First Results from Tests of High Temperature Superconductor Magnets on Tokamak

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Introduction

Coils of steady-state tokamak magnets will have to be superconductive to reduce otherwise high running costs [2, 1]. Present low temperature superconductors have to be cooled using liquid helium which is both expensive and technologically challenging and requires bulky cryostats. This contribution presents results of the first testing of high temperature superconductor (HTS) coils on the GOLEM tokamak.

HTS tape

The HTS used are a 2^{nd} generation of (Re)BCO tape SCS12050-AP supplied by SuperPower Inc., US at 100 \$/m.

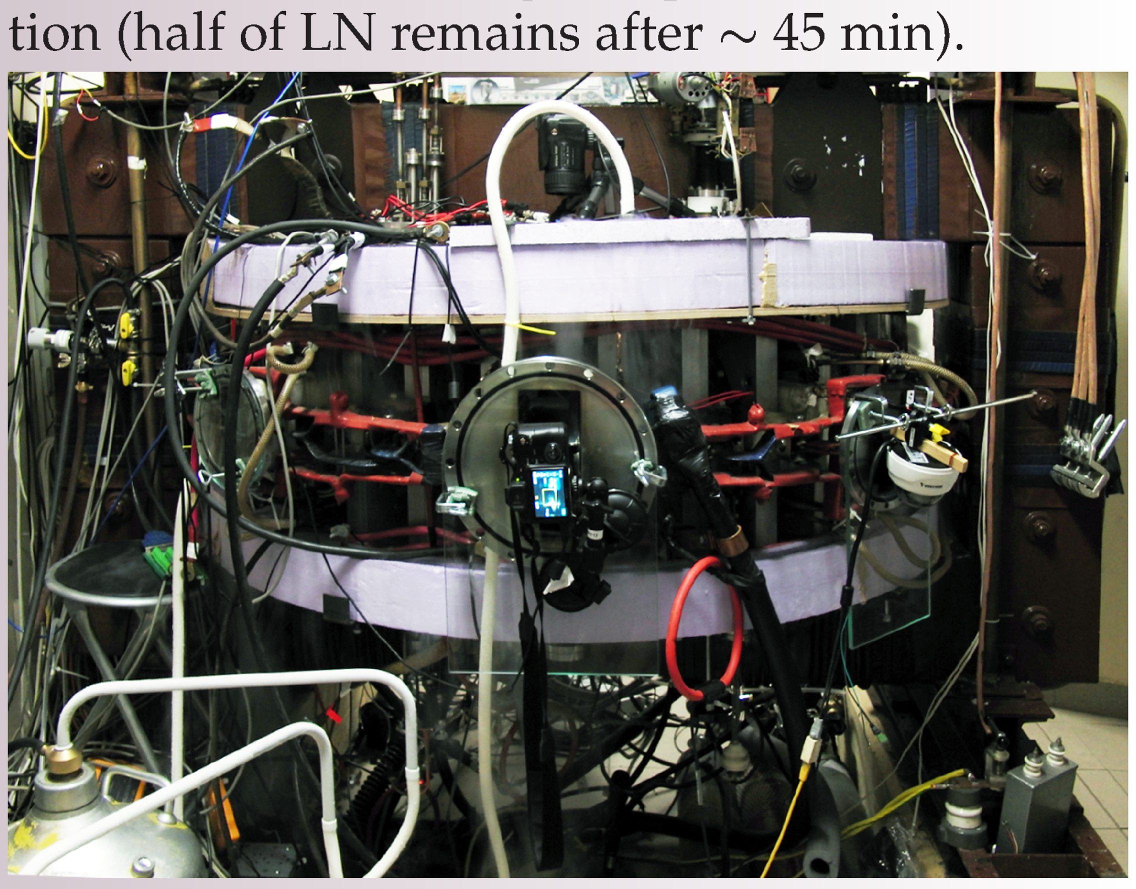
- superconductive below $\sim$ 91 K $\Rightarrow$ liquid nitrogen used for cooling
- maximum current capacity $\sim$ 350 A in superconductive state

Structure of the tape (0.1 $\times$ 12 mm):

- 1 μm thick layer of HTS
- two 20 μm Cu stabilizing layers
- 50 μm Hastelloy substrate

Cryostats and LN cooling

The HTS tape submerged in LN is contained in a circular-basin cryostat cut out from an extruded polystyrene (JACKODUR KF 300 Gefiniert GL), offering exceptional heat insulation (half of LN remains after $\sim$ 45 min).



Each HTS tape turn is insulated using Kapton tape. Both cryostats are filled independently using a pressurized air based system.

References

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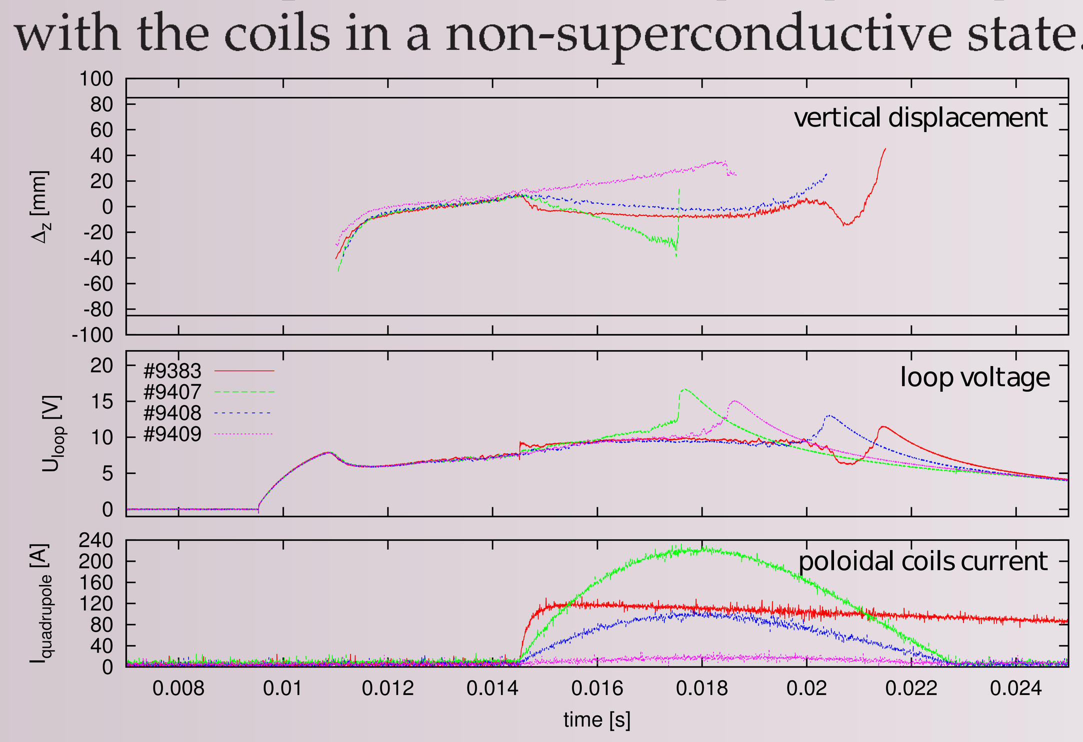
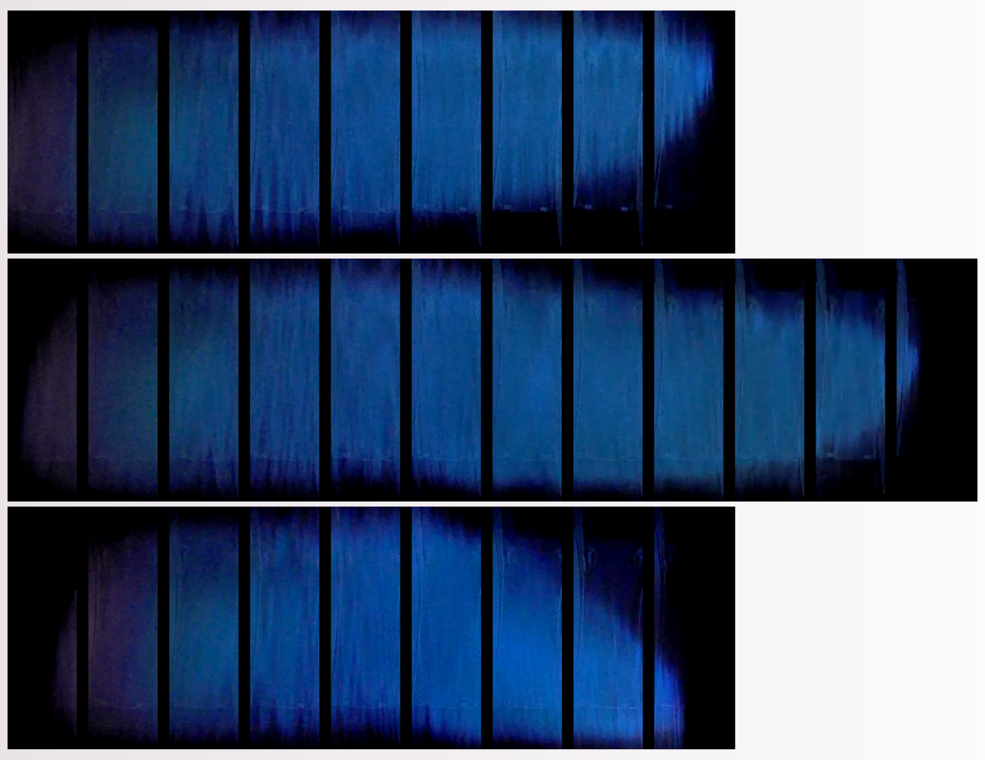
Plasma Position stabilization

With the HTS coils in a superconductive state the coils target current can be reached with up to 10 $\times$ lower capacitor bank chargning voltage than with the coils in a non-superconductive state.



Using a radial magnetic field the plasma pulse can be prolonged by compensating the tendency of the plasma column to go upwards.

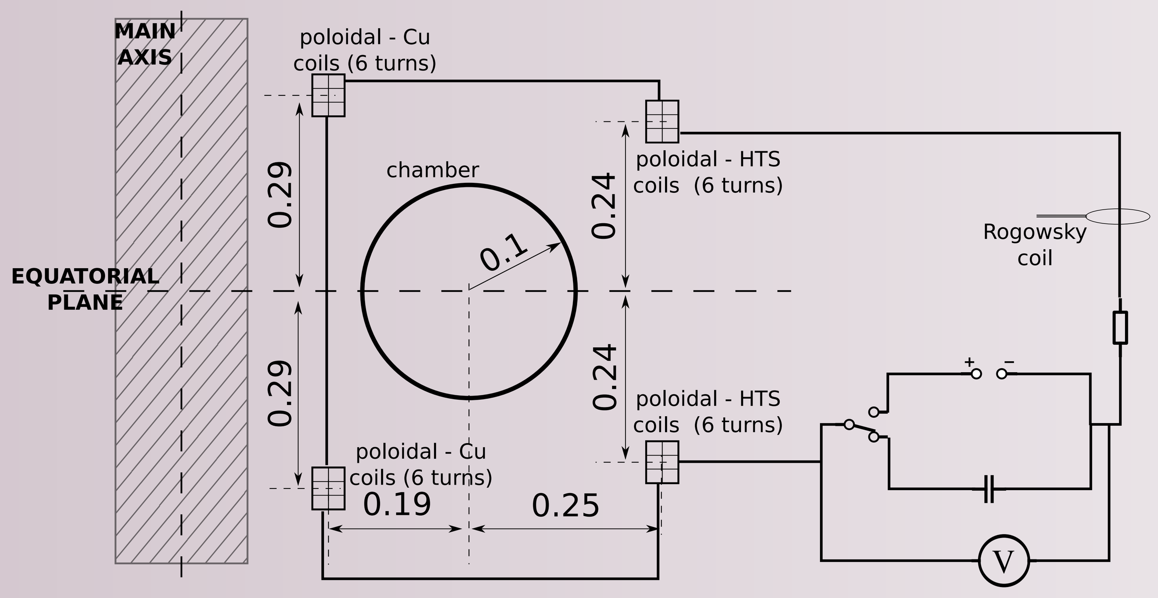


Horizontal position viewed by a HS camera for discharges #9407 to #9409 (bottom to top).

Due to the low resistance the characteristic time constant of the circuit changed and the stabilization pulse was much shorter, making it ideal for fast feedback systems.

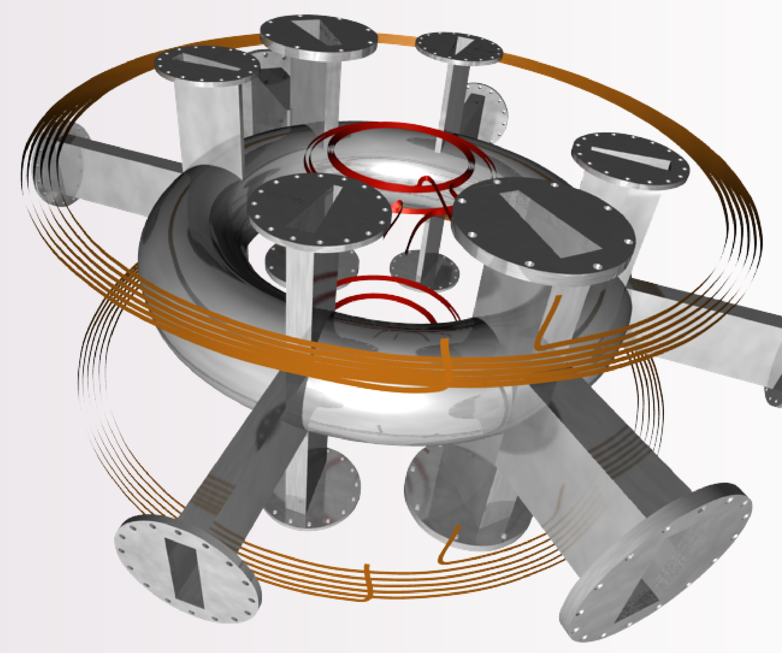
Poloidal coils configuration

GOLEM (R = 0.4 m, a = 0.085 m) is a small iron-core transformer tokamak operating at modest parameters $I_p < 4$ kA, $B_t < 0.5$ T [3]. It is assumed that such low magnetic fields do not affect the performance of the HTS.



A set of 4 six-turn Cu poloidal coils in a quadrupole configuration are used for plasma position stabilization using a radial or vertical magnetic field. The two outer coils were replaced with HTS tape coils with an equal number of turns. All poloidal coils were connected in series to a capacitor bank.

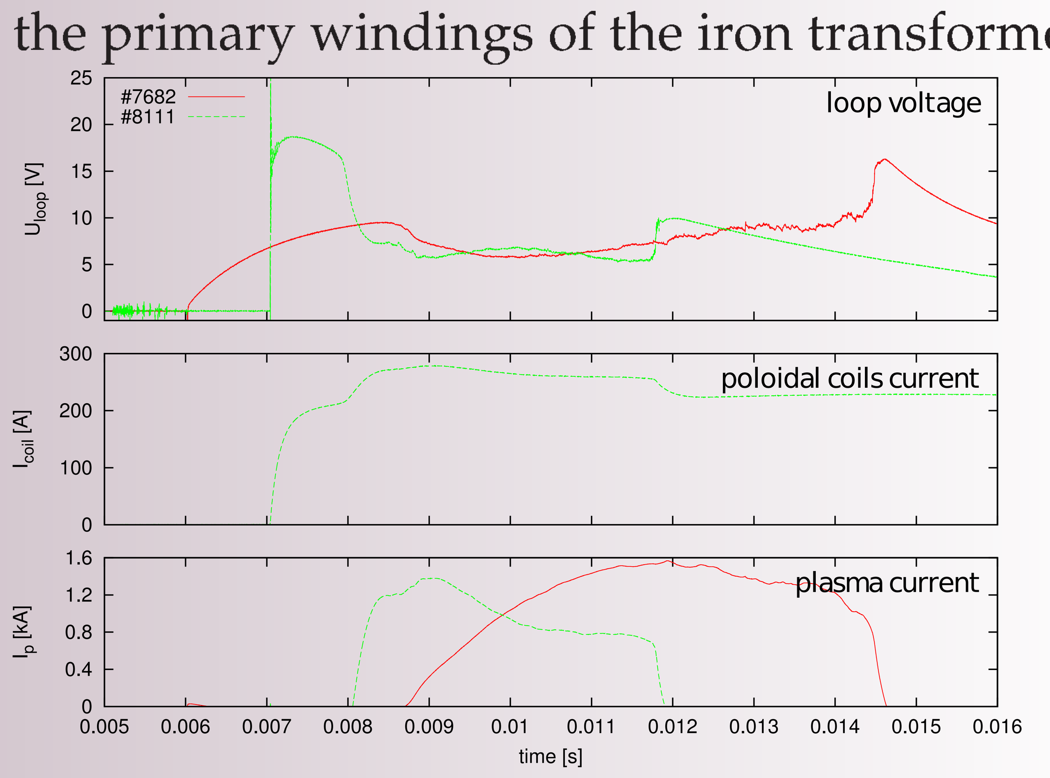
The maximum current was limited by the resistance of the non-superconductive inner poloidal coils and the cables connecting them to the capacitor bank and inductance of the coils.



As in some experiments only the superconductive coils were used, the characteristic time constant of the circuit had to be prolonged by connecting a choke coil in series and/or a resistor was connected in series to limit the maximum achievable current.

Poloidal coils induced current drive

Outer poloidal coils can generate a change of the vertical magnetic flux which induces a loop voltage in the tokamak vessel as a transformer would. With this principle plasma breakdown was achieved and current driven without using the primary windings of the iron transformer.



The breakdown voltage was 20V with a maximum poloidal coils current 280 A for coils in a non-superconductive state, 15V and 480 A in a superconductive state.

Conclusion

- The HTS coils have been routinely and successfully used at the GOLEM tokamak for plasma generation and stabilization.
- Provided the LN cooling is sufficient and sustained, the HTS coils are reliable and can greatly reduce the necessary capacitor bank charging voltage, thus lowering the energy demands for plasma position control.
- The coil currents in fast ramp-up pulse operation (tens to hundreds of kA/s) exceeded those in the tape specification by almost 50 %.

Acknowledgments

We would like to thank Thomas N. Todd for the idea of using the HTS poloidal coils to generate plasma. This work was supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS11/131/OHK4/2T/14.