A Novel High Temperature Superconducting Cable Design for Spherical Tokamaks

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ABSTRACT

- a novel HTS cable design, termed the STAR (Stacked, Twisted, Askew, Rectangular-shaped) cable. By adopting a twisted stacked architecture and an external cooling channel, this design achieves a critical bending radius of 400 mm.
- When STAR cable is applied to the PF coils of the spherical tokamak CTRFR-1, the engineering current density reaches 50 A/mm², and the repetitive discharge time reaches 6 minutes.

BACKGROUND

- The magnets for spherical tokamak operates at magnetic ramp rates of up to tens of Tesla per second (T/s).
- The poloidal field coils of the spherical tokamak need to have a radius of less than 0.5 meters.
- High-temperature superconducting cables need to balance AC loss and cooling channel flow resistance in order to maintain a low-temperature state over dozens of meters of cable.

CHALLENGES / METHODS / IMPLEMENTATION

Low Critical Bending Radius

By using 3 mm tapes and placing the cooling channels outside the skeleton, the skeleton radius of the cable was significantly reduced to 6 mm. A twist pitch of 500 mm and a critical bending radius of less than 400 mm were achieved.

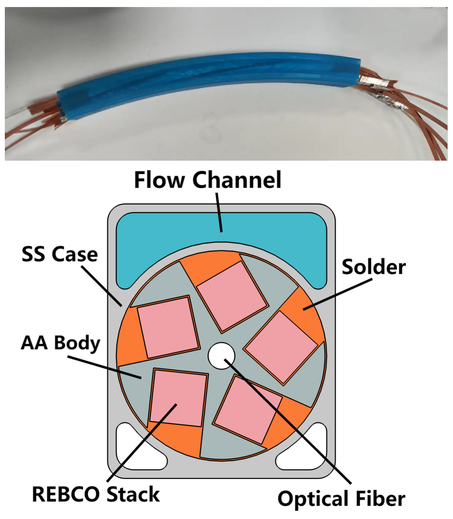

Fig 1. Short Sample and Cross-Section of the STAR Cable

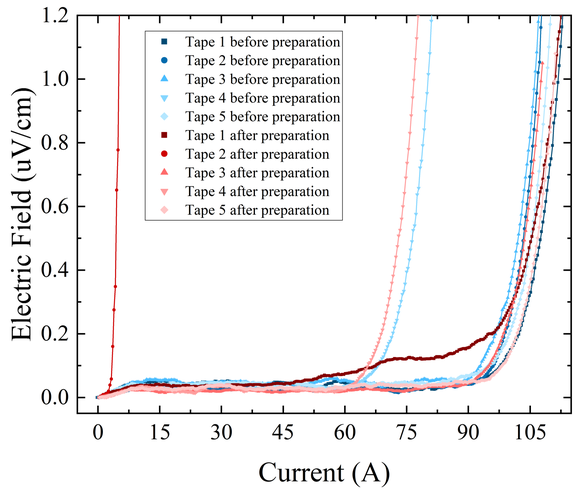

Fig 2. I-V Curves Before and After Preparation of the short Sample

High Engineering Operating Current Density

The STAR cable achieves an overall cross-sectional utilization rate of 21.5%, with an engineering current density of 50 A/mm² at a current operating point of 0.17 (relative to its critical current).

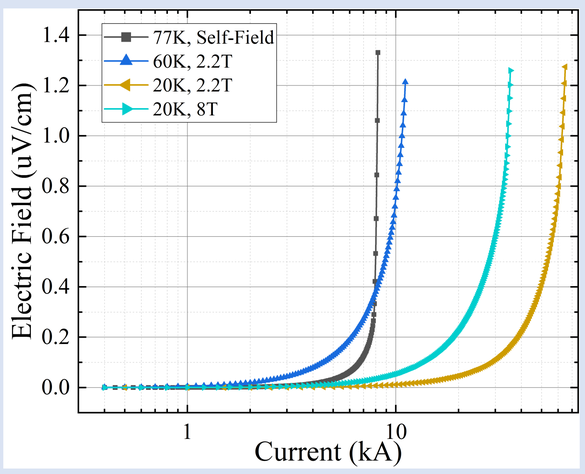

Fig 3. I-V curves of STAR cable by H method

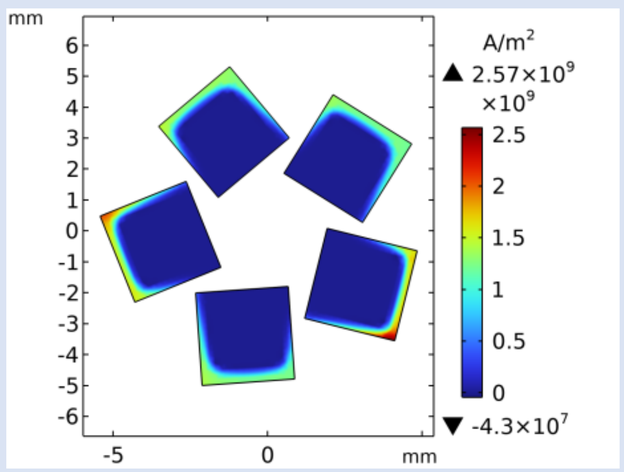

Fig 4. Current density distribution of 10.5 kA at 20K, 2.2T

OUTCOME

Example of Application on the PF4 Coil of the Spherical Tokamak CTRFR-1

The PF4 coil of the CTRFR-1 has a minimum bending radius of only 520 mm, with a maximum magnetic field variation rate of 24 T/s.

Using STAR cables, the average AC loss per discharge is 800 W/m. The maximum length of a single-layer of PF4 is 31 m. After one discharge, the highest temperature is 29.7 K, and the maximum flow resistance is 4.2 kPa. After the discharge, the maximum temperature drops below 20.5 K within 6 minutes, allowing for the next discharge.

TABLE 1. The STAR Cable Scheme of CTRFR-1 PF4 Coil

Parameter	Value	Parameter	Value
Maximum Magnetic Field	2.11 T	Maximum Magnetic Field Change Rate	24 T/s
Number of turns	7*8	AC Loss	~800 W/m
Operating Temperature	20 K	Helium Flow	0.5 g/s @20K, 5bar
Operating Current	10.5 kA	Helium Flow Resistance	4.2 kPa
Maximum Voltage	5.92 kV	Repeated Discharge Time	6 min
Inductance	50.7 mH	Amount of HTS Tapes Used	31 km@3mm

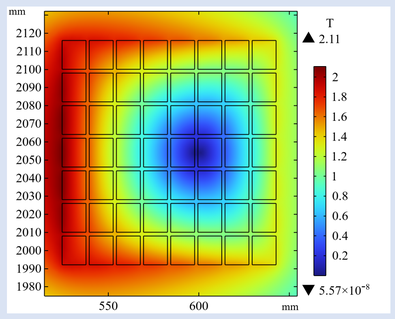

Fig 5. Magnetic Field Distribution of PF4 Coil

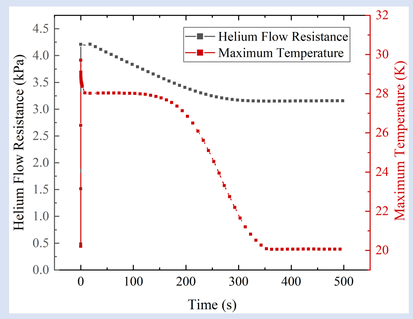

Fig 6. The Maximum Temperature and Flow Resistance after 1 Discharge

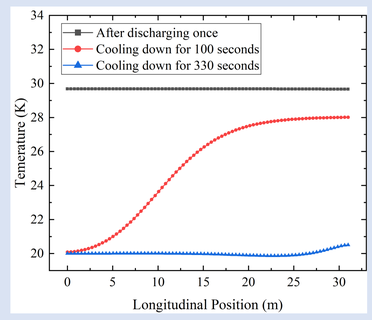

Fig 7. Temperature Distribution Along Length Direction

CONCLUSION

- A new HTS cable structure was designed, achieving a critical bending radius of 400 mm by externalizing the cooling channel.
- With a cross-section utilization of up to 21.5%, the STAR cable achieves an engineering current density of 50 A/mm² under a magnetic field change rate of 24 T/s.
- Taking the PF4 coil of the spherical tokamak CTRFR-1 as an example, the STAR cable can achieve a repeatable discharge every 6 minutes.

ACKNOWLEDGEMENTS / REFERENCES

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