

Short period wiggler prototype for the CLIC damping ring

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Main parameters of the wigglers

- ◆ Period – 50 mm
- ◆ Total length of wigglers
- ◆ Peak magnetic field – 2.5 T
- ◆ Pole gap – 20 mm
- ◆ Beam aperture – 12 mm
- ◆ Total number of wigglers – 104
- ◆ The wiggler design has to be easy-to-produce, reliable and inexpensive

Overview of existing BINP wigglers

	Year	Magnetic field, T	Number of poles	Gap, mm	Period, mm	Length, mm	Vertical aperture, mm
Elettra (Italy)	2002	3.7 (3.5)	45+4	16.5	64	1680	11
CLS (Canada)	2005	2.2 (2.0)	61+2	13.5	34	1120	9.5
DLS (UK)	2006	3.8 (3.5)	45+4	16.4	60	1544	10
Siberia-2 (Moscow)	2007	7.7 (7.5)	19+2	20.4	164	1836	14
CLS-2 (Canada)	2007	4.3 (4.0)	25+2	14	48	1000	9.5
LNLS (Brazil)	2009	4.1	31+4	18.4	60	1162	14
DLS-2 (UK)	2009	4.2	45+4	14	48	1304	13.8
ALBA-CELLS (Spain)	2010	2.2	117+2	12.6	30.2	1892	8.5

NbTi design of the short prototype for the CDR

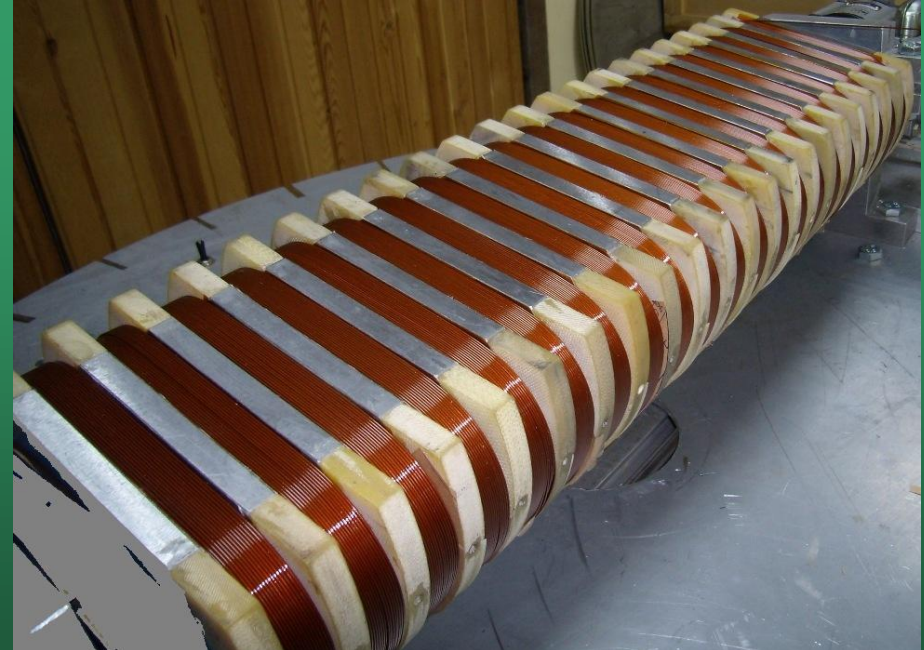
- ◆ Common NbTi wires ($\text{Cu/NbTi} = >1$) don't meet the requirements of the CDR. Engineering current of the NbTi wigglers at 4.2 K should be by a factor of 1.3-1.5 higher if the wigglers would be made of common NbTi wires.
- ◆ The NbTi wire, containing $\text{NbTi/Cu} = 1.5/1$, was used in the BINP discussed here. The same wire was used previously as shown in above table.
- ◆ The SC wire parameters are
 - Insulated diameter 0.92 mm
 - operational current 660 A at 6 T magnetic field in the coils
 - number of filaments 375
 - filament $\varnothing 34 \mu\text{m}$

Design principles, first prototype

- ◆ The design principles are shown on the one half of the first prototype.
- ◆ The coils were wound around the iron yoke without internal wire splicing.
- ◆ The neighbor coils are wound in opposite directions.
- ◆ Fiber glass plastic was placed between the coils
- ◆ Dry winding
- ◆ Epoxy compound impregnation at 15-20 bar pressure.
- ◆ Epoxy compound is
 - epoxy – 50 mass parts
 - Al_2O_3 powder – 50 mass parts
- ◆ Active quench protection was used.



15+6 coils in one half

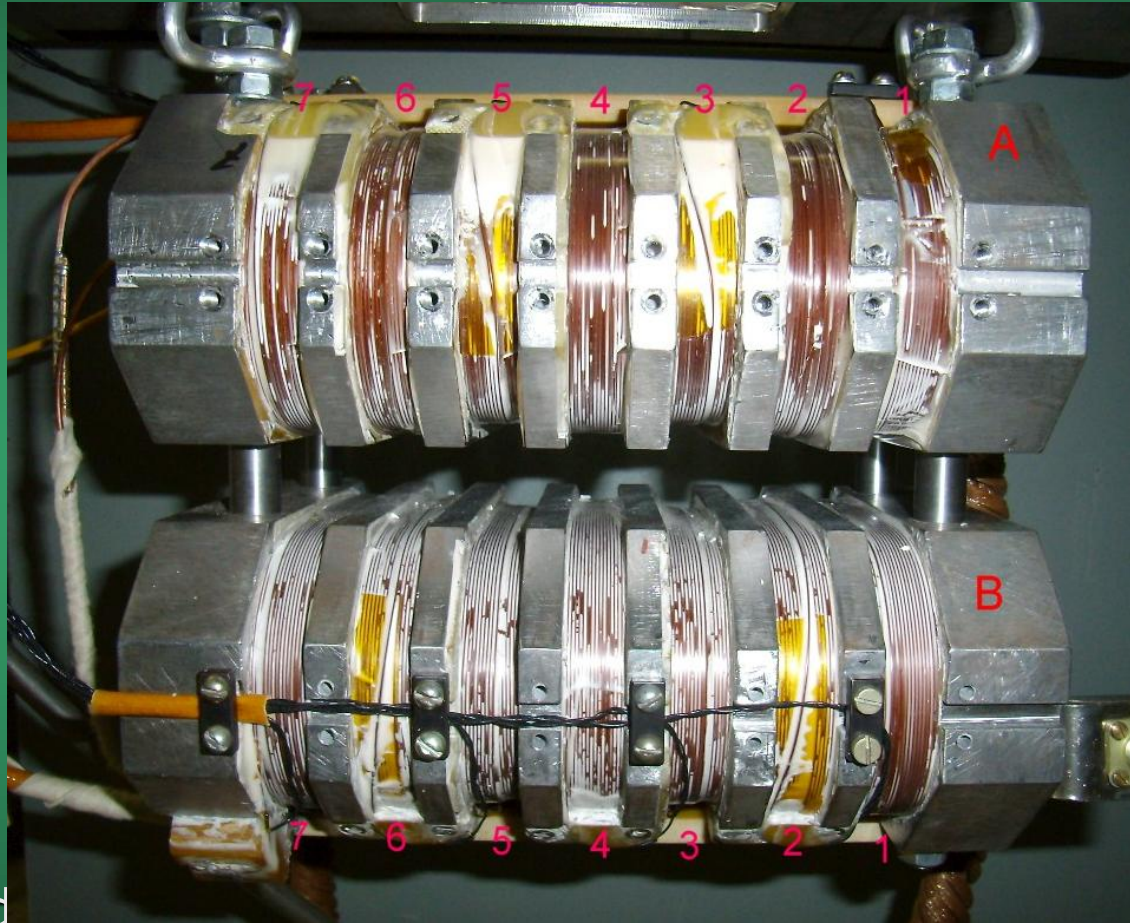


Design principles, second prototype

The same design, but

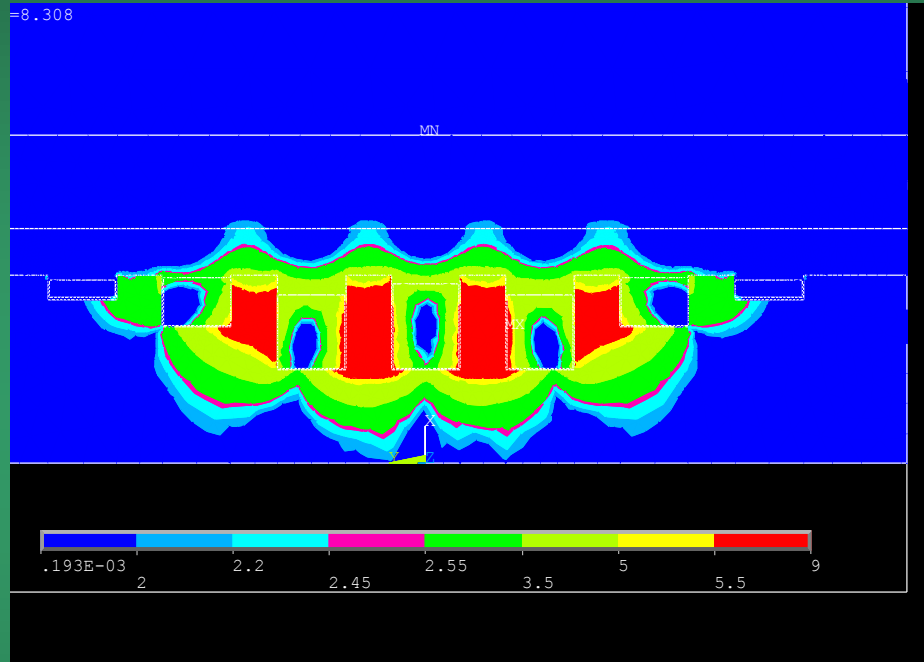
- the straight parts of the coils were rounded
- the fiber glass plastic was removed.

High heat capacity $\text{Gd}_2\text{O}_2\text{S}$ powder was added to the epoxy compound.
Its quantity is 10% of the total mass of the compound.



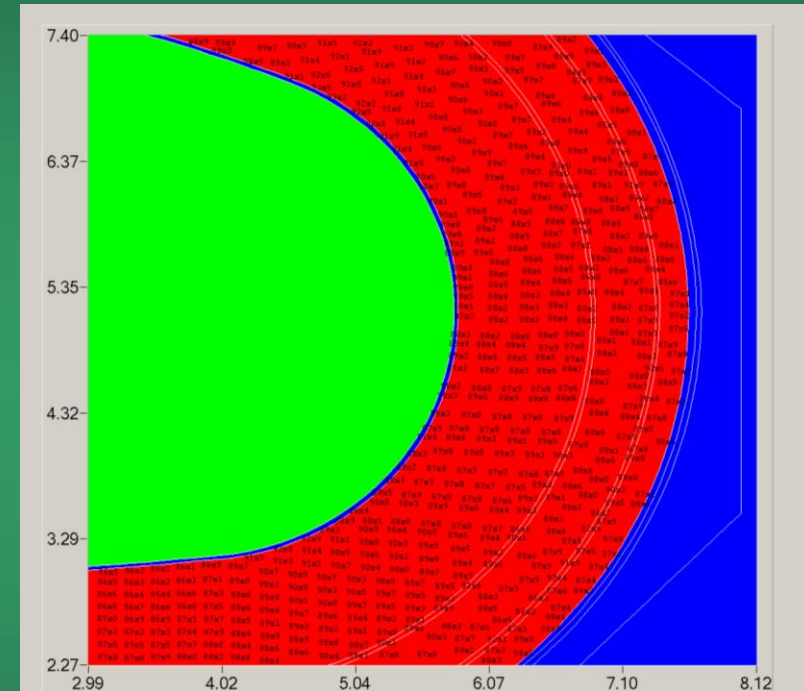
Magnetic fields calculations

ANSYS 2D calculations and MERMAID 2D and 3D calculations



Magnetic fields in the working volume.
ANSYS 2D.

Second prototype. Really wound coils
are shown.



Maximal magnetic fields are
in the central coil at round
parts.

MERMAID 3D.

Stability and Protection of the wiggler

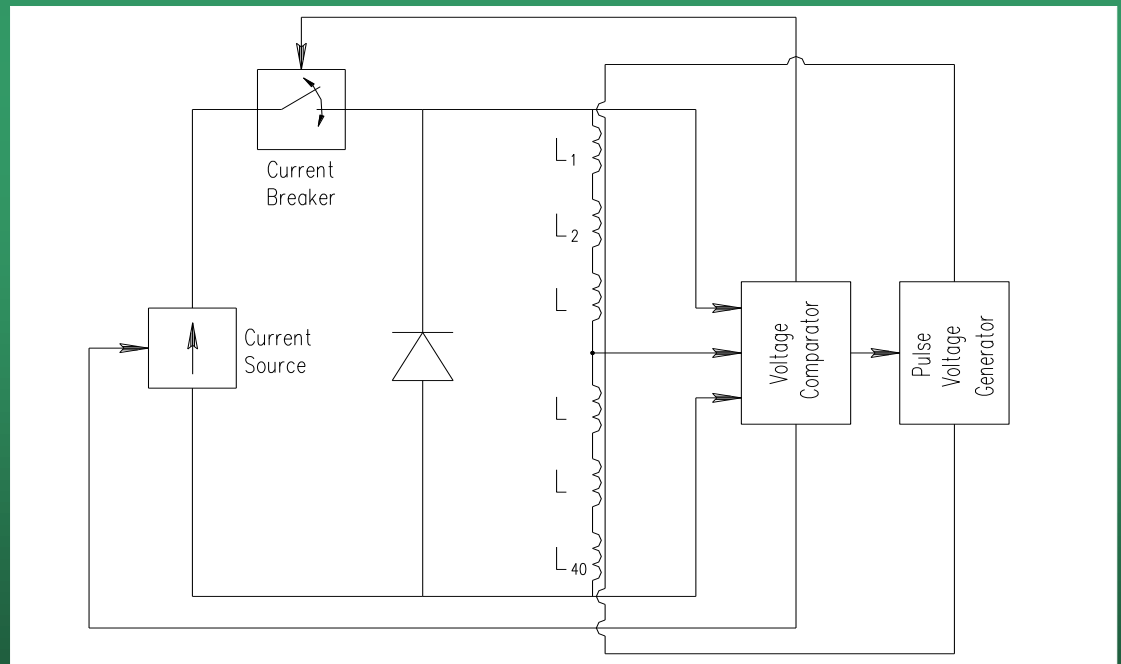
- ◆ Stability parameters of the considered wiggler design are low due to less amount the copper stabilizer and high I_{op}/I_c ratio. These factors cause high risk of a degradation.

To increase stability of the wiggler

- epoxy compound with fine powder is used
- all possibilities to increase I_c should be used

- ◆ Active protection is considered as a main method of the wiggler protection.

It was tested in the first prototype.



Epoxy impregnation



One half of the wiggler is
Prepared for the impregnation.

The half of the wiggler after
impregnation.
The $\text{Gd}_2\text{O}_2\text{S}$ powder is seemed to be
completely precipitated on the
bottom.

Four wiggler parts were successfully
impregnated by this way.



Impregnation area. Autoclave
presses the impregnated wiggler by
1.5-2 MPa at 90° C.

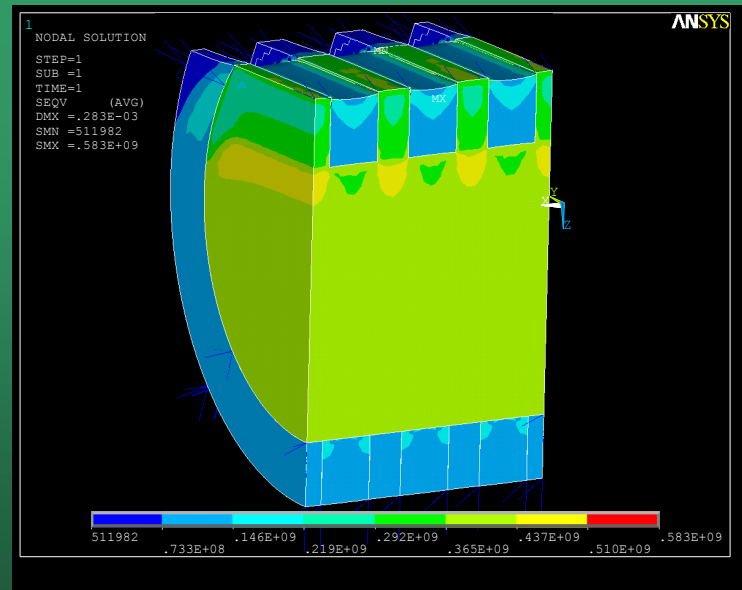
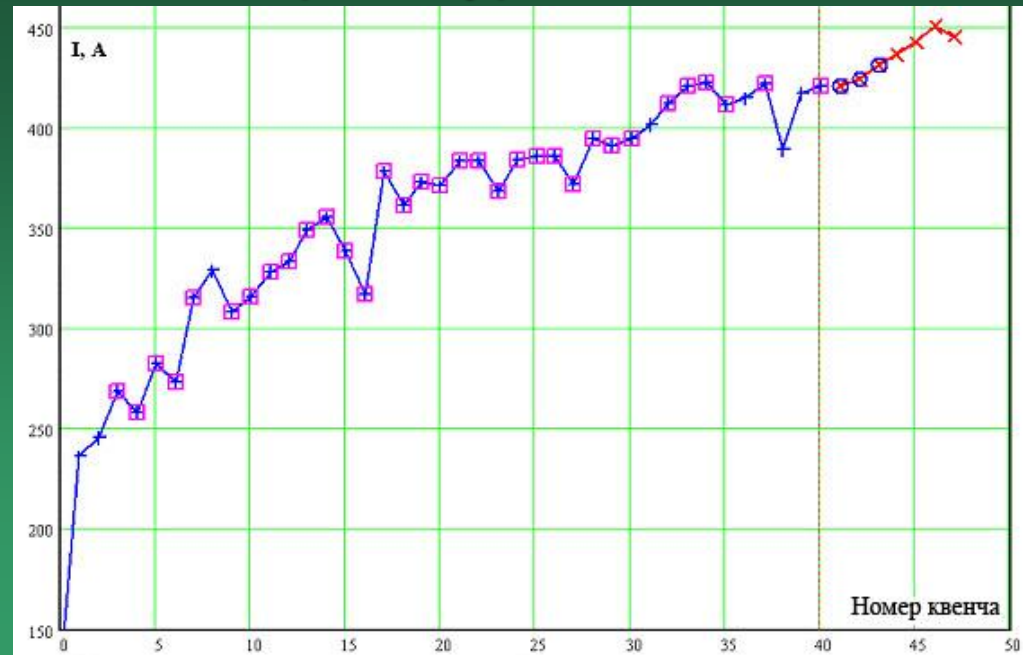


Test results of the first prototype

The first prototype was tested three times. A strong degradation was observed.

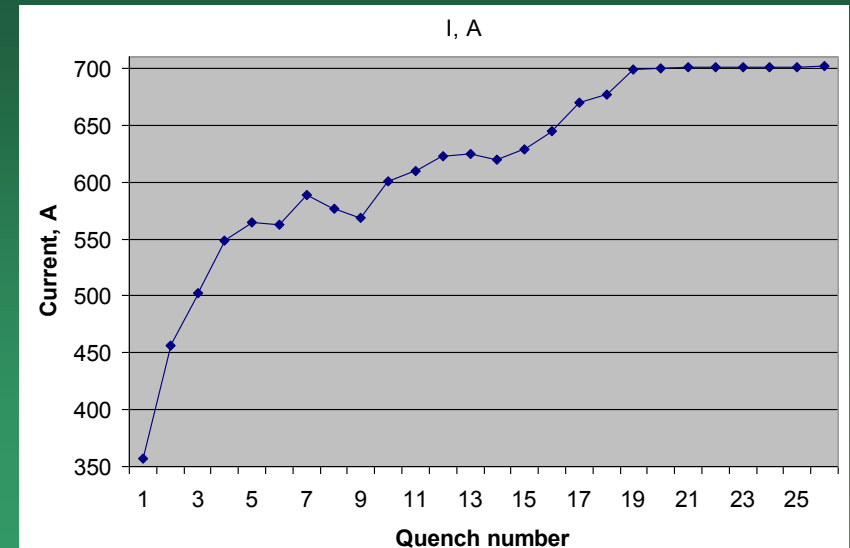
The maximal current was 450 A at 1.9 K (CERN) that is too far from the operational 660 A.

The main reason of the degradation was the glass fiber spacers due to much difference between the thermal contraction of the spacers and the iron. ANSYS calculations have Proved this conclusion.



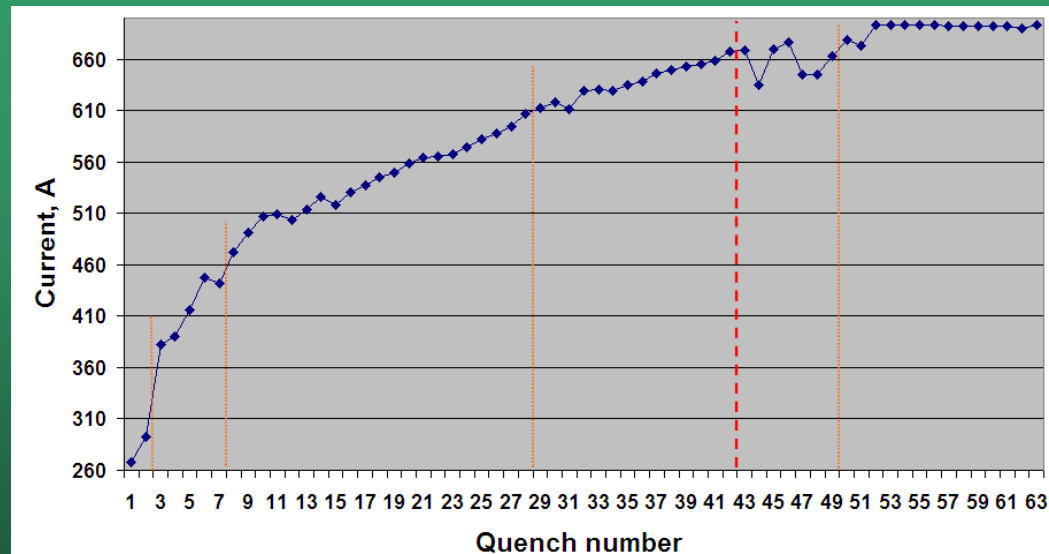
Test results of the second prototype

- ◆ One half of the second prototype was tested separately with iron plate.
- ◆ Operational current of 660 A and critical current of 700 A were achieved.



One half training history

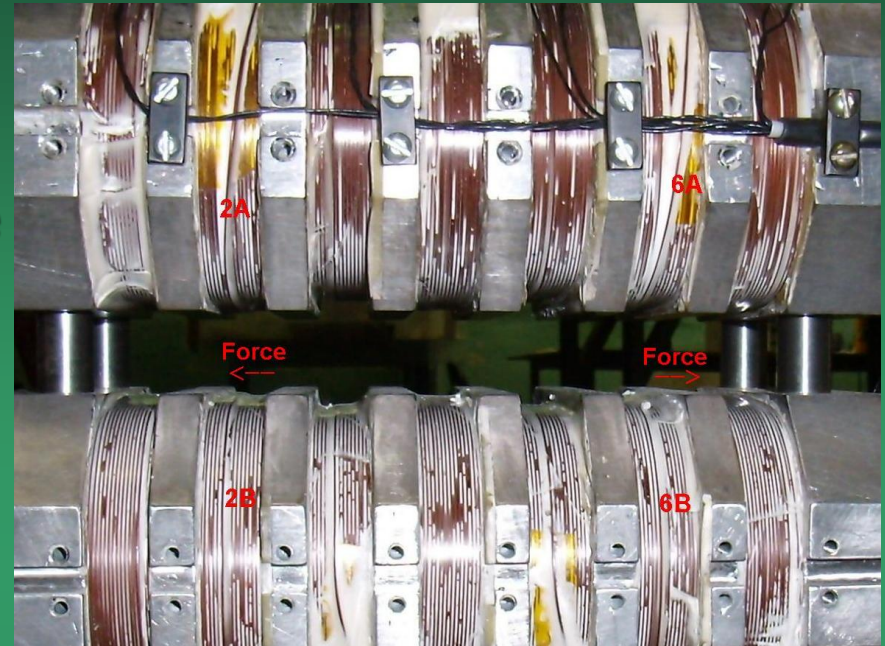
- ◆ In the second prototype test operational current of 660 A and critical current of 693 A of the second half were achieved.
- ◆ High ramping rate is seemed to be the main reason of much training quenches.
(5 times higher)



Second prototype training history

Test results of the second prototype, conclusions

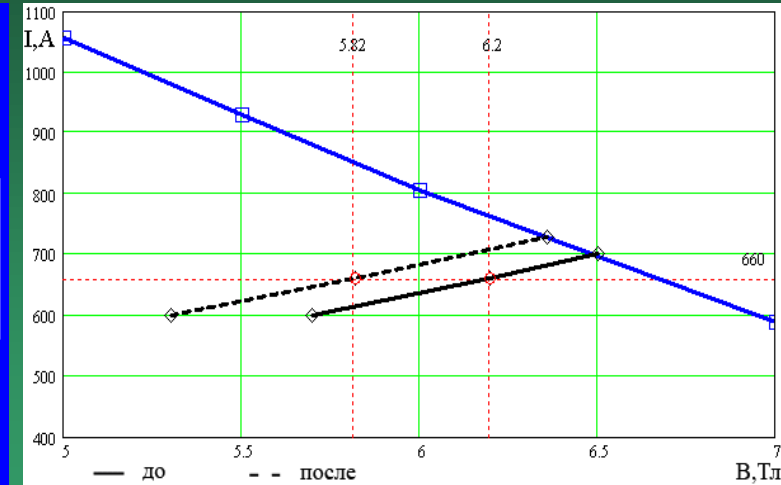
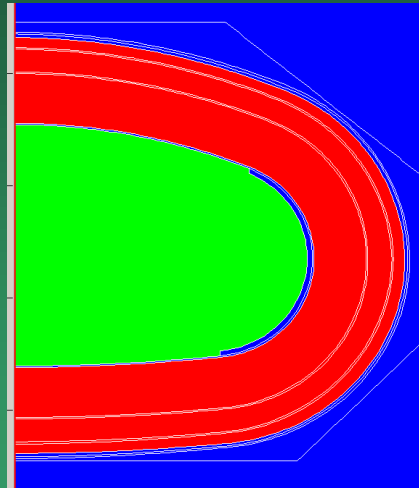
- ◆ 1. Operational current of 660 A was achieved – the main result.
- ◆ 2. Training quench statistics shows:
 - 88% of the quenches of the one half test were in the 6A coil.
 - 56% of the quenches of the wiggler test were in the 6B coil. The 6A and 6B coils contains $\frac{1}{2}$ turns of central coil.
 - the central coils (4A, 4B) induced the training quenches.
- ◆ 3. The influence of the high ramping rate was not understood during the wiggler test. It was by a factor of 5 higher than in the one half test, so a heat generation due to AC loss was by a factor of 25 higher.
- ◆ 4. The depth of grooves in the iron, where the coils are wound, is not optimal. SO, in the conducted tests the maximal magnetic field was about 2.2 T in the working volume. Nevertheless, it does not affect the maximal field inside the coils.



Outer turns of 6A and 6B coils are not backed by iron walls as in 2A and 2B.

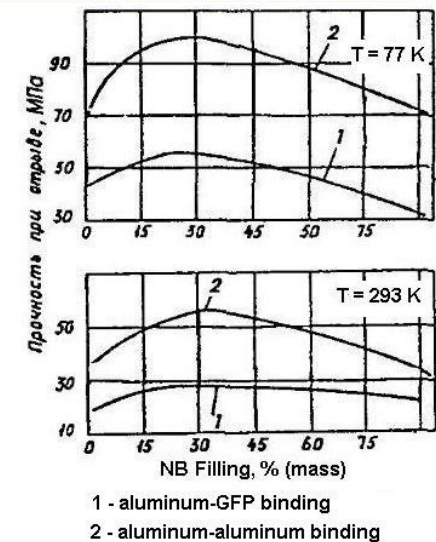
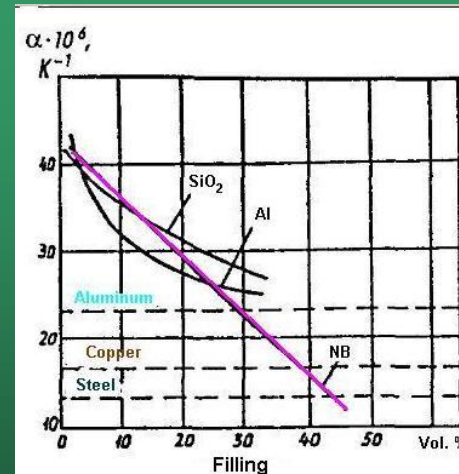
Possible improvements of the NbTi design

- 1. Removing of 2 mm of iron at the round parts will increase the critical current up to 730 A. It will improve the stability.



- 2. Taking BN as a filling powder for the epoxy compound is more advantageous according the shown table and plots.

Properties	TiB ₂	SiC	Al ₂ O ₃	BN	AlN
Cryst. structure	Hex.	Hex.	Hex.	Hex.	Hex.
Density, g/cm ³	4.52	3.19-3.21	3.9-4.0	2.25	3.25-3.3
α , 10 ⁻⁶ 1/K	4.6-8.1	4.63-4.7	3.6-9.5	0.8-7.5	53
E, GPa	500	350-490	380-490	90	350-380
σ_t , GPa	1.29	0.4-1.7	0.2-6.5	1.2-1.38	3.5-7.0
T _m , K	3253	2873-2970	2312	3253	2703



Conclusions

- ◆ The short prototype of the wiggler were tested up to the critical current that prove the possibility to use NbTi wiggler design at 4.3 K for the CDR.
- ◆ The developed technology of the epoxy impregnation seems reliable and effective.
- ◆ Improvements of the current design are shown which should increase stability of the wiggler.
- ◆ The reasons of premature quenches of the first and second prototypes are understood and discussed how can they be minimized.