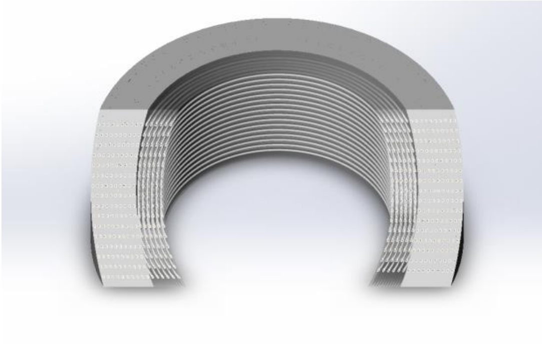

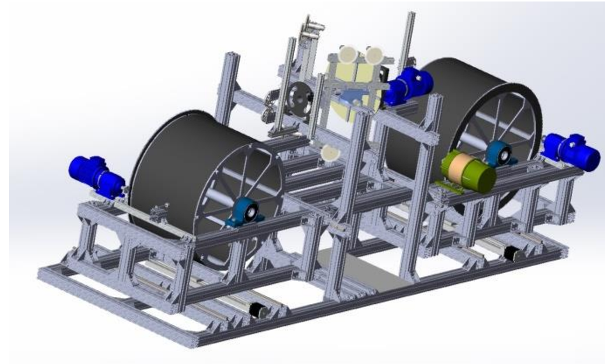

Development of superconducting magnetic energy storage for the power system of the particle accelerators Booster and Nuclotron of NICA

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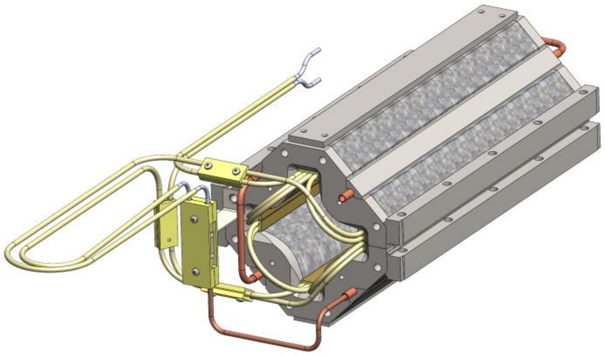
27th International Conference on Magnet Technology,
15-19 Nov. 2021, Fukuoka, Japan

High current HTS magnets at JINR

- SMES for NICA (2022-2023, 2023-2025 two stages)
- Nuclotron upgrade (with HTS windings) and further R&Ds for accelerator magnets
- Medical cyclotron SC230 (LTS and later HTS coils)
- R&D of irradiation defects, and artificial pinning centers technologies (at 2-3 T from LNe to LN2 at 65 K?)

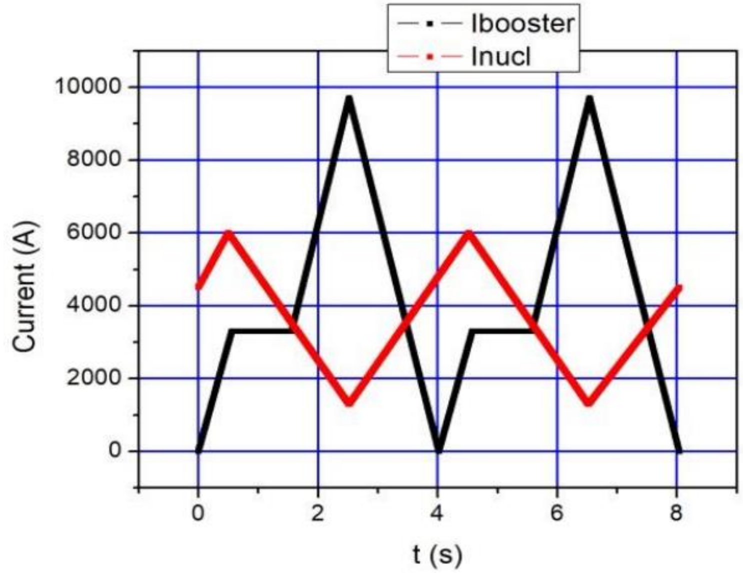
- Pulse current and large HTS magnets

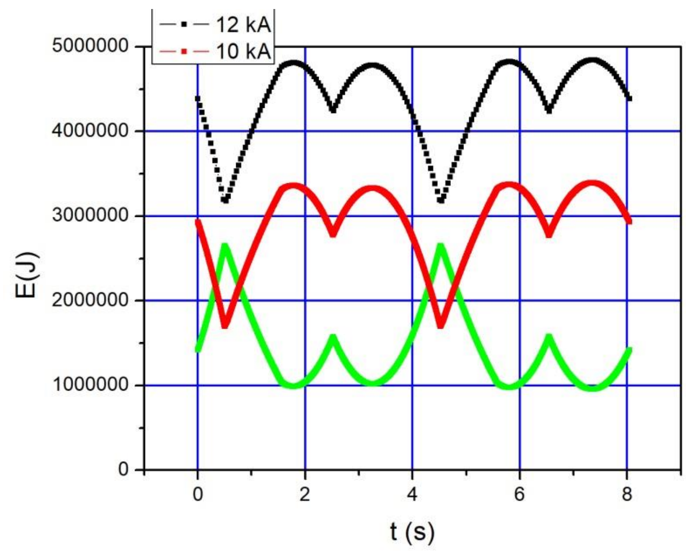
with forced flow cooling, cables for them



The task and problems of NICA SMES

- Booster and Nuclotron magnets are pulse, collaboration mode – “antiphase with shift”
- Energies – up to 1.7 MJ during «collaboration», 2.2 MJ for Nuclotron, 1.5 MJ for Booster
- Field and current choice – 6 T 8-10 kA
- Therefore, size order ~ 1 m
- Why HTS conductor?
- CORCC on a tube choice
- Why LNe?
- The pulse solenoid frame must be dielectric – what kind of?
- Stray field must be <2*10^{-5} T «at beams» - shielding?
- Cryostat (dielectric vacuum vessel), current leads (30 K - all HTS)





SMES design features

2 more reasons for an HTS SMES @ LNe: there are many qualified people at JINR who have made and now operate with a lot of SC magnets, cryogenic devices, complicated electronics; and it's time to start with HTS magnets, and LNe cooling.

This way, we need:

- Power system which determines a magnet (3 or 1 coils, 2 or 1 loads, energies, currents)
- 1 m solenoid (not a Brooks coil, for HTS – for cables optimization)
- The HTS cable for it (current capacity, mechanical properties, hydraulics, thermal stability etc.)
- Frames of Ø0.5-1 m, strains inside elastic limit at 100 millions cycles at 6 T and 2-3 kA/cm^2, but dielectric ones, and for a round cable
- Cabling and winding technologies and an HTS workshop
- Cryogenic system (LNe – never before) - ordering
- Protection (HTS NZ very precious detection and very fast energy evacuation)
- Test and research facility (tapes and cables VI curves, AC losses, NZP velocity, mechanical cryogenic properties, coils tests, HTS tapes and cables commissioning tests) should be prepared and applied

Collaboration for the NICA SMES

- JINR – SMES solenoid, power system and cryogenics ordering, HTS tapes ordering and reel-to-reel diagnostics, a part of R&Ds and ordering, commissioning tests and putting into operation all the power system (in 2 stages)
- ASIPP (Academy of Sciences Institute of Plasma Physics, Hefei, China)

– in the frames of Russia-China scientific partnership program –

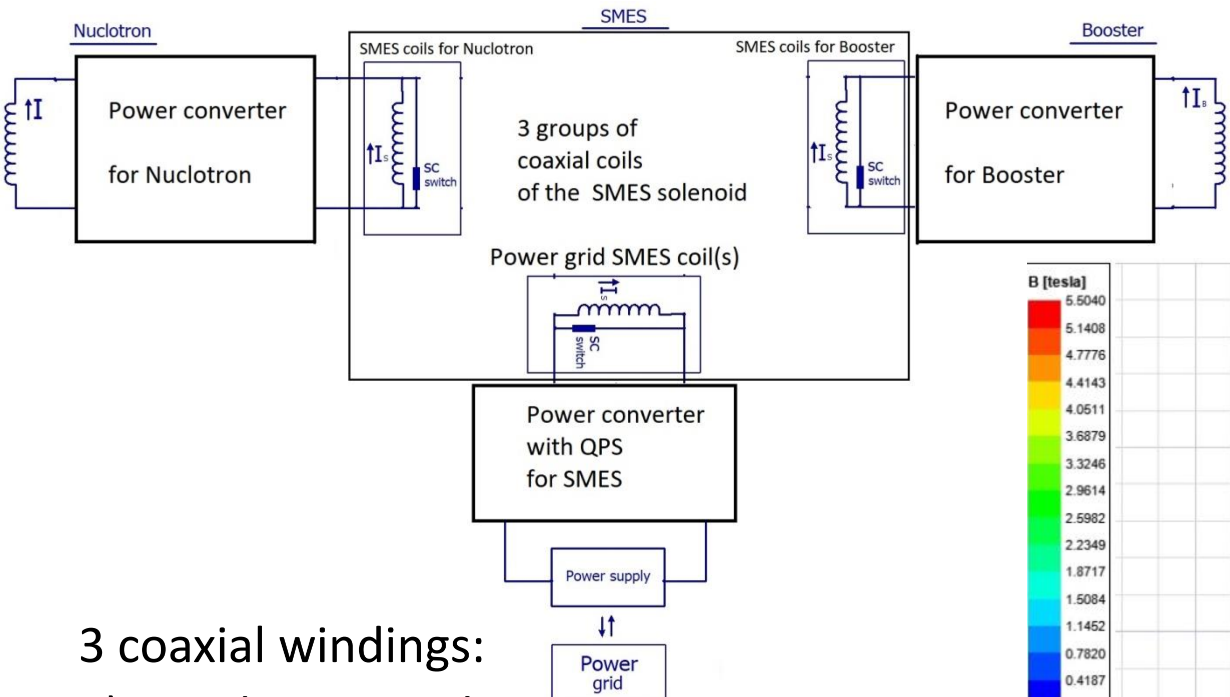
a part of R&D, 0.5-1 MJ HTS solenoid, a part of HTS tapes, cryostat and a pair of CLs, a magnetic shield if we will need, participation in putting into operation

By contracts:

- MEPhI – a part of calculations and measurements (magnetization, AC losses and mechanical properties of HTS tapes in CORC cables), one layer cable coil diagnostic system development (Hall probes array, magnetic spot)
- S-Innovations (SuperOx) – HTS tapes manufacturing
- LM-Invertor (Russia) – semiconductor converters R&D, manufacturing and putting into operation
- Cryotec (Germany) – 500 W 30 K neon liquefier R&D, manufacturing and putting into operation
- Superplast (Russia) – polymer composite plastics and compounds

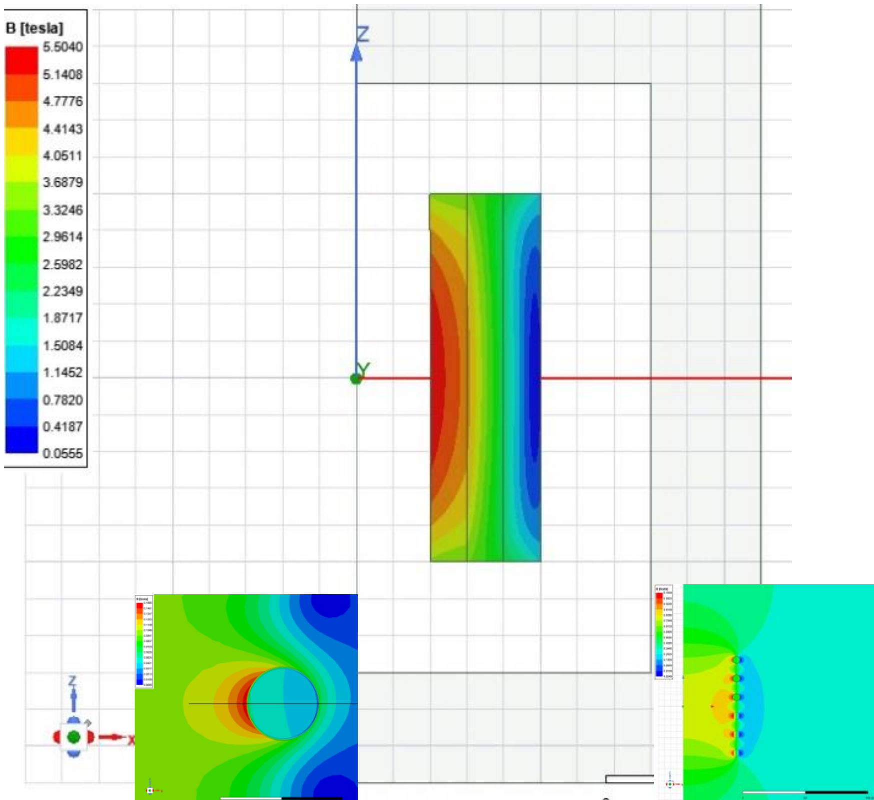
Power system «basic option» – a transformer type SMES and PWM converters

- Total galvanic isolation of the loads and the power grid



Protection – energy evacuation to

3 controlled load resistors arrays



3 coaxial windings:

1) supply, up to 4 kA, 200 turns

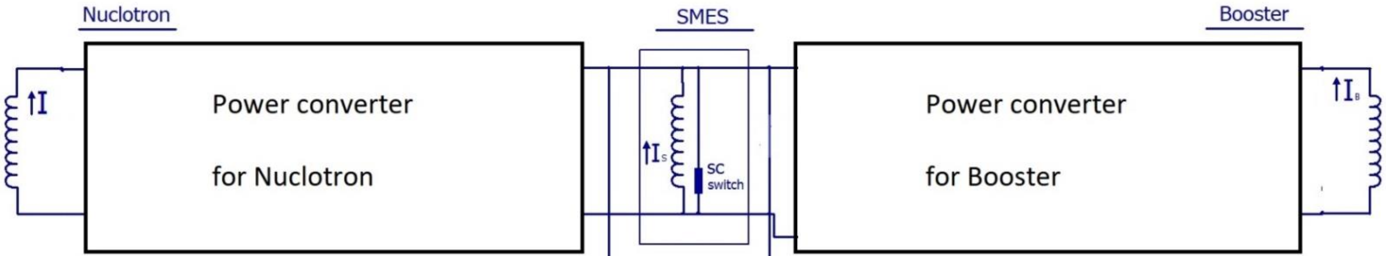
2) Booster circuit, up to 8 kA, 250 turns

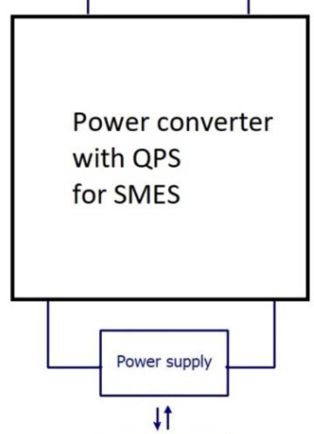
3) Nuclotron circuit, up to 8 kA, 225 turns

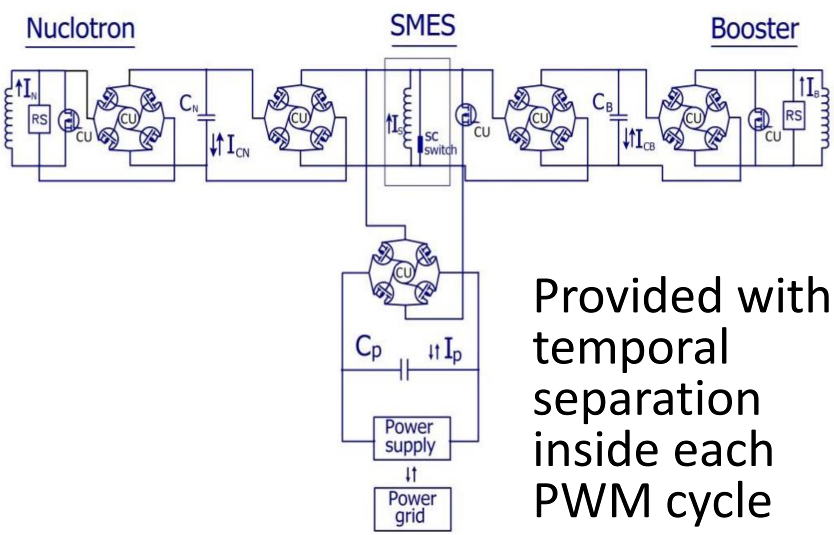
Or 1) and (2)+3)) at «single load» modes

Power system «backup option» – SMES with 1 coil and PWM converters

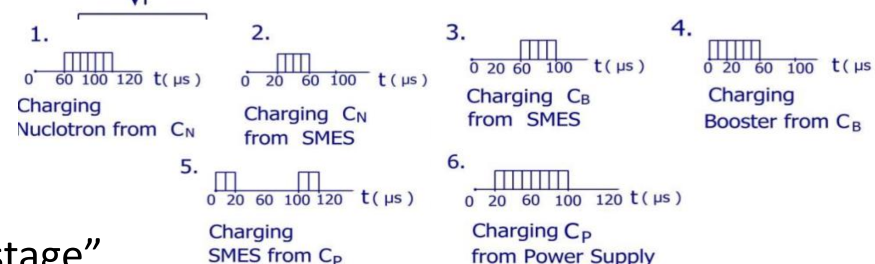
- Isolation is just «power», not galvanic







Provided with temporal separation inside each PWM cycle

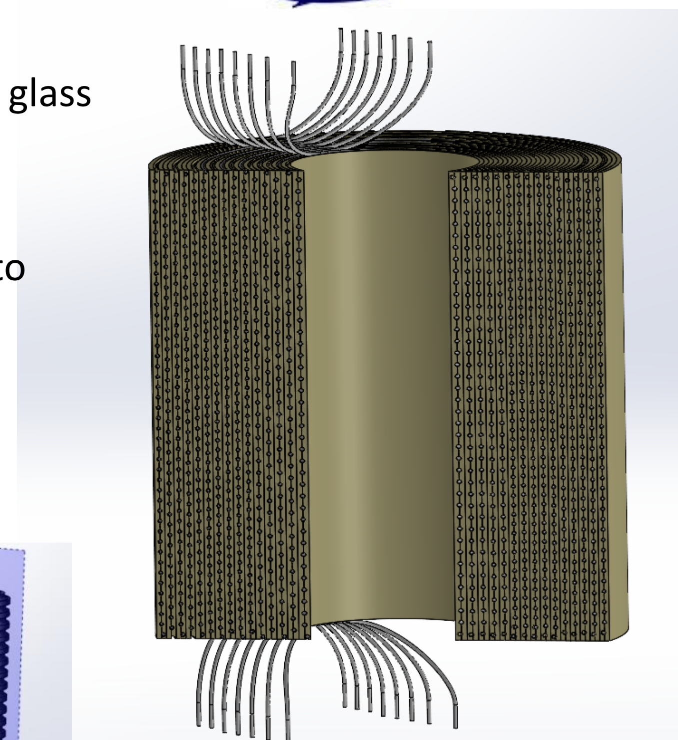


Both two mentioned option and the third "1st stage" option "only Nuclotron" can be done with the same HTS solenoid, but with different connections

LHEP ЛФВЭ

The HTS solenoid design features

- Winding layer-by-layer
- CORC cable with cooling channel of tube Ø6 мм (8 mm Melchior tube), Hastelloy tape bandage
- Glass plastic frames with milled grooves (as an option – wound glass fiber tubes with 3D printed mountable on them groove parts)
- Screwing onto, or mounting with fiberglass bandage winding
- LNe forced flow cooling of each layer in parallel from bottoms to tops of a layer coil



Protection features under development:

Temperature margin 3-5 К plus Iop<70%*Ic (Top+Tm)

(trying not to quench!)

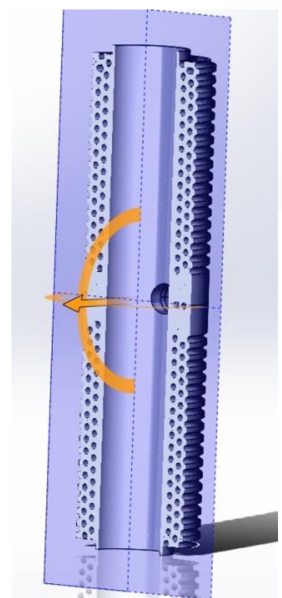
NZ detection and quench preventive steps

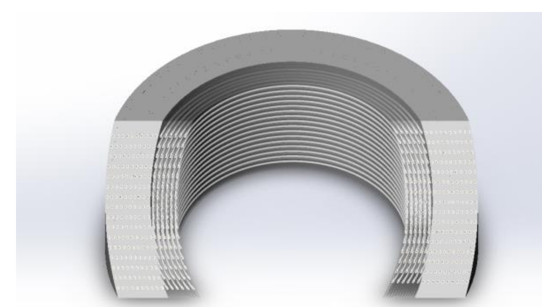
- temperature, vacuum, bridge potential

probes <1 mV (10-100 μV is better),

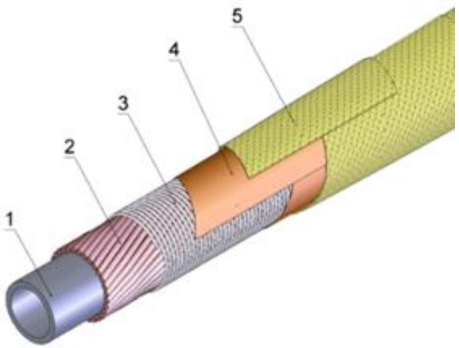
But if quench anyway:

Energy evacuation to 3 resistors arrays at V<1 kV



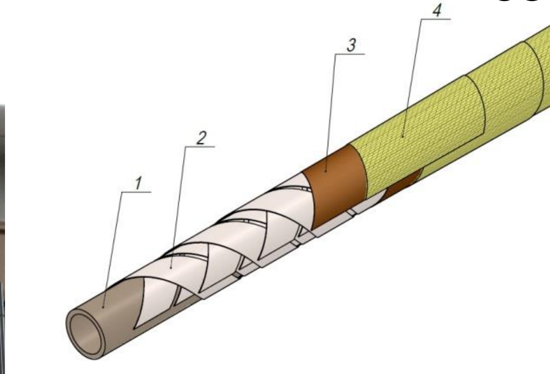


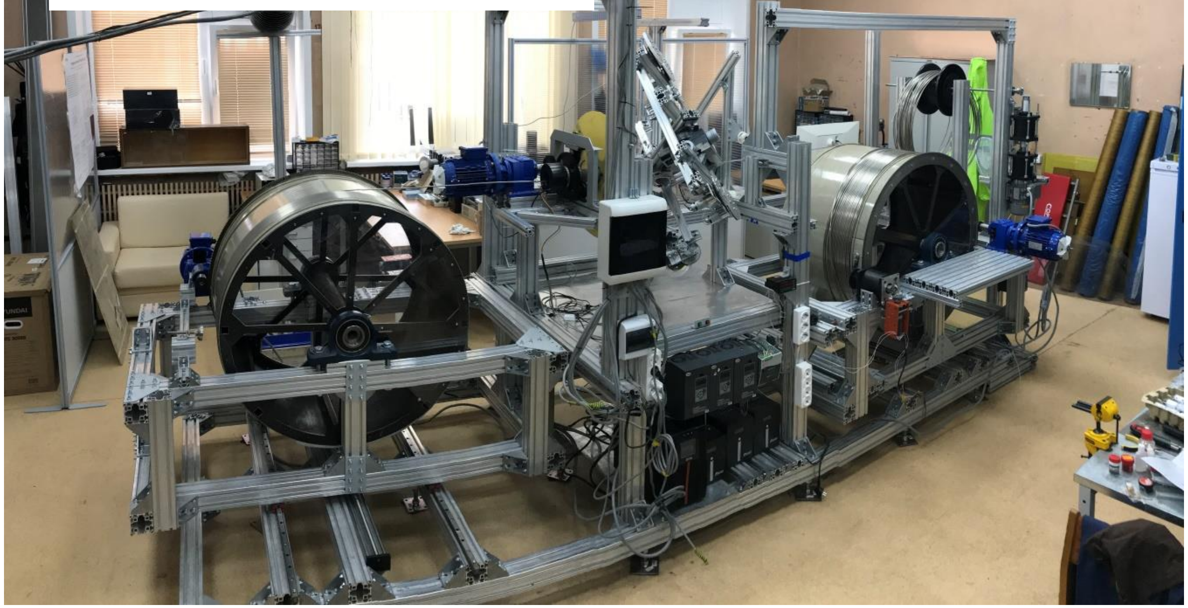
HTS cabling workshop

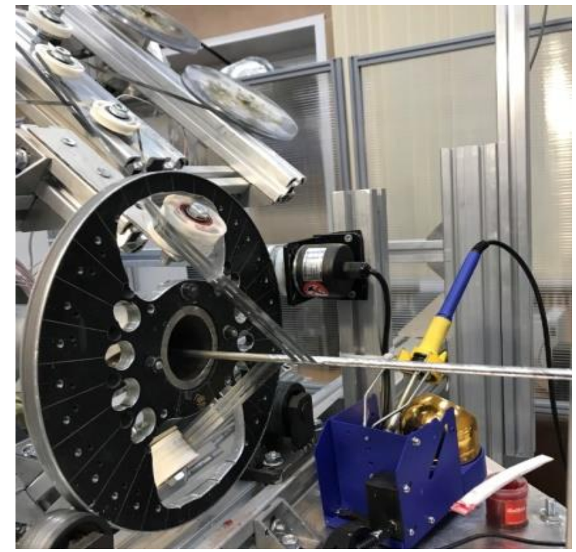


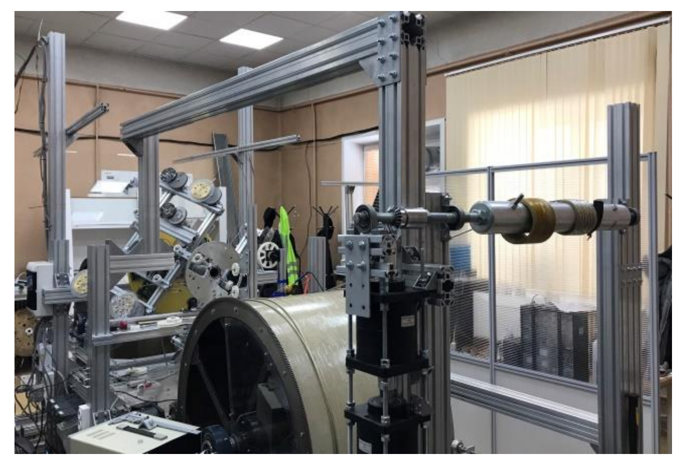
CORC cables up to 100 m, up to 10 HTS or bandage tapes per a pass,

solenoids up to 400 mm



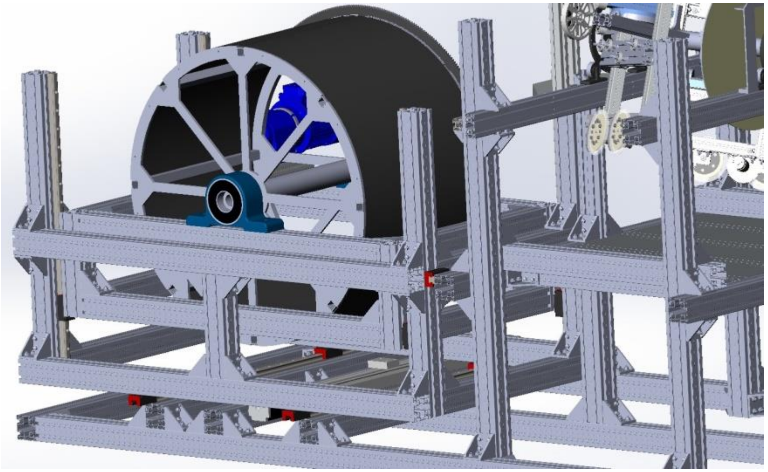


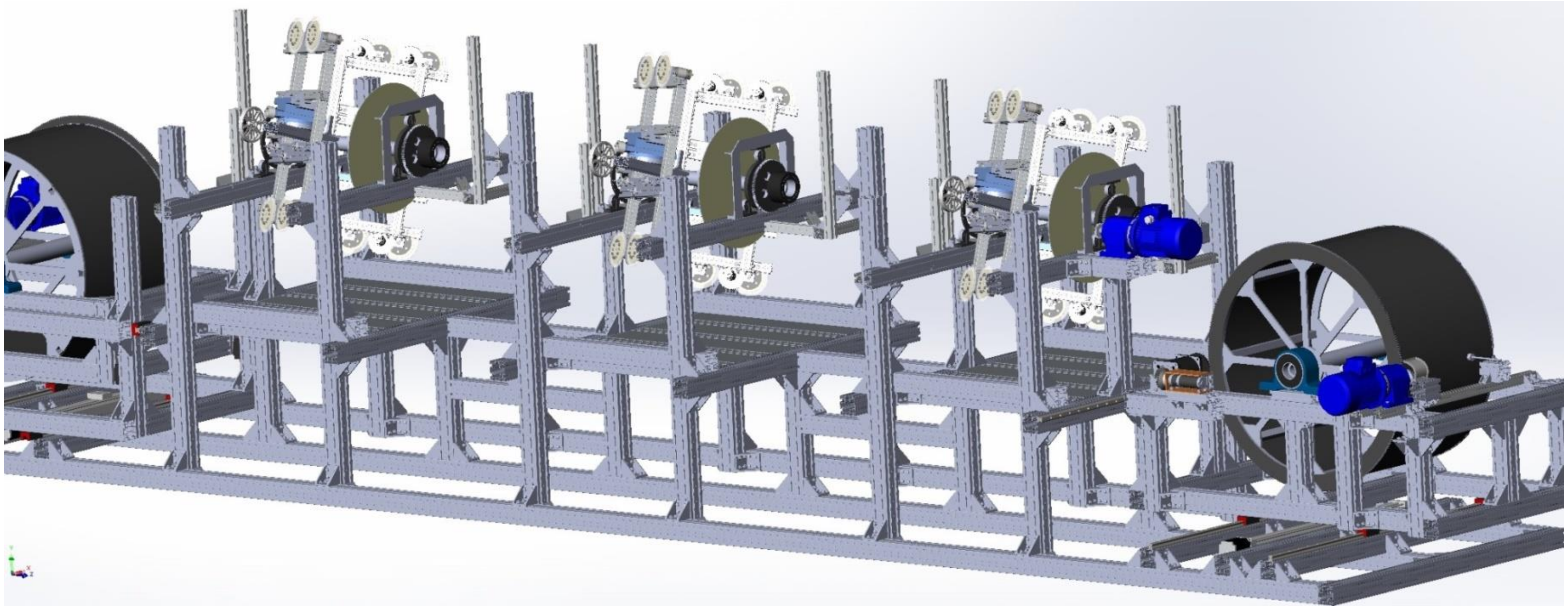




HTS cables and windings manufacturing plans

SMES solenoid manufacturing machine will consist of:
Cabling machine with 3 units, 10 tapes each
Solenoid unit with changeable diameter mandrel 0.4-1 m
Glass plastic frame tubes can be wound on the same.
Parameters:
Winding up to 3x2x5 tapes onto Ø8 mm tube,
winding the solenoid layer by the same pass,
cable length up to 200 m, and coil diameter up to 1 м,
coil length up to 1 m too.
Automatically controlled cable (~500 N) and tapes (~10 N) tensions independently of velocity is developed.

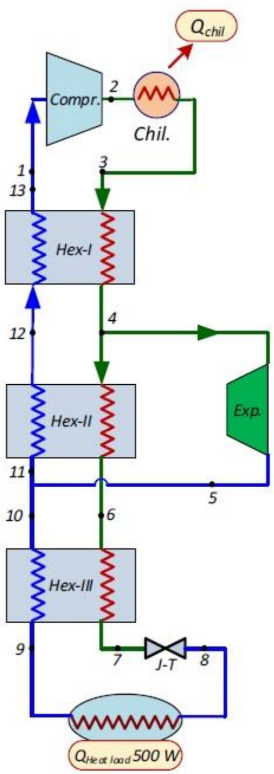


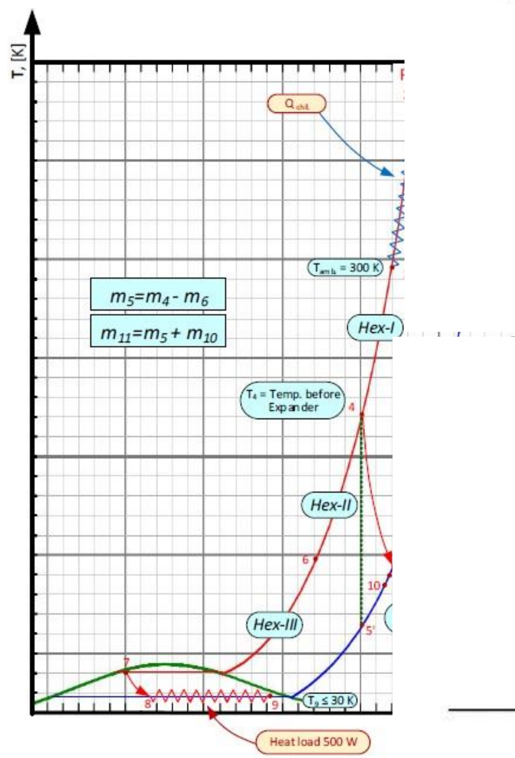


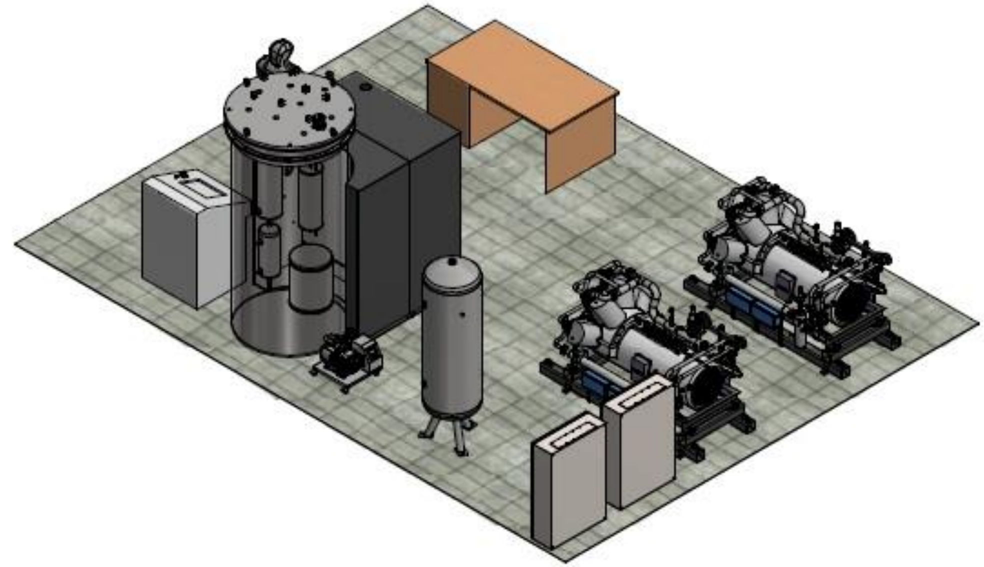
Neon liquefier

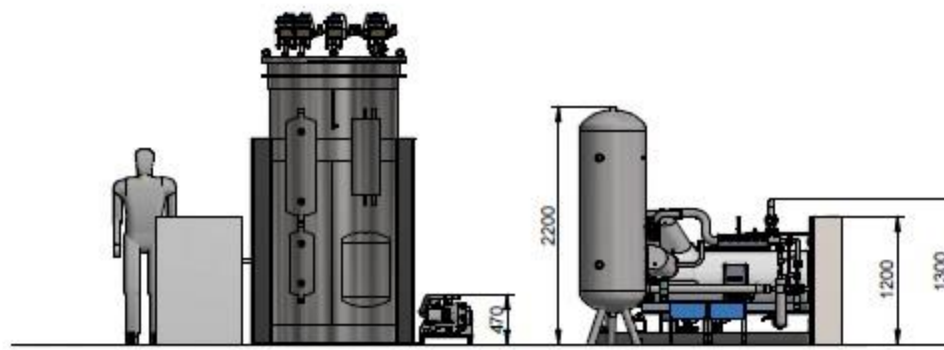
Provides force flow cooling to 28-30 K

With 500 W at LNe









Conclusions

- SMES solenoid should be made in 2022
- And put into operation with the 1st stage of power system in 2023 (in another building, without magnetic shield).
- The HTS high current magnets manufacturing and LNe cryogenic test facility based on the liquefier and the existing Nuclotron magnets power supply will be placed in the same building .
- The 2nd stage of power system must be put into operation in 2024-25, maybe with magnetic shield, if we remove it to the accelerators building.
- Power systems are being developed, and the Ne liquefier is under construction now, the HTS tape batches are being manufactured.
- The collaboration for this work is being completed.
- All R&Ds for the SMES development – Ne cooling, HTS cabling and winding technologies, power systems with SMES, structural plastics, AC losses, HTS NZP and quench protection system – are being carried out, and they will be useful for many other magnets and applications.

Thank you for your attention!