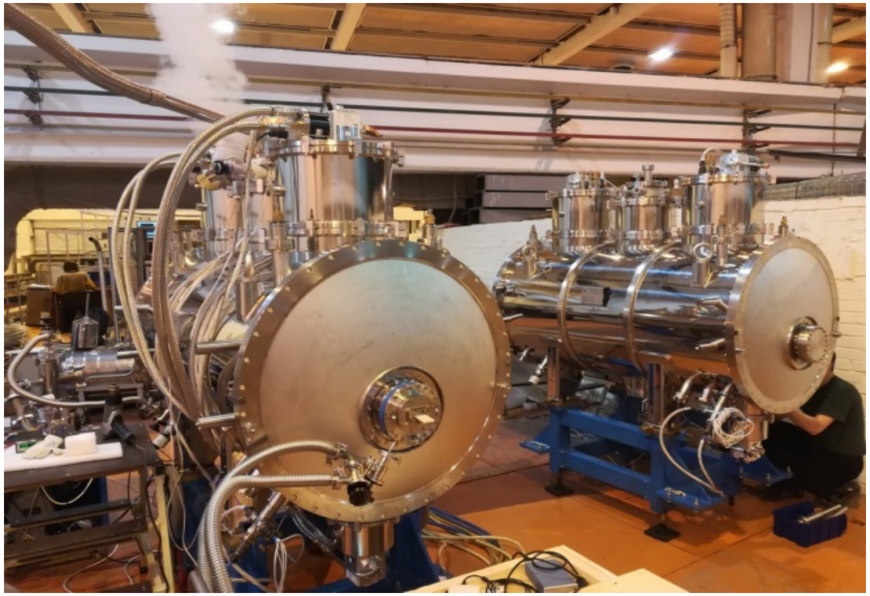
Superconducting 3 Tesla 54-pole indirect cooling wigglers with a period of 48 mm for Kurchatov Synchrotron Radiation Source



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Budker Institute of Nuclear Physics, Novosibirsk

Superconducting wigglers for Kurchatov SRS

The scientific program of Kurchatov SRS need to create two new experimental stations based on two identical Superconducting Wigglers:

- ❑ “Belok-2” (biology studies)
- ❑ “VEU” (exploration of materials in extreme conditions)

The parameters of SCW magnetic system was optimized for max photon flux on region 10 Kev – 35 Kev.
The parameters for optimization:

$\boldsymbol{Bp}$ [T]- magnetic field on pole;
λ_0 [mm] - period of wiggler;
g [mm] –magnetic gap;

←

E=2.5 [GeV] – beam energy
ε [Kev] – phonon energy;
L=2m – length of wiggler

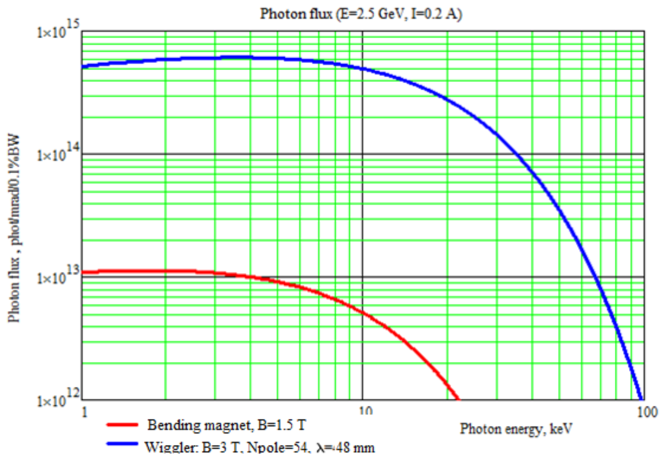
The main required parameters of SCW:

Parameters:	
Magnetic field, T	3.0
Period, mm	48
Main pole number	50
Magnetic gap, mm	14
Beam gap, mm	10

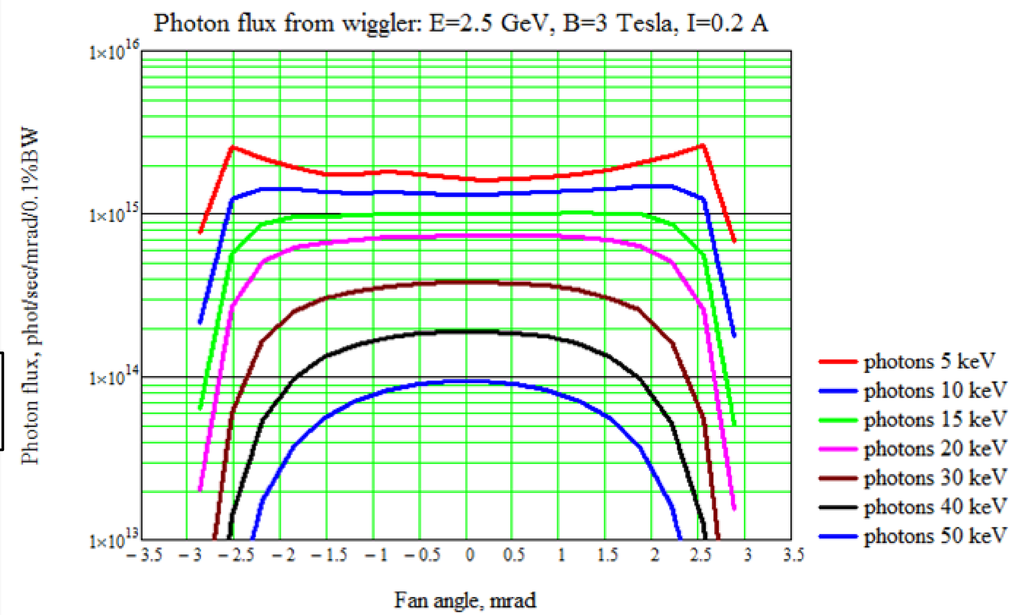
The using of SC gives a possibility obtain max magnetic field on the magnetic pole with a min geometric size. It solves the main task of MPSCW design: to put max number of pole inside of available space of straight section and reach max photon flux in required region.

Superconducting wigglers for Kurchatov SRS

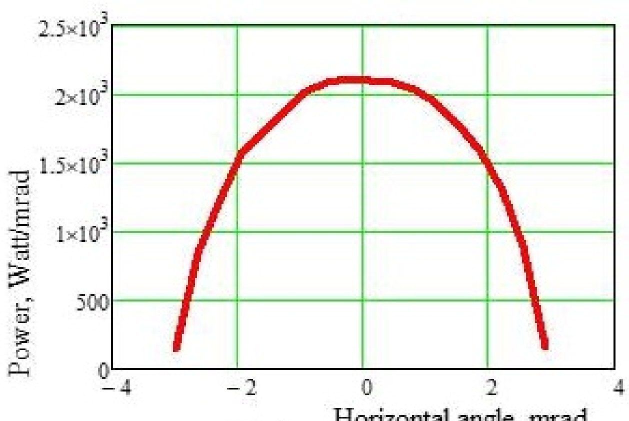
Radiation characteristics



Photon flux of 54 pole 3 T Wiggler and
1.5 T Bending magnet (integrated on vertical angle)



Spectral – angle distribution of photon flux



Radiation power angle distribution (I=0.2 A). Total power is equal to ~10 kW

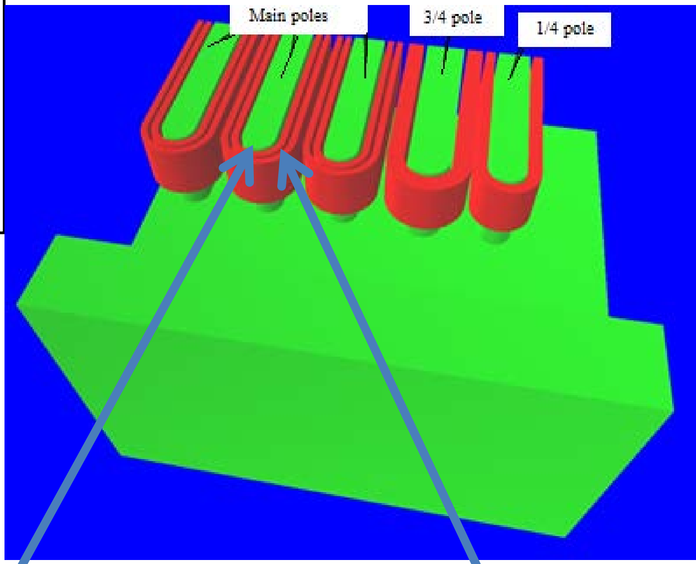
Superconducting wigglers for Kurchatov SRS

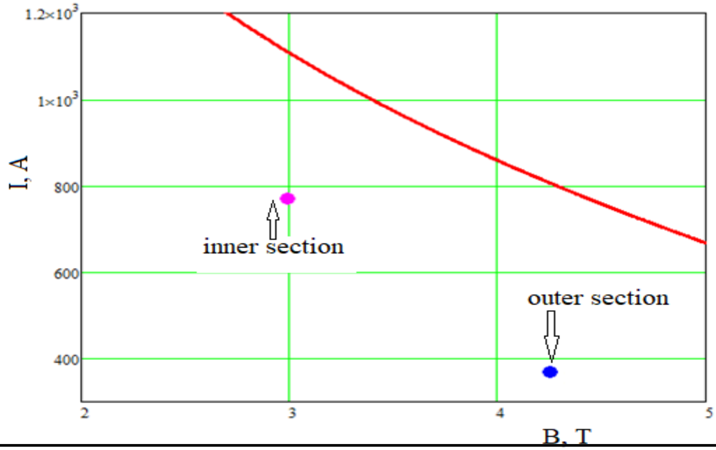
- The optimized dimensions of SC coils for obtaining of the field of 3 T with a period of 48 mm and magnetic gap of 14 mm
- The winding divided on two section (outer section with lower field powered by 770 A, inner section by 370 A)
- Independent power supplies allows zeroing of field integrals
- Overcooling of magnet down to ~3 K: Shifting of SC wire parameters and increasing of field level.

	Inner section	Outer section
Turns number in layer	62	62
Layers number	4	4
Current	370	770

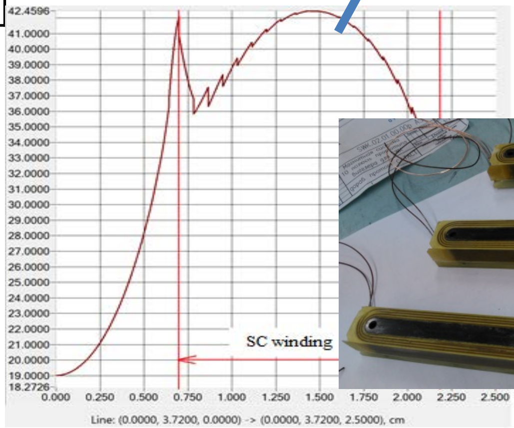
Wire parameter	
Diameter, mm	0.85/0.91 (with insul.)
Ratio of NbTi/Cu	1/1.4
Critical current (at 7 T)	~520 A

Magnetic system design

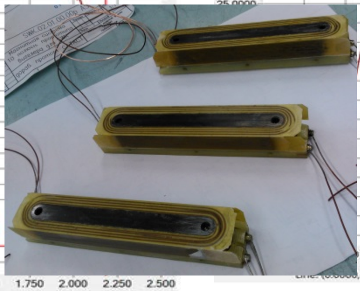


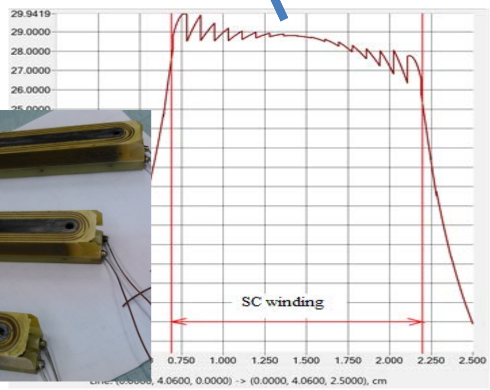


Field-current working points of inner and outer sections



Field distribution in inner section



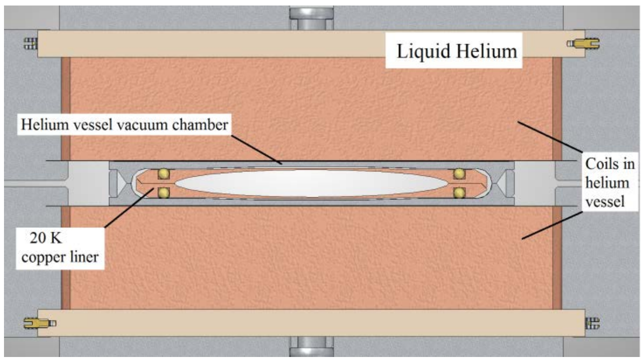


Field distribution in outer section

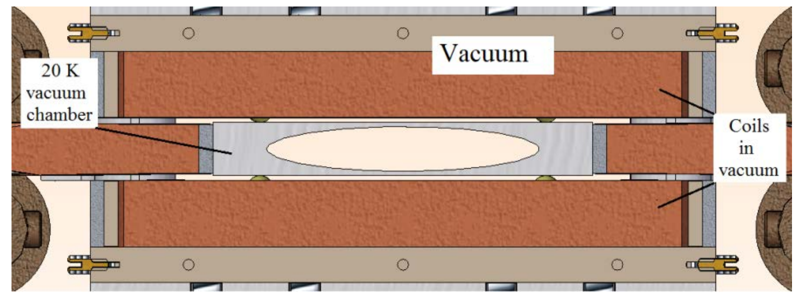
Superconducting wigglers for Kurchatov SRS

Magnetic system design

- Magnetic gap of 14 mm is very small size for placing of beam chamber (with 10 mm beam gap) and vacuum chamber of helium vessel inside of gap simultaneously.
- Removing of helium chamber and remain SC magnet in vacuum makes it possible 14 mm magnetic gap.
- In this case the SC coils will be cooled indirectly due to heat sinks.

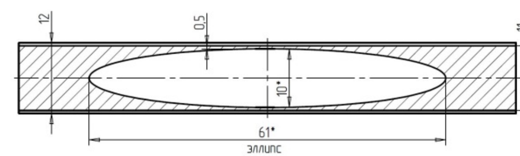


Cross-section of SCW magnet **immersed to LHe**



Cross-section of SCW magnet with **indirect cooling**

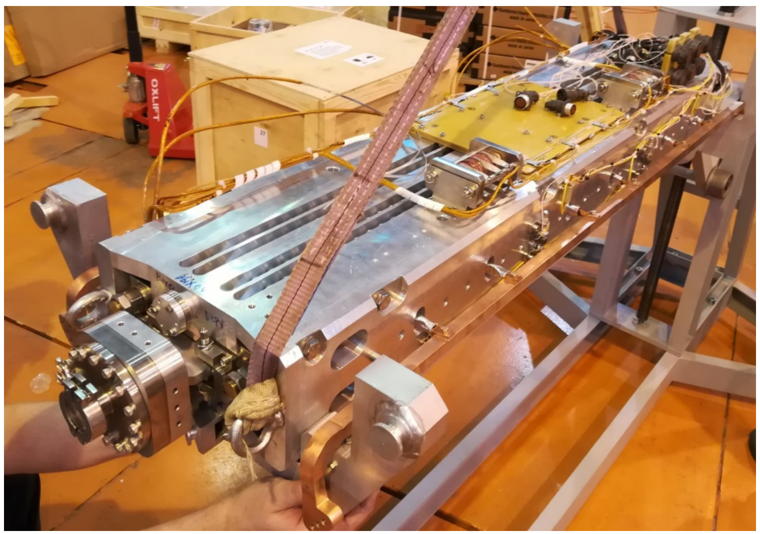
- The beam vacuum chamber is extruded from Aluminum alloy 6063 (АД31) - this provides structural rigidity to keep the gap between the magnet to avoid of thermo-contacts.
- Beam chamber is cooled by copper heat sinks arranged along of the chamber



Superconducting wigglers for Kurchatov SRS

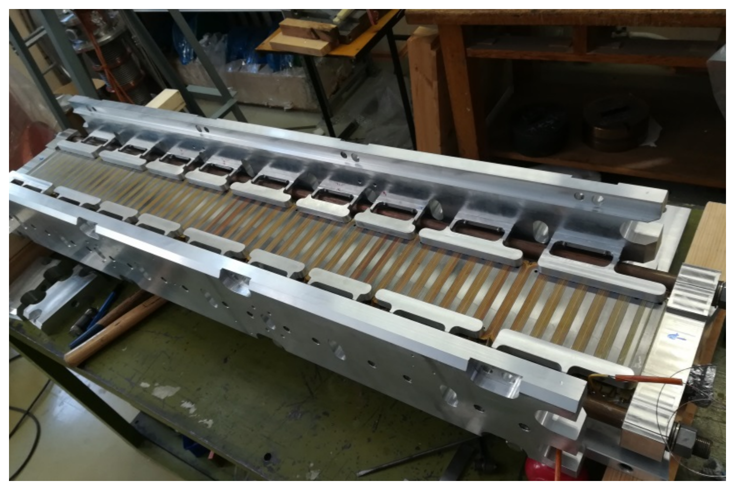
Magnetic system design

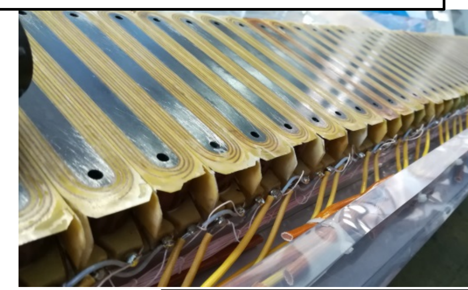
- The material of the SC Magnet frame is Aluminum alloy 6063 (АД31) - this provides structural rigidity and high thermal conductivity at ~ 3 - 4 K.
- The coils are cooled due thermal contact with the Al frame (attached with stainless bolts through highly heat conductive grease (APIEZON N)
- During cooling process the coils slide along the AL frame due to a difference in thermal expansion coefficient of ~2 mm
- The coils are bandage together with beryllium bronze rods along the magnet



Assembling of 54-pole indirect cooling 3Tesla wiggler for KSRS, (March 2019)

The bottom half of SC indirect cooling 3Tesla SC magnet during assembling



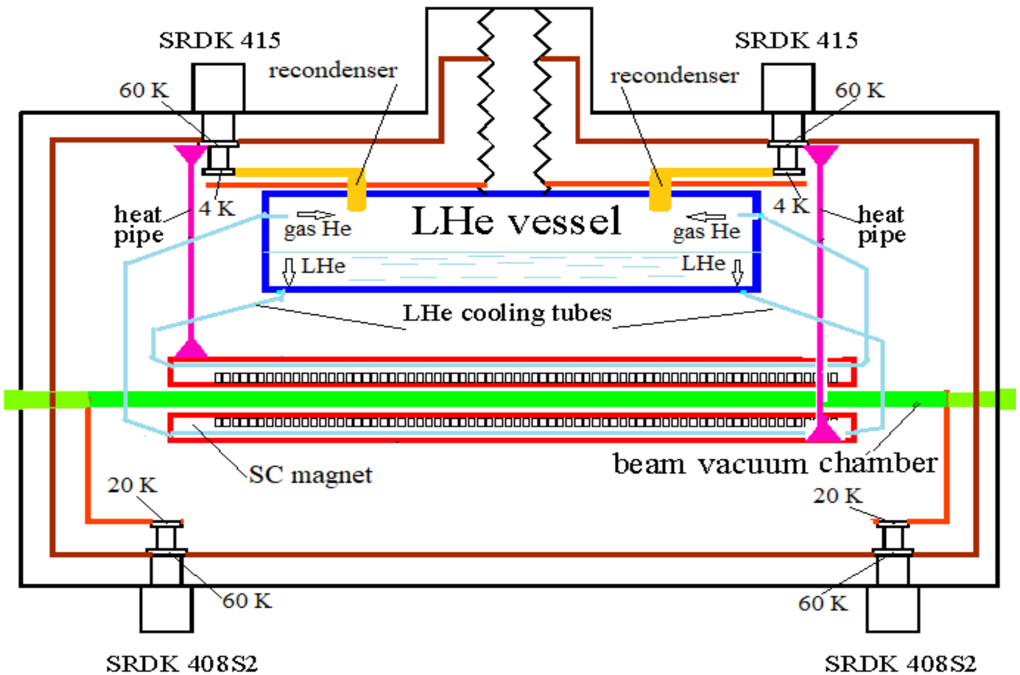


The commutation of SC coils connected in series

Superconducting wigglers for Kurchatov SRS

Indirect cooling SC Wiggler with zero LHe consumption

- ❑ Main concept: Full interception of heat in-leaks to LHe in the critical points on 60K, 20K and 4K cryo-coolers stages to prevent LHe evaporation;
- ❑ To reduce the magnetic gap and increase the field, the helium vessel chamber is removed from magnetic gap (the wiggler with indirect cooling).
- ❑ The magnet is cooled with liquid helium circulated inside of 9 mm diam. channels drilled inside of Al frame body
- ❑ Helium is cooled in a small vessel located in a vacuum of a cryostat outside the magnet
- ❑ Pre-cooling is carried out from the 60K stage through nitrogen heat pipes of a siphon type. The thermal bridge closes after 64 K (nitrogen freezing).



Assembling of indirect cooling SCW for KSRS, (March 2019)

Superconducting wigglers for Kurchatov SRS

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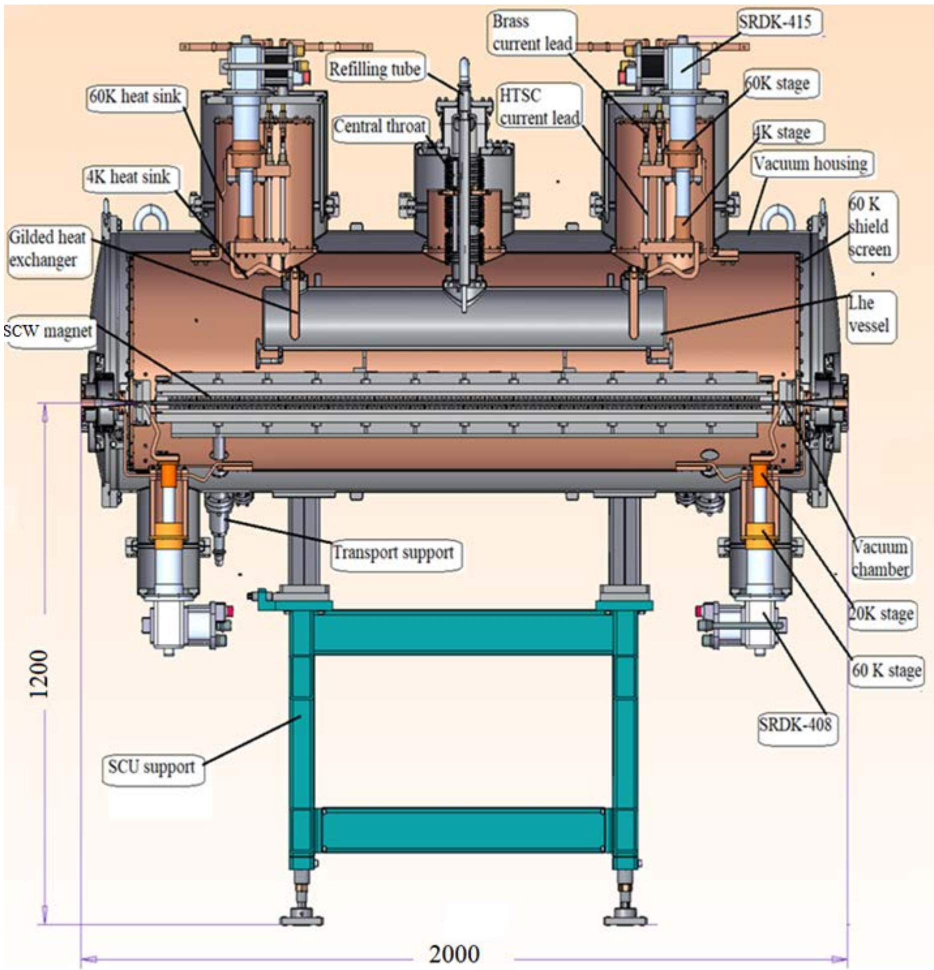
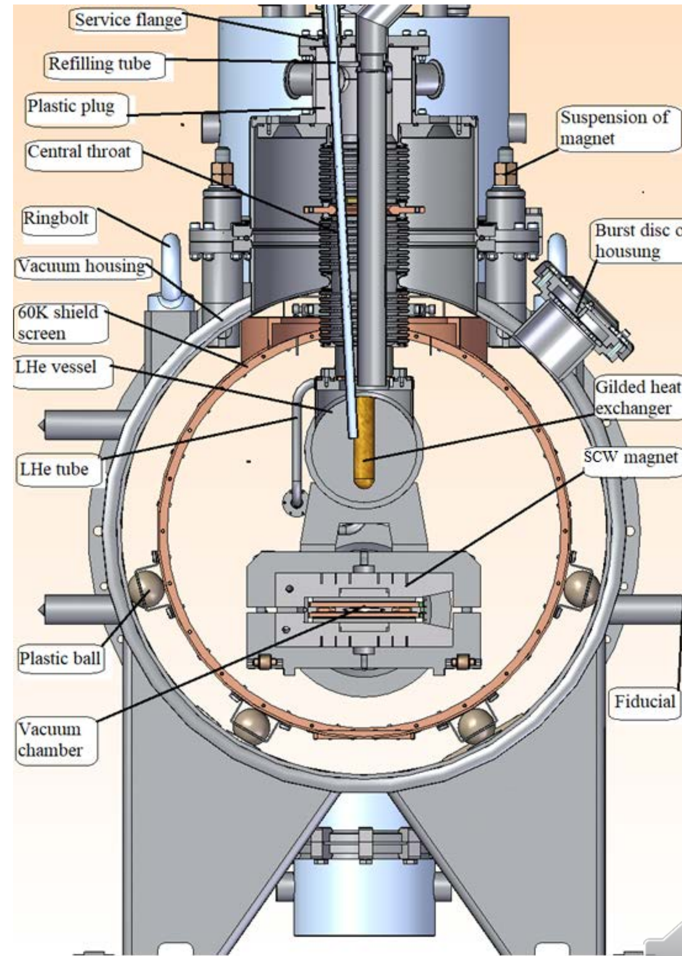
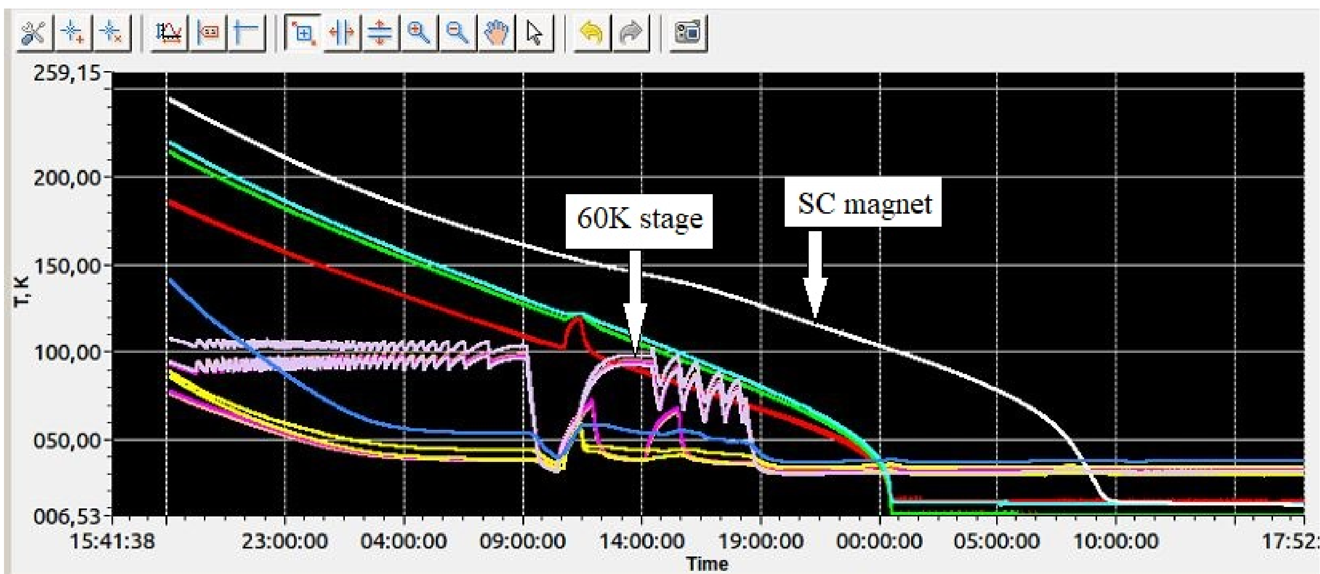


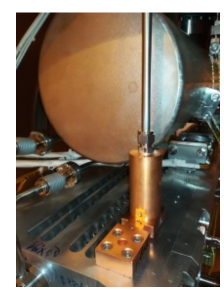


Superconducting wigglers for Kurchatov SRS

Precooling down of SC magnet with N2 thermo- siphon heat pipe

- N2 heat-pipe is used as heat conductor between 60K stage of the cryo-coolers and the magnet.
- Maximal extracted power ~100W for one pipe. It takes ~ 5 days to cool the ~ 1000 kg magnet down to LHe temperature.
- The heat pipe is operated as a “thermal switch” and automatically disconnected from magnet at nitrogen freezing point (64K) ;
- The problem: High cooling power of 60K stages (~200W) leads to early freezing of Nitrogen. For prolongation of cooling needed to heat 60K stages to melt N2. Heating with resistors is not convenient;
- New approach: automatically **switch off and switch on the compressors** for heating.
- Possible not using of Lhe from Dewar – gas helium is sucked into helium vessel during cooling down process, cooled and begins to liquefy and accumulate automatically



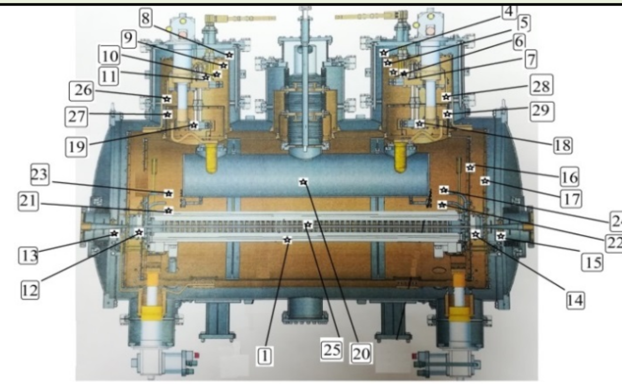


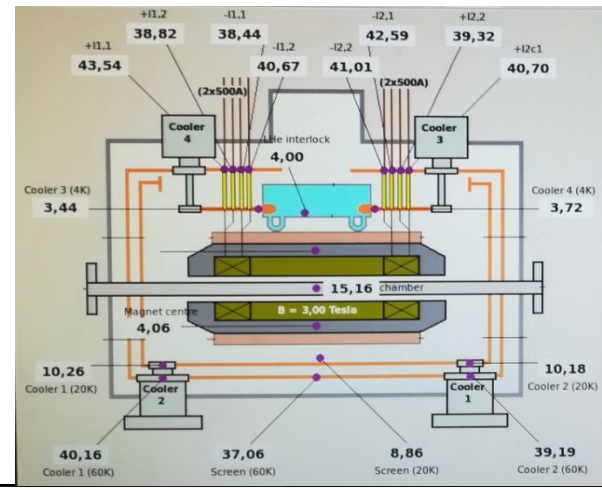
Superconducting wigglers for Kurchatov SRS

Indirect cooling SC Wiggler

Heat budget of zero boil off cryostat for SCW:

	Outer screen (60 K), W	Inner screen (20 K), W	Lhe vessel (4 K), W
Thermal radiation	8	0.05	0.0002
Central throat	2.5	0.3	0.06
Bellows of vacuum chamber	5.3	0.25	0.04
Suspension system	0.5	0.1	0.01
Current leads (thermal conductivity)	50	0	0.3
Current leads (Joule heating)	50	0	0.3
Diagnostic wires	5	0.1	0.01
Liner	10	10	0.2
Total	131.3	10.8	0.92
Cooling power	180 (at 50 K)	15 (at 20 K)	3 (at 4.2 K)



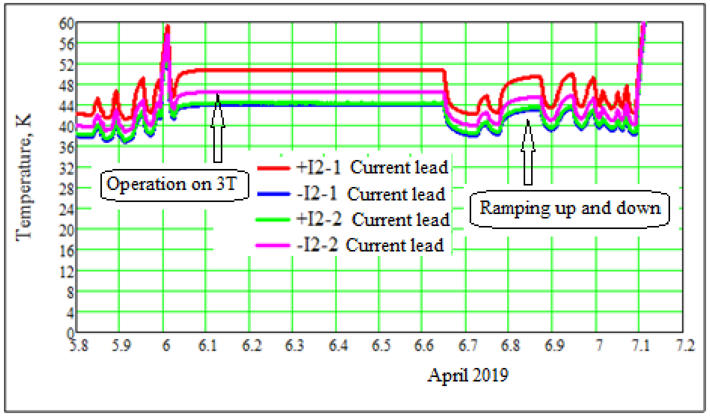


Temperature distribution at indirect cooled cryostat

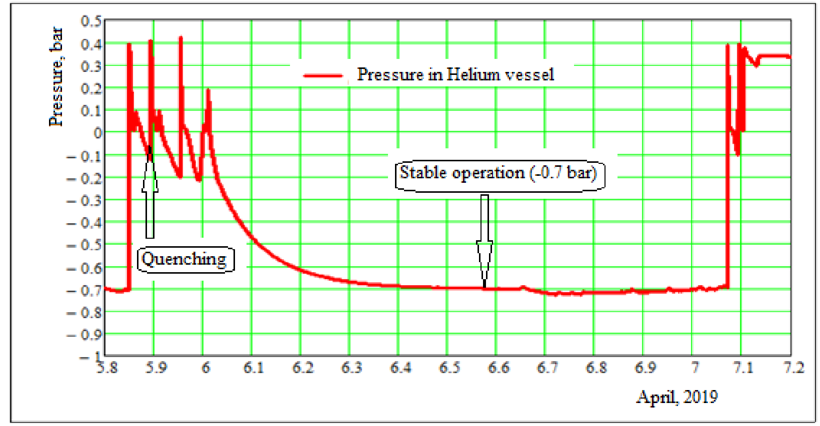
- Heat budget: The total cooling power of all cryocooler stages exceeds the corresponding heat inleaks;
- The cooling power of 4K stages exceeds (in factor 3) the heat inleaks. Excess power capacity goes to the overcooling of helium vessel with SC magnet and a decrease pressure relative to the atmosphere;
- Increasing of field level, Decreasing of helium losses during a quench, Save cry-coolers life, Recondensation and increase of LHE level in SCW cryostat.

Superconducting wigglers for Kurchatov SRS

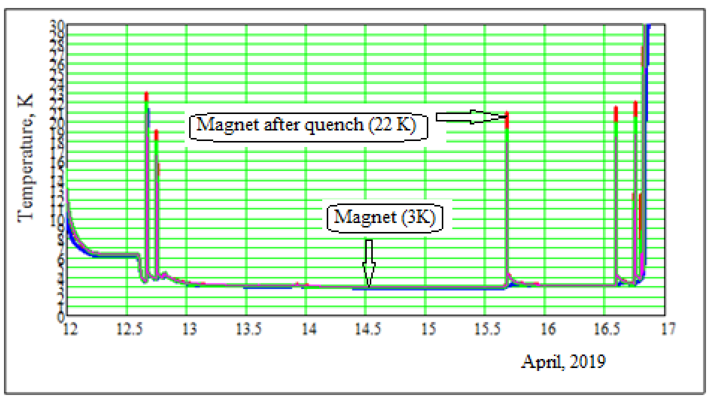
Test results of SC indirect cooling wigglers in Kurchatov SRS (2019)



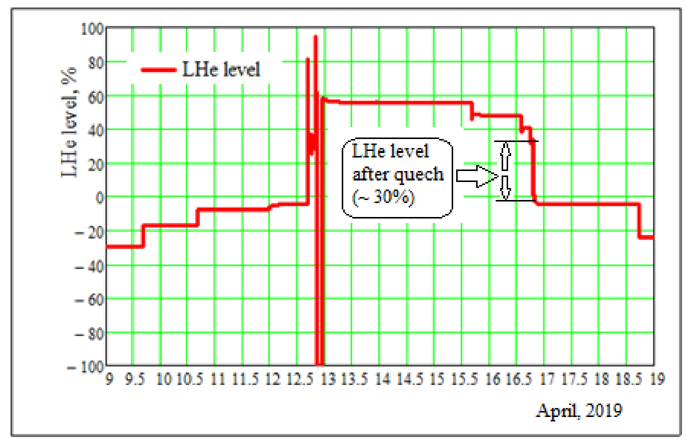
Temperature behavior of current leads (36K – without current, 52K – stable operation on 3 T)



Pressure in helium vessel behavior (reduced relative to external pressure -0.7 Bar)



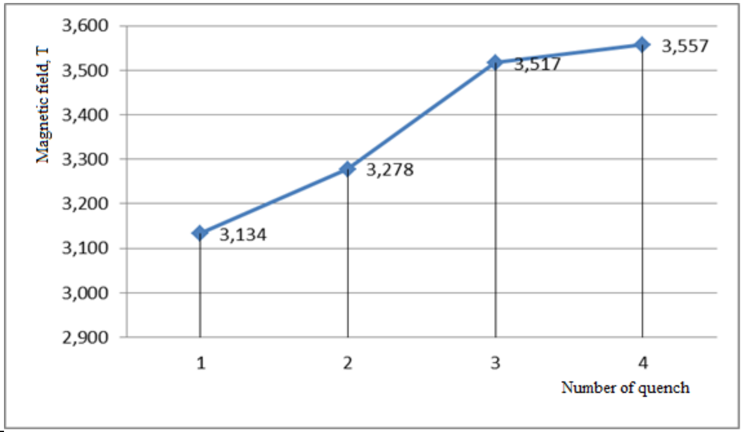
Temperature behavior SC magnet (~ 3K – stable operation on 3 T, increase up to 22 K after quench)



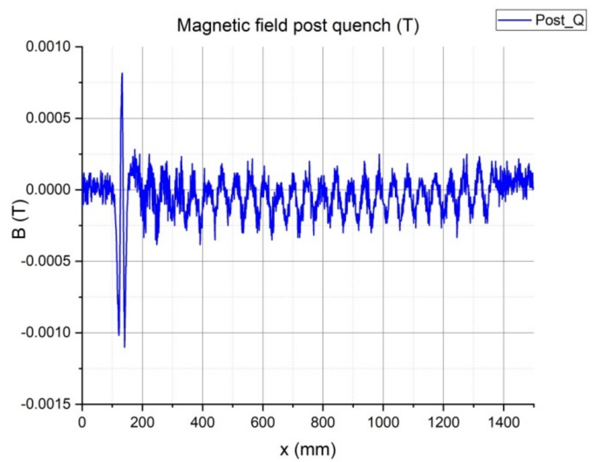
Lhe level behavior (~ 30% for one quench)

Superconducting wigglers for Kurchatov SRS

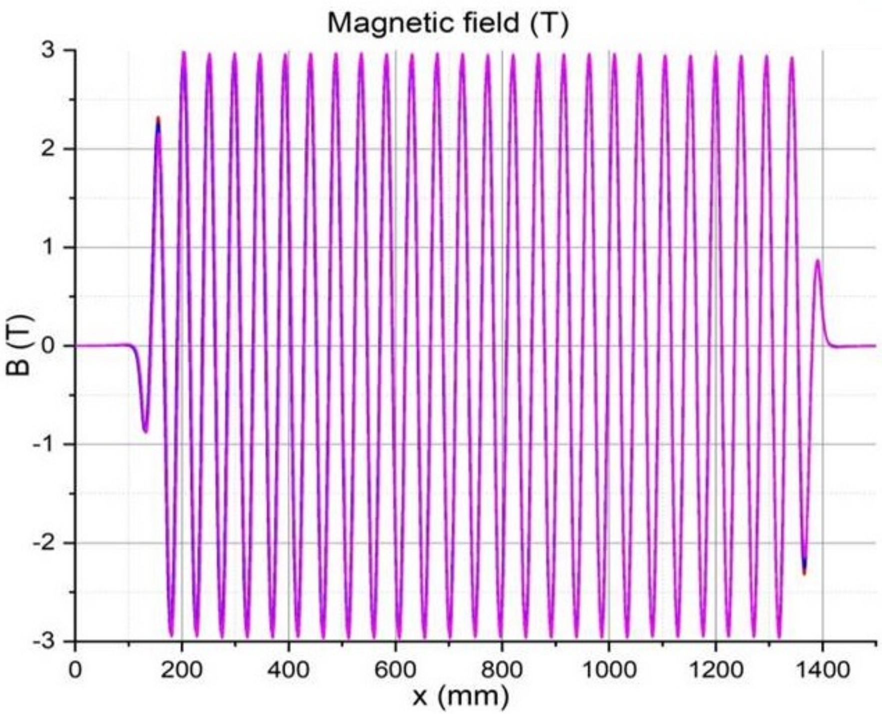
Test results of SC indirect cooling wigglers in Kurchatov SRS (2019)



The training of magnet coils up to max magnetic field of 3.56 T



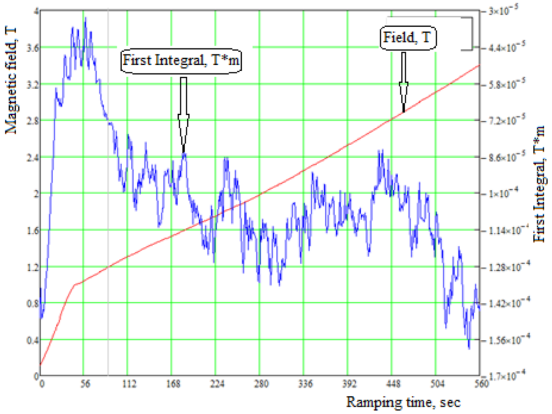
Residual magnetic field after a quench (< 5 Gs)

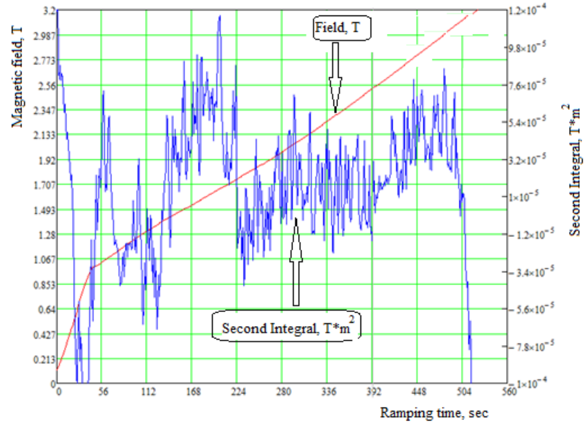


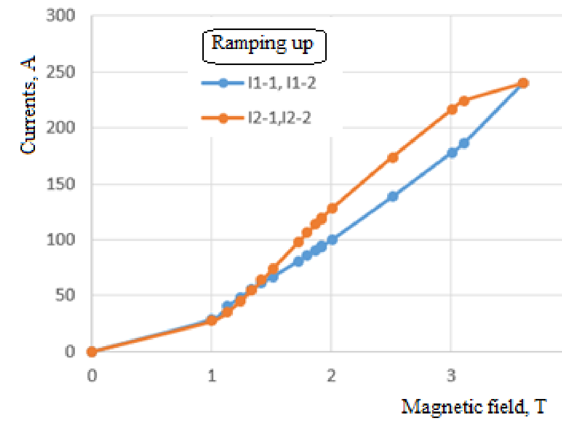
The measured magnetic field on working field 3T

Superconducting wigglers for Kurchatov SRS

Test results of SC indirect cooling wigglers in Kurchatov SRS (2019)

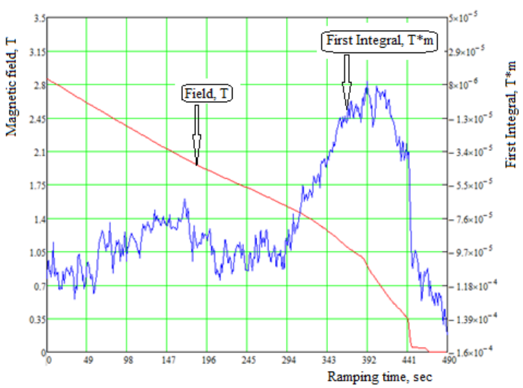


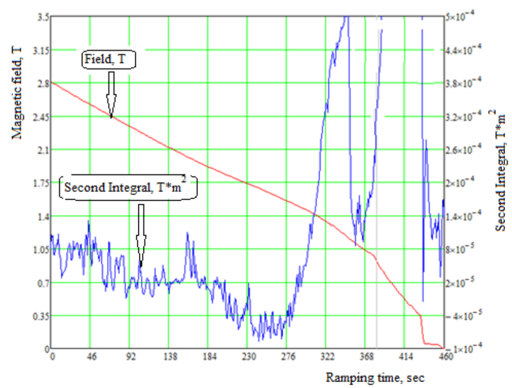


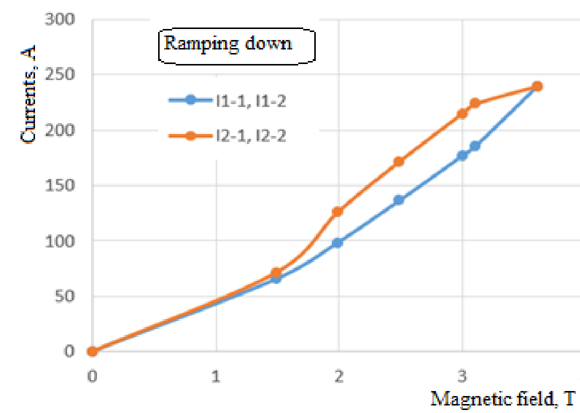


Behavior I_{First} and I_{second} field integrals during ramping up and ramping down (measured with stretched wire method). $I_{First} < 1.7\cdot10^{-4}$ T·m, $I_{Second} < 1\cdot$T·m^2

Currents ratio for ramping up and ramping down with minimal field integrals.

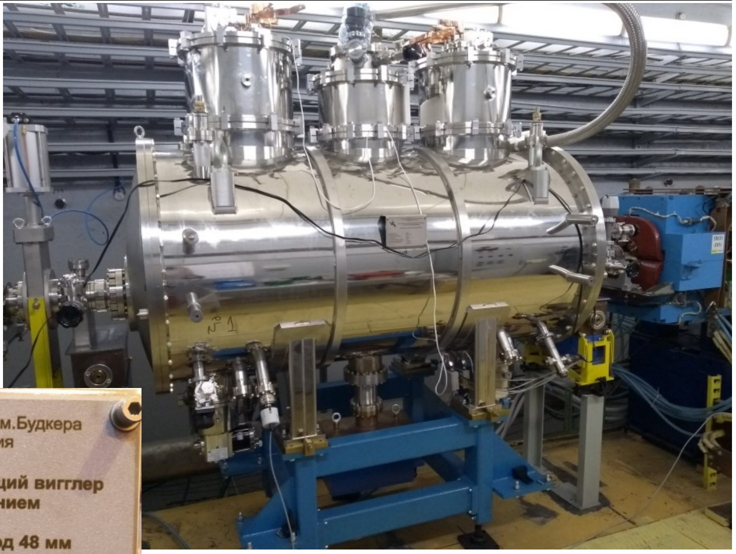


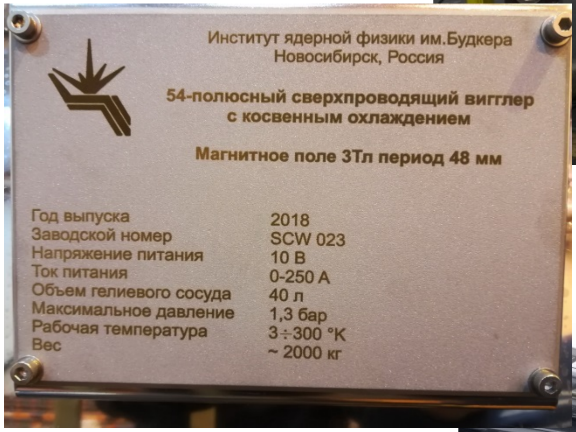




Superconducting wigglers for Kurchatov SRS

Working (max) magnetic field, T	3 (3.6)
Period, mm	48
Beam aperture, mm	10
Horizontal aperture, mm	60
Magnetic gap, mm	14
Main pole number	50
Number of ¾ poles	2
Number of ¼ poles	2
Magnet length, mm	~1350
Currents, A	400+370
Radiation power (B=3 T, I=0.2 A, E=2.5 GeV), kW	~ 10
Horizontal angle of radiation, mrad	± 3
Critical energy of photons, Kev	~ 12.5
Stored energy, kJ	~ 20
Ramping time, min	< 5
Field stability	≤ 10-4
Magnet temperature, K	2.9
Liquid helium consumption, l/h	0





New 3T SC wigglers installed on the storage ring of Kurchatov SRS (June 2019)

- ❑ **Current status:**
- ❑ The both Wigglers are installed to storage ring (June 2019)
- ❑ Preliminary commissioning with beam was carried out
- ❑ Final commissioning is planned to 2020.

Thanks for your attention!