Performance of 7 T Dry Solenoid for THz Spectroscopy

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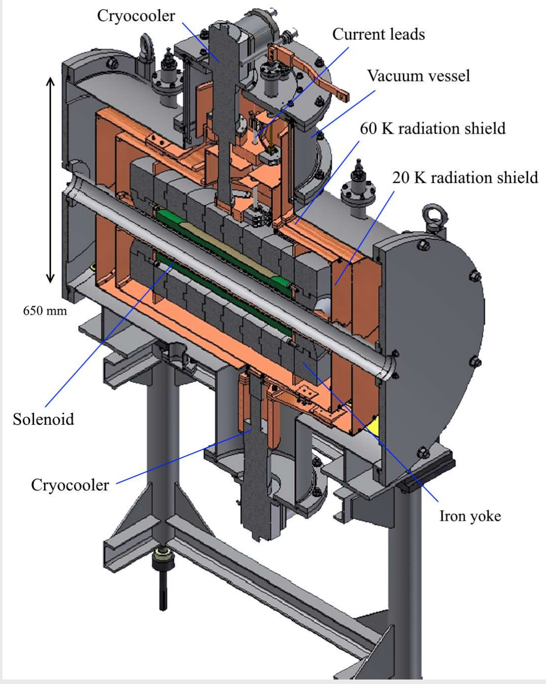
The little developed spectroscopy in THz range has been intensively developed at present. It concerns especially new spectroscopy methods particularly which is known as THz time-domain spectroscopy. In this method the time signals of molecules radiation are measured that is the coherent radiation of free induction on self-resonant frequencies after excitation by a short laser impulse.
Besides developing of the THz range the current trend of the modern spectroscopy is in developing fast dynamic methods in real time. The demands of these methods is caused by researching the physical, chemical and biological processes which are intrinsically fast and not repeatable in details due to various instabilities and which are principally singe-stage such as explosions or detonating waves. In this situation such classical methods as step-scan Fourier spectroscopy or well known time-domain spectroscopy do not work because they are founded on stroboscopic measurements of many events where the regular repeatability is a necessary condition.

The superconducting solenoid on the base of NbTi wire was developed for such purposes to create >6 T magnetic field in the working volume of 0.2 m length and ∅40 mm, see Tab. 1. The field uniformity should be < 0.5% in this space. The superconducting winding is surrounded by the iron yoke to increase uniformity of magnetic field and to reduce stray field.
The superconducting winding consists of 20 main layers and additional two layers of 0.1 m length by the but-ends of the solenoid. The space between these additional layers is filled with G-10 material.
The SC wire was wound on copper former, see Figures below. The insulation between the former and the wire were the G-10 foils of 0.5 mm thickness. The winding was impregnated by epoxy compound (epoxy + alumina filler) at 18 bar pressure.
The SC wire parameters are 0.92 mm of insulated diameter, 1.3 of Cu/SC ratio; the critical current is 370 A at 7T@4.2K. The RRR of copper is ~ 110. The winding were wound of two pieces of SC wire. Total length of the wire is 4.5 km. The splicing was done with PbSn solder at the outer surface of the solenoid on the length of ~ 40 cm.

Electrical scheme. The solenoid was powered via HTSC current leads manufactured by SuperOx company. The quench protection of the solenoid was based on passive methods, i.e. by the subdivision for two sections with 0.01 Ohm shunts with diodes, and by presence of secondary circuits represented by the copper former and the iron yoke. The effect of the later can be shown from the tests.

The solenoid has its own cryostat to keep it at about 4 K temperature by using two cryocoolers of SRDK-408S2 and SRDK-408D2 by Sumitomo HI. These cryocoolers give cooling capacity of 1W@4.2 K, 15W@22 K and ~ 80W@50 K. The copper former of the solenoid is directly connected to the cryocooler cold head of 1W@4.2 K by special copper links. The iron yoke is fixed to the solenoid, so is also cooled by this cold head. The suspension strings, the 60 K radiation shield and the HTSC current leads are cooled by the two cold heads of 80W@50 K. The 20 K radiation shield is cooled by 15W@22 K of cold head. There is only 20 K radiation shield between the copper former of the solenoid and the vacuum vessel having 80 mm of inner diameter.

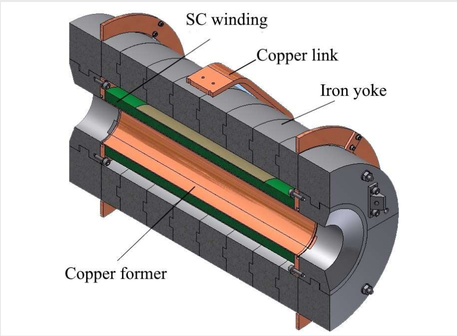
The results of the tests are presented below.



The cross-section of the cryostat

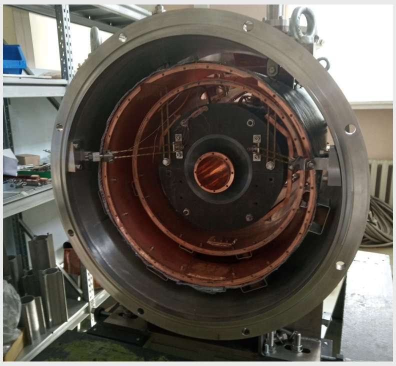
Table 1 - Design parameters of the solenoid

Internal diameter of the winding, mm	104
Warm bore diameter, mm	80
Winding warm length, mm	500
Turns number 550*20 + 560	11 560
Maximal magnetic field on the winding, T	6.48
Operating current, A	240
Io/Ic ratio	0.80
Inductance (2E/I^2), H	3.31
Magnetic field at the center of solenoid, T	6.45
Stored energy, kJ	85.5



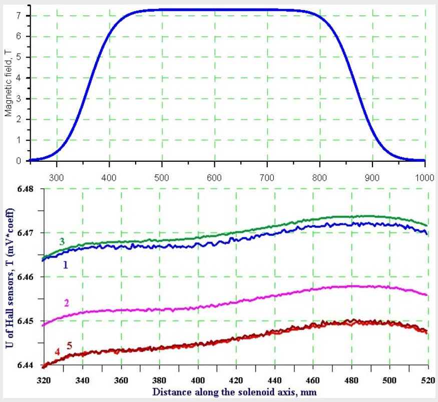
The cross-section of the solenoid

The solenoid after vacuum impregnation with epoxy filled with Al_2O_3 powder.



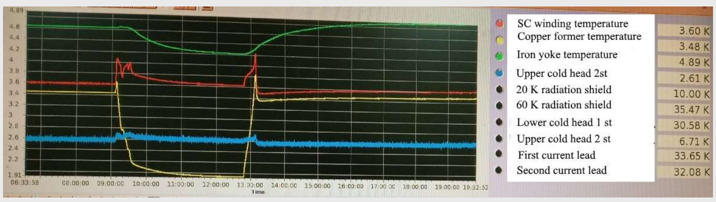
The solenoid being assembled

The assembled solenoid during the test



Magnetic field inside the solenoid. The uniformity in the working space is about ± 0.25 %.

The solenoid was tested in liquid helium bath two times to confirm the operating current, for quench training and field mapping. The solenoid reached parameters of the Tab. 1. There was one quench at 196 A current. The results of field mapping are shown on the figures right.
The solenoid cryostat is equipped with temperature sensors to control the operation in all regimes, see Figure below.
The solenoid cooling in the cryostat took 13 days. The main reasons for such long cooling are large cold mass of the iron yoke and moderate capacity of the cryocooler. Modern cryocoolers have cooling capacity more by a factor of 1.5-2. The solenoid temperature was below designed, about 3.8 K, so the solenoid was powered up to 7.5 T without quenches.
The field mapping was done in the ranges of the filed of 6.0 T --- 7.3 T.
The second quench at 7.5 T was provoked by powering the solenoid at higher ramp rate, ~ 1 A/s. After this the solenoid powered up to 7 T.
The dry design allows to evaluate the efficiency of secondary circuits during the quench by analyzing the temperature increase in the iron yoke and the copper elements of the solenoid design including radiation shields and the copper former. It was estimated that about 15% of stored energy was dissipated in these elements



The temperature sensors behavior during the final powering up to 270 A current

Main results:
- the maximal magnetic field is 7.5 T (in own cryostat)
- two training quench happened at 205 A current and at 275 A (~ 7.5 T at high ramp rate)
- the uniformity of the magnetic field is satisfying the demands
- the operating magnetic field can be 7 T
- the cooling down period is 13 days