

## Superconducting Magnet for Thermonuclear Neutron Source

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January 18, 2016 (STH37, HP103). Some estimates and conceptual solutions are presented in [1, 2] for superconducting magnets of the Thermonuclear Neutron Source (DEMO TNS) based on the tokamak principle with the conventional aspect ratio 3. It is presently under design by the Kurchatov Institute<sup>1</sup>. The main parameters of this facility are as follows: plasma major radius  $R_0 = 2.75$  m, plasma minor radius  $a_{pl} = 1$  m, plasma cross section vertical elongation  $k = 2.1$ , plasma current  $I_{pl} = 5$  MA. The toroidal field magnets should produce the field of  $B_0 = 5$  T on the plasma axis and  $B_m$  of 12 T on the inner side of coils. The outer dimensions of coils are 9 m x 5 m, the stored energy 6 GJ, the coil radial thickness 0.5 m, inner bore radius for inductor  $R_i = 0.5$  m. The thickness of protection against irradiation between coils and the vacuum vessel should be at least 0.5 m. Because of tight space for TF magnet inner legs, the constructive current density of 28 MA/m<sup>2</sup> is required which is almost twice as high as in the magnets of tokamaks existing so far. The cross-section of the conceptual magnet design is shown in Figure 1.

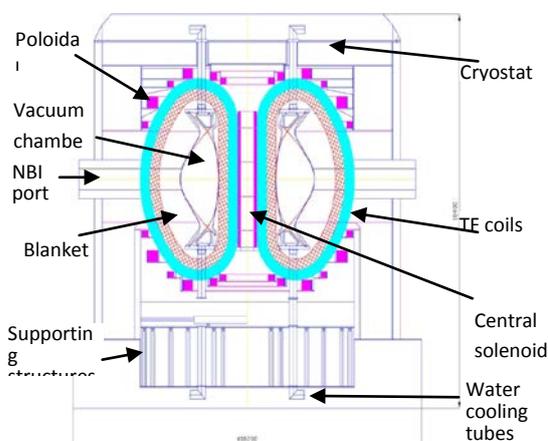
Because of strong space restriction, the coils cases could not be thick enough to withstand the vertical tension of about 6000 t per each of 18 coils; as well as toroidal compression which keeps the centering forces from 12 T field radial pressure, and the toroidal pressure which is three times higher than the radial one due to low angle of wedges supporting coils inner legs. The average effective Tresca stress is estimated as 480 MPa. However, one should take into account the unavoidable local overstresses which usually are 1.5-2 times higher than the average stress. Thus, the stress could be considerably higher than acceptable 700 MPa value for SS 316 LN at helium temperature. Therefore it is suggested that the turn cases should help the coil case. For that they should be rather thick square rolled bars (of two halves) with the oval channel inside (like for ITER CS) rather than the usual thin wall conduit. However the turn insulation has to be put inside the case to be loaded by single turn forces only, while the force from turn to turn will be transferred directly through the metal (to get the structure like TF radial plates in ITER). For better filling of almost triangular coil cross-section the turns should be as small as possible. The coil cross-section of 25 mm x 25 mm seems reasonable if wound in the form of four double-layer pancakes with 36 turns, two with 24 turns and two with 12 turns, overall 144 turns with the single turn current of 26 kA. In the base magnet version, the LTSC materials at hand could be used, for example, the Nb<sub>3</sub>Sn wire produced at ChMP (Chepetsky Mechanical Plant, RF) for ITER toroidal coils. The 0.82 mm wire can carry 200-220 amperes at 12 T and 5K. So for 40 % margin in terms of  $I_c/I_{op}$  the cable has to have no less than 160 wires. To prevent the current degradation, the cable should be tightly twisted like the Rutherford type cable (Figure 2). This cable could be fabricated in three steps: 1) seven wires twisting and compaction to 2.3 mm diameter, 2) two layers Rutherford type 38 mm wide tape fabrication 3) tape bending along its axis (to reduce AC losses) and to produce four layers 16 mm wide and 10 mm thick cable with 196 wires. Such thickness allows "winding after reaction" which simplifies considerably the coil manufacturing. Also the tight cable twisting could prevent the current degradation.

Taking into account the uncertainty in heating due to irradiation the cooling efficiency could be increased by pushing liquid He (LHe) across and along the winding through the special holes

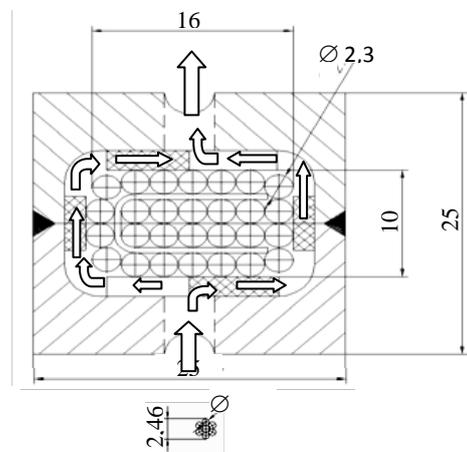
<sup>1</sup> In collaboration with the Joint Stock Company "Dolezyl Research and Development Institute of Power Engineering", Moscow, and with "D. V. Efremov Institute of Electro-physical Apparatus", St. Petersburg, RF.

and channels in the turn and coil cases, as shown in Fig.2. It will be necessary to leave 1.5 - 2 mm wide gap around the cable for LHe passage, as well as to install small ceramic plates to fix the cable inside the case. This allows to eliminate the numerous communications<sup>2</sup> around the magnet, poor insulation of which has been the reason of many (18) breakdowns inside cryostat for all six existing force-cooled SC magnet systems for tokamaks. Another thing needed for magnet reliability is the reduction of voltage during magnet protection discharge. Basing on experience of T-15 the dumping voltage should be  $\pm 3$  kV<sup>3</sup>. This is less than that adopted for ITER, but still too much for single step turn insulation discussed above. Dumping voltage could be considerably reduced when using inductive coupling with the coil and turns cases. They all are in good inductive coupling with the coils though need artificially reduced resistance to get the main part of energy dissipation in these structures. They could be warmed up to 60K or so, while the energy dissipated in protective resistors will be reduced considerably. This allows to put them inside of the cryostat and to reduce the number of current leads. Also, simple SC switches could be used in this case.

We concluded that the construction of an SC magnet with parameters needed for TNS is in principle feasible. However, the present version of our magnet has rather small margins: in mechanical stresses estimated for coil cases, the number of wires in the cable needed for 26 kA/turn, the cross section of highly conductive stabilizing material and in providing the proper cooling of the magnet. For reliable magnet operation either  $R_0$  should be increased by 15-25 cm, or an HTS material should be used. Certainly the latter requires more R&D for the design and construction. However, the difference is not too significant, because the main steps of that R&D are practically the same, as for LTS magnets: design and test of current carrying cable, winding and tests of model coil, finally the prototype coil manufacturing and tests. Of course, this alternative requires a considerable increase in HTS material production, and surely a major cost reduction. The optimization of winding with three layers: NbTi in outer winding, Nb<sub>3</sub>Sn in the middle one and HTS in innermost would have to be achieved too and seems very attractive.



**Fig. 1.** Cross-section of the DEMO-FNS design.



**Fig. 2.** Cross-section of current-carrying element having 28 sub-cables 7 wires in each. The arrows show the He flow direction in the case of “cross-flow” cooling. Cross-section of a single sub-cable is shown below that of the whole element.

<sup>2</sup>Communications are current leads from the coils, feeders connecting them with the leads from cryostat, liquid He conduits, as well as electrical cabling of various sensors. All of them are placed in the cryostat vacuum which in principle provides good insulation. However, breakdowns can occur, for instance due to mechanical disturbances during plasma current pulse or current disruption.

<sup>3</sup> T15 was the tokamak with biggest toroidal Nb<sub>3</sub>Sn coils  $R_0=2.5$ m and inner bore  $a=1.06$  m wound by monolithic electroplated cable after reaction; constructed at the Kurchatov Institute in 1988 and successfully operated till 1995.

## References

- [1] “ВАНТ” Сер. Термоядерный синтез, 2014, т. 37, вып. 3 с.6-14 (in Russian). ВАНТ is the acronym of “Voprosy Atomnoy Nauki i Techniki (Problems of Atomic Science and Technology), a journal published by Kurchatov Institute.
- [2] Proceedings of 25 IAEA Fusion Energy Conference FEC 2014 St. Petersburg, Russia, 13-18 Oct, 2014, Poster FIP/P 7-10, D.P. Ivanov, I.O. Anashkin, B.N. Kolbasov, M. S. Novikov, S. I. Novikov, S.A. Shuvaev, "Superconducting Magnet for Russian Fusion Neutron Source DEMO FNS".