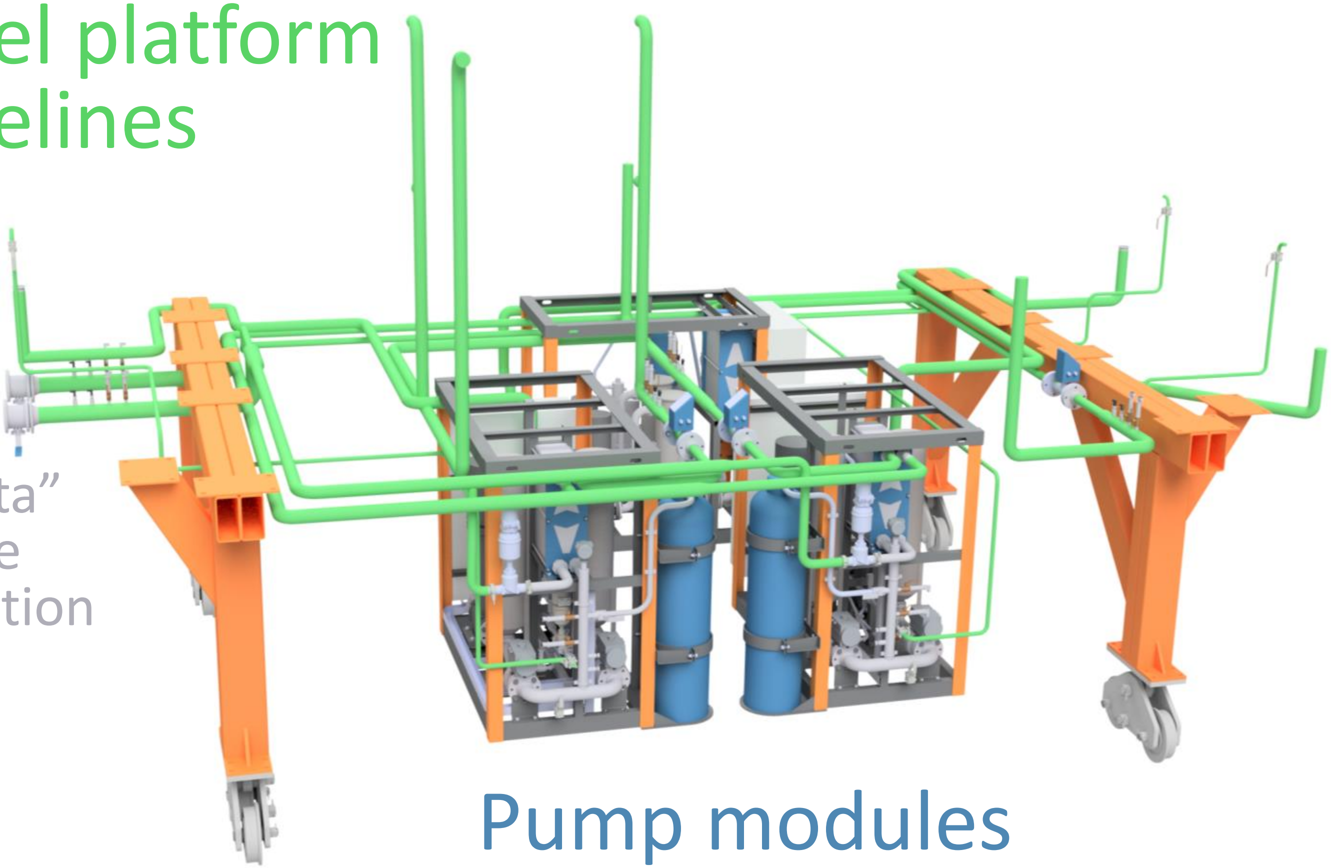
MPD

Cooling system

0 Floor: pump modules + “Kometa” connection



Installation 0 floor



0 floor equipment

Kometa connection

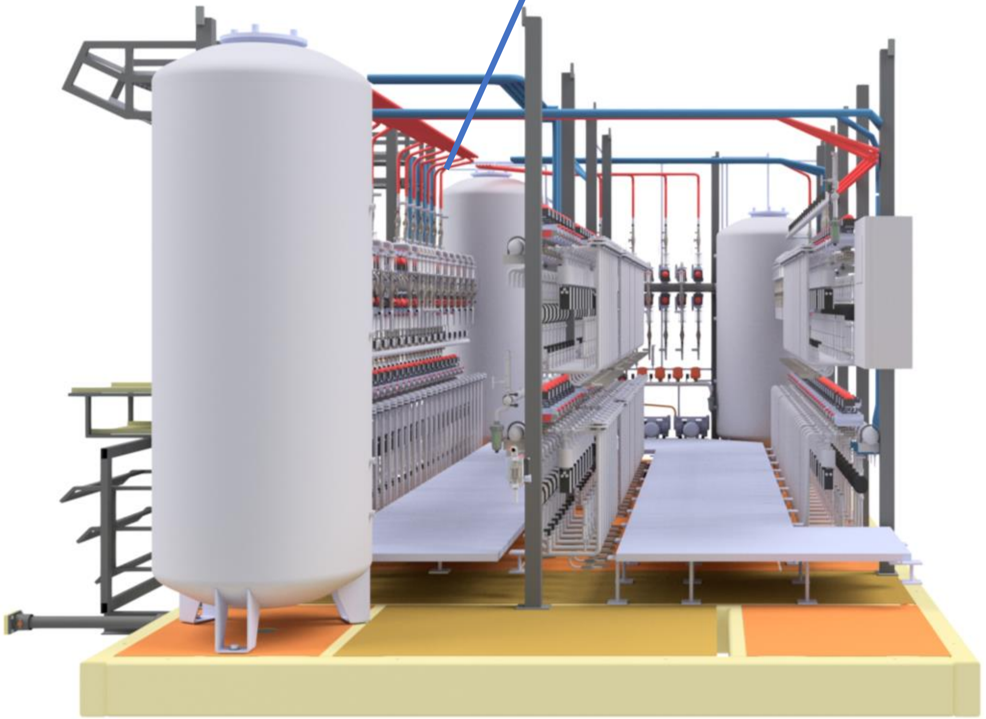
Pump module

Done:

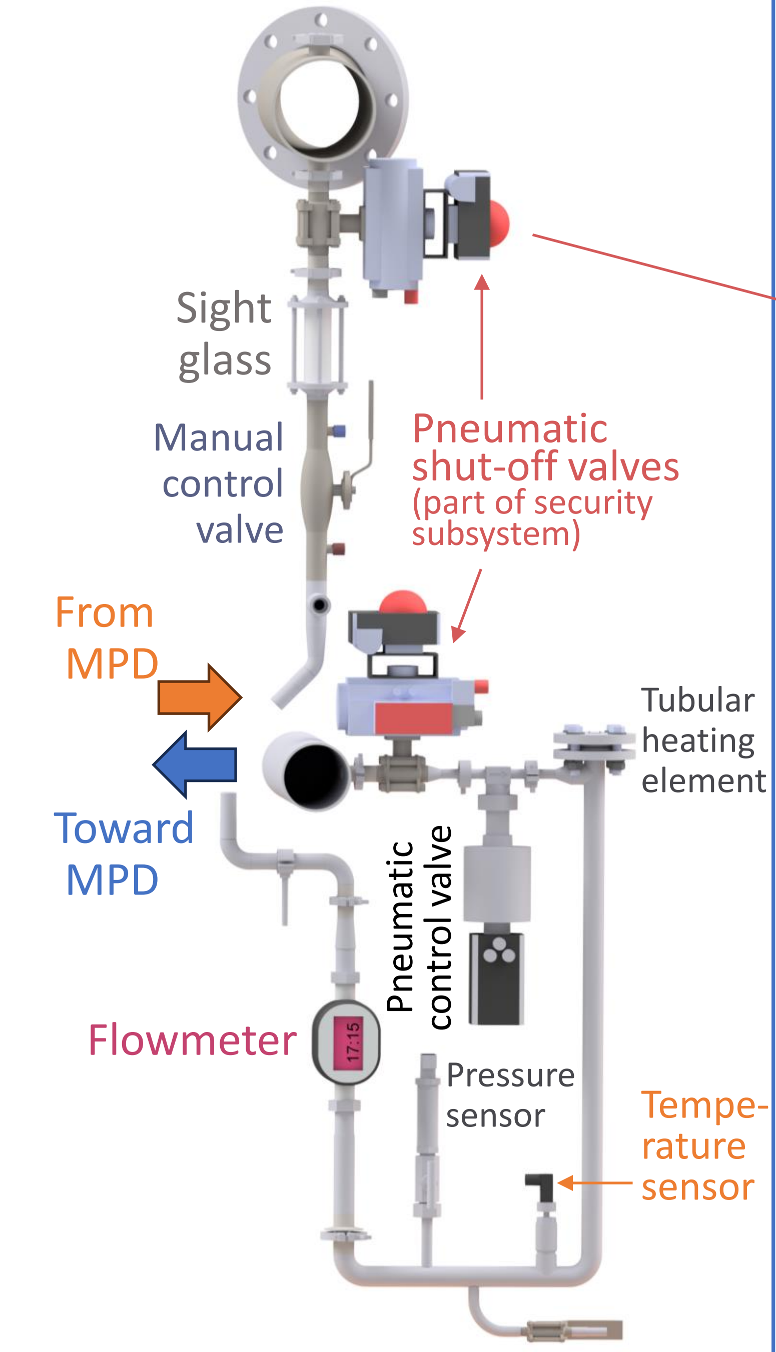
- ✓ Installation of three pump modules;
- ✓ Stainless steel pipelines "pump modules – manifolds" and "pump modules – Kometa pipeline";
- ✓ Cables and compressed air for automation equipment.

Installation 1st floor

- 3 independent closed contours;
- <u>116</u> controlled water subcontours.



1st floor equipment



Installation 1st floor

Done:

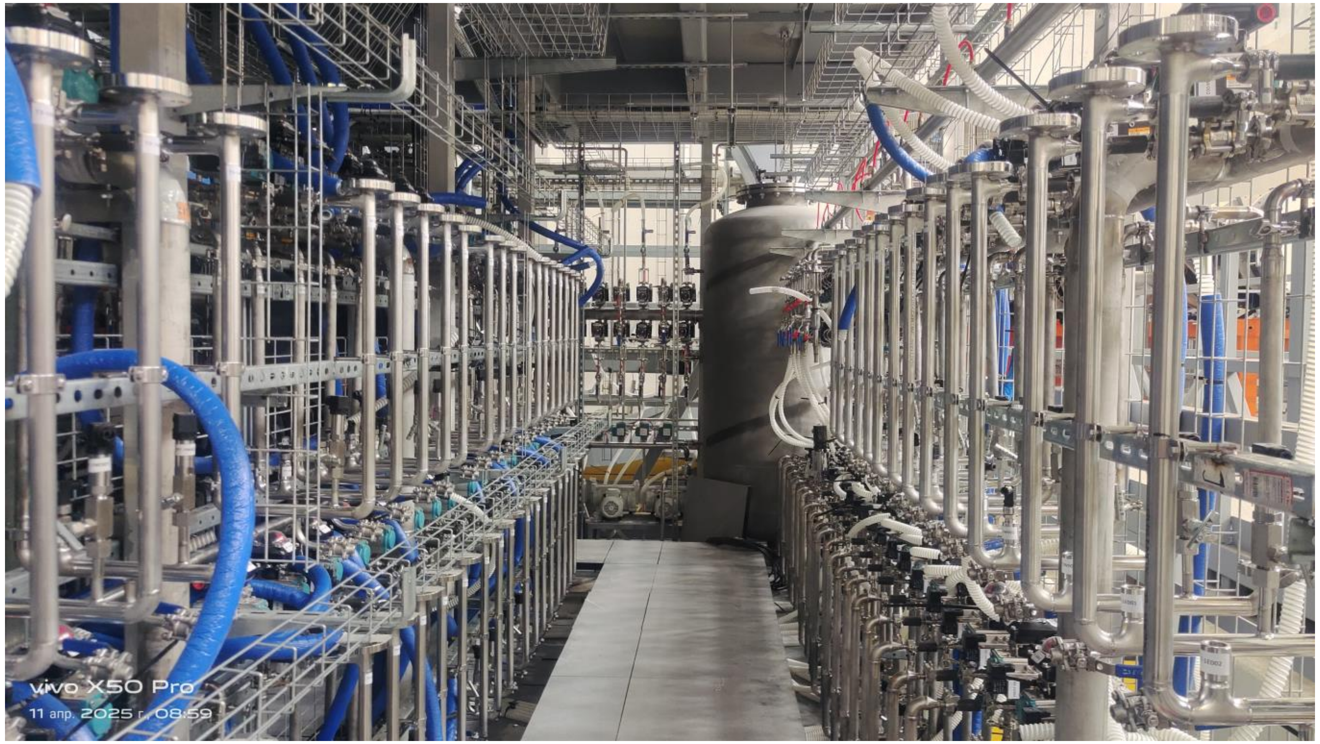
✓All steel manifolds;

✓All steel enclosures for subcontours;

✓All vacuum tanks;

✓All pneumatic shut-off valves;

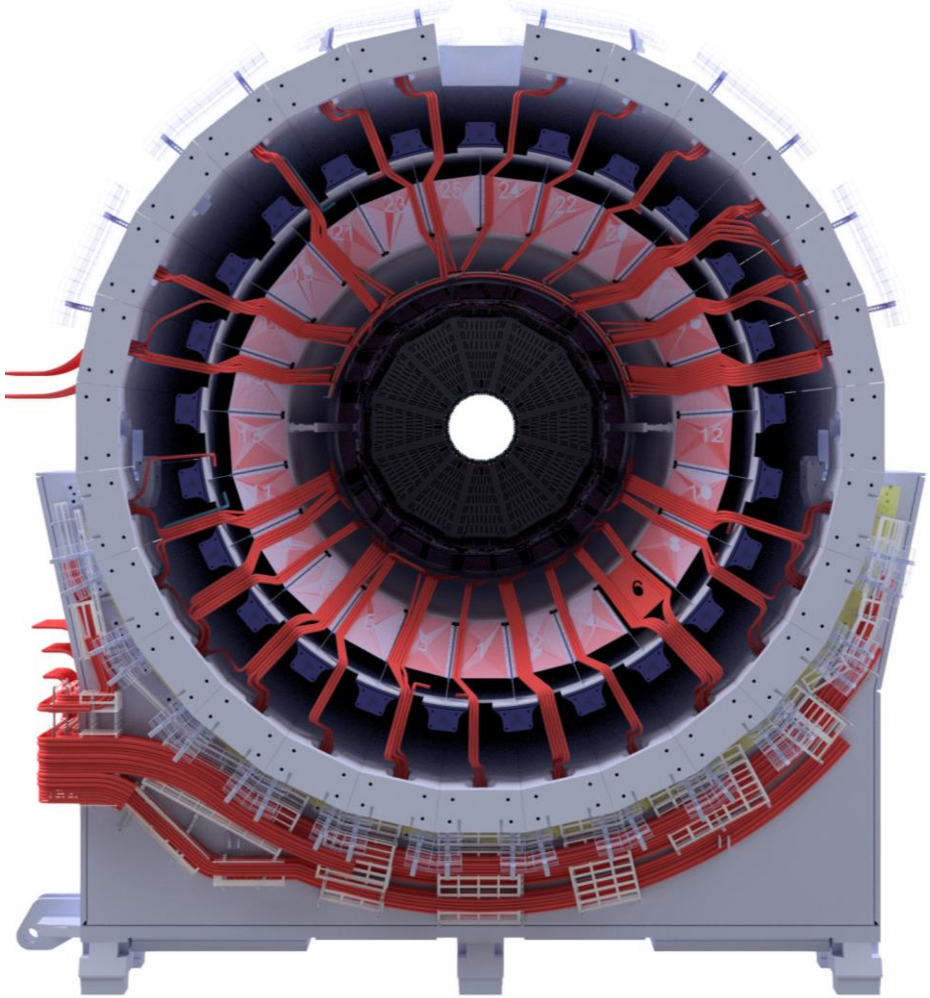
✓ Raised floor.



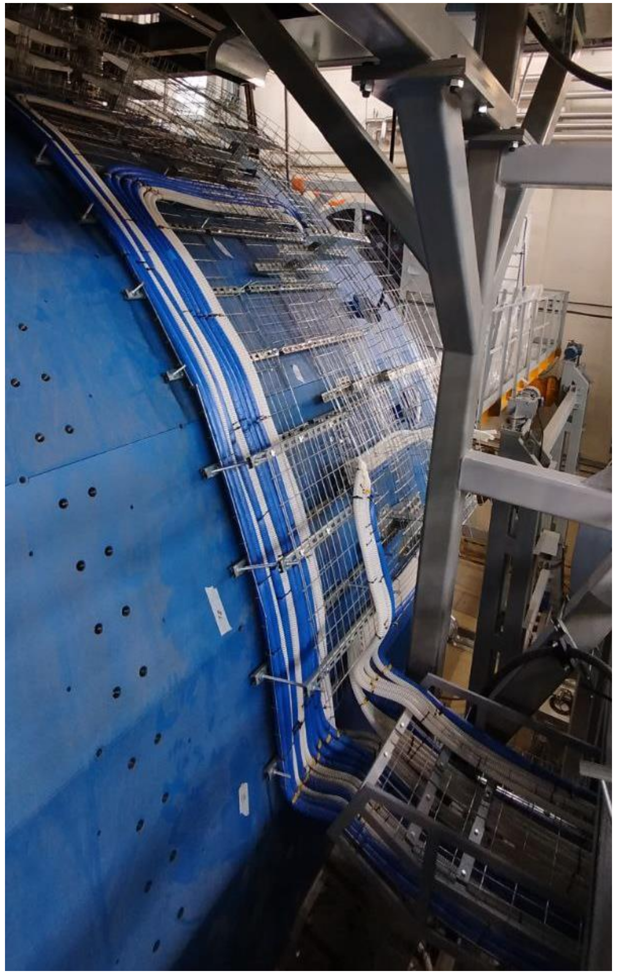
To do:

- Install electronic cabinets with cables;
- Install flow, pressure, temperature sensors;
- Install heaters;
- Install control pneumatic valves.

Installation of pipes



3D pipe routing with support trays



Done:

✓3D model of 232 pipelines;

✓Installation of 90 % pipe routing from platform to MPD windows

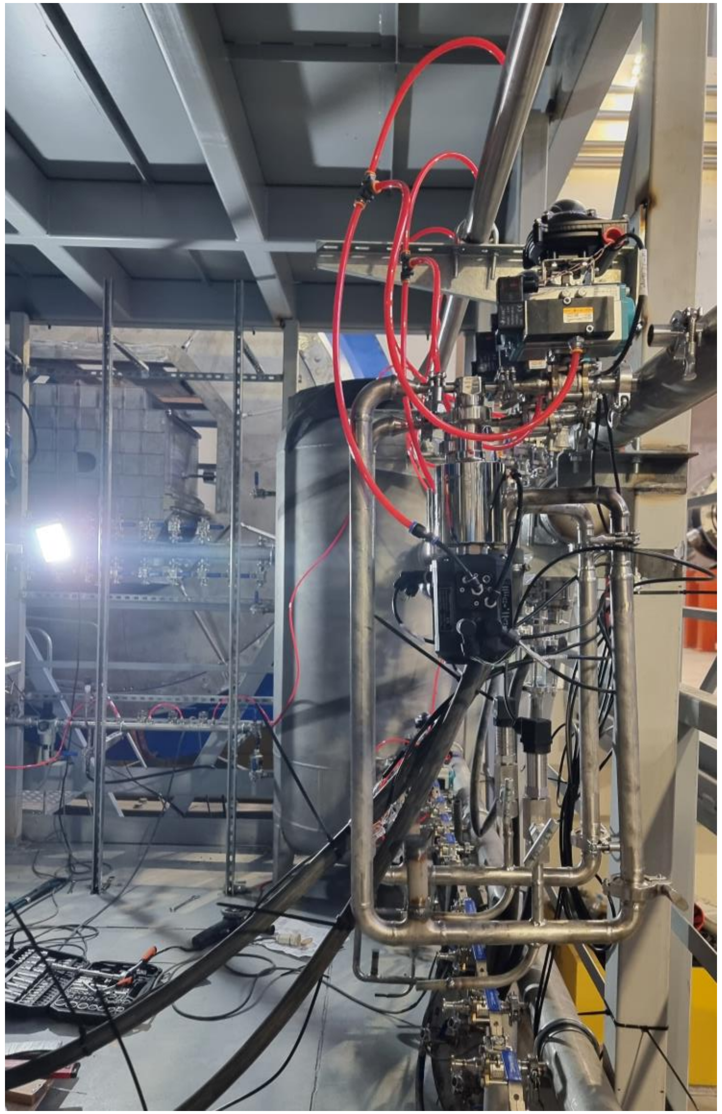
Test run

Test run

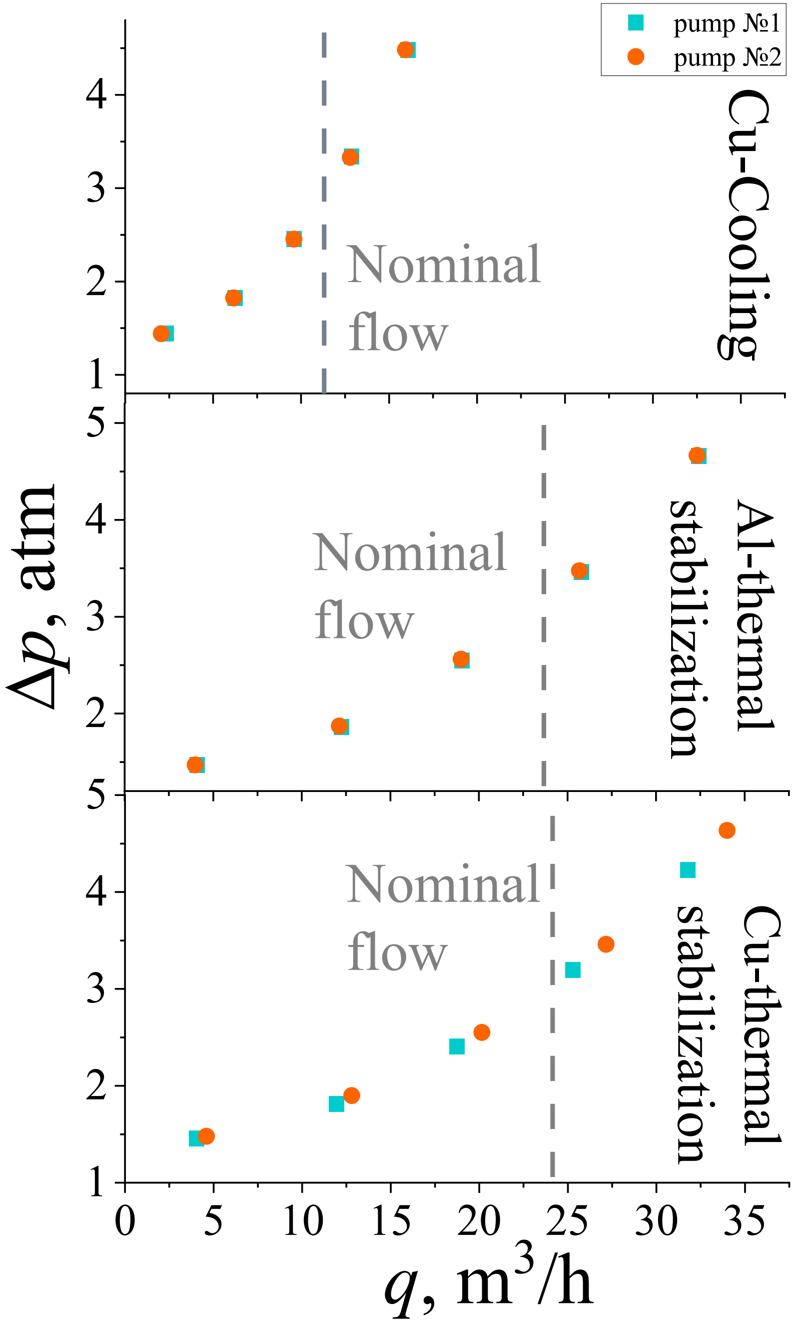
16 December 2024 – three pump modules were washed and tested

Key founds:

1. Hydraulic losses on platform steel pipeline <u>0,4 – 0,6 atm</u> at nominal flow;
2. System stability at high pressure (10 atm): <u>no leaks, no breaks</u>;
3. At nominal flow contours have 1,5 atm surplus that is enough for water supply.



Testing process: red hoses – air supply, **thick black** hoses – temporary water lines



High-precision thermometry

What is the problem?

TPC of STAR & ALICE: thermal stability in gas volume ±0,1 °C

But

Best GOST “AA” sensors:

$\Delta T_{\mathrm{Pt100}} = \pm\,(0{,}1 + 0{,}0017\ |T|)\ °\mathrm{C} \approx \pm\,0{,}15\ °\mathrm{C}$

…We need 260 channels and sensors with error ~ ± 0,03 °C

What should we do

The plan:

1. Calibrate measurement channels;
2. Calibrate sensors;
3. Develop database;
4. Introduce correction algorithm to PLC.

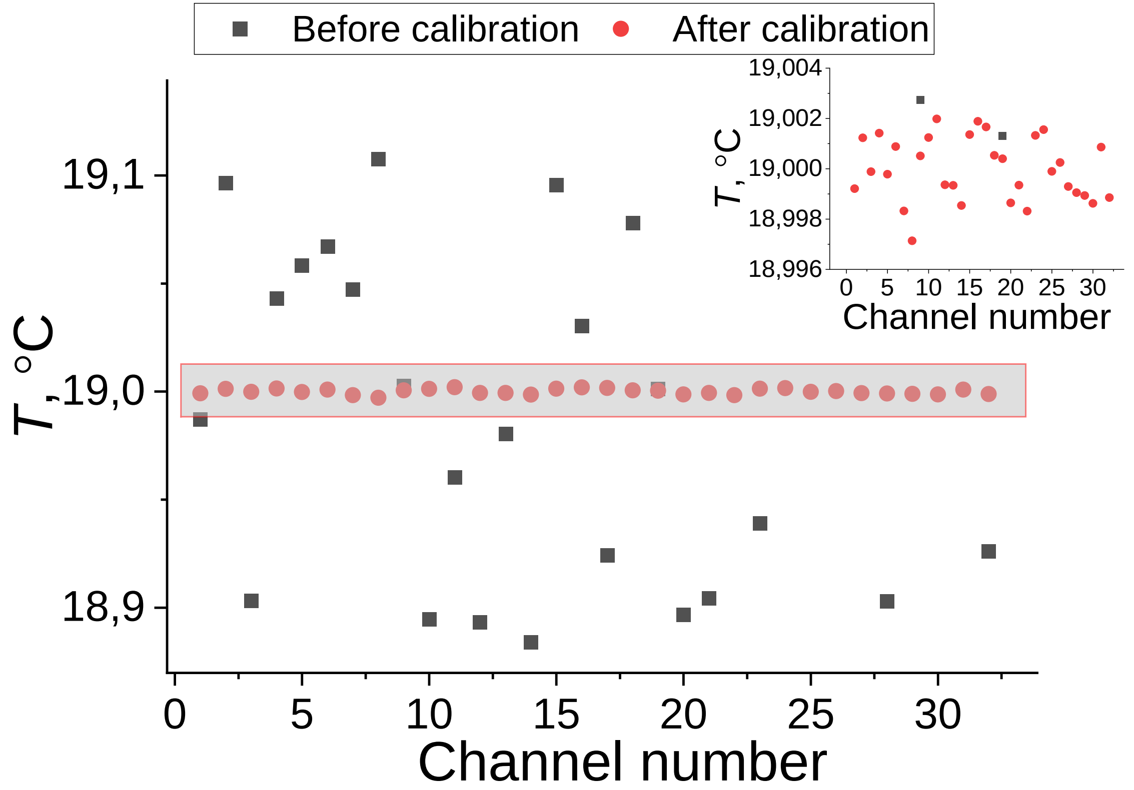
HF Analog Input modules

Siemens 1512-2

Programmable logic controller

Measurement channel calibration

1. Take very stable resistance R_i (Yokogawa) and validate it (Keithley).
2. Calculate ideal temperature T_i if sensor Pt100 has resistance R_i;
3. Plug resistance to Siemens AI and find correction between ideal T_i and siemens-measured $T_{siemens-i}$
4. Build map of corrections for **all channels** for **different temperatures** (correction depends on T!)



Yokogawa 2793/01 decade resistance box

0.001 Ohm precision, **2 ppm/°C** stability

Sponsored by ArcoLab LLC

Keithley DMM7510 multimeter

Sensor calibration

1. Put sensors in calibrator chamber.
2. Measure raw T_raw_i temperature from i-th sensor at T_etalon temperature of calibrator sensor;
3. Build calibration functions P projecting T_raw_i to T_etalon for each i-th sensor at j-th temperature.

Calibrator Elemer TK-150-MK

Polynomial calibration function:

$$P_i(a[0]_i, a[1]_i, \ldots, a[k]_i, ., a[n]_i, T_i) = a[0]_i + a[1]_i \cdot T_i + \ldots + a[k]_i \cdot T_i^k + \ldots + a[n]_i \cdot T_i^n$$

Searching coefficients a_i for each sensor by minimization

Least-squares error L^2:

$$L^2 = \sqrt{\sum_{j=1}^{m} \left(P_i(T_i^j) - T_{etalon}^j \right)^2}$$

OR

Chebyshev's norm L^∞:

$$L^\infty = \max_j \left| P_i(T_i^j) - T_{etalon}^j \right|$$

Sensor calibration

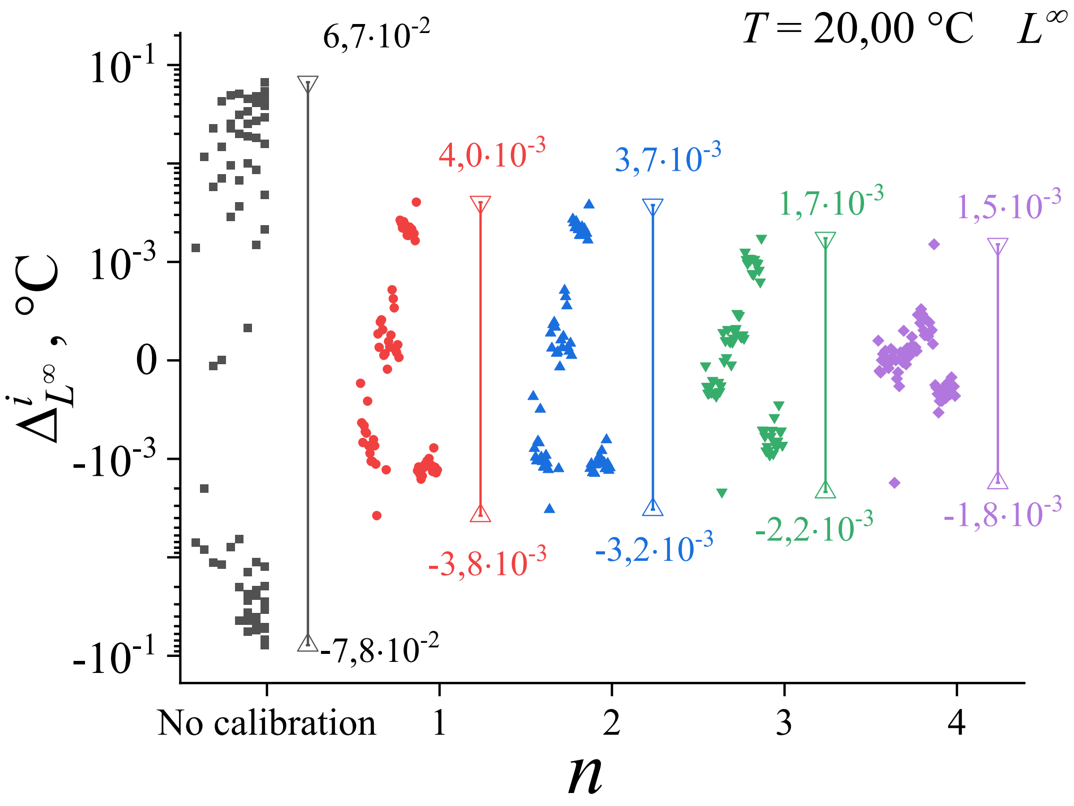
Calibration even by linear function reduces spread of sensor readings by a factor of 19 (from 0,145 °C to 0,0073 °C);

Error relative to mean sensor value ≈

0,01 °C from sensors + 0,006 °C from channels ≈ **0,016 °C**

Absolute temperature error ≈

0,01 °C from sensors + 0,01 °C from calibrator + 0,006 °C from channels + 0,003 °C from Keithley ≈ **0,03 °C**



Spread of sensor readings **Δ** for calibration polynomial of order ***n***

Software concept

Temperature	Correction ΔT
19	0.02
23	0.01
27	0.01
37	0.03

Channel *j*

Module *i*

Temperature	Correction ΔT
19	0.04
23	0.11
27	0.21
37	0.23

Sensor *k*

MySQL

PLC starts

Get calibration coefficients from database

Read raw bits from Analog Input

Apply channel calibration

Compute raw temperature

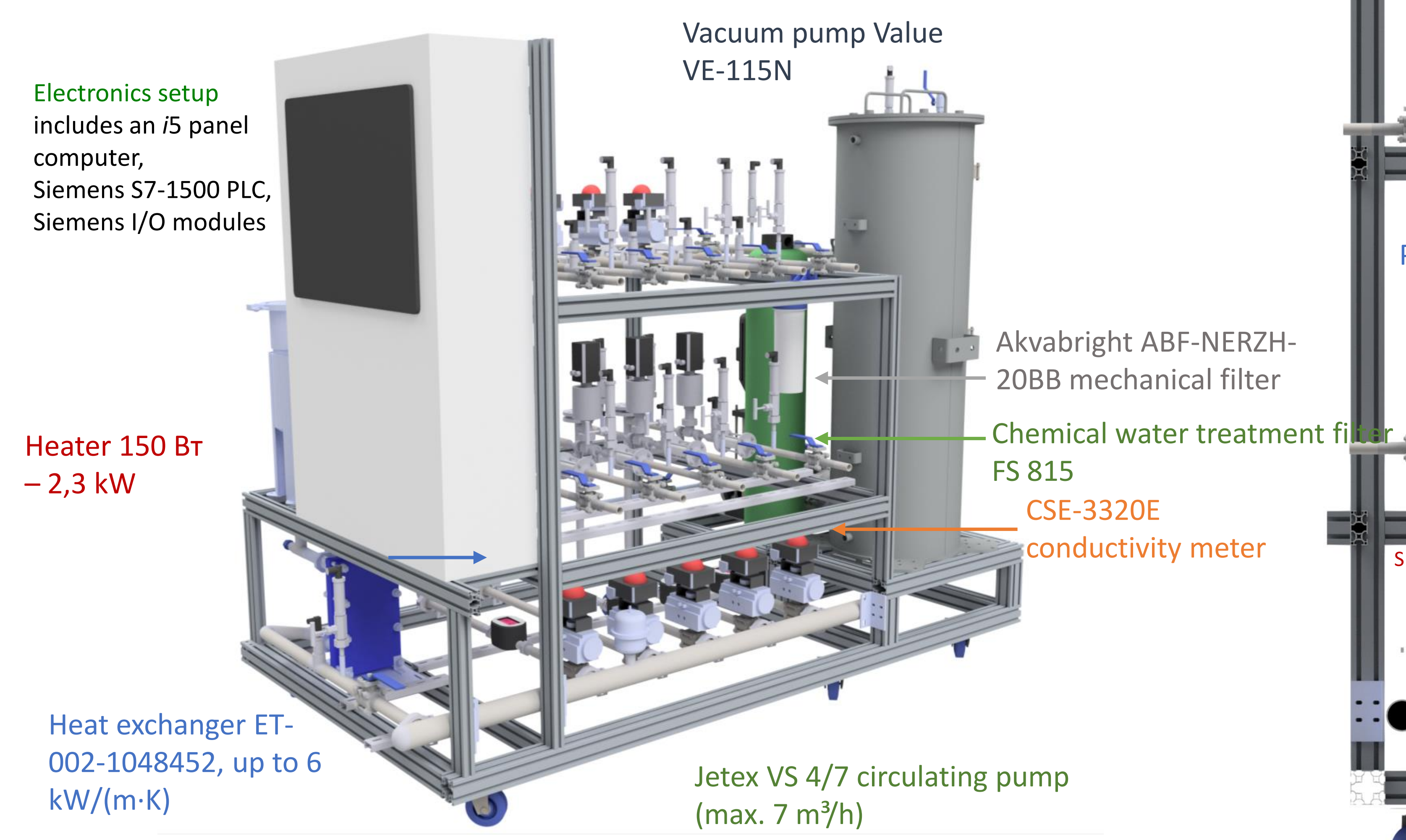
Apply temperature sensor calibration

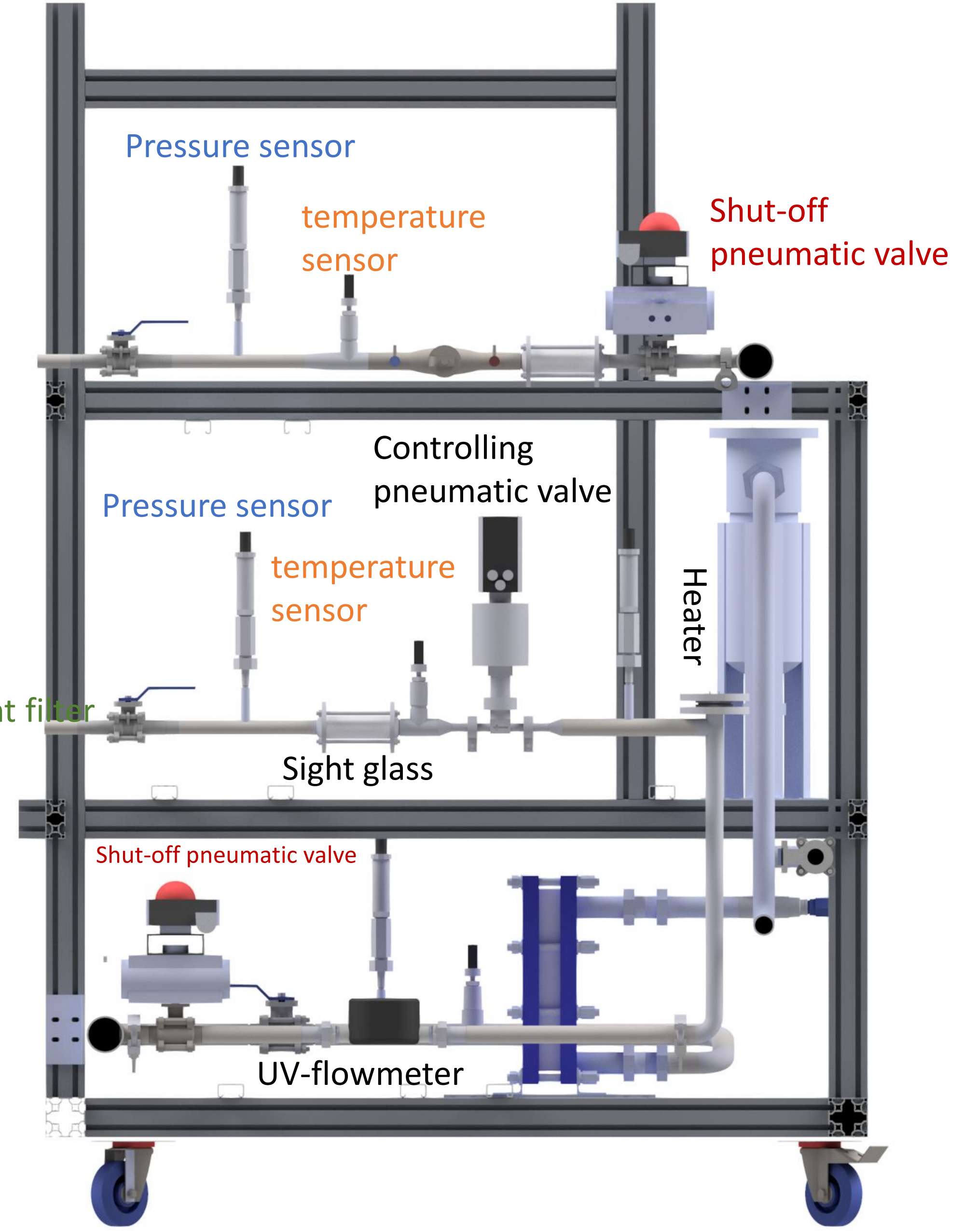
Measurement loop

Use corrected temperature for monitoring and regulation

Research stand status

Research stand design



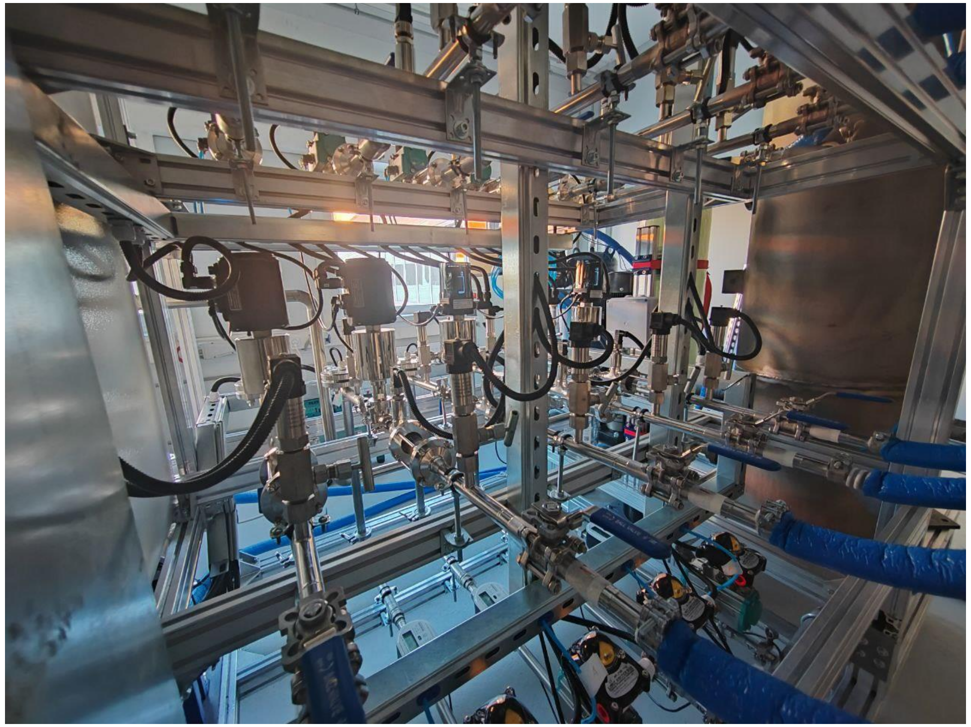


Research stand status

Planned Experiments:

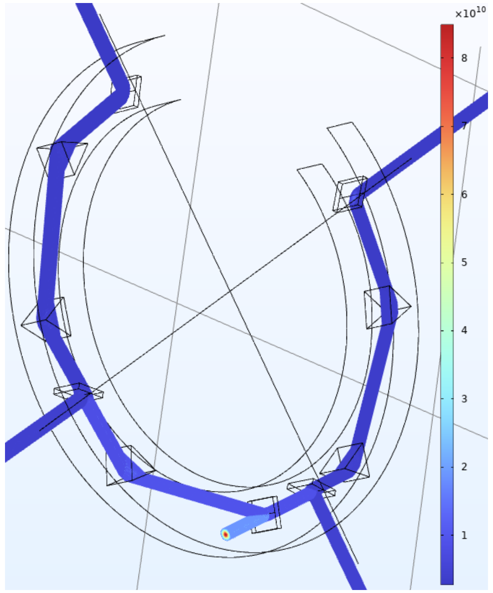
- Debugging of control algorithms for hydraulically coupled subcontours;
- Debugging of thermal stabilization regimes on the operational ROC chamber;
- Development and testing of algorithms for cavitation lock removal;
- Hydrodynamic studies of new radiators (synchronization modules and FEC card readout controllers);

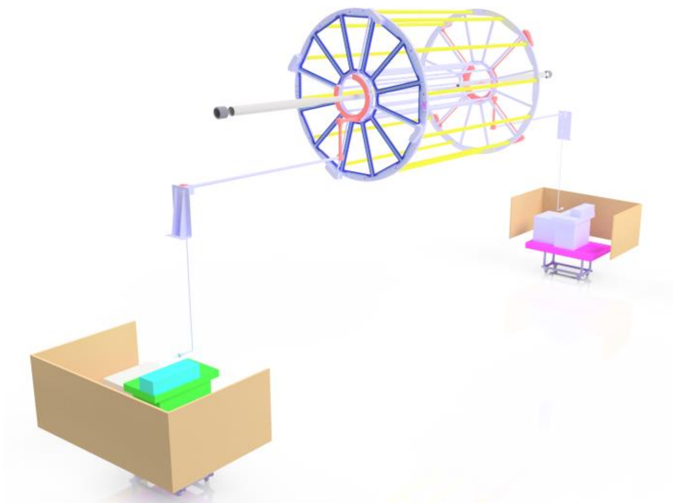
Vorticity air detector test

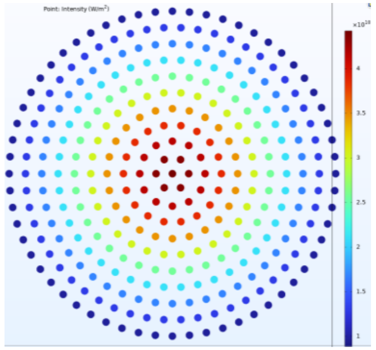


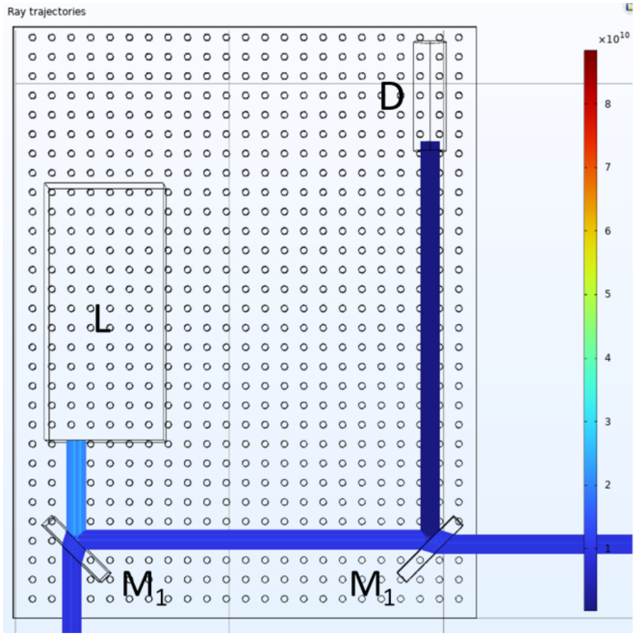
Subcontours

Thank you









Co-authorship and gratitude

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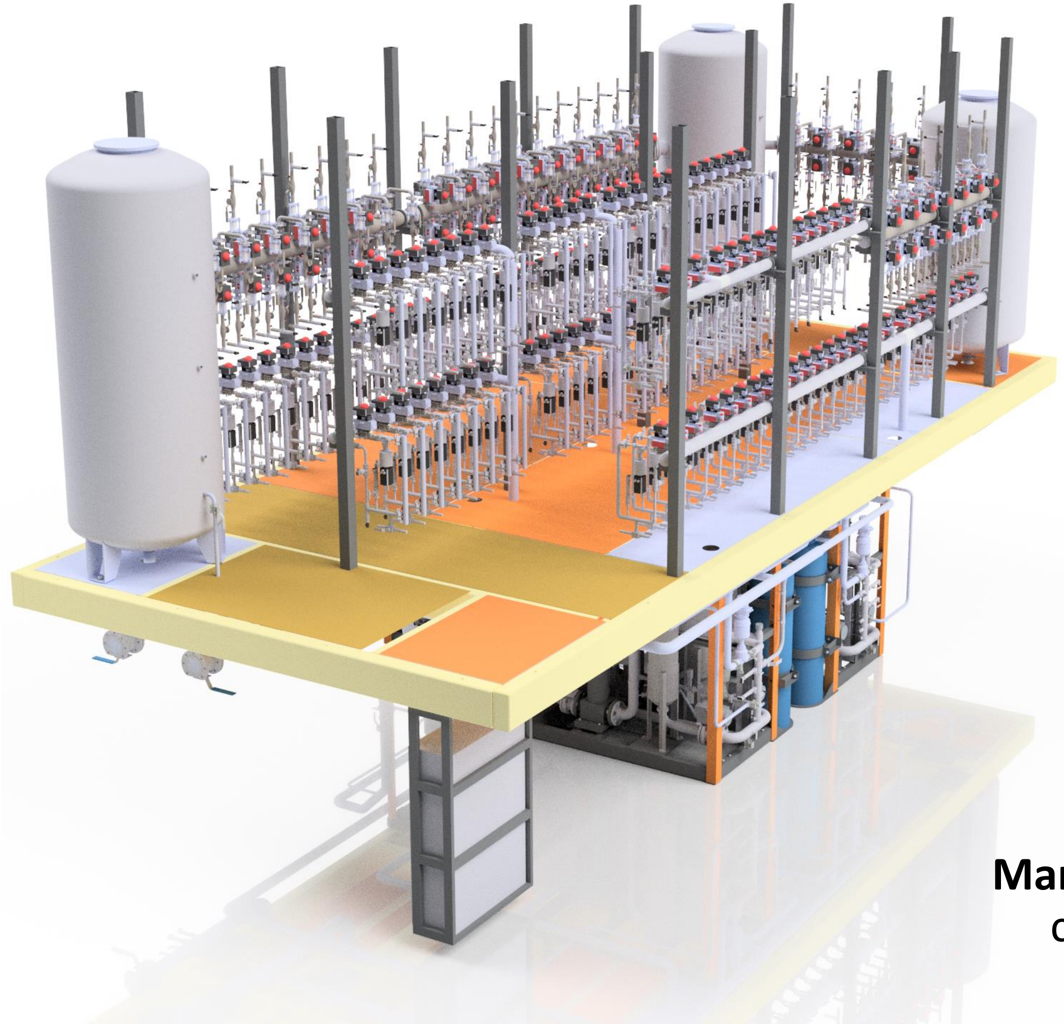
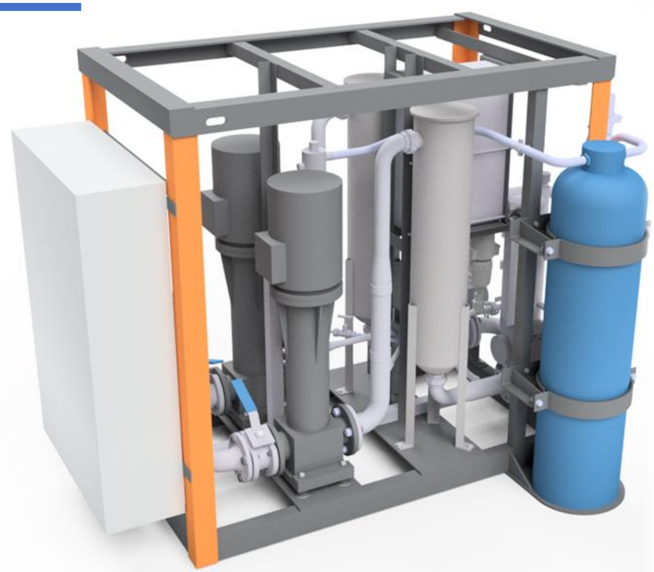
Nelli Pukhaeva (NOSU)

Installation of
Vacuum tanks, Pump modules, Manifolds

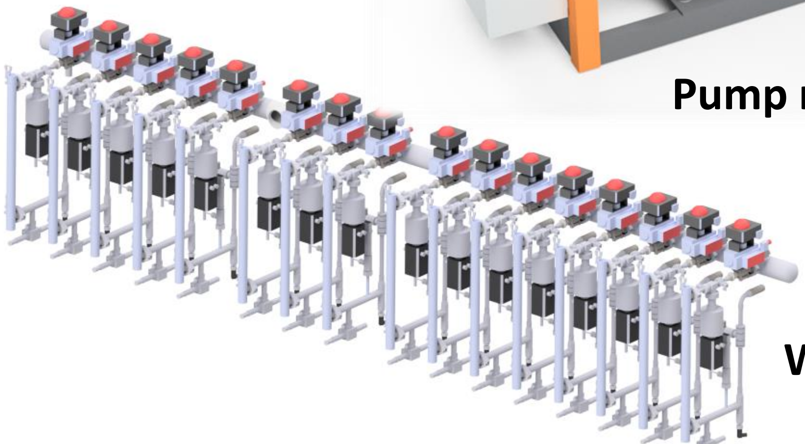
Water plant

Assembled at platform





Pump module



Manifolds: redistributes water from the contour line to the individual sub-contours

Water Tank: An airtight reservoir that contains water below atmospheric pressure. Tested for leaks at 0.2 atm and 10 atm.

Pump modules - photos

Assembled under 1st floor of platform

Water tanks & manifolds

Heat exchanger and thermal sensor for TPC gas mixture

Thermal stabilization of TPC gas

Motivation

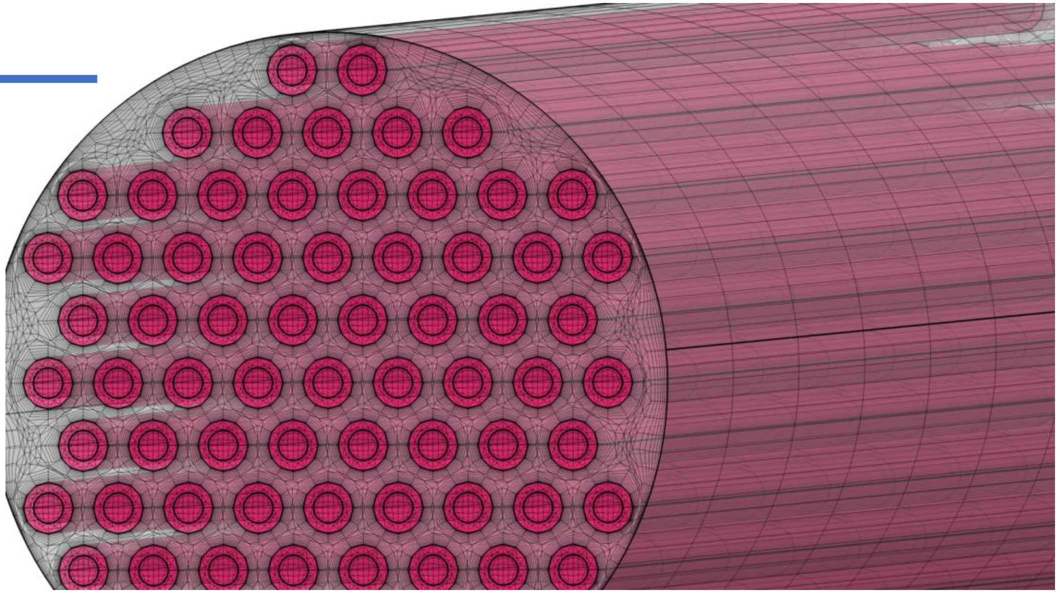
Thermal stabilization ±0.1 K is needed for reliable event reconstruction in $Ar_{0.8}(CO_2)_{0.2}$

Challenges

- Measure gas temperature with accuracy better than ±0.1 K
- Prepare gas at a specific temperature to feed into the TPC
- Minimize the influence of the environment on the gas supplied to the TPC

Heat exchanger

Initial concept by
I.A. Balaschov



Mesh for computations

Shell-and-tube heat exchanger:

- Gas flows in small tubes with large surface area;
- Water environment outside of small tubes provides heat exchange

Stationary 3D Navier-Stokes equations for gas and water:

$$\begin{cases} \nabla \cdot \vec{u} = 0 \\ \rho_0 (\vec{u} \cdot \nabla)\vec{u} = \nabla \cdot \left[-p\mathbf{I} + \mu_0 \left(\nabla\vec{u} + (\nabla\vec{u})^T \right) \right] + \rho_0 \beta \left(T_0 \right)\left(T - T_0 \right) \vec{g} \\ \rho_0 C_{p0} (\vec{u} \cdot \nabla) T = \nabla \cdot \lambda_0 \nabla T \end{cases}$$

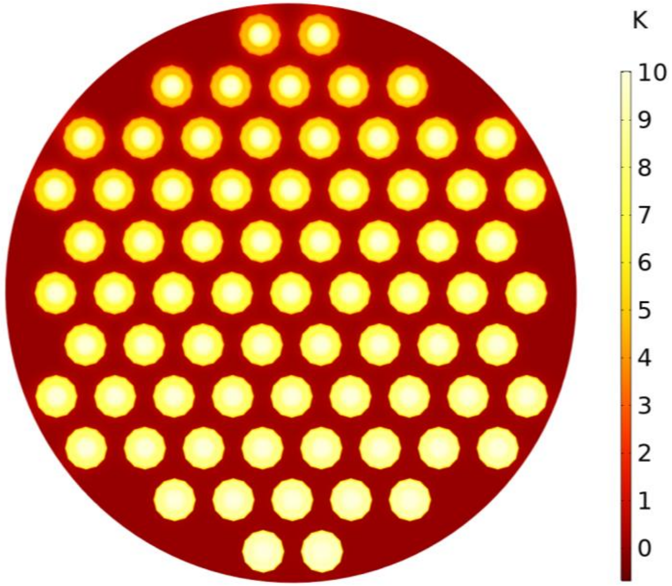
$\vec{u}$ – fluid velocity;
μ – dynamic viscosity;
p – pressure;
$\mathbf{I}$ – identity matrix.
λ_0 – heat conduction coefficient at reference temperature T_0;
C_{p0} – heat capacity at reference temperature T_0;
β – compressibility,
ρ_0 – density at reference temperature T_0.

Heat exchanger

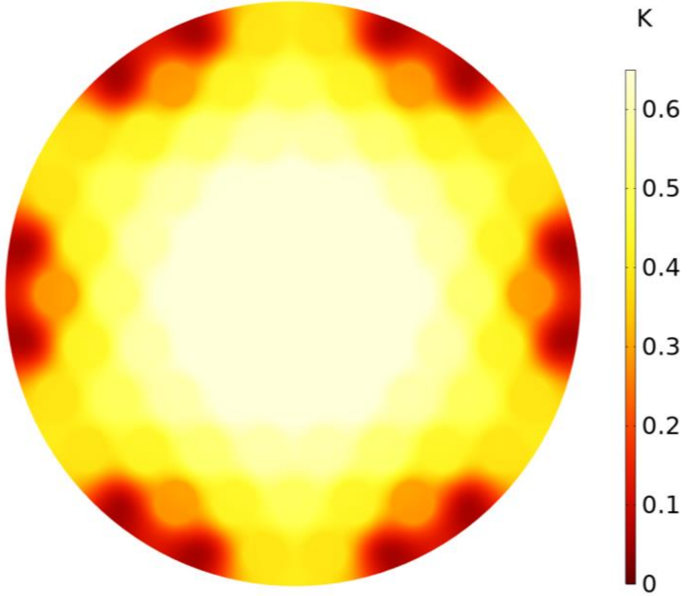
Prototype simulation parameters:

ΔT decreased by 10-15 times

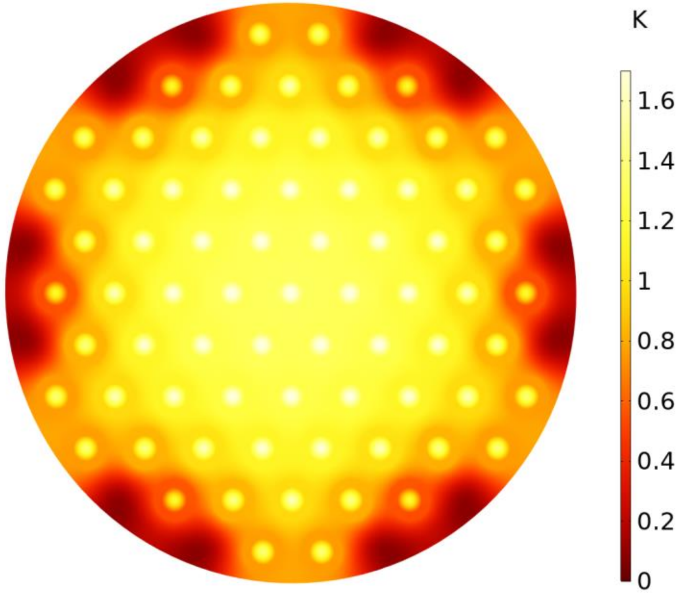
- Length 0.55 meters;
- Inlet gas is 10 K hotter than water;
- Water flow is 0.1 m^3/h;
- Gas flow is 20 — 200 l/min.



At inlet



At outlet – 20 l/min

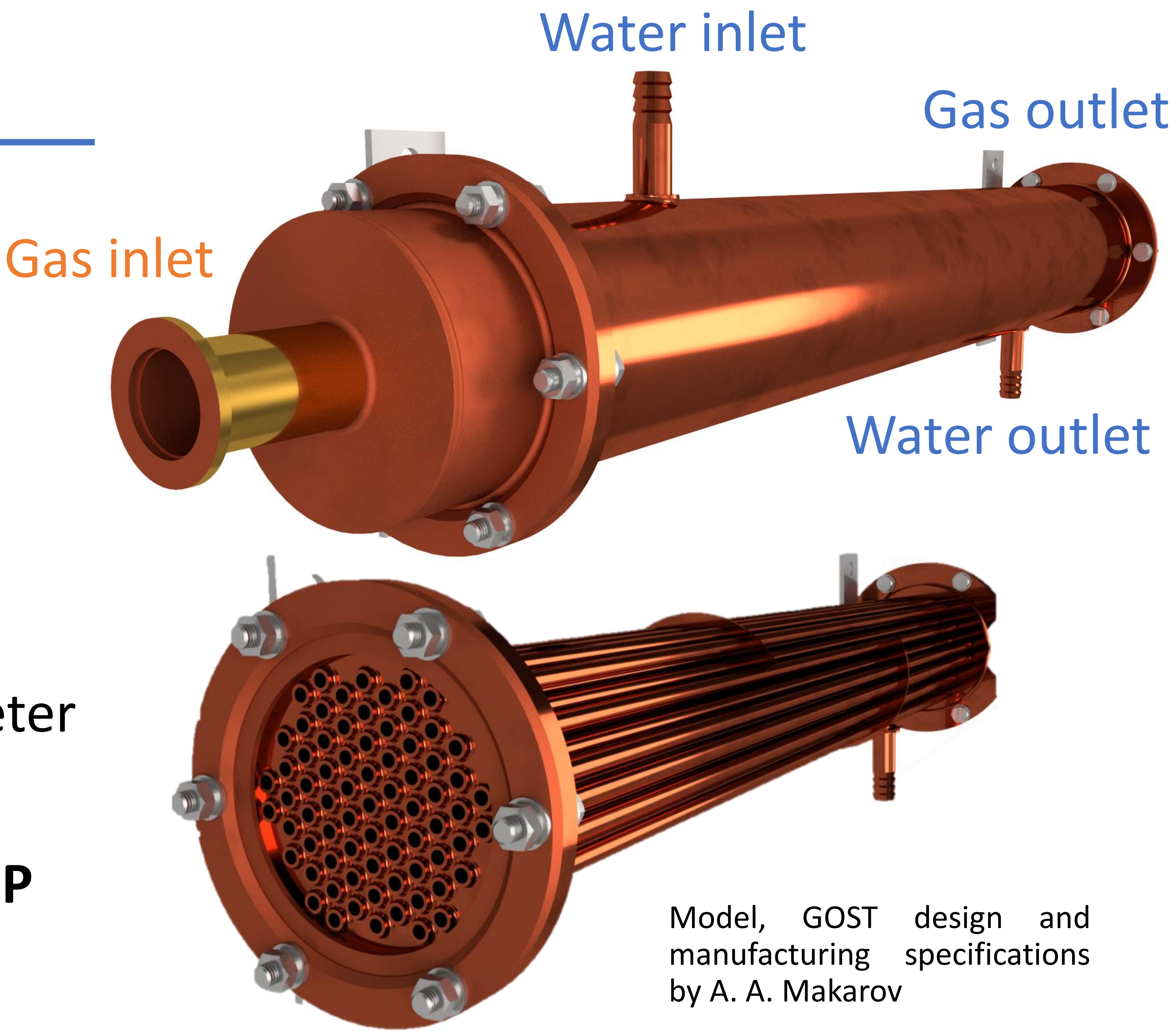


At outlet – 200 l/min

Heat exchanger

Shell-and-tube heat exchanger for gas thermal stabilization:

- 74 gas pipes of 6 mm diameter
- ~8 kg weight
- **Being manufactured at LHEP**

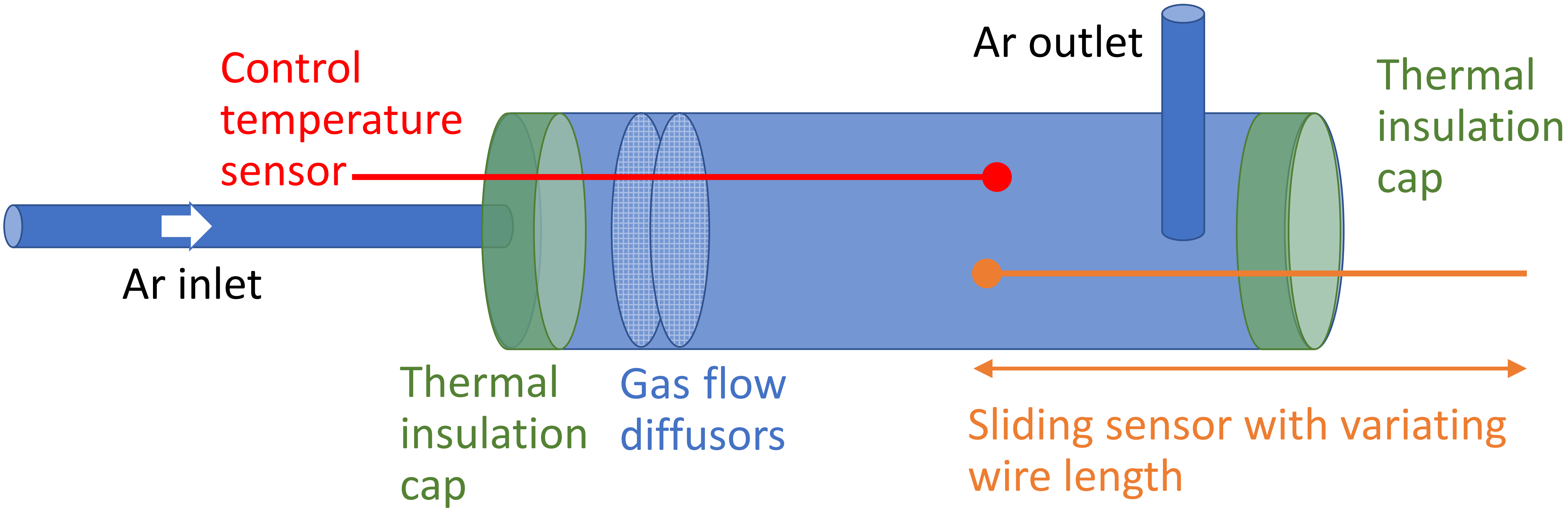


Model, GOST design and manufacturing specifications by A. A. Makarov

Gas temperature sensor

The gas volumetric heat capacity is 10^4 less than that of liquids and solids

To measure temperature of gas (not a wire or a wall) a sensor must be drown deep in gas

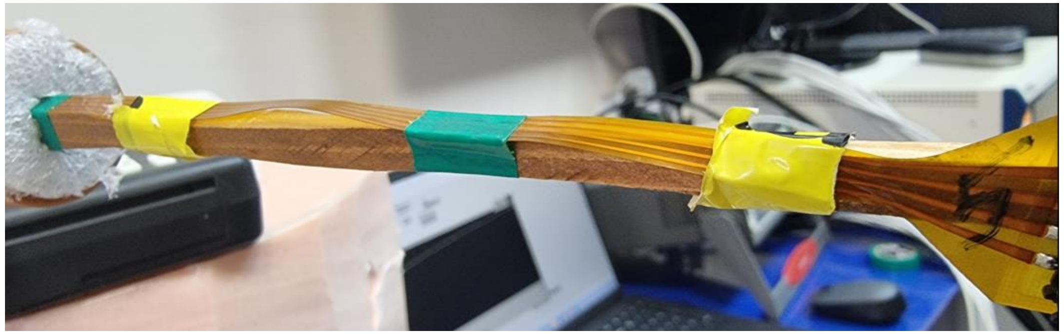


Gas temperature sensor

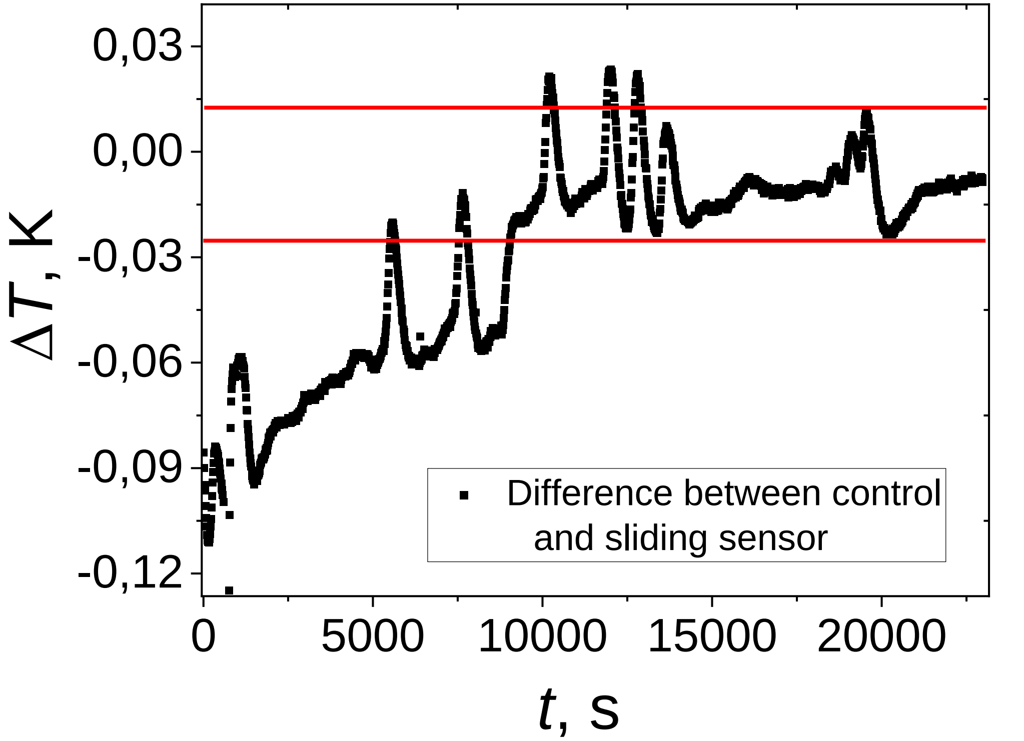
Experiment was motivated by Gleb Meshcheryakov

- Argon flow ≈ 800 cm^3/min;
- Water jacket is around testing tube;
- Pt100 RT + NI Controller;

Testing tube with sensor fully in



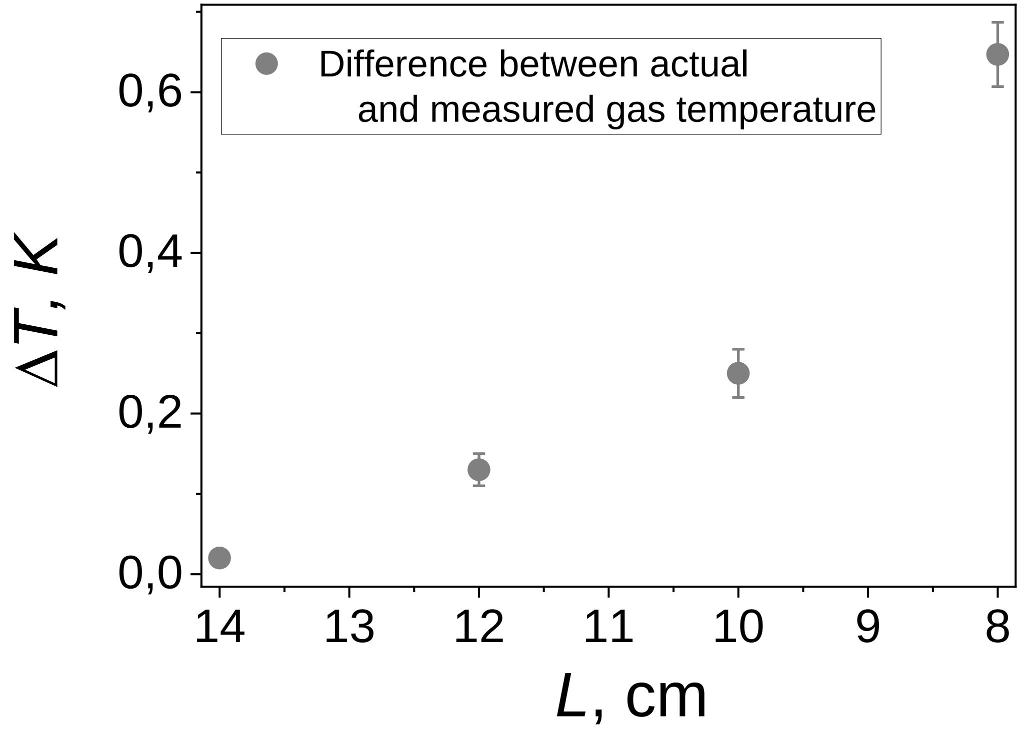
Sliding sensor almost out of tube



Time dependence of ΔT between the control and the full-drown sliding sensor

<0.03 K gradient is achieved inside the testing tube with gas about 15 °C and room temperature 21 °C

Gas temperature sensor



Difference between control and sliding sensor temperature on the length of wires inside gas

Prototype of gas temperature sensors with swagelok and wire support

Conclusions

- Pumping modules, vacuum tanks, and collectors have been delivered and installed on the platform;
- A shell-and-tube heat exchanger for the thermal stabilization of the flowing gas has been developed. The prototype is being manufactured in the LHEP workshops;
- Prototypes of temperature sensors for the flowing gas have been proposed and manufactured, with an expected measurement accuracy of 0.03 K;
- Experiments conducted have shown the necessity of thermal stabilization of the gas line using a water jacket.

Event	Date
Finalizing of platform pipes installation for MPD cooling system	November 2024
Assembling of temporary scheme for pipe washing and testing	November 2024
Connecting of pump modules for testing	November 2024
Continuation of assembling	December 2024

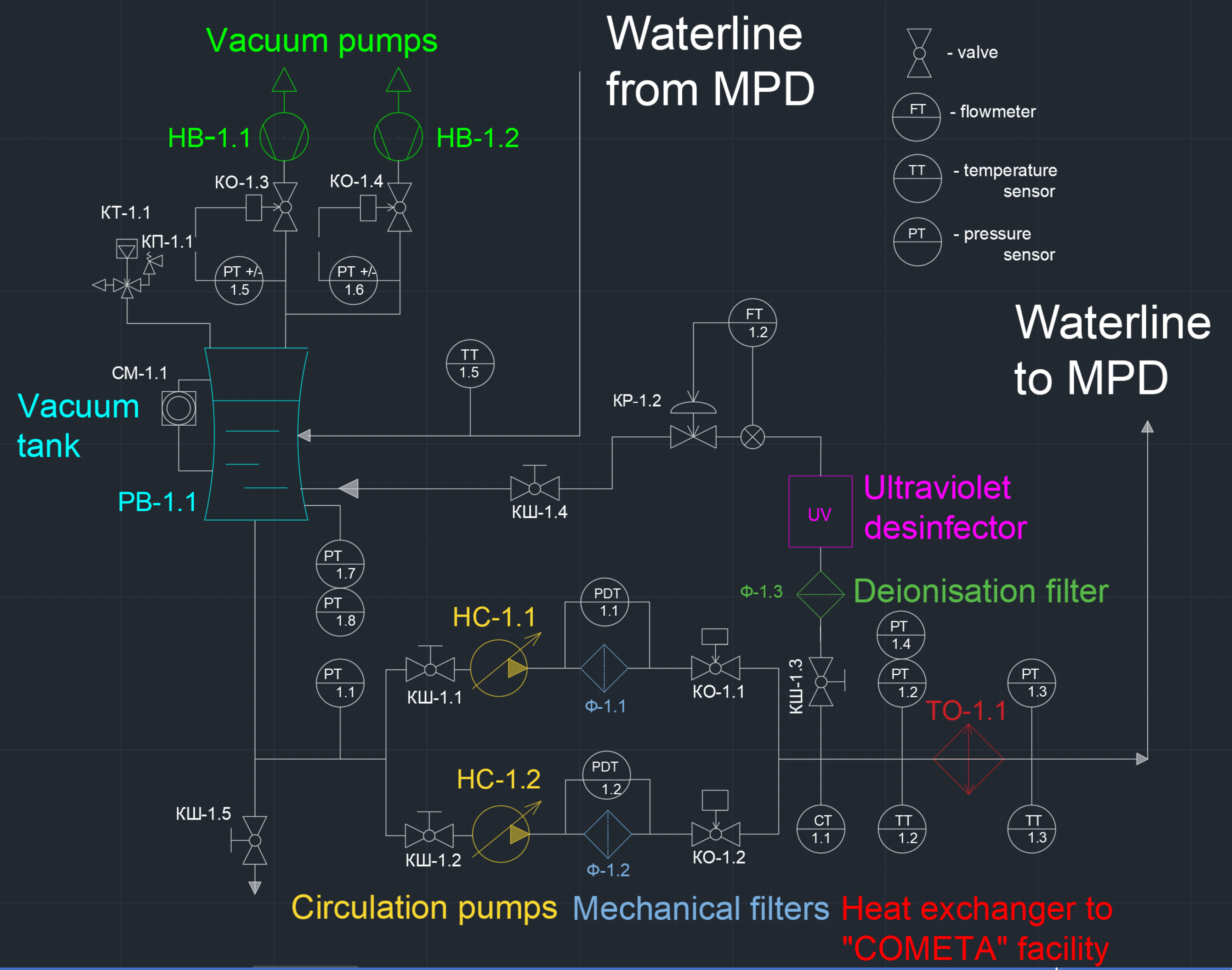
Scheme

The pump module & vacuum tank

- provides circulation,
- maintains low pressure,
- filters,
- thermally stabilizes

water before entering MPD

Principal scheme of water plant:



Pump module – main equipment

aquaPro UV- 12GPM-HT
ultraviolet sterilizer *

Heat exchanger “Ridan” XB95BR
removes heat to “COMETA”

Jetex V-VS 32-03
circulation pumps x2

Filter MVN- 07-02
removes > 20 μm particles x2

Ion-exchange CWO filter FSD1315
removes charged impurities

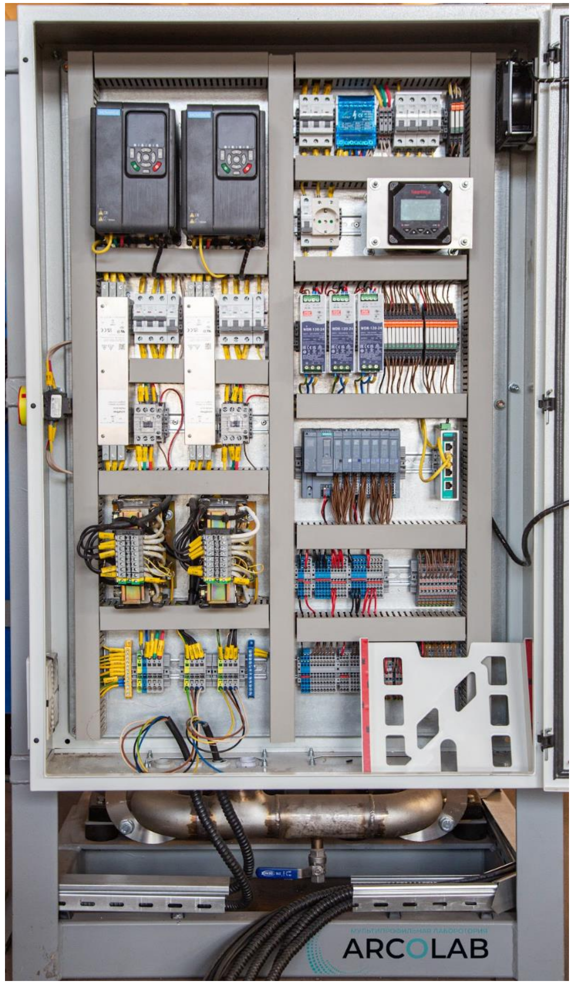
Pump module – control equipment

Frequency converter

EMC input filter

Automatic switches

N Bus zero



Automation cabinet

PLC Siemens
I/O modules
Read from sensors,
Control valves

Temgy DN 20 flowmeter
flow measurement

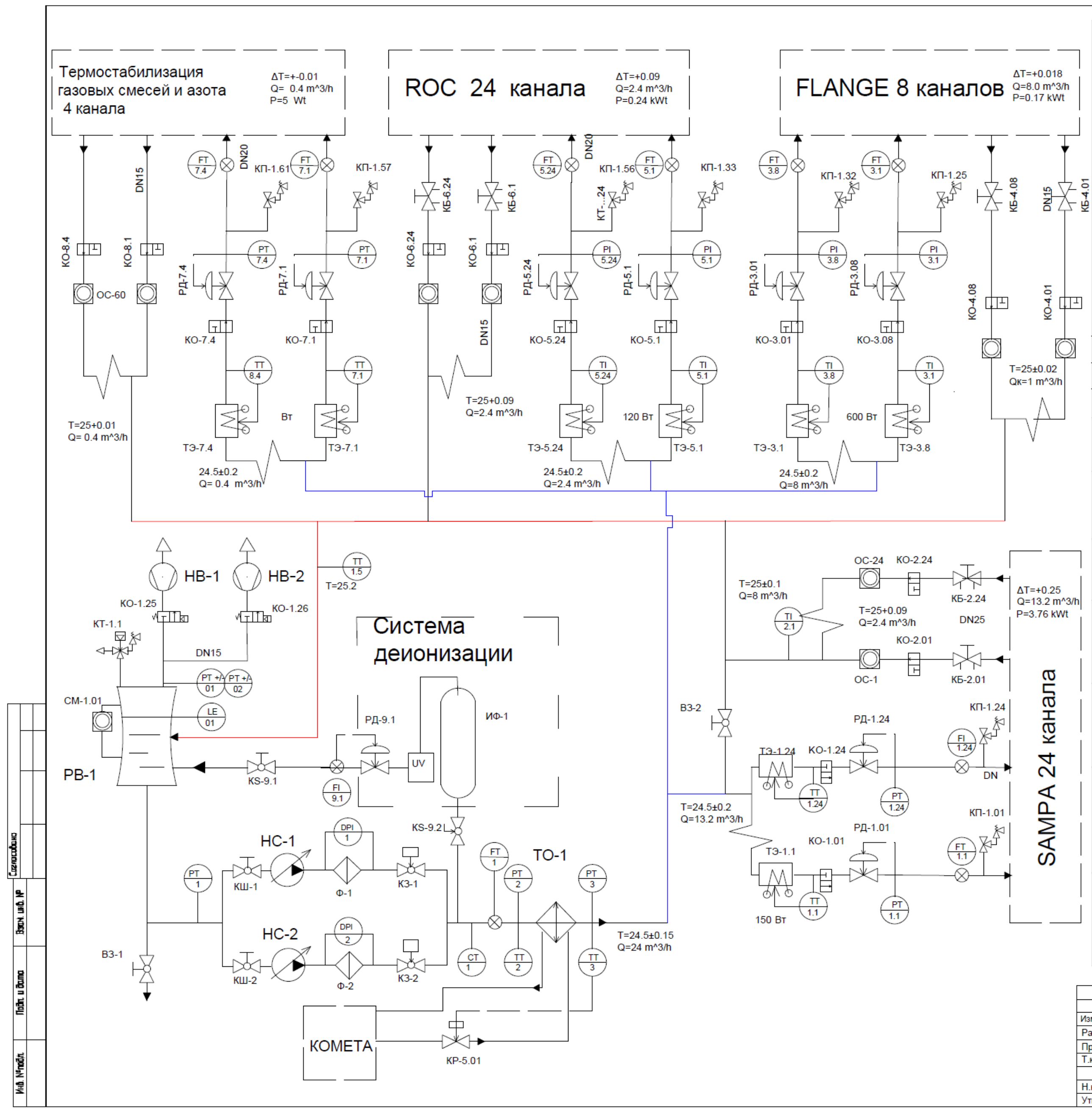
Bürkert 2702 & 2301 pneumatic control valves
controls flow, smoothens transitions

CCT-8930 conductometer
controls ion concentration

Pt-100-B
thermometer

Aplisens pressure sensors
Pressure control

Схема Cu-TS замкнутого контура



Обозн.	НАИМЕНОВАНИЕ	кол.	Примечание
Ф-1...2	Фильтр 10...30 мкм	2	40 м^3/h
НВ-1...2	Вакуумный насос KNF N 026 ANE	2	1.3m^3/h @P=0.1Bar
РВ-1	Резервуар вакуумный	1	V=1500L P=0.1Bar
КР-5.01	Регулятор (Buerkert 2301+8692+ST20)	1	Kv13 DN40
НС-1.1	Насос GRUNDFOSS CRN 32-3 (30m^3/h@35m@4kWt)	2	24 m3/h DN 65
К3-1...2	Кран с пневмоприводом Burkert 8805	2	DN 65
ТО-1	Теплообменник (Danfoss/Ридан XB12)	1	3.8 m^2 & 22 kWt
РД-8.1...4	Регулятор давления (Buerkert 2301+8692+8323)	4	Kv 0. DN15
РД-1.1...24	Регулятор давления (Buerkert 2301+8694+8323)	24	Kv 0.64 DN15
РД-3.1..08	Регулятор давления (Buerkert 2301+8694+8323)	8	Kv 1.6 DN 15
РД-5.1..24	Регулятор давления (Buerkert 2301+8694+8323)	28	Kv 0.16 DN15
КБ-2.1...24	Кран балансировочный Vexve 240	28	Kv=? DN 20
КБ-4.1...8	Кран балансировочный	32	Kv=? DN 20
К0-1.1..24	Кран шаровой с пневмоприводом Burkert 8805 тип А	60	DN 20
К0-2.1..24	Кран шаровой с пневмоприводом 8805 тип В (НО)	60	DN 20
К0-4.1..08	Кран шаровой с пневмоприводом	8	DN 20
ТЭ-1.1..24	ТЭН	24	N=150 Wt
ТЭ-3.1..8	ТЭН	8	N=600 Wt
ТЭ-5.1..24	ТЭН	24	N=120 Wt
КШ-1.1...2	Кран шаровой Vexve 232 (BURKERT TKU001)	2	DN65
В3-1...2	Кран шаровой Vexve 232 (Burkert 2657)	2	DN15
КТ-1.1	Кран трехходовой с пневмоприводом Burkert	1	1/2"
КТ-1...56	Кран трехходовой	56	1/2"
КП-1...60	Клапан предохранительный D7C-S LORCH	60	7мм 2Бара
ОС-1...60	Смотровое стекло END-Armaturen SG30021	60	DN20
РД-9.1	Регулятор расхода (Buerkert 2301+8694+8035)	1	Kv 1.6 DN 15
ИФ-1	Фильтр деионизационный	1	2 м^3/h
UV	Кварцевая лампа	1	
	КИП		
TI-...39	Термопара PT100	39	
PI-01...50	Преобразователь давления	32	
FI-01	Расходомер BURKERT 8035	1	12. m^3/h DN50
FI-03...27	Расходомер ультразвуковой (Burkert)	24	0.25 m^3/h DN15
FI-28...36	Расходомер ультразвуковой (Burkert)	8	0.5 m^3/h DN15
FI-37...61	Расходомер (Burkert)	24	0.1 m^3/h DN15
СТ-1.1	Датчик электропроводности	1	5-7

Изм.	Дата	Лист	№док	Подпись	Дата
Разраб.	Новиков				
Проверил	Галуза				
Т.контр.					
Н.контр.	Сенкевич				
Утвердил	Левков				

Термостабилизация ТСР
Медная подсистема

Схема комбинированная принципиальная

Литера	Лист	Листов
О		

ООО ТурбоЭнерджи

Копировал Формат А2