First Results from Tests of High Temperature Superconductor Magnets on Tokamak.

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It has long been known that high temperature superconductors (HTS) could have an important role to play in the future of the tokamak fusion research [1,2]. In this paper we present first results of the use of HTS in a tokamak magnet. In the experiment, the two copper poloidal field coils of the small tokamak GOLEM in Prague [3] were replaced by two coils with 6 turns of the 2nd generation HTS (Re)BCO tape, Fig.1. Two simple liquid nitrogen (LN) cryostats were assembled to cool the HTS tape to below the critical temperature at which it becomes superconducting. Plasma pulses were then fired in a normal way and the tokamak operated exactly as expected. There had been concerns that the plasma pulses and pulsed magnetic fields might cause a "quench" in the HTS, i.e. cause a sudden and potentially damaging transition from superconductor to normal conductor. However, many plasma pulses were achieved without any quenches. In addition, experiments without plasma have been performed to study properties of the HTS in a tokamak environment, i.e. critical current and its dependence on magnetic and electrical fields generated in a tokamak both in DC and AC operations, maximum current ramp-up speed, performance of the HTS tape after number of artificially induced quenches etc. No quench has been observed at DC currents up to 250A during bench tests. The HTS was kept on the full current for tens of minutes with no observed changes in resistivity.

Fig.1. Plasma pulse in GOLEM with HTS poloidal field coils.

Although it is known that the critical current in HTS strongly depends on magnetic field, for the GOLEM conditions, where magnetic fields at the coil position do not exceed 0.5T, little effect has been observed for perpendicular field up to 0.5T and superconductivity has been achieved at ~90.5^{0}K. In the AC tests, current up to 1kA through the tape (6kA-turns through the coil) has been achieved with no degradation of the HTS performance afterwards and the rate of the current ramp in the HTS of ~0.6MA/s has been achieved. In typical plasma pulses such a high level of current in equilibrium field coils is not needed and plasma operations have been performed with moderate I_{HTS} ~ 50-100A current in the tape. This probably explains the absence of quenches during plasma pulses as the current was much below the critical value. However in some cases plasma disruptions occurred with corresponding induced electrical fields, and they also did not cause quenches. In future experiments, increases in both the plasma current and pulse duration are planned.

Considerable experience has been gained during design and fabrication of the cryostat, coils, isolation and insulation, feeds and cryosystems. The tokamak GOLEM is now routinely operated with HTS coils and design and construction of next step HTS tokamaks have started and are on-going. The next step in the application of HTS magnets in tokamaks is construction of a fully-HTS tokamak that has started at the Tokamak Solutions UK premises in the Culham Science Centre, UK. It is planned to operate a small tokamak with A=2 and circular cross section in steady state with plasma currents of 10-20kA driven by Electron Bernstein Wave current drive at densities above $10^{19}m^{-3}$. In parallel, the design and manufacture of a high-field (3-5T) HTS TF coil for a spherical tokamak will be carried out.

1. L Bromberg et al, Fusion Eng. and Design, 54 (2001) 167, 2. G Janeschitz et al.; *"High Temperture Superconductors for Future Fusion Magnet Systems - Status, Prospects and Challenges*" Proceedings of the 21st IAEA Conference, Chengdu, 16–21 October 2006, IT/2-2, http://www.swip.ac.cn/xsyd/p1292/papers/it 2-2.pdf, 3. V. Svoboda et al., *Multi-mode remote participation on the GOLEM tokamak*, Fusion Eng. and Design 86 (2011) 1310