Design and Testing of a Gas-helium Conduction Cooled REBCO Magnet for a 300 kvar HTS Synchronous Condenser

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Vancouver, Canada
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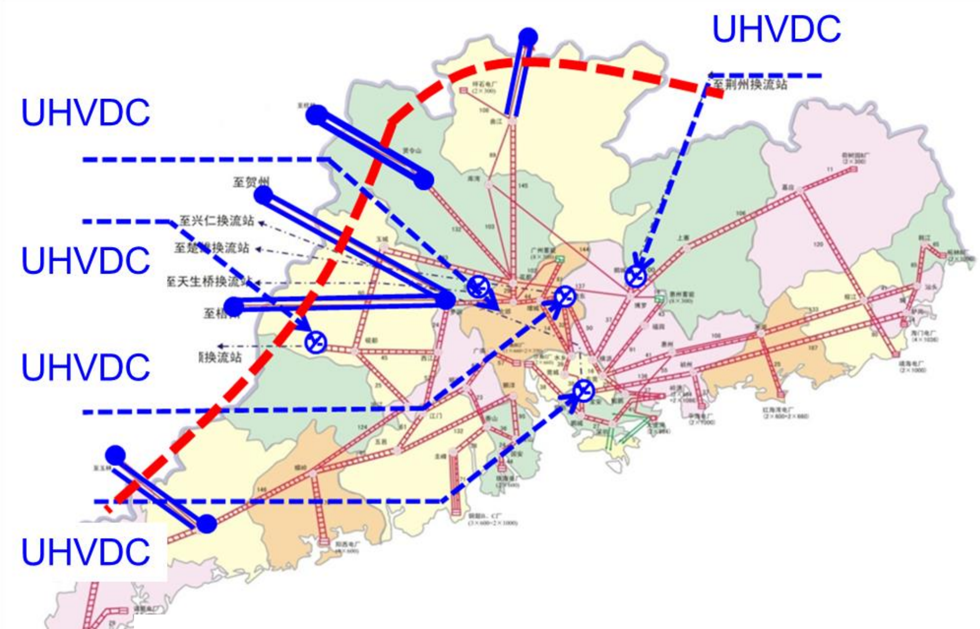
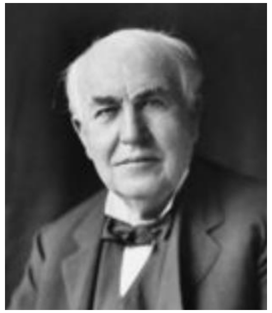
□ Outline

- Background
- Project overview
- Test of the magnet prototype
- Summary

□ Background



UHVDC transmission lines layout in Guangdong Province, China



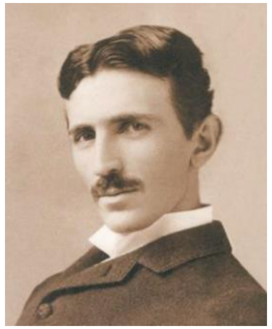
Thomas Edison

Transmission Lines: UHVDC

- Voltage and current, the same phase
- All active power

DC → AC

AC → DC



Nikola Tesla

Distribution Lines：AC

- Voltage and current, with phase lag
- Active and Reactive power

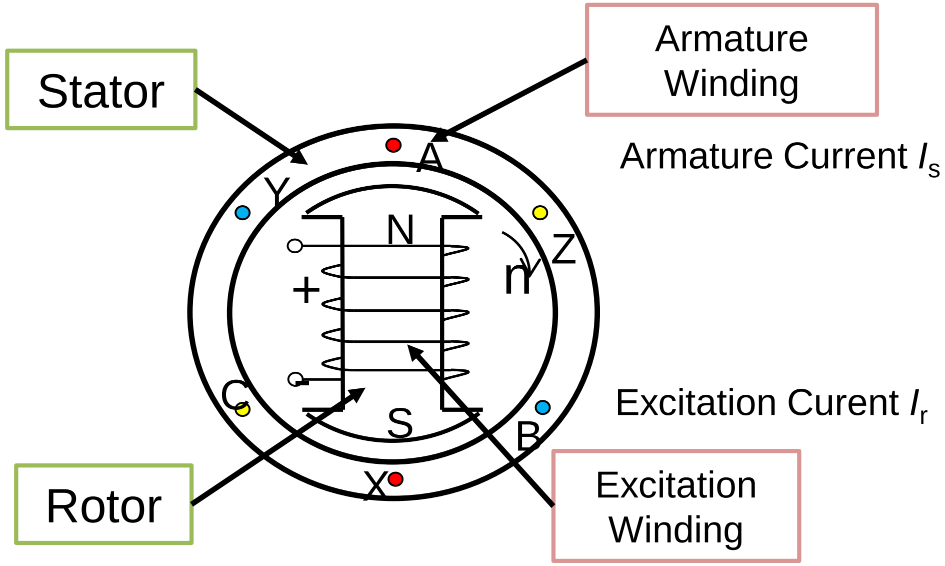
✓ Lack of reactive power in UHVDC, in rectification or inverter operation.

✓ Stable and reliable **reactive power condensers** are in need in China.

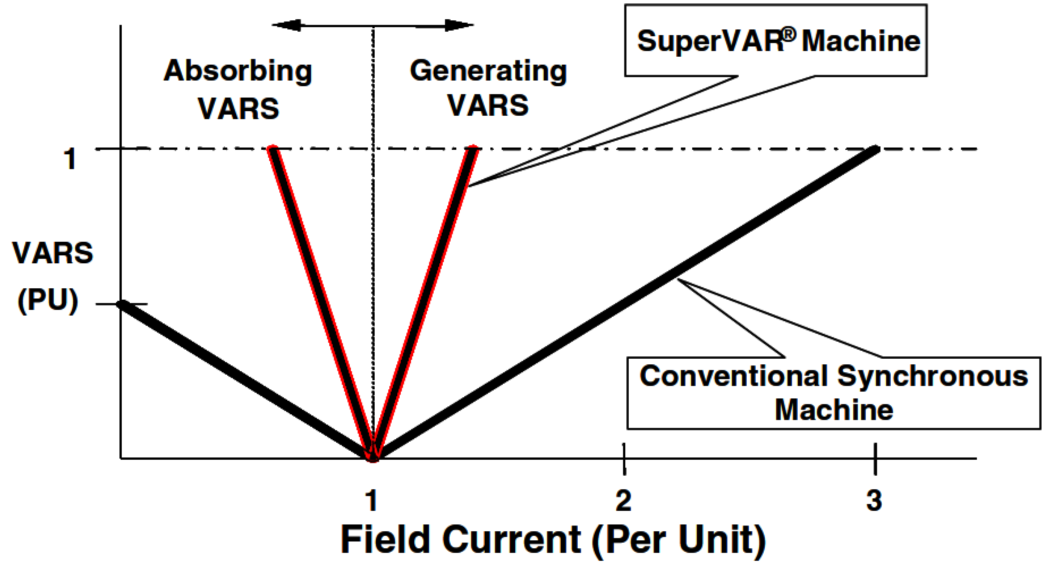
Dynamic synchronous condenser

Conventional DSC：

- A special case of synchronous motor
- No mechanical load, only reactive power
- Excitation current to control output



Sketch of synchronous motor



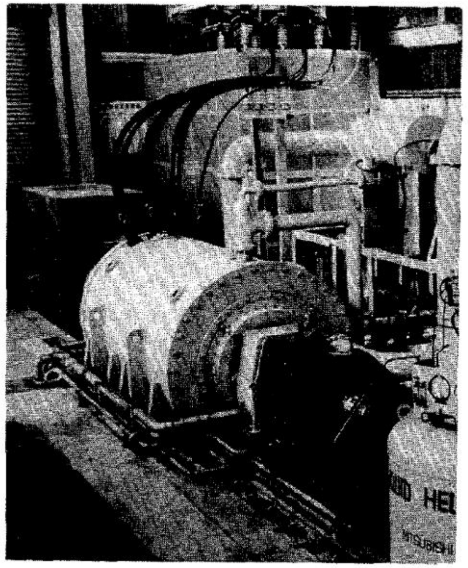
Kalsi S, et al. *IEEE Transmission & Distribution Conference, Dallas, TX*. 2006.

Technical merits of HTS DSC

- High efficiency (nearly no heat loss in rotor)
- Long lifetime of HTS rotor
- Small synchronous reactance, fast response time
- Small volume, light weight
- Strong capability of VARs compensation

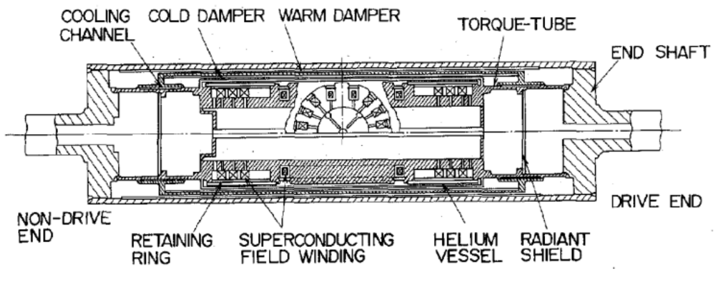
□ Background

30MVA superconducting DSC

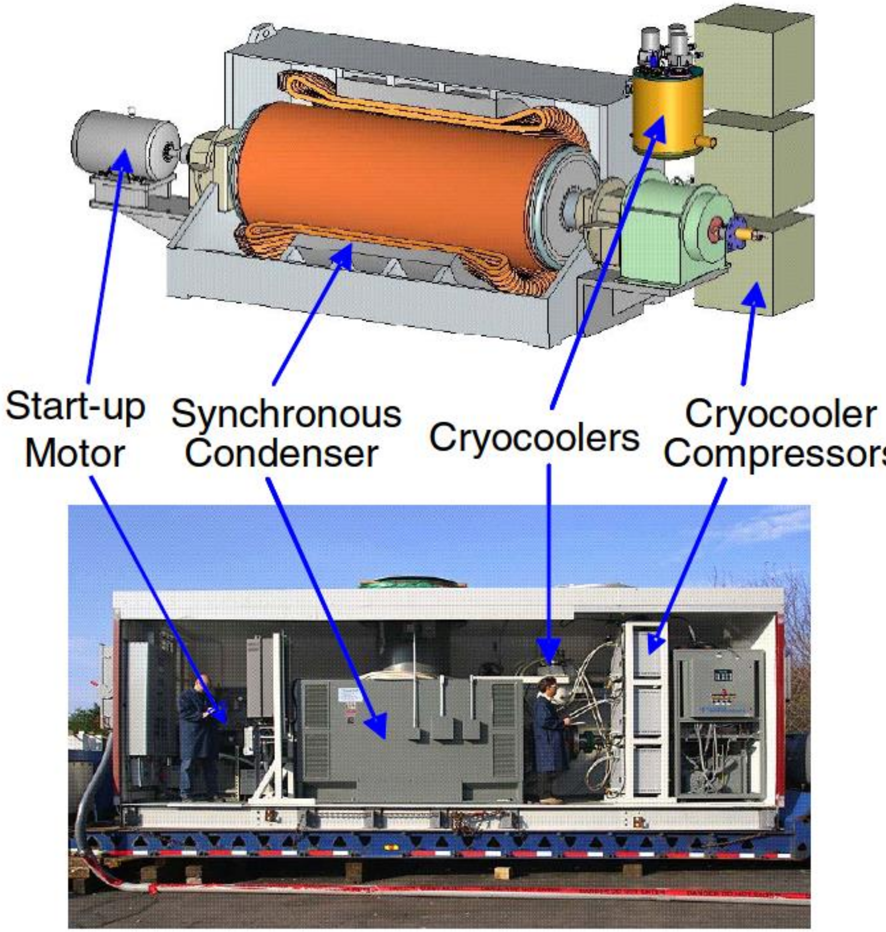


Mitsubishi, Japan, 1985

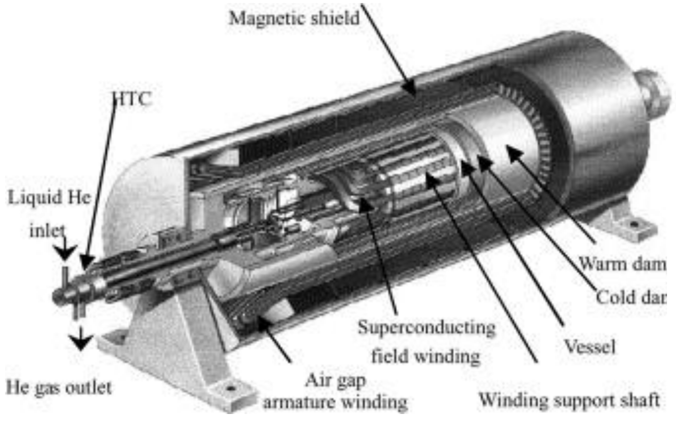
IEEE Trans. Magnetics, VOL. MAG-21, NO. 2, MARCH 1985



AMSC --- 8 Mvar/13.8 kV SuperVAR^{TM} HTS DSC

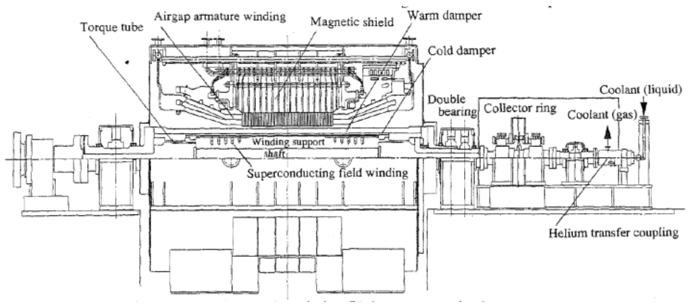


70MVA superconducting generator



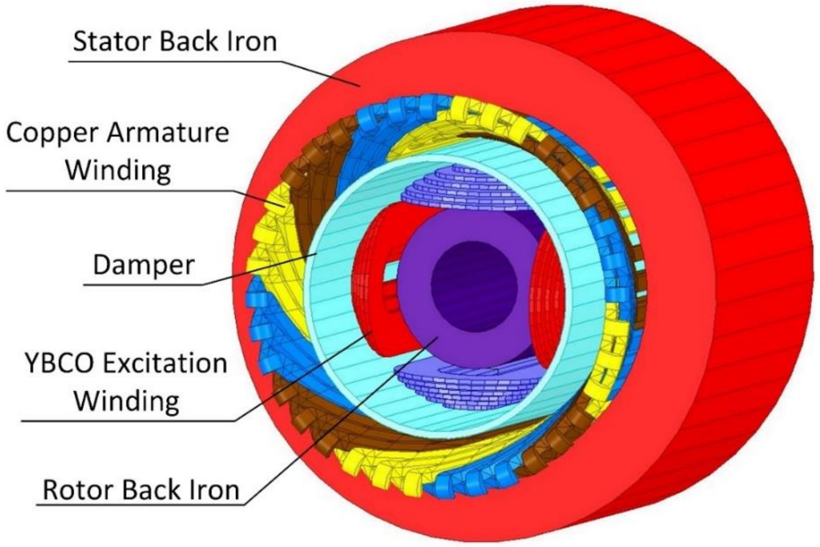
Hitachi, Japan, 1997

IEEE Trans. Appl. Supercond. VOL. 7, NO. 2, JUNE 1997

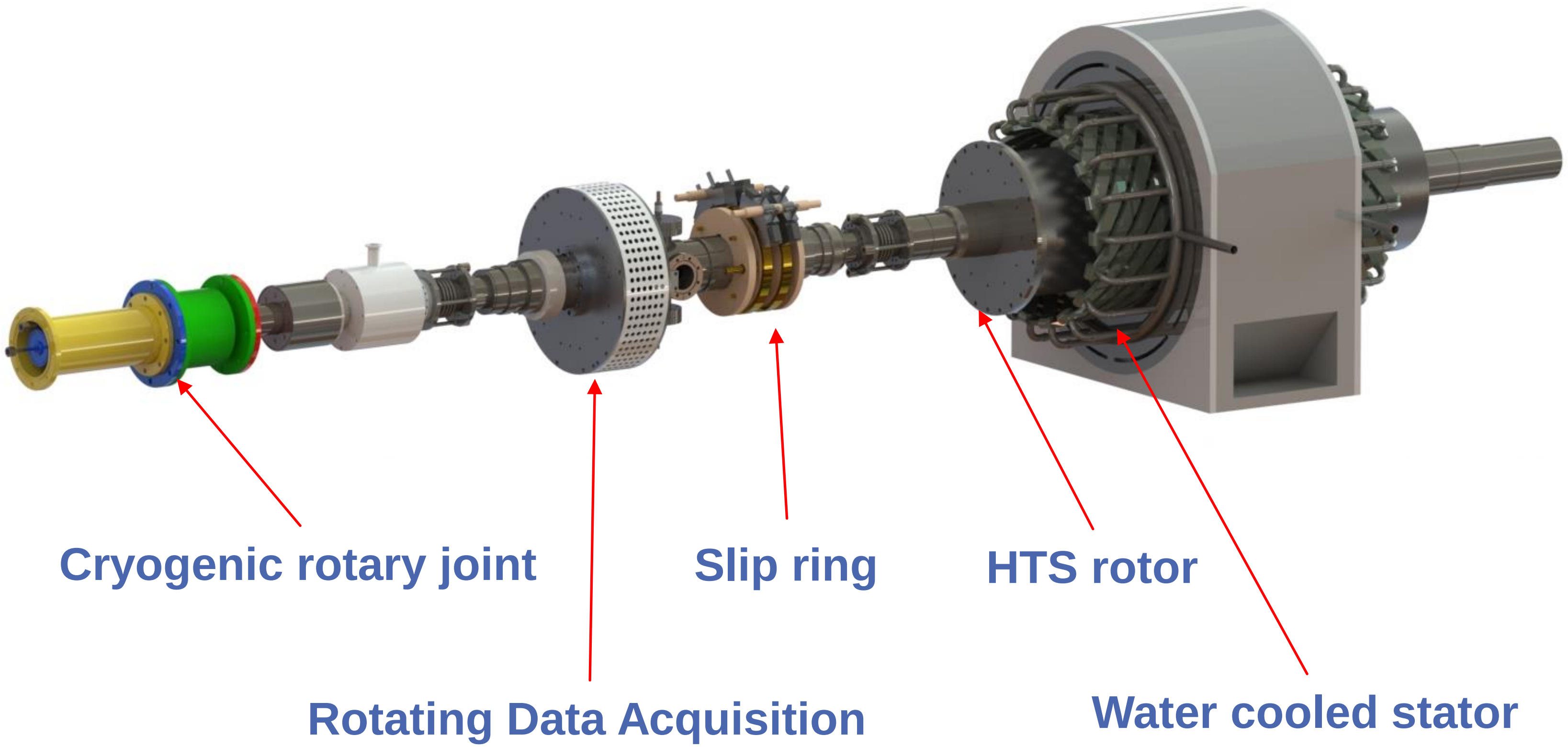


10 Mvar HTS synchronous condenser (2018-2021)

Funded by China Southern Power Grid

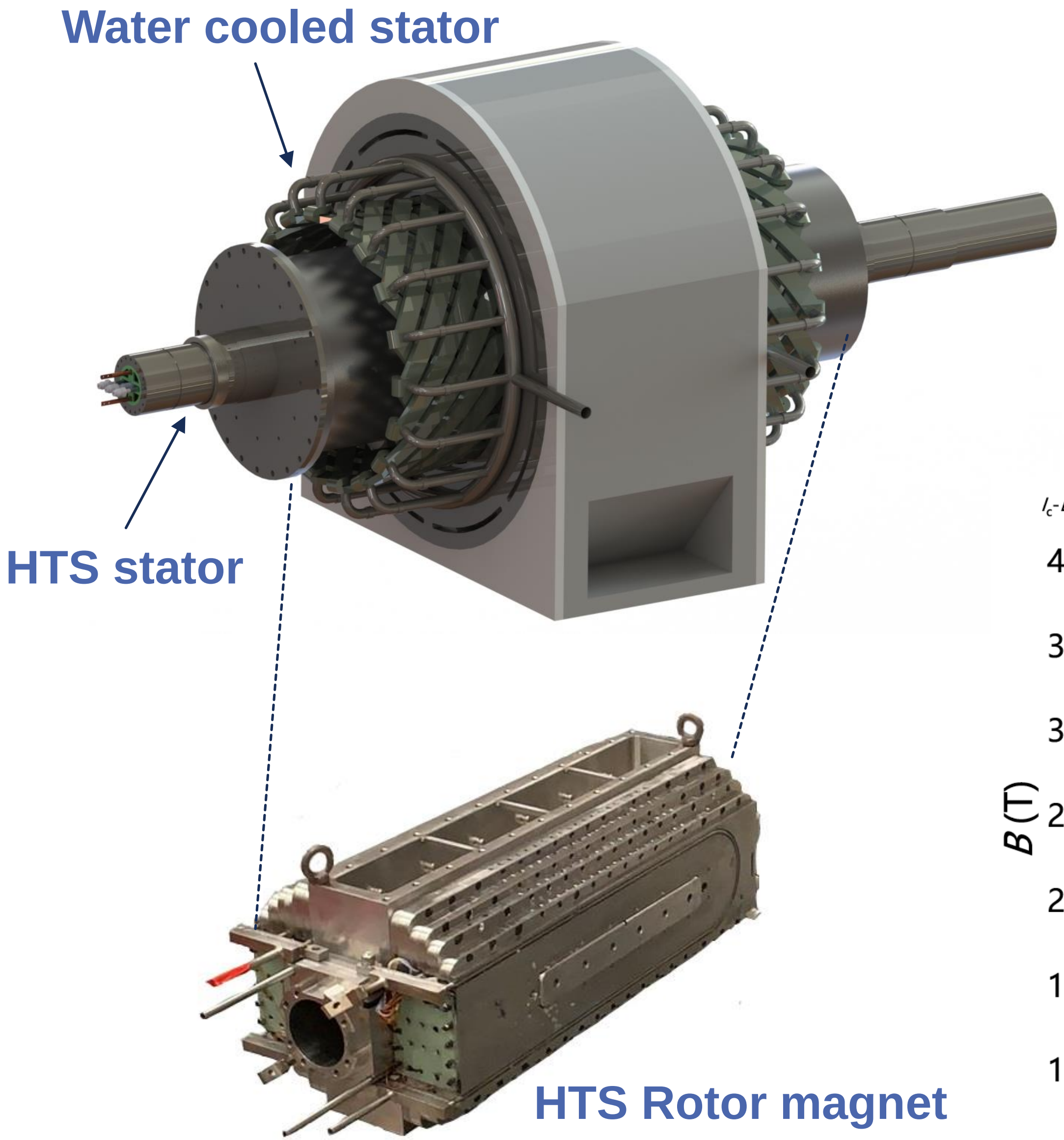


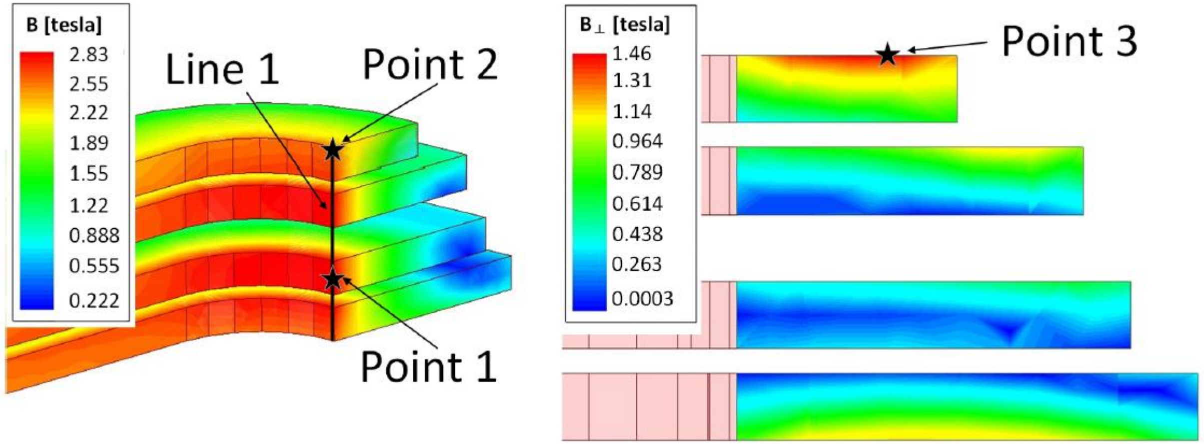
Phase 1 (2018-2019): 300 kvar prototype
Under construction

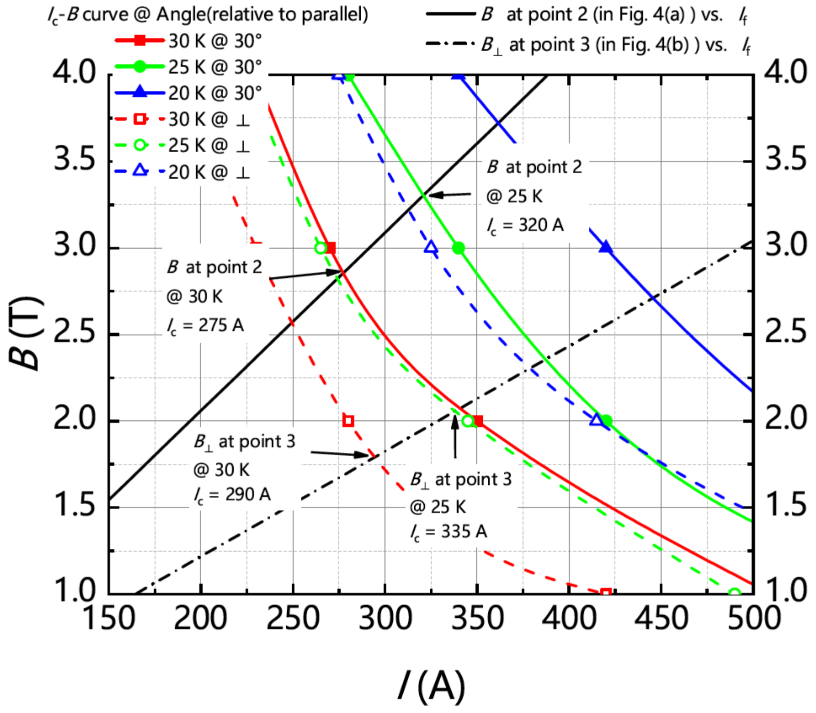


- 10 Mvar, 1500 rpm
- REBCO rotor magnets
- Gap field > 1.4 T
- Non-ferro teeth
- Cooled by 20 K gas helium

□ Project overview

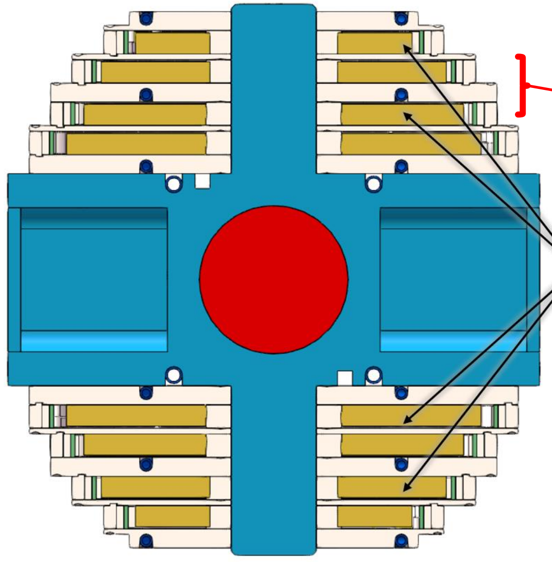


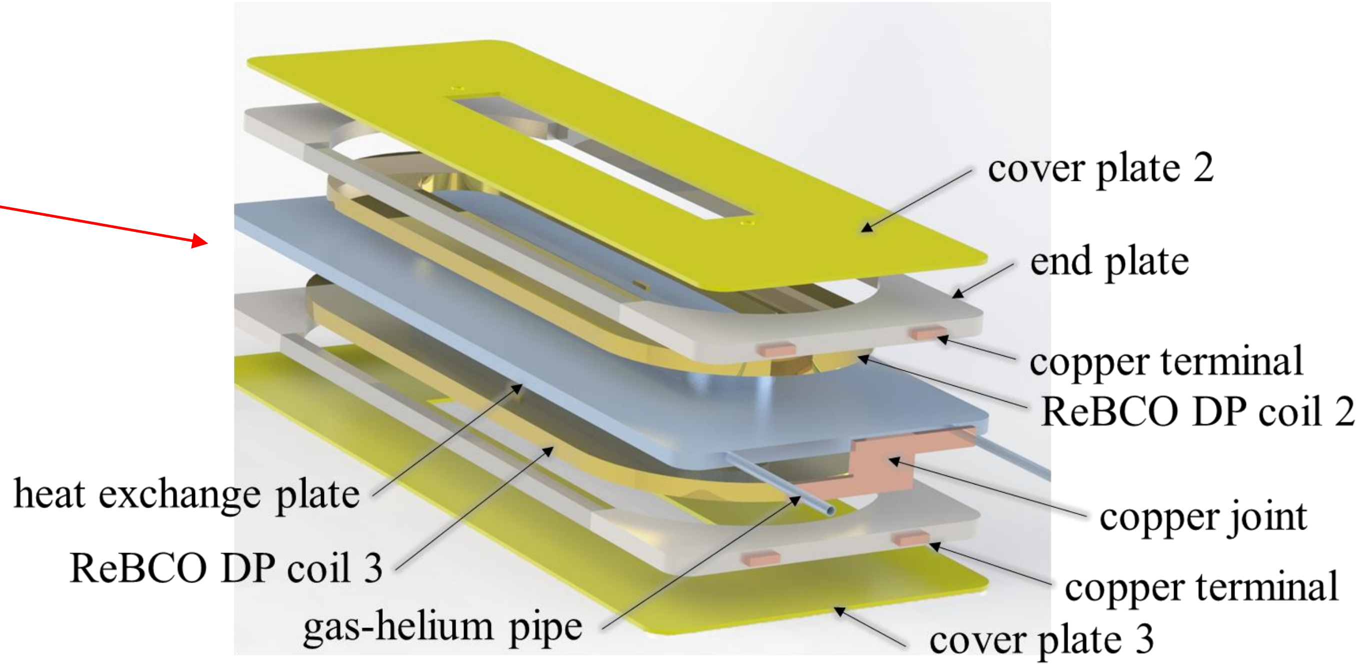




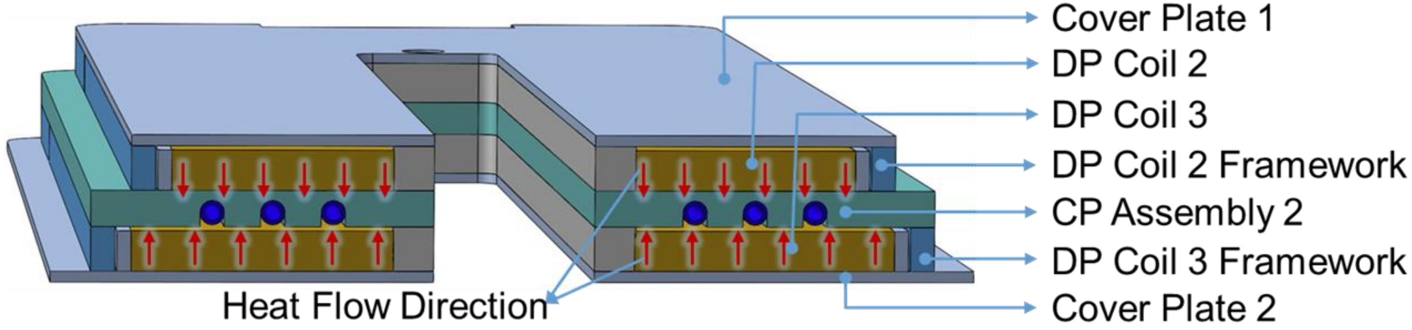
- ✓ Consider the angular dependence of REBCO tapes
- ✓ 30º field at point 2
- ✓ 320 A @ 25 K

☐ Test of the magnet prototype



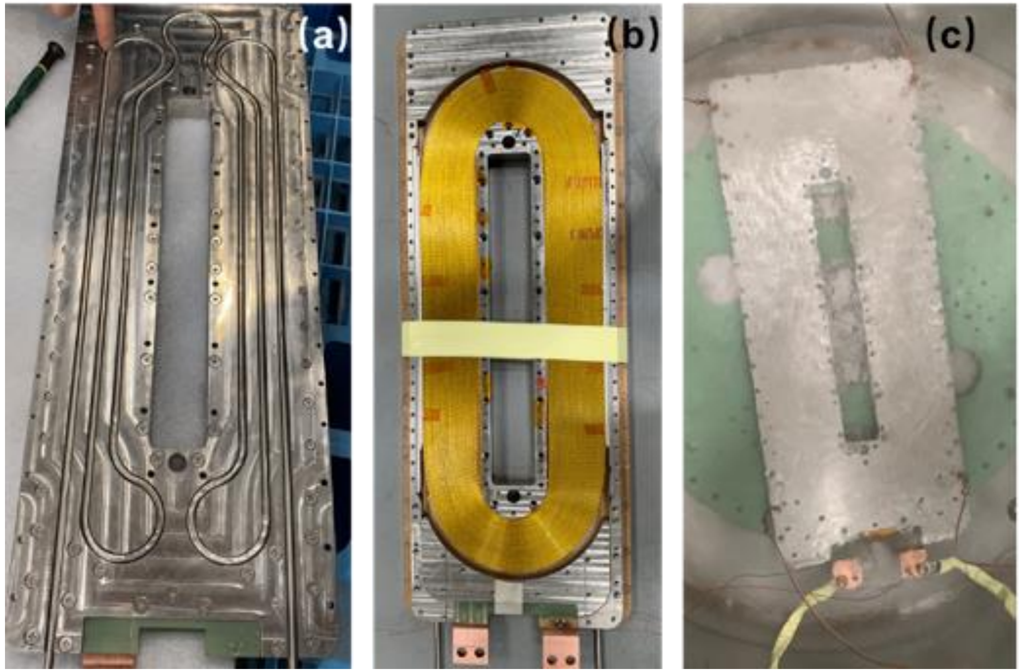


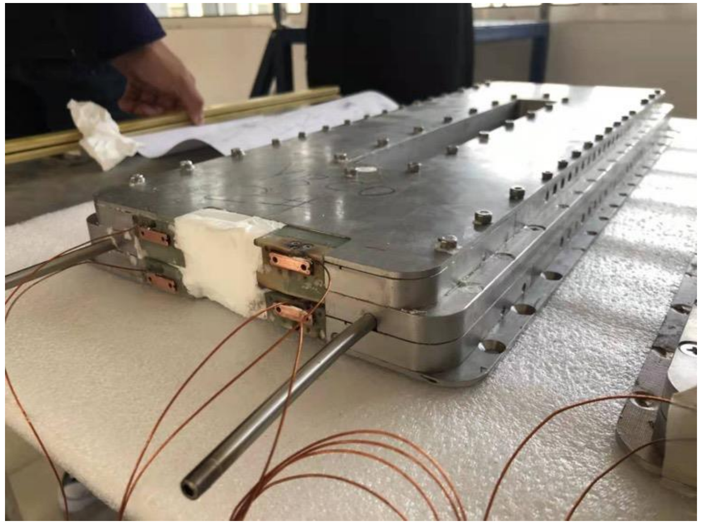
Items	Description
Coils type	Racetrack shaped double pancake
Wires	REBCO 5 mm tape from SSTC
Rated current	280 A @ 20 K
Efficient length	300 mm
Coils Turns	170, 230, 270, 310

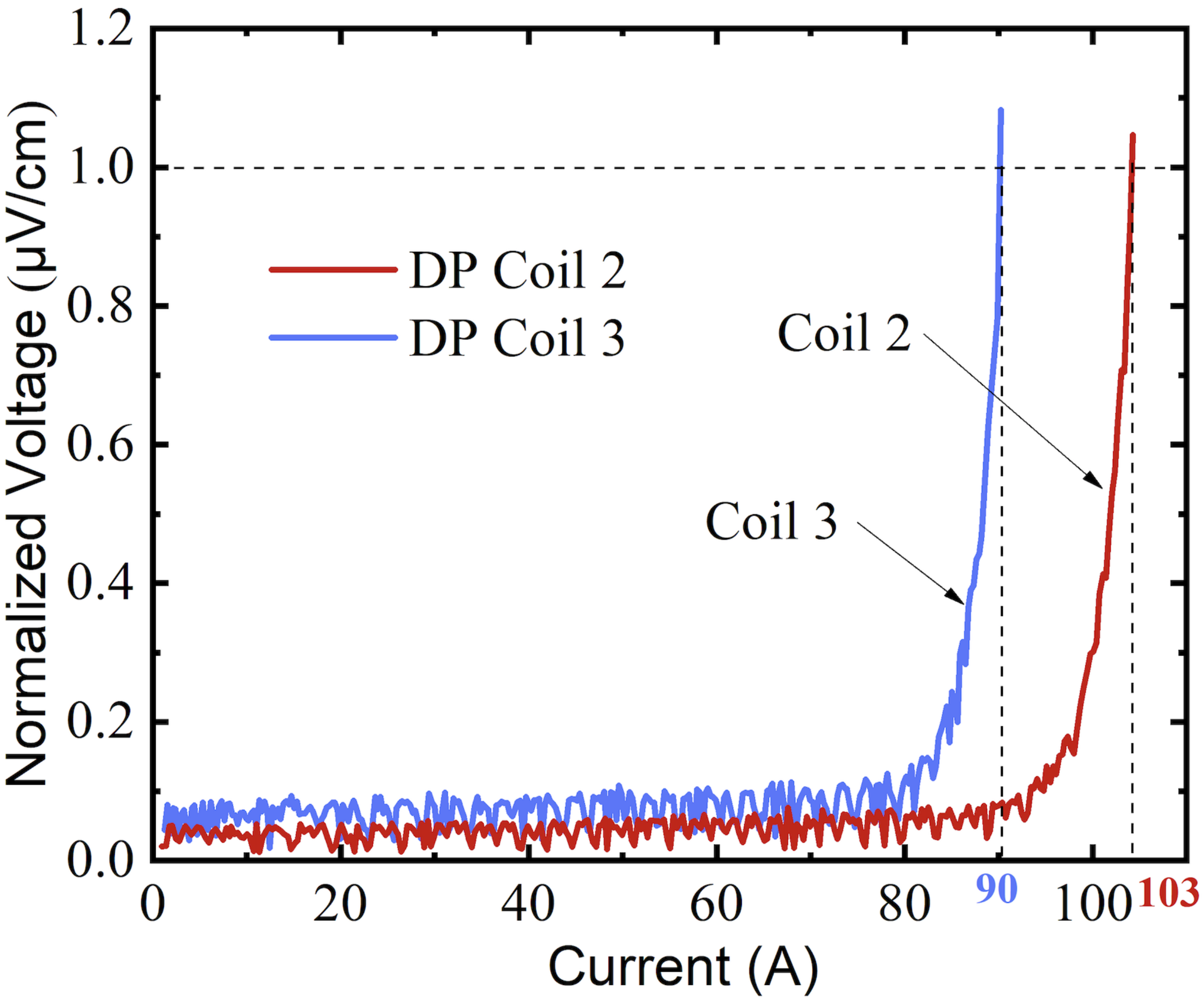


Distributed Pipes In Plates (**DIP**) structure for cooling magnets

□ Test of the magnet prototype

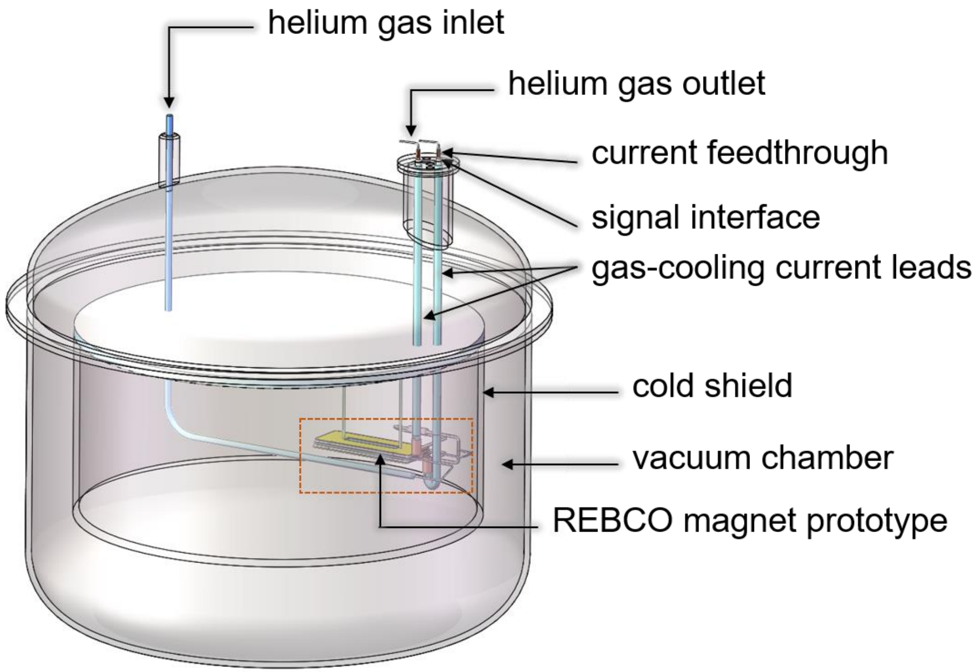


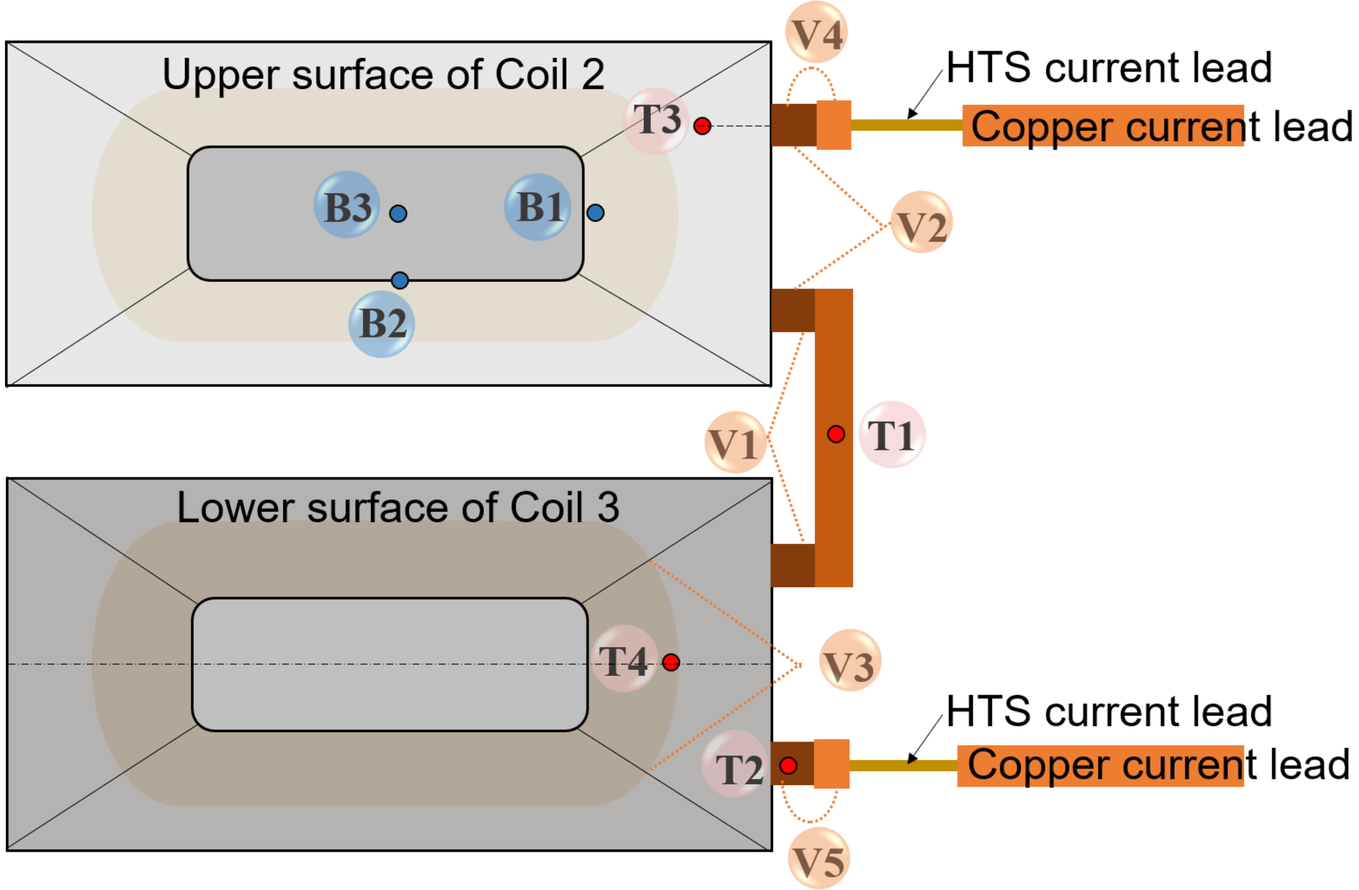




Coil 2: 103 A @ 77 K
Coil 3: 90 A @ 77 K

Test of the magnet prototype



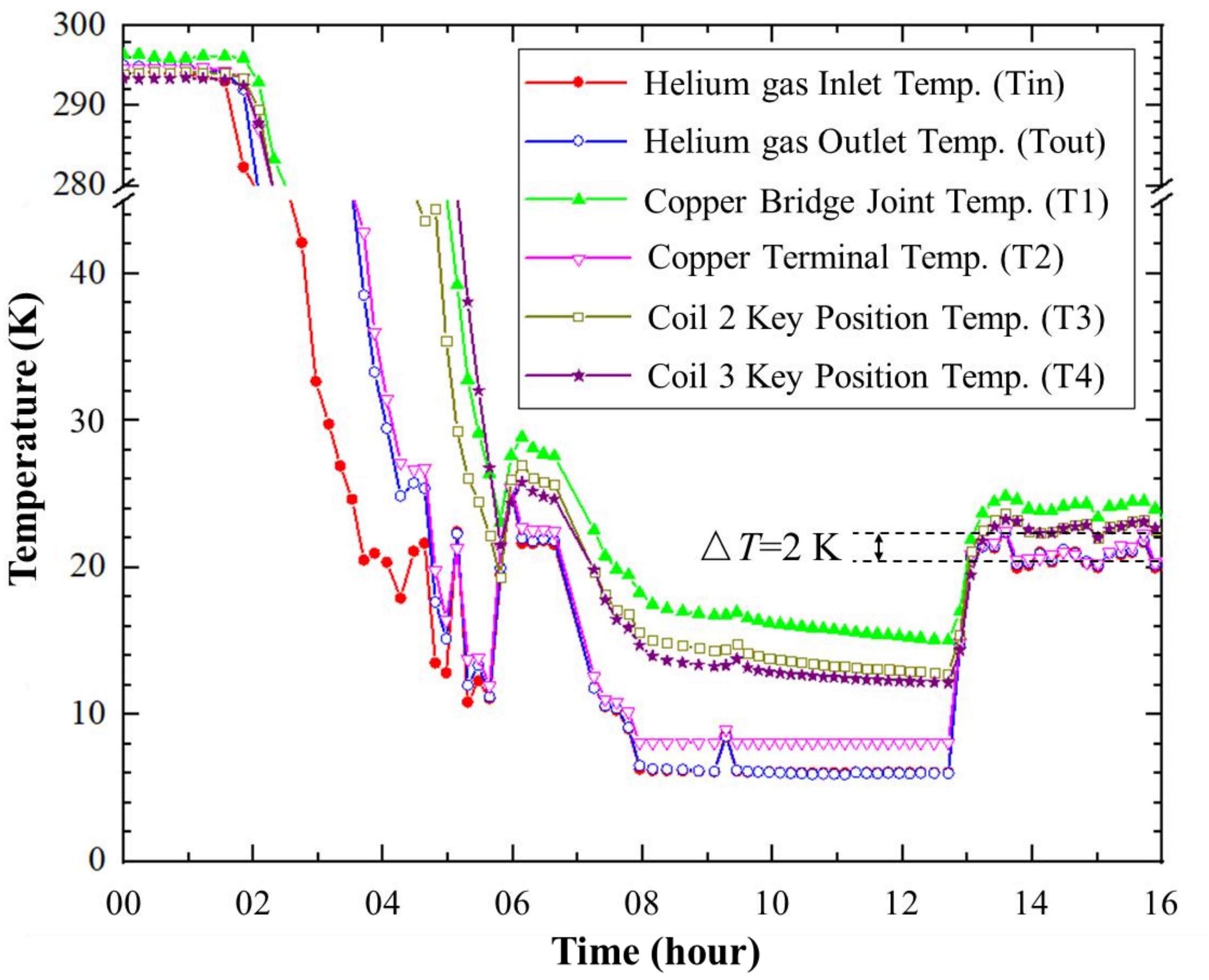


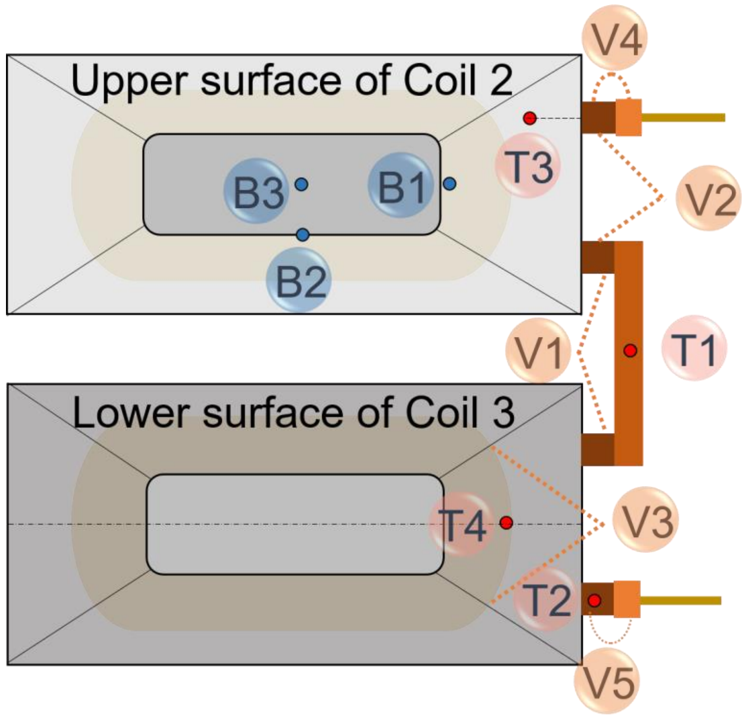
Temperature sensors:	T1 - T4
Voltage taps:	V1 - V5
Hall sensors:	B1 - B3

Acknowledgement to ASIPP

☐ Test of the magnet prototype

Cooling Process

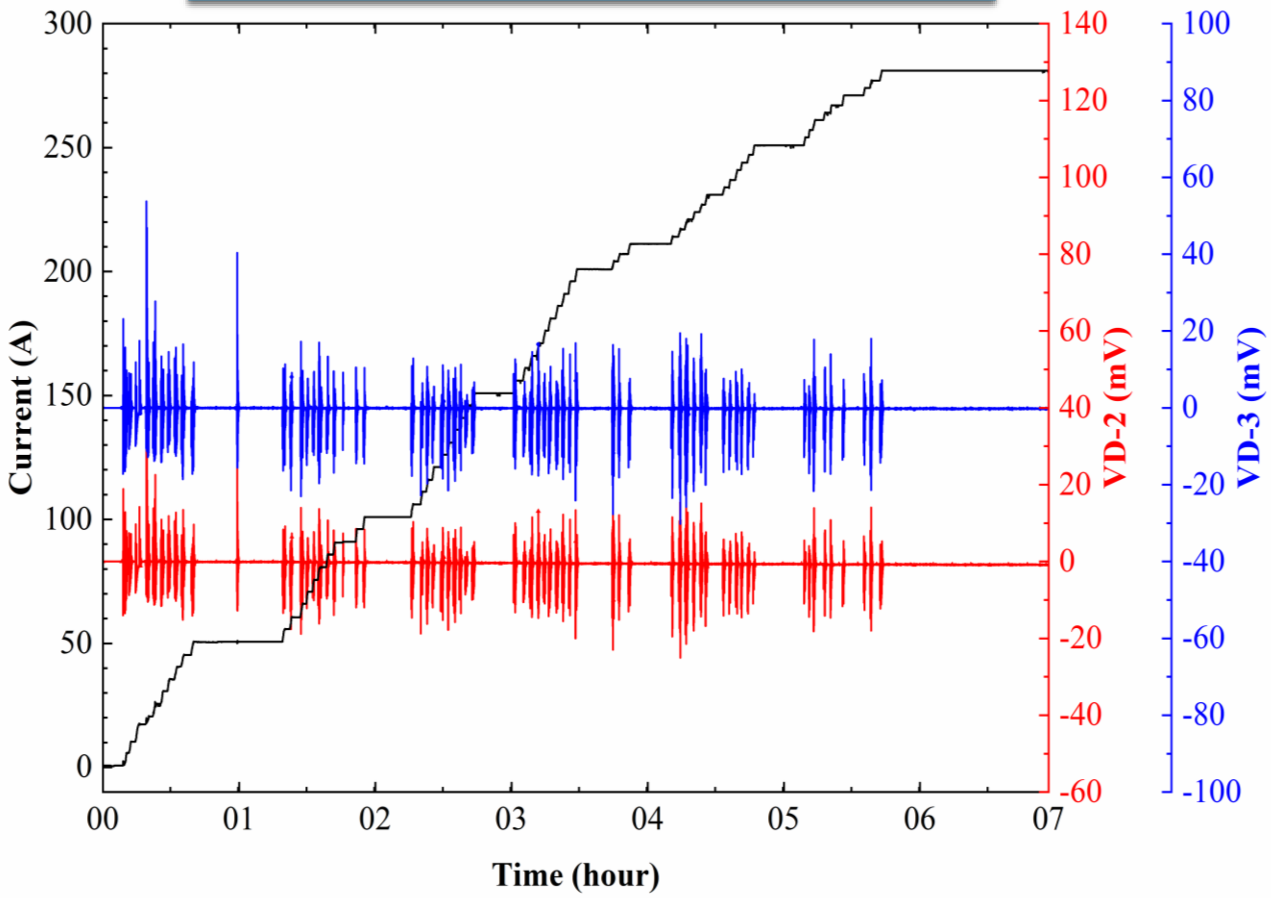




- ✓ Surface temperature of Coil 2&3 was 2 K higher than the helium gas.
- ✓ Surface temperature of Coil 2&3 was very close.

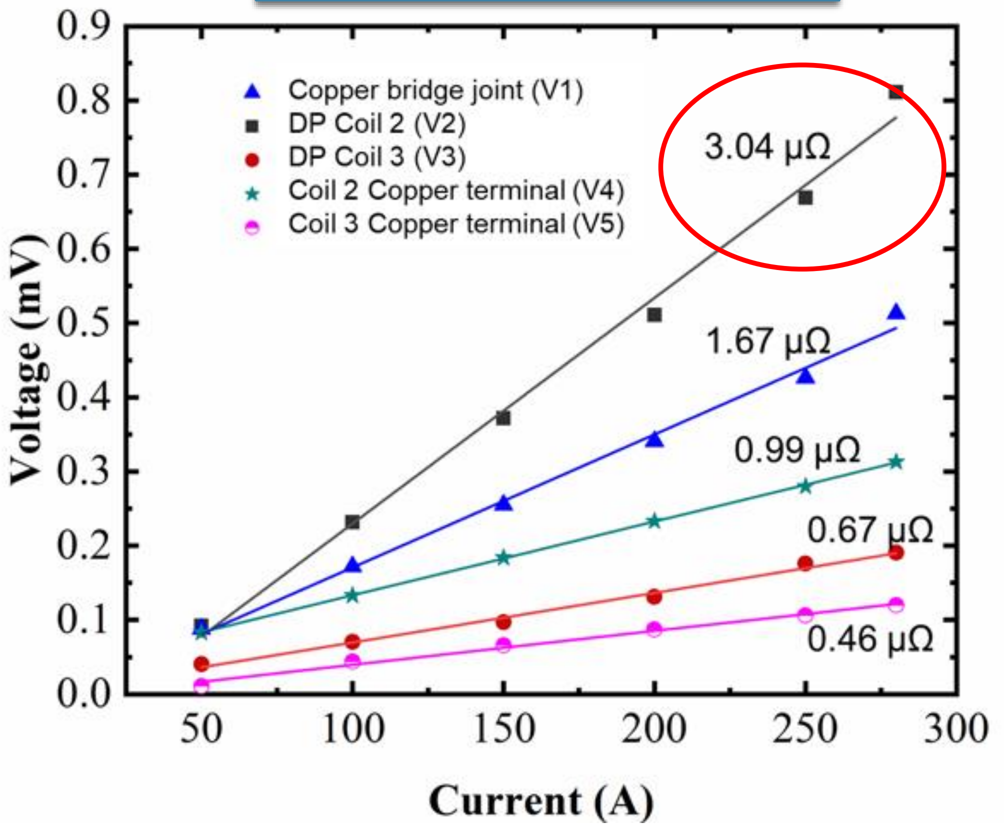
☐ Test of the magnet prototype

Current ramping from 0 to 281 A



- Current manually increased up to 281 A
- Voltage fluctuations were caused by inductance
- A stable operation current at 281 A was achieved

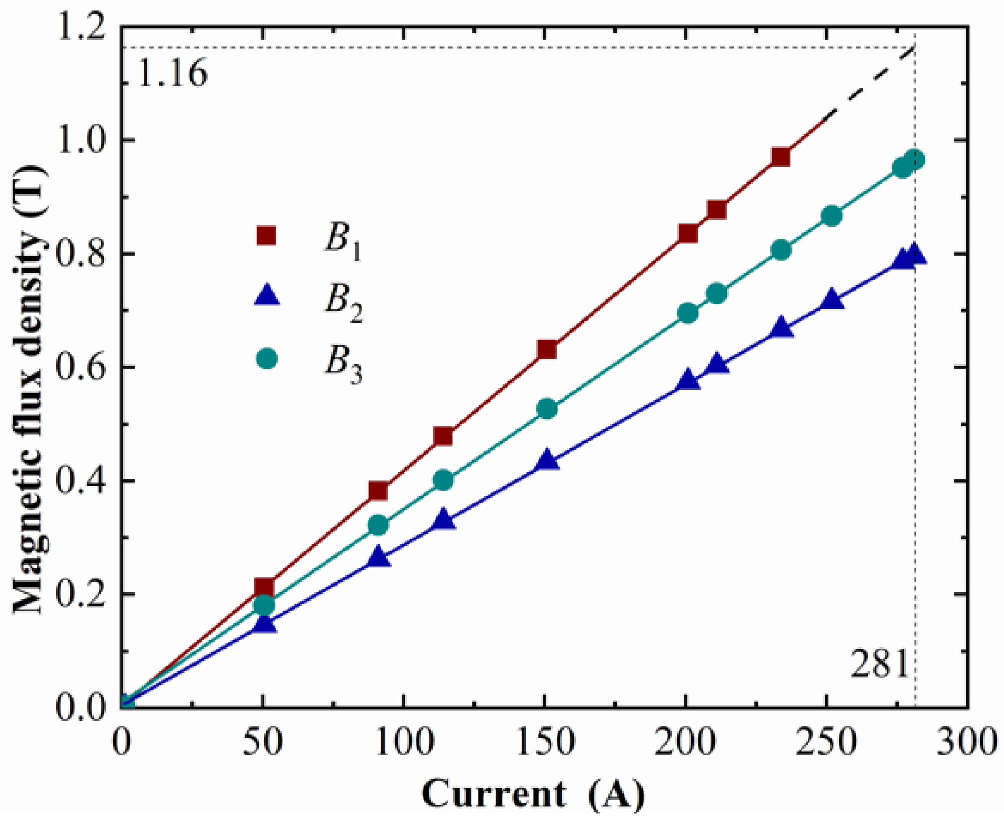
Resistance vs. Current



- The body resistance of Coil 2 is quite high, suggesting a bad connection between copper terminal and HTS tape

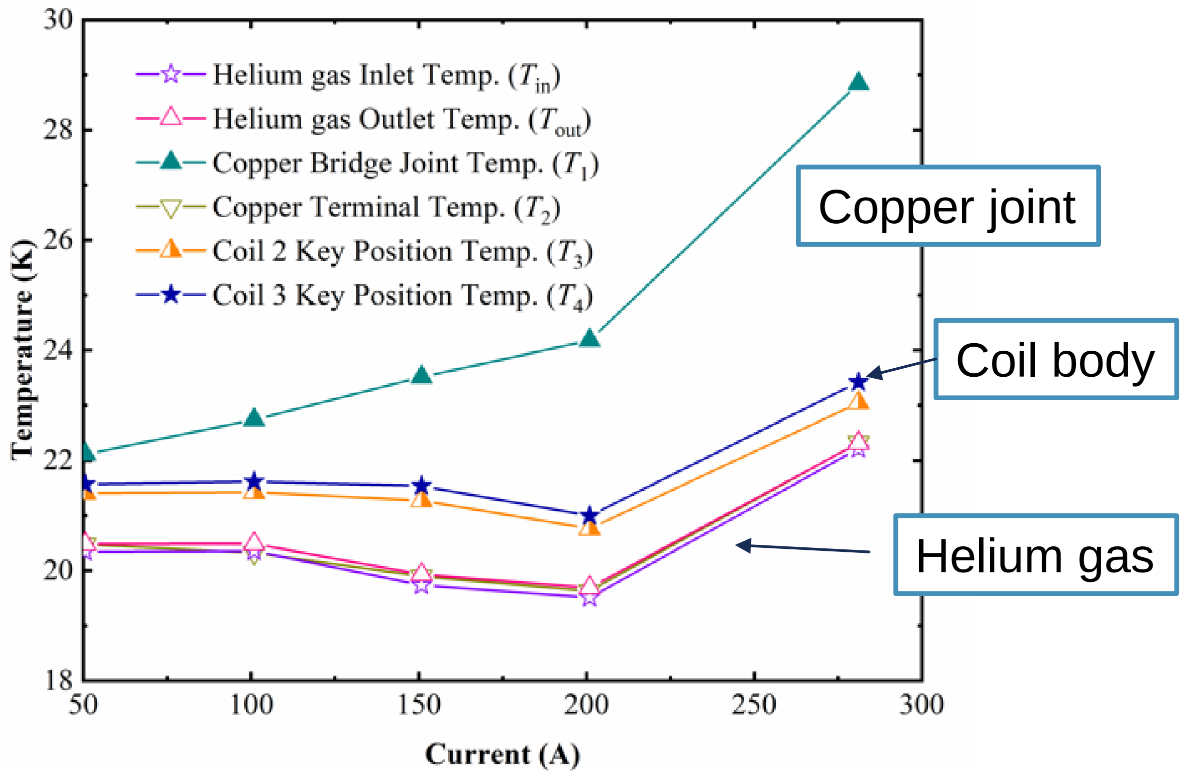
☐ Test of the magnet prototype

Field values at different positions



- Surface field reached up to 1.16 T
- The result was in good agreement with the simulation

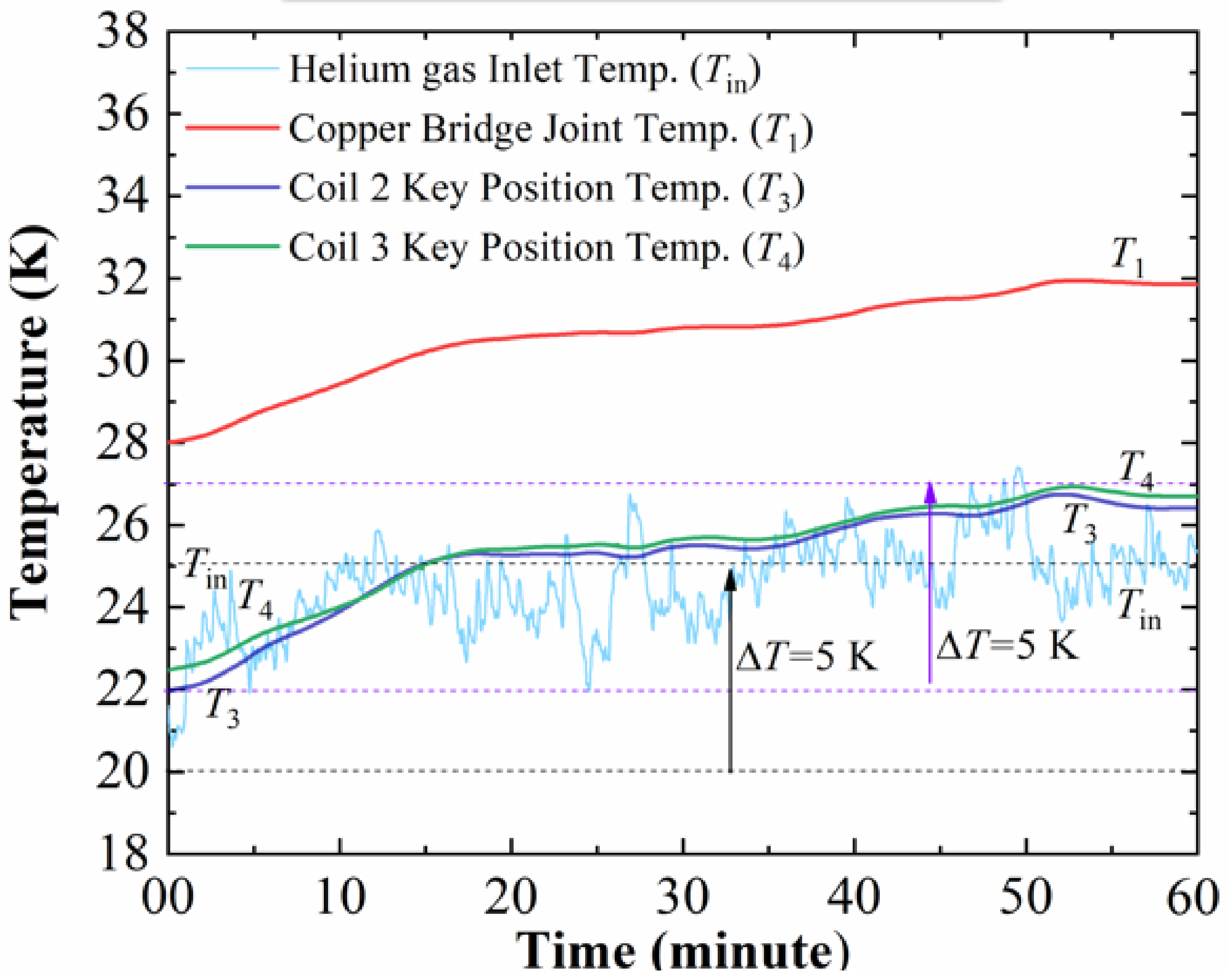
Stable temperature vs. operation current



- Both Coil 2 and Coil 3 can reach a thermal stable state.
- Up to 281 A, the temperature difference between coils and helium gas remained ~2 K.

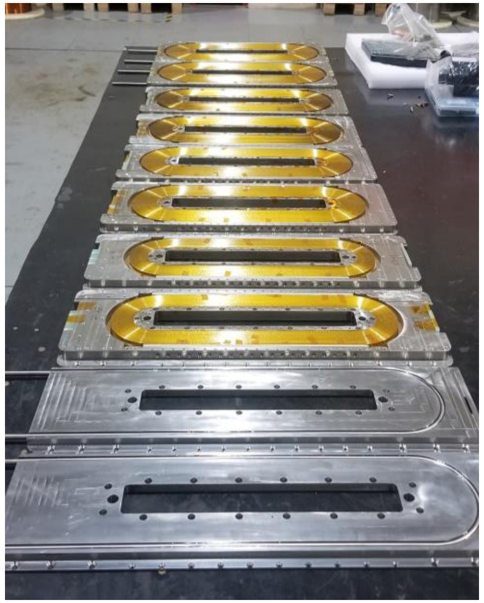
☐ Test of the magnet prototype

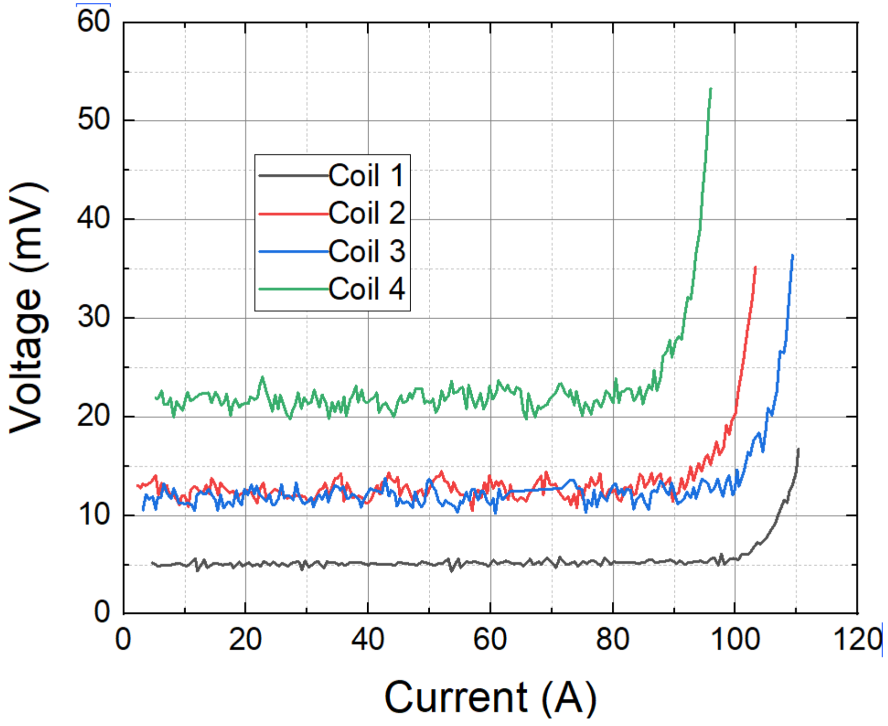
Thermal stability test @ 281 A

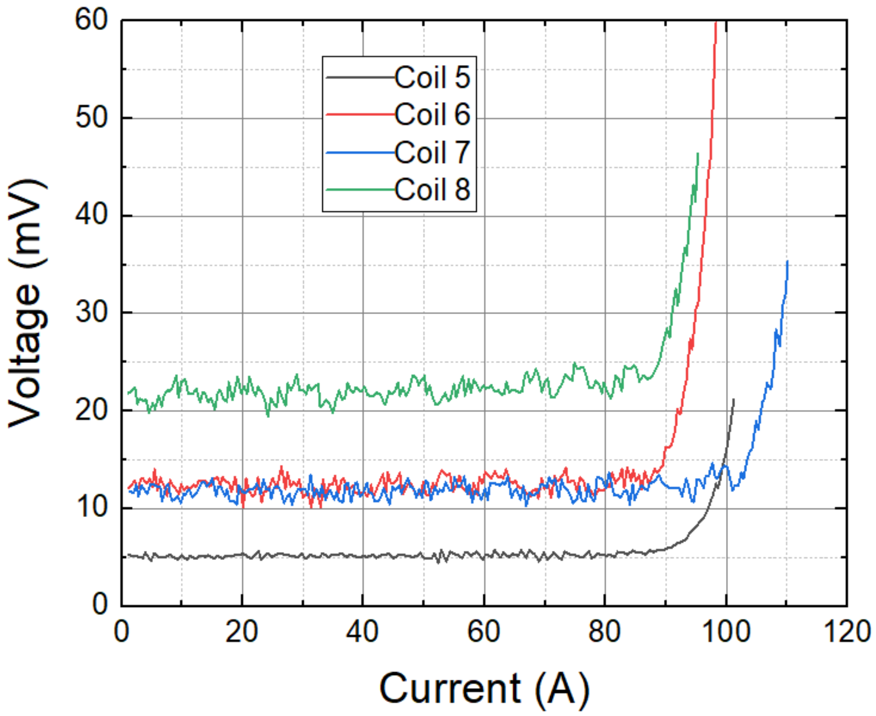


- ✓ Hold the operation current @ 281 A
- ✓ Adjust temperature of helium gas from 20 K to 25 K.
- ✓ Temperature of coils rose from around 22.5 K to 27 K.
- ✓ Temperature of coils could come back to stable again.

☐ Test of the magnet prototype





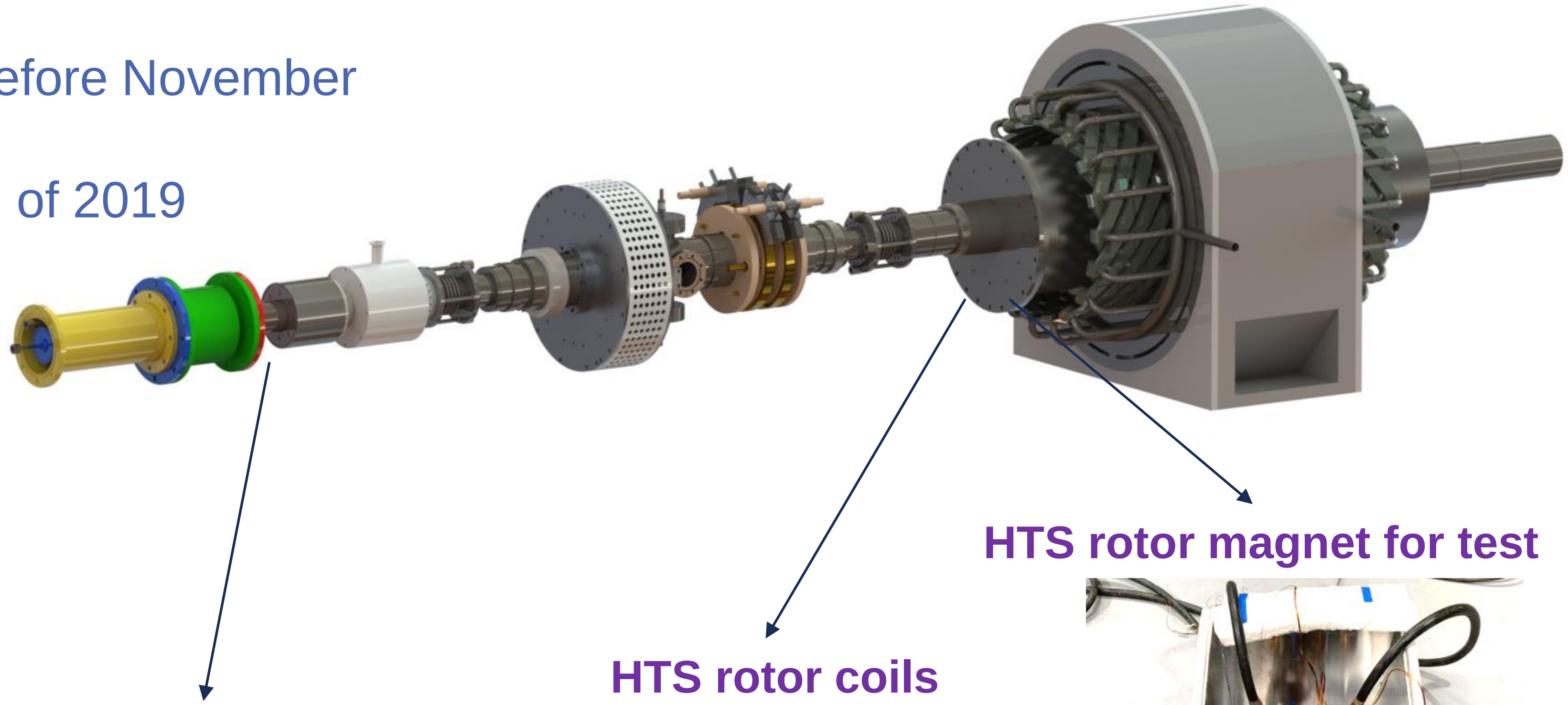


	Coil 1	Coil 2	Coil 3	Coil 4	Coil 5	Coil 6	Coil 7	Coil 8
I_c @ 77 K (1 μV/cm)	101	103	109	95	110	95	110	96
I_c @ 77 K (0.1 μV/cm)	93	95	100	85	103	89	100	90

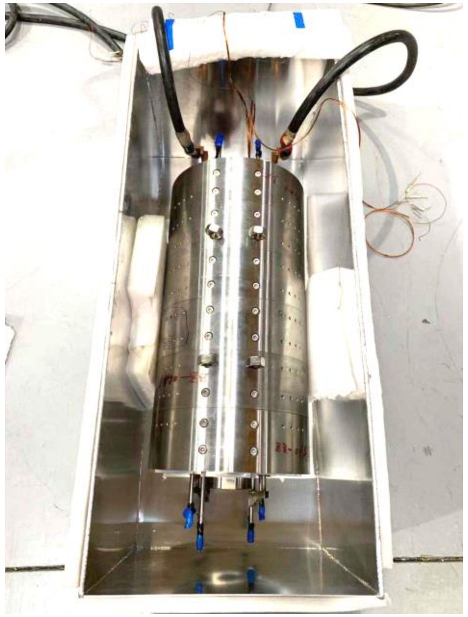
□ Ongoing project

Assemblage before November

Test at the end of 2019

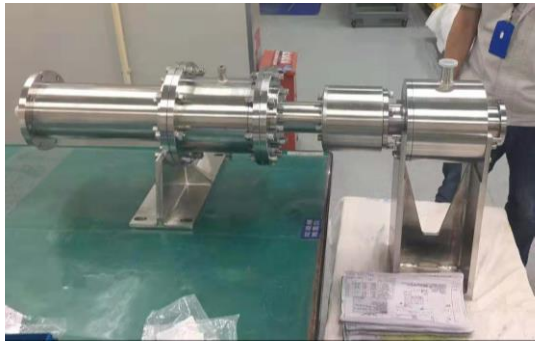


HTS rotor magnet for test



HTS rotor coils

Cryogenic rotary joint



Summary

- ✓ A 300 kvar HTS synchronous condenser is under construction as Phase I of a 10 Mvar HTS DSC project in China.
- ✓ A gas-helium conduction cooled structure was proposed, and magnet prototype was designed and fabricated.
- ✓ Testing results showed the DIP structure could help coils work safely under rated conditions.

Acknowledgement

- ✓ Magnet Producer： Xi'an Superconducting Magnet Technology Co.,Ltd
- ✓ HTS material: 上海超导 Shanghai Superconductor
- ✓ Stator: 上海电气 SHANGHAI ELECTRIC

THANKS

For Your Attention

敬请指正赐教!