Development of indirect cooling cryogenic system with nitrogen and helium heat pipes for superconducting insertion devices in BINP.

Tsukanov V.M[1], Mezentsev N.A, Safronov A.N, Khrushchev S.V, Shkaruba V.A

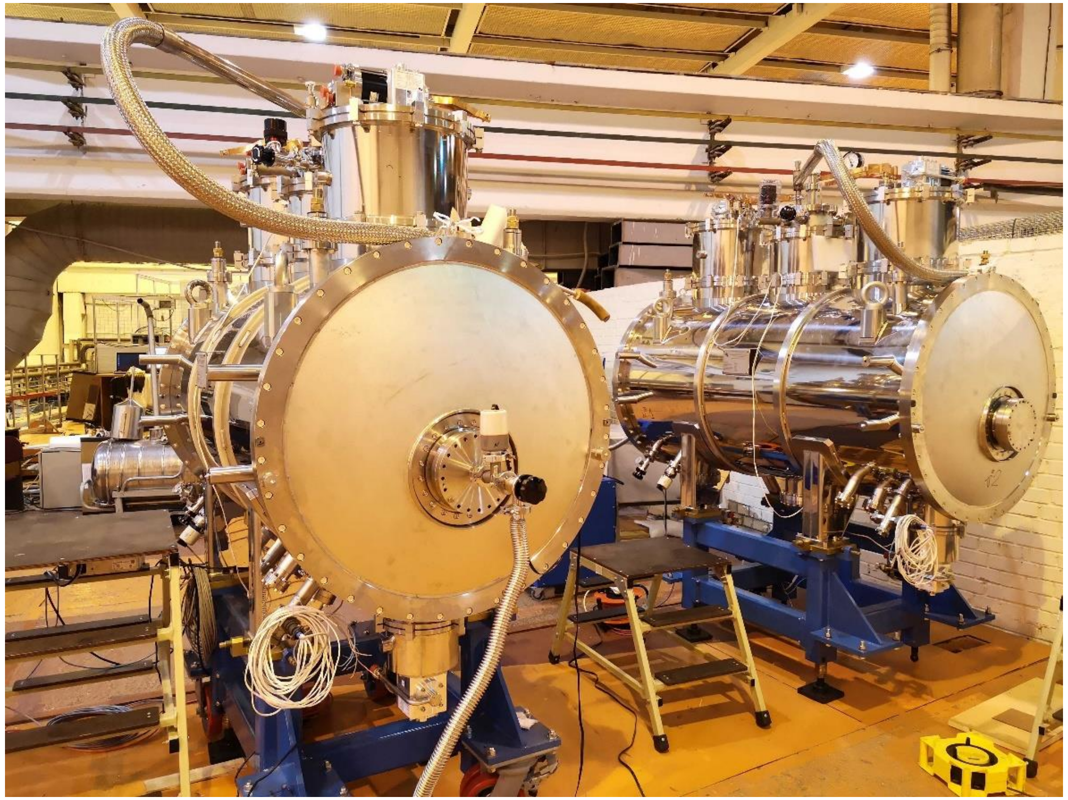
- The using of indirect cooling cryogenic system based on cryocoolers for superconducting insertion devices (wigglers and undulators) gives opportunity, in contrast to magnets immersed into liquid helium, to reduce the size of the magnetic gap due to the removal from it the walls of the helium vessel and increase the magnitude of the magnetic field. To increase the cooling efficiency of such a magnet, which is in vacuum and does not have direct thermal contact with cryogenic liquids, the heat pipes of siphon type filled by nitrogen and helium is used as the heat conductors for connecting of superconducting magnet with cryocoolers stages. The article describes the principle of operation, design and application features of the heat pipes on several indirectly cooled superconducting insertion devices created in BINP.

- We began to deal with heat pipes in 2009. At the moment, we have made 3 projects of “dry” superconducting devices using heat pipes.
  - **1. The first superconducting wiggler with indirect cooling (a “dry” magnet) was manufactured and delivered to a synchrotron radiation source in Karlsruhe (Germany) in 2014 - 2015.**
- The magnet cooling system consists of two parts. At the initial stage cooling was carried out by two nitrogen heat pipes, which provide thermal contact of the magnet with 1 (60K) stages of the SRDK-415D cryocoolers. Outside valves were used to fill the tubes with nitrogen. In the first version, we used resistive heaters to maintain the optimum temperature of heatpipe condensers.
- Heat pipes work efficiently up to the freezing point of nitrogen (about 60 K). After this temperature achived only a helium system is used, which includes a helium volume with inner heat exchangers installed at the cryocoolers 2 (4K) stages and outer heat exchangers installed at the ends of the magnetic system. Temperature equalization along the magnetic system was carried out by massive copper plates.

- **2. In 2017-2019, 2 wigglers had been manufactured for the Kurchatov Synchrotron Radiation Source, Moscow.**

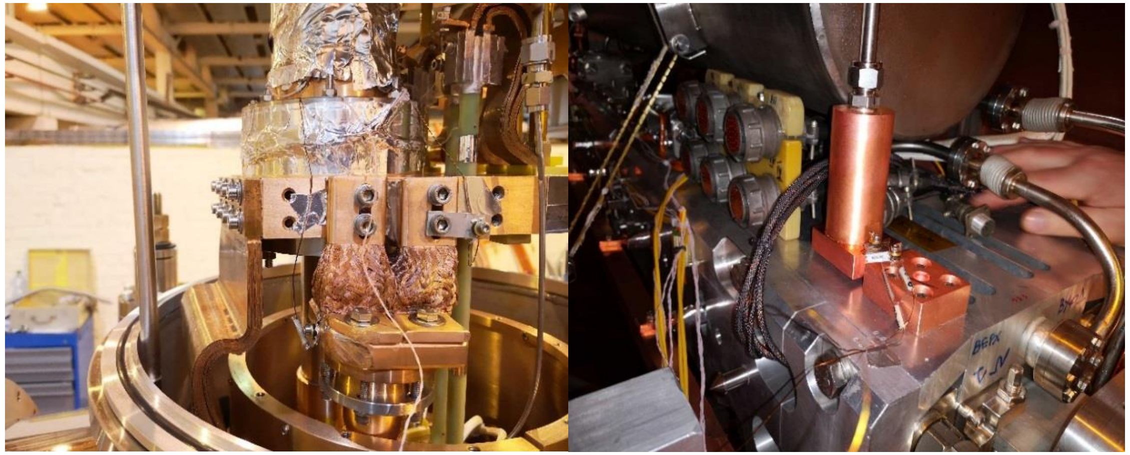
- The following changes were made in cooling system. Nitrogen heat pipes were installed completely filled and ready to work, without external valves, which greatly simplified the assembly process, and increased the reliability of the wiggler. Before installation, we performed a long-term test of the tightness of the structure using helium under high pressure (more than 100 bar). The principle of controlling heat pipe temperatures had also been modified. Unlike the 1st option, the thermal regimes of the heat pipes were controlled by turning on and off cryocoolers, without using additional heaters.

- Some changes also were made in helium cooling system. To cool the magnetic system, holes were drilled along the entire length along the yoke, which made it possible to obtain uniform cooling along the entire length of the magnet and make unnecessary copper plates. Installed inside the helium volume, highly efficient condensing heat exchangers connected directly to the low-temperature heads of cryocoolers made it possible to abandon the use of liquid helium in the cooling process. To cool the magnet, it is sufficient to provide a continuous supply of gaseous helium at a pressure of 1-1.4 bar. Helium gas can be supplied either from cylinders or from a Dewar vessel.

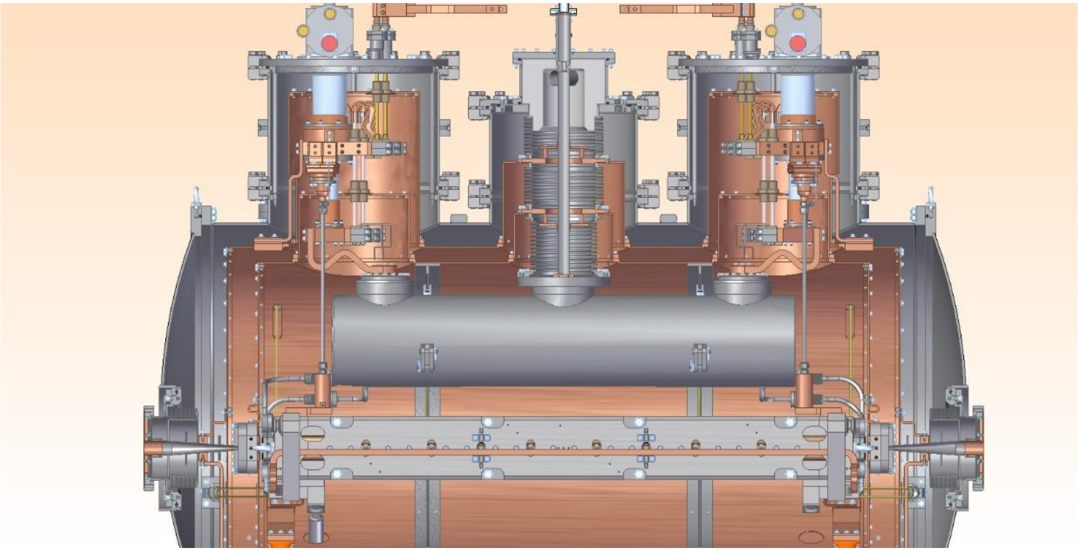


Wigglers prepared for ring mounting.

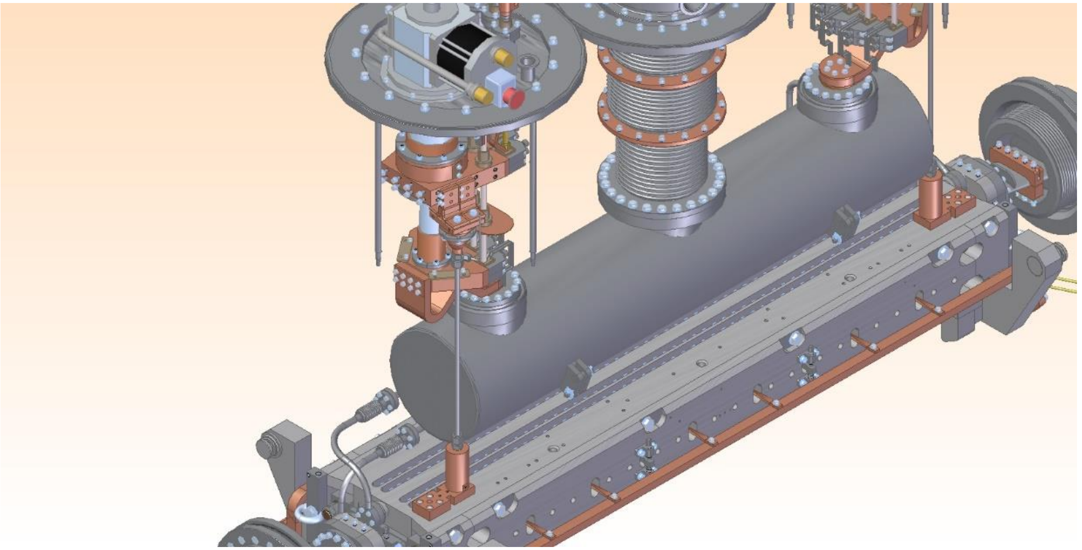
A recondenser (connected to 1 (60K) stage SRDK-415, an evaporator (mounted on a magnet) and a heat pipe assembly.



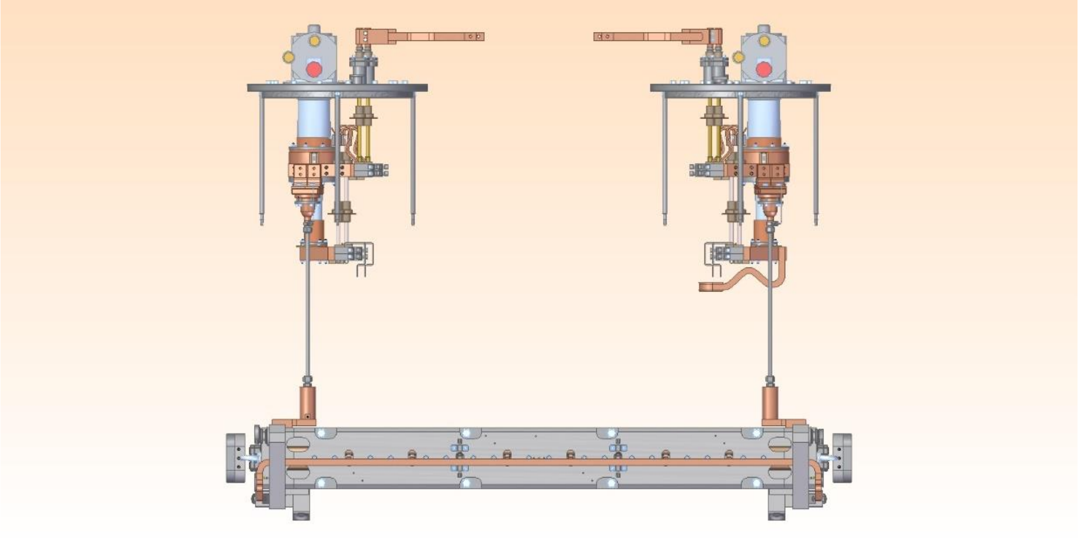
Installing heat pipes in a wiggler. Two thermal sensors are installed on the heat pipes of the condenser and the evaporator, which allow controlling the efficiency of the heat pipes by the temperature difference along the heat pipe.



Section of a 3D wiggler model.

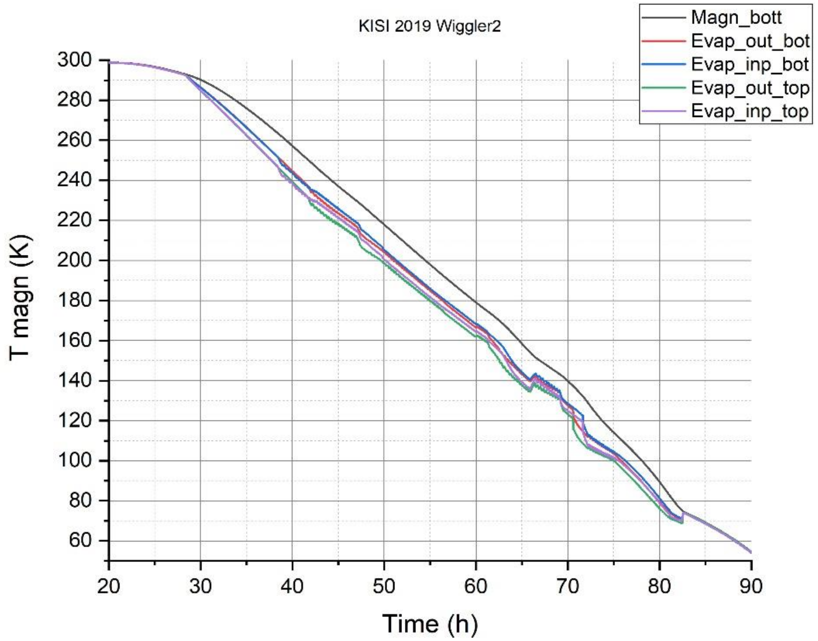


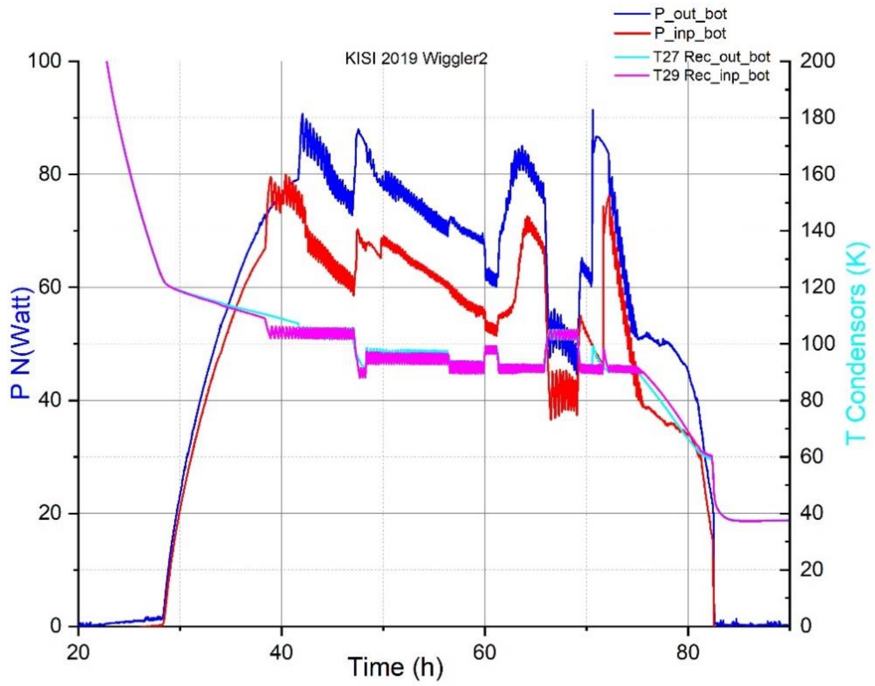
3D model of the cooling system.



Arrangement of nitrogen heat pipes.

3D models of wiggler, cooling systems and the arrangement of nitrogen heat pipes.

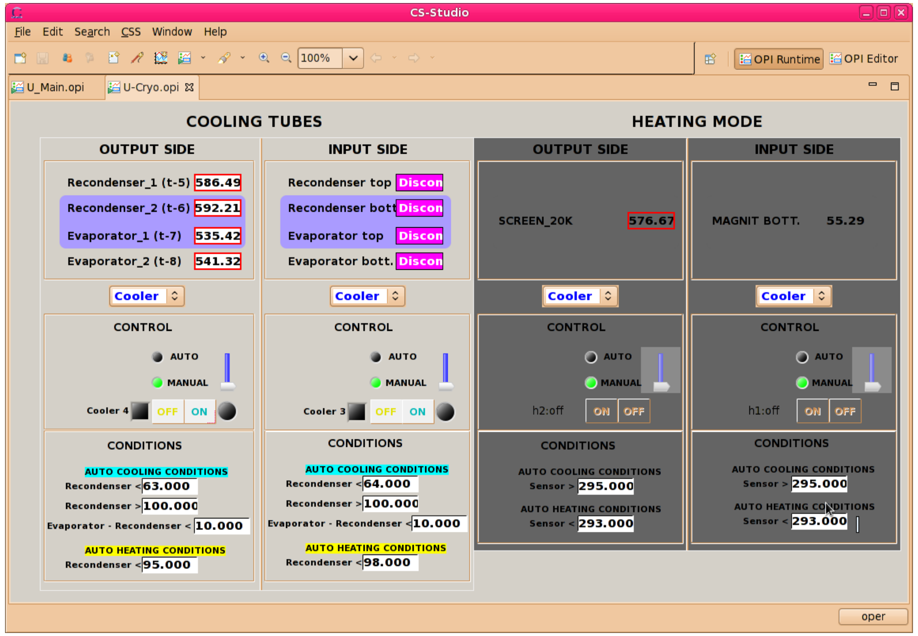


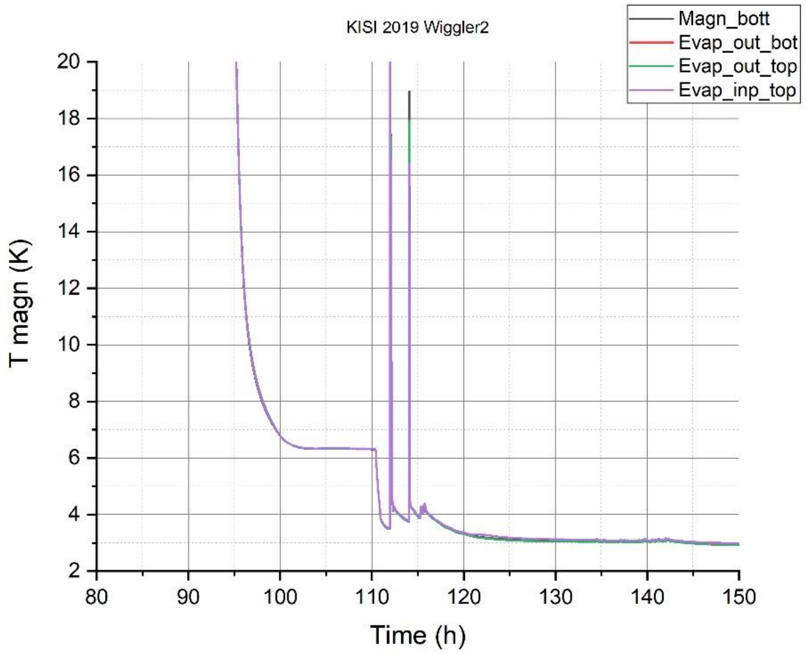


The operation of the nitrogen part of the cooling system.

The temperature difference between the center of the magnet (Magn_bott) and the ends of the magnet (Evap_inp/out_bot heat pipe evaporators) is determined by the heat flux flowing along the magnet. When 70 K is reached, the heat pipes turn off and the flow stops. Subsequently, the magnet is cooled only by a helium system.

The change in the power of nitrogen heat pipes during cooling down. During the cooling down process, we changed the temperature settings of cryocolers second stages (T27Rec_out_bot and T27Rec_inp_bot), the graphs show the effect of this temperature changing on the power of the heat pipes.



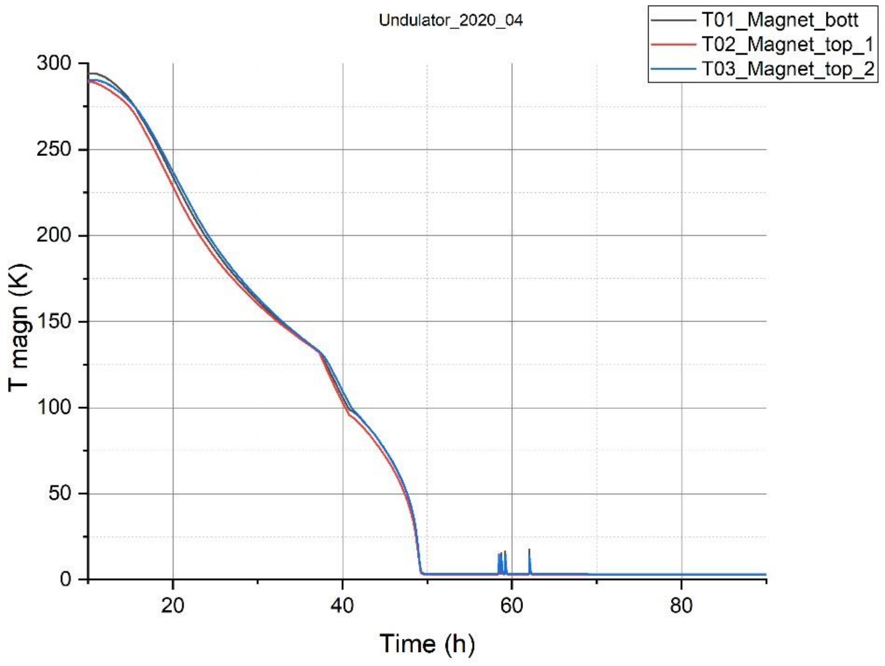


Control panel for heat pipe operating modes. In the process you can change the temperature settings of the condenser heads of the heat pipes, as well as switch to manual control of the operating mode of the cryocoolers.

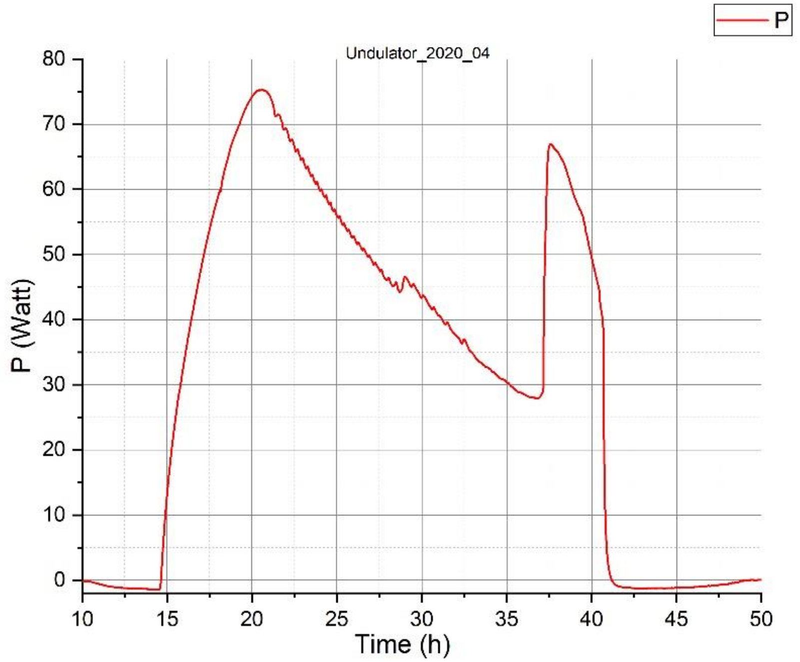
Exit to the operating mode. At a temperature of about 6.2 K, the process of accumulation of liquid helium (100h - 110h) began. The closure of the helium volume led to a decrease in the temperature of the magnet to 3 K (> 110h). In this case, a reduced pressure is created in the helium tank. The final temperature of the magnet in a stationary state depends on the amount of heat inleaks and characterizes the quality of manufacturing a cryostat.

3. We are currently testing the magnetic prototype undulator system.

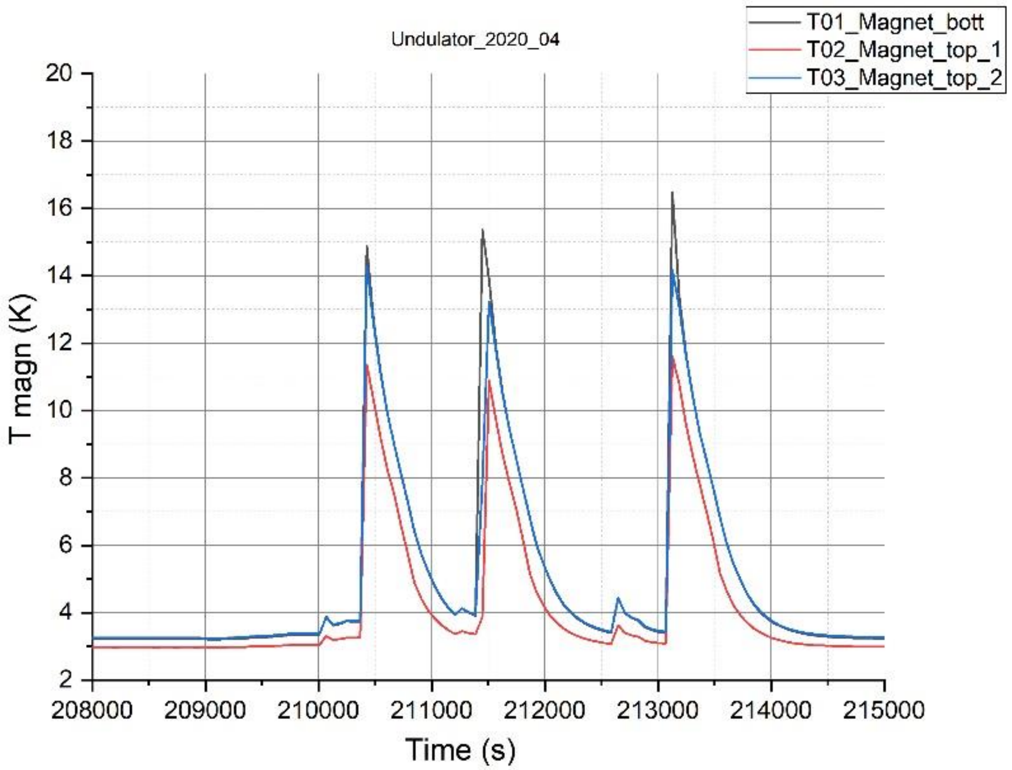
We used only nitrogen and helium heat pipes for new cooling system. This eliminates the need for liquid helium.



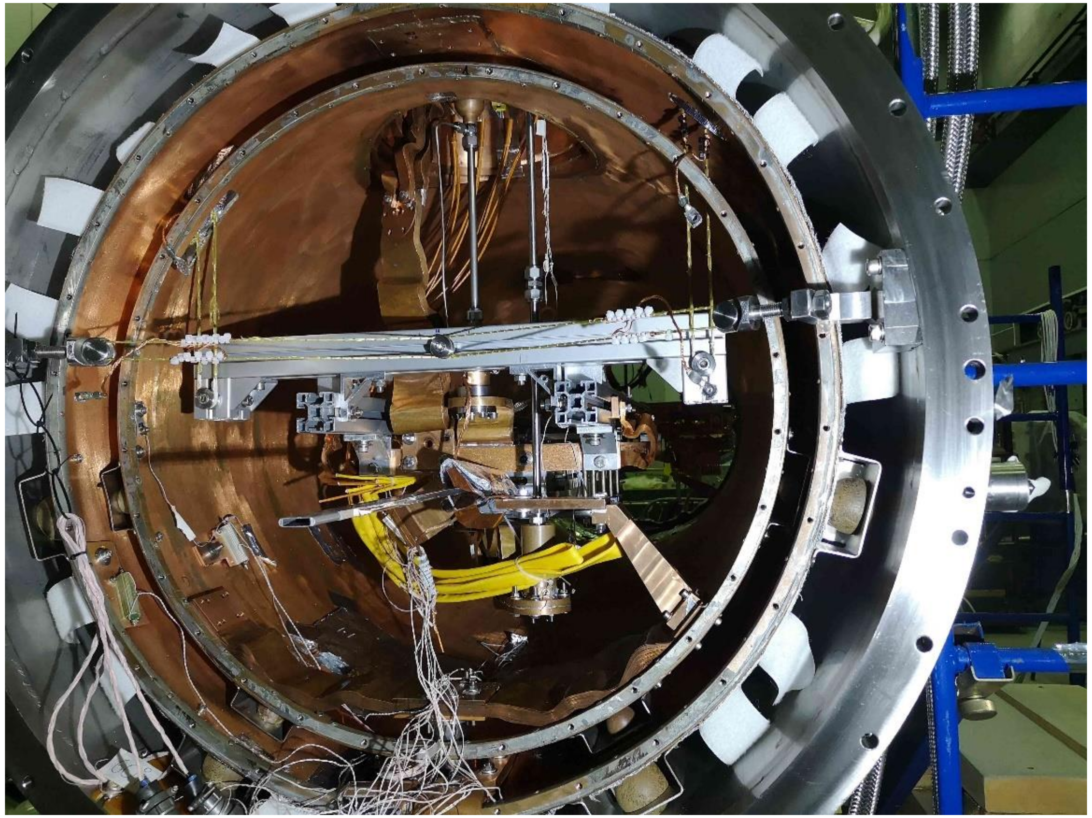
Graph of cooling down the prototype of the undulator using nitrogen and 2 helium heat pipes.



Graph of the efficiency of the nitrogen heat pipe on the prototype of the undulator in the process of cooling down the magnet. The cooled mass is about 80kg.



Recovery after quench of superconductivity. It takes about 10 minutes to return to working condition.



View of the experimental cryostat when testing the prototype of the undulator at the side of heat pipes location.