Cryogenic Design and Thermal Stability Analysis of a HTS Magnet for Radiation Blackout Mitigation Experiment

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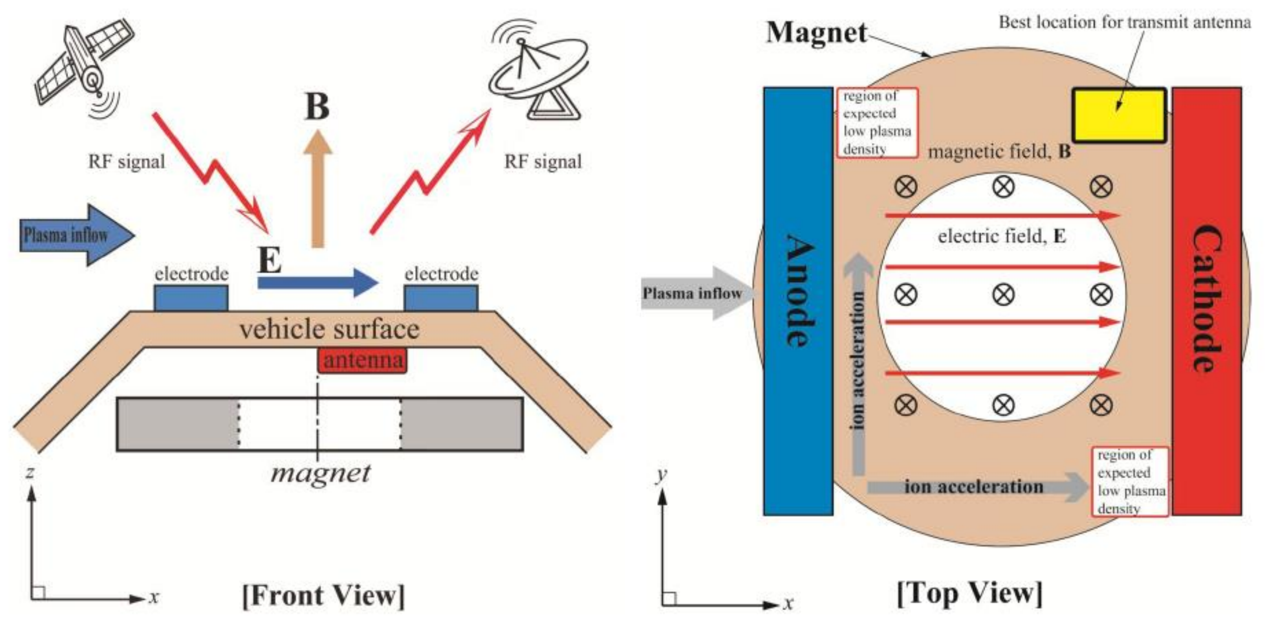
Background

- Radiation blackout is a communication interruption phenomenon during hypersonic or re-entry flight, caused by a plasma layer around a vehicle attenuating or reflecting radio waves. A vehicle in the radiation blackout phase will lose all contact with ground stations or satellites.
- A method proposed to reduce the plasma density around senders and antennas is to apply crossed electric and magnetic fields. The Helmholtz-Russia Joint Research Group COMBIT will demonstrate this method at flight relevant conditions in an arc-heated wind tunnel (L2K facility) at the German Aerospace Center (DLR) in Cologne.
- A conduction cooled HTS magnet produced by KIT is applied to generate the required magnetic field,



Courtesy of A. Gülhan, DLR Cologne, Joint Research Proposal Helmholtz Russia Joint Research Group

Schematic view of the crossed E×B method to reduce plasma density

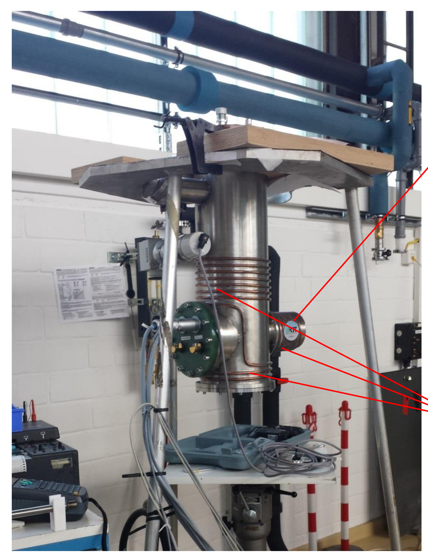
Challenge

- Larger than 2 T magnetic field outside the cryostat is required.
- Maximum diameter of cryostat is ~100 mm, including cryostat wall, thermal shield and MLI.
- Other strict space restrictions in L2K tunnel.
- Cryostat wall will be exposed to the plasma beam, with a temperature of ~450 K.

Cryogenic system

Cryogenic design

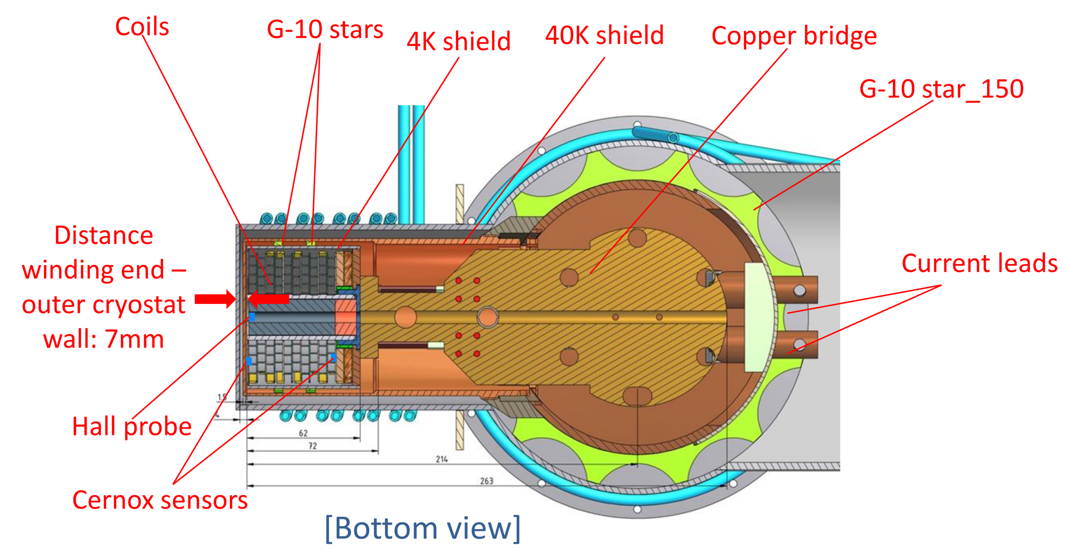
- The magnet is conduction coolded by a Cryomech PT415-RM type cryocooler, which has a 2nd stage cooling power of 1.35 W at 4.2 K and a 1st stage cooling power of 36 W at45 K. The remote type cooler is chosen, because the motor in vacuum might overheat due to the heat load from the plasma beam and the heat produced by the motor.
- Both thermal shield and 4 K cold mass are gold coated to reduce radiation heat loss.
- A pair of HTS current leads is used between magnet and thermal shield.
- Cooling water pipes are applied around cryostat to take away the heat from 450 K plasma beam



Cryostat including magnet ready for test

Calculated heat load of cryostat

	40K region [W]	4K region [W]
Radiation	0.93	0.007
Support spring	---	0.001
G-10 star_150	1.24	---
G-10 stars	---	**0.12**
Instrument wiring	0.01	0.032
Soldering joints	---	**0.287**
Current leads	**22.67**	**0.06**
Total	**24.85**	**0.51**



Schematic view of the cryostat

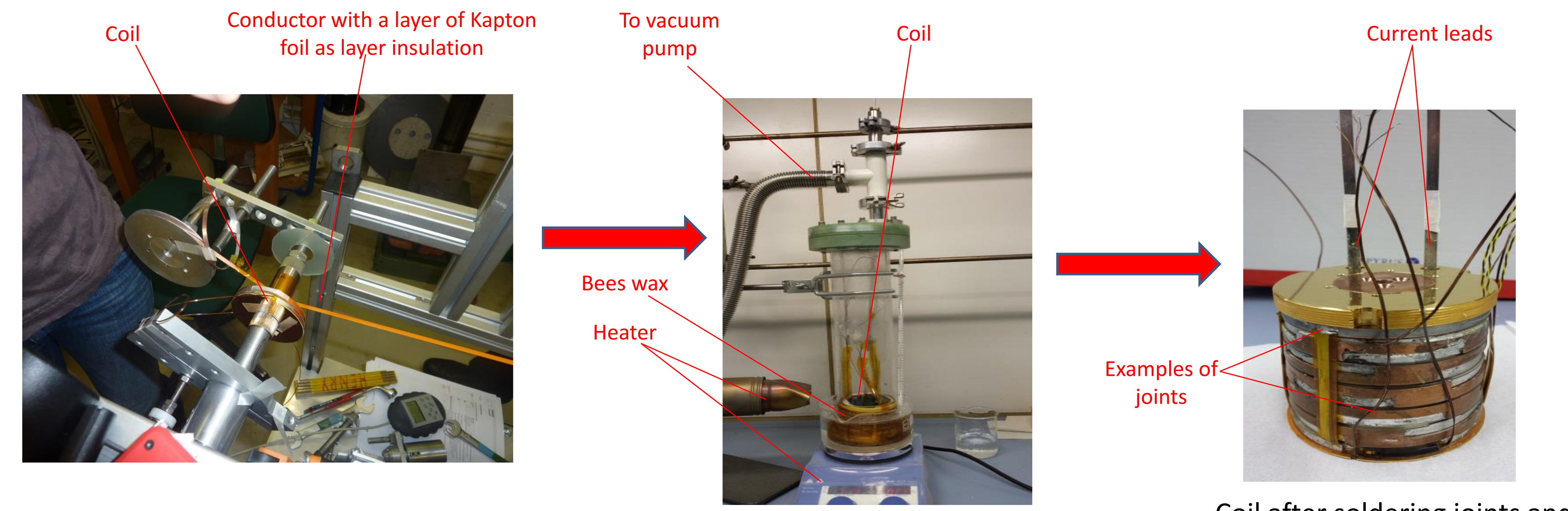
Design and fabrication of the Combit magnet

Parameters of Combit magnet

Parameter	Value
Number of double pancakes	5
Outer winding diameter [mm]	70
Inner winding diameter [mm]	25
Turns per pancakce	~186
Conductor length per double pancake [m]	~55
Self-inductance L [mH]	70
Operation Current I_{op} [A]	135
Magnet field center with I_{op} B [T]	4.82*
Field outside cryostat with I_{op} B [T]	2.04*
Stored Energy at I_{op} E [J]	637
Mass of coil [kg]	1.75

* The magnetic field is calculated by the software of Opera

Fabrication of the coil



Winding of double pancake coils

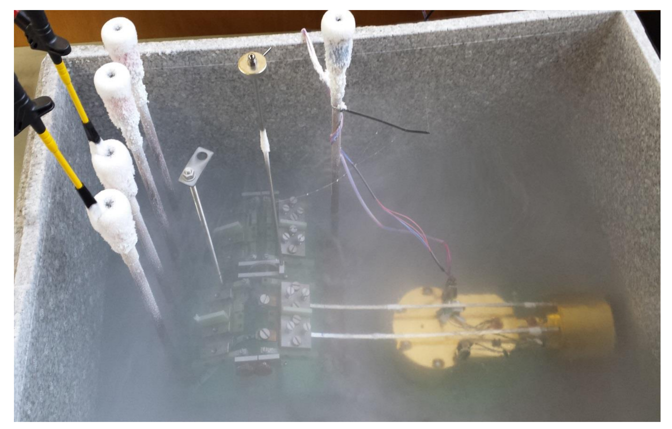
Vacuum impregnation with Bees wax

Coil after soldering joints and current leads

Test results

Magnet test in LN_2

- In LN_2 magnet quenched at 30 A and reached a 1.07 T magnetic field at magnet center.
- Functions of quench detector, voltage taps and Hall probe were checked.

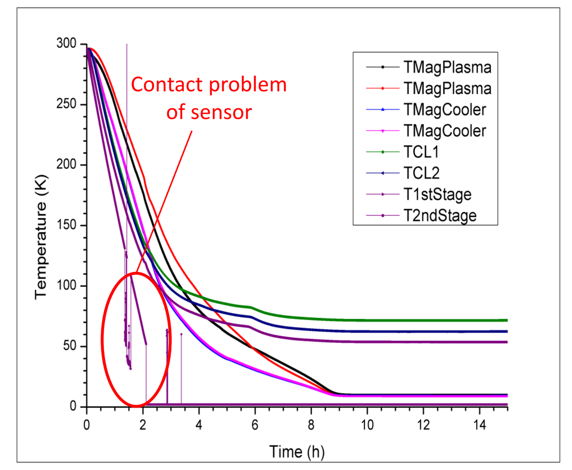


Magnet test in liquid Nitrogen

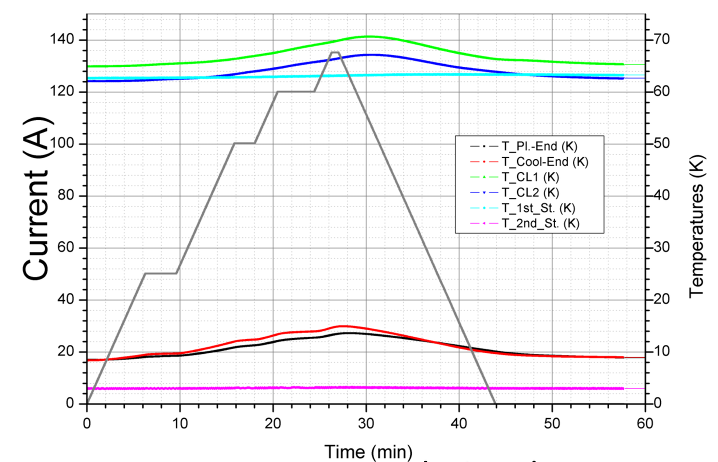
Magnet test with cryocooler

- The Magnet was fully cooled down within 10 hours. Without current, the coil and thermal shield temperatures are ~9 K and ~62 K respectively.
- The magnet reached the designed current of 135 A without any quench. The measured magnet field outside of cryostat is 2.1 T, which is ~10% higher than calculation value. The corresponding field at magnet center is 4.94 T.
- Measured Joule heat of all joints is 0.24 W at 135 A. The Joule heat of joints contributed much more to the coil temperature rise than AC loss.
- Combit magnet passed the test and was transported to German Aerospace Center (DLR) in this week.

- A bulk YBCO cylinder was levited in air by Combit magnet



Cool down curve of Combit magnet



Temperature curves during the test

Magnetic levitation to demonstrate magnetic field

Conclusion and further work

- The Combit magnet reached the design current 135 A without quench. The measured magnetic field outside of cryostat is 2.1 T, and the corresponding field at the magnet center is 4.94 T.
- The static heat load of 4 K region is ~ 0.25 W, which corresponds to the design value.
- The measured Joule heat of all joints at 135 A is ~ 0.24 W, which is the main heat loss. It caused obvious temperature rise on the coil. By contrast, the temperature rise of the coil contributed by AC loss is only several Milikelvins due to the magnet size.
- The Combit magnet was transported to German Aerospace Center (DLR) this week. Further tests in plasma beam will be carried out at DLR in the next weeks.