SUPERCONDUCTING 7 TESLA WIGGLER FOR DELTA SYNCHROTRON RADIATION SOURCE: TEST RESULTS

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Introduction

The multipole superconducting wiggler was designed, fabricated and successfully installed and tested on DELTA Synchrotron Radiation (SR) Source. The wiggler represents a multipole magnet with alternating high magnetic field of 7 Tesla along movement of particles in storage ring. The magnet is immersed into liquid helium of a special cryostat with working temperature of ~4.2K.
The wiggler consists of 22 pairs of poles superconducting magnet with 18 full field poles, 2 with a three-quarter field strength and 2 with one-quarter field poles. The magnet array produces a sin-like magnetic field variation on the magnetic axis of the device with first and second field integrals close to zero.

The Dortmund Electron Accelerator (DELTA, Germany) operated at 1.5 GeV synchrotron radiation source requires a superconducting wiggler as an insertion device for three x-ray beamlines with photon energies up to more than 30 keV. The wiggler has a period of 127 mm, magnetic field of 7 Tesla and the length from flange to flange of 2.2 m operated with zero boil-off mode [7]. The conception and main approaches for the design of the magnetic and cryogenic system as well as the main parameters and the test results of new 7 Tesla superconducting wiggler for DELTA synchrotron light source are presented.

MAIN PARAMTERS OF THE WIGGLER

The magnetic structure of the superconducting wiggler for the DELTA synchrotron radiation source is a sequence of superconducting magnets with transverse, alternating magnetic field with amplitude of 7tesla in the operating mode. The main parameters of the wiggler are given in Table 1. The magnet assembled and ready for installation into the cryostat is shown on Figure 1.

Figure 1: Superconducting 7 Tesla wiggler for DELTA SR Source.

Table 1 Main Parameters of the Wiggler

Period	125 mm
Nominal magnetic field	>7 T
Maximum peak on-axis field	7.2 T
Full vertical aperture	10 mm
Full horizontal aperture (entry/exit)	90/120 mm
Magnetic length	1408 mm
Maximum length flange-to-flange	2500 mm
Pole scheme	-1/4,3/4,-1,1…-3/4,1/4
Transverse field homogeneity $\Delta Bz/Bz$ at $x=\pm 20$ mm, $z=0$	$\leq 2*10^{-3}$
Max. stray field on axis at each end of the cryostat	0.001 T
Maximum Ramping Time	< 15 min
Power supply stability $\Delta Bz/Bz$	$< 2*10^{-5}$
Field stability (2 week), 0.5-7 T	10^{-4}
Period for LHe refill with beam	>6 month

The cryostat, in which the magnet is placed, is a vacuum volume, in which there are 2 thermal screens with temperatures of 50K and 20K, a helium volume with a magnet inside [3,5,6]. To achieve zero liquid helium consumption the cryostat is equipped with cryocoolers to intercept and remove heat from the screens, from a copper liner, which is a heat shield from the heat coming from the electron beam, and with two copper fingers, which are connected to 4K cold heads of the cryocoolers to re-condense the evaporated liquid helium and return it to the helium volume. Figure 2 shows the assembled cryostat ready for site acceptance testing. In July 2018 elements of the superconducting wiggler was delivered in the hall of the DELTA SR source, assembled, tested for vacuum, cooled to helium temperature and subjected to acceptance tests.

COOLING DOWN OF THE WIGGLER

After assembling of the wiggler, pumping out of insulating vacuum and conducting leak test the wiggler magnet was cooled down by two steps:

- Cooling down with liquid nitrogen.
- Cooling down with liquid helium.

It was required about 300 liters of liquid nitrogen for preliminary cooling down of the wiggler magnet. Simultane-

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ously with magnet cooling by liquid nitrogen the two coolers SUMITOMO SRDK408S2 were switched on to cool down shield screens. Time duration of cooling down of the magnet to temperature ~120K was ~40 hours. After that liquid helium vessel was pumped out and filled with gas helium (washing procedure).

Figure 2: Superconducting 7 Tesla wiggler during site acceptance test in DELTA SR Source.

To cool down the magnet down to liquid helium temperature it was required about 300 liters of liquid helium within 2-3 hours. Simultaneously with cooling of magnets two coolers SUMITOMO SRDK415D were switched on. Temperature of magnet behavior with time during cooling down is shown on Figure 3 and 4 below.

After cooling down quench training of the magnet was conducted.

QUENCH TRAINING RESULTS

The first quench was made on August 2, 2018 at the field level of 6.2 T and after 8 quenches the field level was reached up to required field of 7.2 T. Quench history is shown on Figure 5.

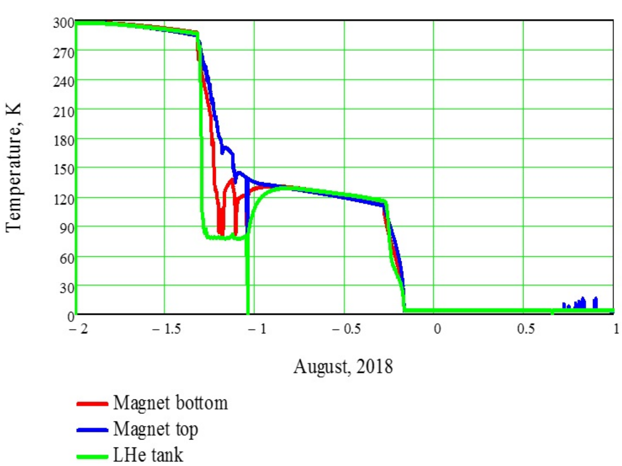

Figure 3: Temperature of magnet and LHe tank during cooling down with liquid nitrogen.

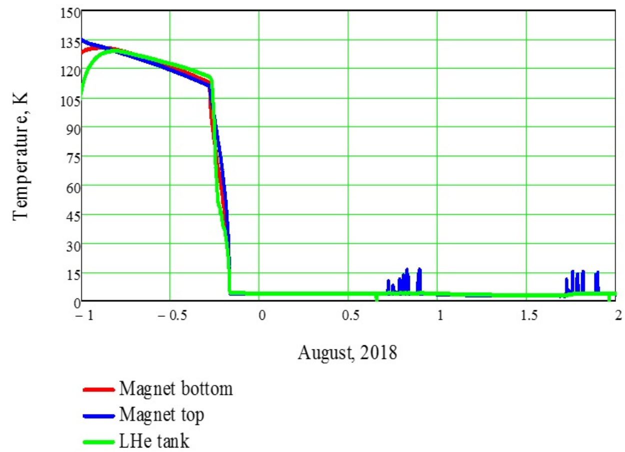

Figure 4: Temperature of magnet and LHe tank during cooling down with liquid helium (cryocoolers SRDK 415 activated).

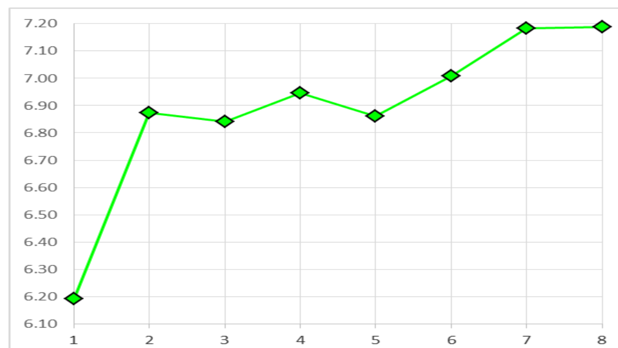

Figure 5: Quench history of 7 T SCW during site acceptance test.

Despite the long transportation from BINP to DELTA, the number of quenches need to obtain the required field level of 7.2 T was significantly (by 10 times) less compared to the training that was conducted for the first time after the magnet Assembly during the Factory Acceptance Test [1]. During a quench ~ 50 liters of liquid helium was evaporated, which corresponds to the stored energy of the magnetic field at 7 Tesla. During a quench the magnet temperature was increased at level less ~18K (Figure 6).

STABILITY TEST

Long term stability test during 72 hours was conducted at field level of 7 Tesla. During this time, all parameters took stable values. Figure 7 shows the steady-state parameters of the cryogenic system during the long-term stability test. Effective the work of the cryocoolers decrease the temperature of the magnet dropped below 3K, the insulation vacuum was stabilized at the level of 2-3*10^{-8} mbar, the pressure in the helium vessel was established at the level of 0.2 bar [4].

The stability of the power supply currents throughout the test provided the accuracy of the wiggler field is not worse than 3.5*10^{-5}.

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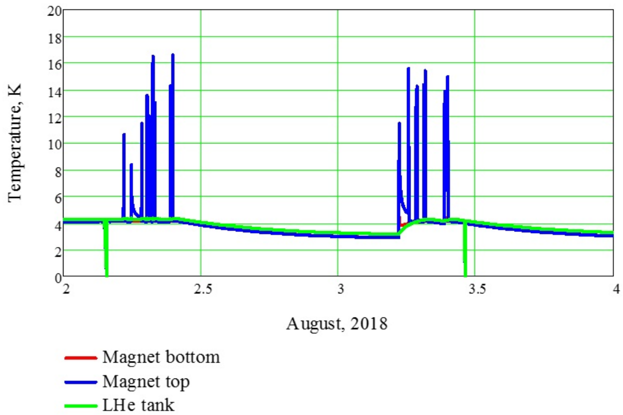

Figure 6: Temperatures dynamics of the magnet and the LHe tank during quench training.

MAGNETIC FIELD MEASUREMENTS

Dynamical stability of first and second field integral during ramping up and down of the wiggler field with help of stretched wire method was tested [2]. Second field integral stability is defined by power supplies stability at low level of currents and speed of currents, as slower ramping field as better field integral stability during ramping. The field integrals show the value satisfied to wiggler specification at any regime. Time of field ramping up 0-7 Tesla is near 7-12 minutes. Magnetic field integrals measurement was made with current-driven stretched wire method.

Magnetic measurements with use of Hall probe were conducted at following set field levels: 1, 2, 3, 4, 5, 6, 7, Tesla. The measurement results are shown in Figure 8.

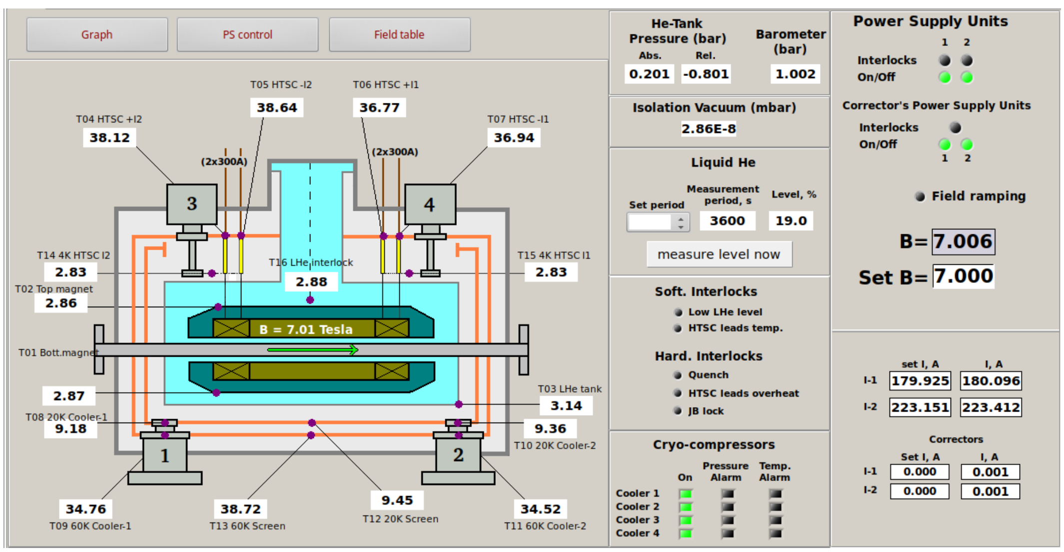

Figure 7: Parameters of cryogenic system during long term stability test August 13-16, 2018.

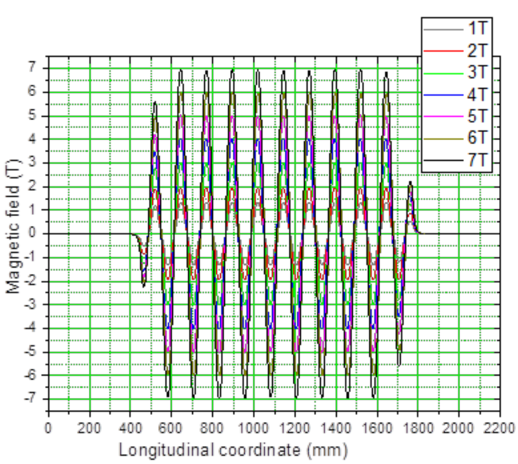

Figure 8: Hall probe magnetic measurements at different levels of set field.

CONCLUSION

Superconducting multipolar wiggler is ready for continuous operation with a field of 7 T as a generator of high-power synchrotron radiation with an electron energy of 1.5 GeV.

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