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Manufacture and tests of a 1 MJ HTS Magnet for a SMES-FCL

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Abstract

An magnet was manufactured and tested for a 1 MJ/1 MVA Superconducting Magnetic Energy Storage and Fault Current Limiter system (SMES-FCL) with HTS tapes recently. It consists of 46 double pancakes with an inductance of 13.3 H, and the rated operating current is 388 A, the maximum magnetic field is up to 3.5 T. In this paper, the fabrication and tests of the 46 double pancakes, the assemblage of the magnet are described in detail. And then, the fundamental performances testing of the magnet were carried out at liquid nitrogen and sub-cooled liquid nitrogen, respectively. And then, the magnet was soaked in liquid neon and cooled with four AL325 cryo-coolers to keep zero neon vaporization. After the whole 1 MJ/1 MVA SMES-FCL were field installed and tested, it had been put into operation since January 6 of 2017 at a 10.5 kV wind farm locating in Yumen, Gansu Province of China.

I Design Results Of the 1 MJ HTS SMES-FCL Magnet

Table I Parameters of the 1 MJ HTS SMES-FCL Magnet

Parameters	Design Value	Measured Value
Inner diameter (mm)	598	598
Outer diameter (mm)	782	783
Height (mm)	686	688
Number of double pancakes	46	46
Length of Bi2223 tape (km)	22.5	23.1
Length of 2G tape (km)	5.8	5.95
Inductance (H)	12.5	13.3
Rated current (A)	400	387.8
Max. ($B_{//}$) (T)	1.5@400A	/
Max. (B) (T)	3.5@400A	/
Operating temperature (K)	25-27	27
Stored energy (MJ)	1.0	1
Operating voltage (V_{DC})	1700	1700
Voltage during fault current limiting (V_{DC}, last for 100 ms)	7000	/
Voltage between magnet and ground (V_{DC}, last for 5 minutes)	7000	7000

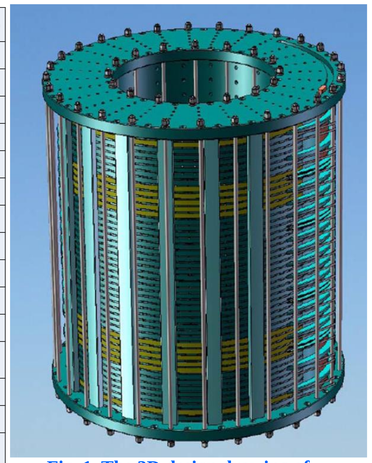
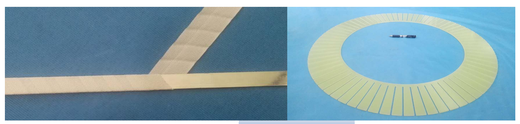
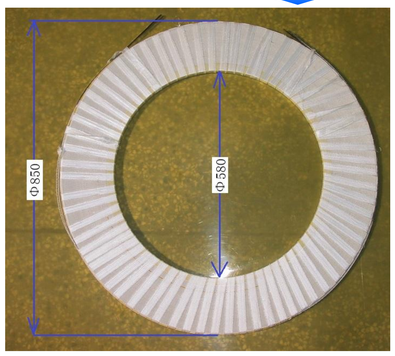


Fig. 1. The 3D design drawing of the 1 MJ SMES-FCL magnet.

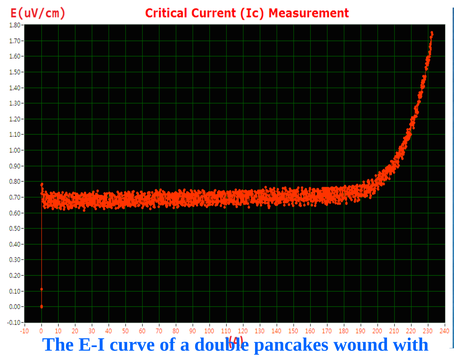
II Insulations of HTS Tapes and the Magnet



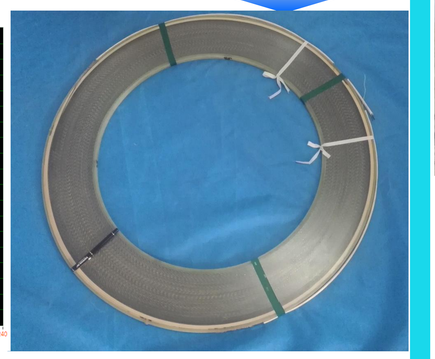
- ✓HTS tapes wrapped by silk tape;
- ✓GFRP plate serves as the inter-double-pancakes insulation and the cooling channel of the magnet;
- ✓Vacuum pressure impregnated with epoxy resin;
- ✓Gelled in the oven at 78 ℃ for 24 hours;
- ✓Solidified at 130 ℃for 12 hours



Before epoxy resin impregnation



The E-I curve of a double pancakes wound with two parallel 220A tapes tested at 77 K after wingding.



After epoxy resin impregnation

Fig.2. A double pancake wound with two parallel Bi2223/Ag tapes reinforced by stainless steel

III Construction of the HTS Magnet

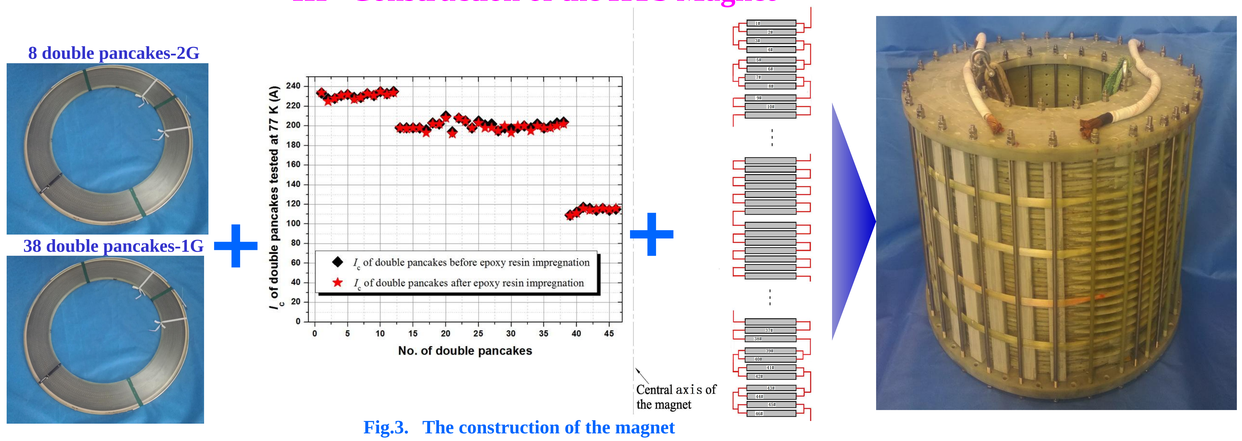


Fig.3. The construction of the magnet

IV Performance Tests, Installation and Operations of the HTS SMES Magnet

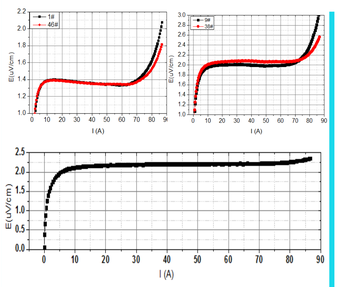


Fig.4. The E-I curves measured at 77 K of the magnet and some double pancakes.
(a) Pancakes 1# and 46# at two ends of the magnet;
(b) Pancakes 9# and 38# at two ends of the 30 double pancakes connected in series;
(c) The E-I curve of the HTS magnet.

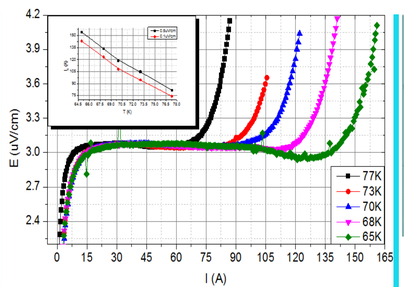


Fig.5. The E-I curves of double pancake 9# tested with the HTS magnet at 77 K, 73 K, 70 k, 68 K and 65 K. The inset graph was the Ic-T curves of double pancake 9# at the criterion of 0.1μV/cm and 0.5μV/cm.

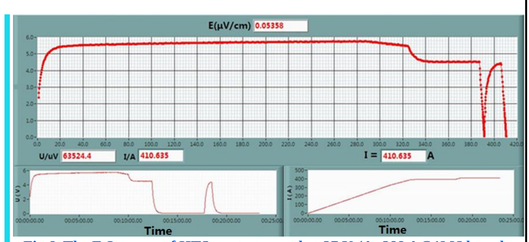


Fig.6. The E-I curves of HTS magnet tested at 27 K (At 388 A@1MJ lasted for 5 minutes and 410.6 A@ 1.12 MJ lasted for 5 minutes).

The magnet were integrated with the Dewar and four AL325 cryo-coolers. The neon gas was liquefied and lasted for over 70 hours when the magnet were immersed by liquid neon. The E-I curve of the magnet were measured at 27 K

Fig.7. A photo of 1 MJ/1 MVA SMES-FCL installed and put into operation since January 6 of 2017 at a 10.5 kV wind farm locating in Yumen, Gansu Province of China.

V Conclusion

There were many irreplaceable advantages of the SMES-FCL, applied in electric utilities as well as the integration of renewable energy sources. In this paper, the fabrication and the main techniques of the 1 MJ/1 MVA HTS magnet were presented: the insulations of the conductors and the magnet, fabrication of the double pancakes, the connection and the assemblage of the magnet. The performances testing in liquid nitrogen and sub-cooled nitrogen of 65 K were also described in detail. Cooled by four AL325 cryo-coolers, liquid neon has been obtained successfully with a temperature of 25-27 K. Dipped in liquid neon, the HTS magnet could be operated well and securely.