Design and Fabrication of HTS DC Bias Winding for 500kV Saturated Iron Core Fault Current Limiter

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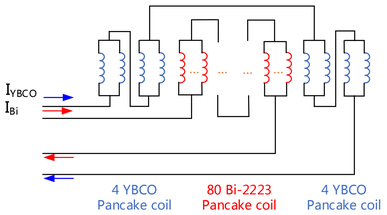
Introduction

Saturated iron-core superconducting fault current limiter is a kind of promising device for short-circuit current limiting. During normal operation, large ampere-turns created with DC in the secondary superconducting HTS winding drive the core into saturation. This lowers impedance of the copper winding in the primary AC side near to that of an air - core winding. During a fault, a large fault current demagnetizes the core and drives it from the saturated to unsaturated state (linear B - H region). This increases the primary AC winding impedance. The increased impedance limits the fault current to the desired level.

The HTS DC bias winding with Bi2223 and YBCO is developed. Since strongly anisotropic Bi-2223 exhibits an enormous suppression of irreversibility field to the very low value of ~0.2 T at 77K, the second-generation YBCO is used to optimize the magnetic field distribution. The HTS DC winding is composed of 80 Bi-2223 double pancake coils and 8 YBCO double pancake coils, and the rated ampere-turns are 468000 at 72K. The used Bi-2223 tape is produced by Sumitomo, and the critical current is 220A (77K, self-field). The used YBCO tape is produced by Shanghai Superconductor, and the critical current is 100A (77K, self-field). Both of the Bi-2223 and YBCO double pancake coils are fabricated, and the critical current is more than 175A (77K, self-field) for each double pancake coil, which are essentially in agreement with the simulation results.

Structure of the winding



- Winding type: Solenoid with double pancake coils.
- Number of coils: 8 YBCO and 80 Bi-2223 double pancake coils.
- Excitation mode: Independent for YBCO and Bi-2223.
- Operation temperature: 72K.
- Cooling method: Decompression

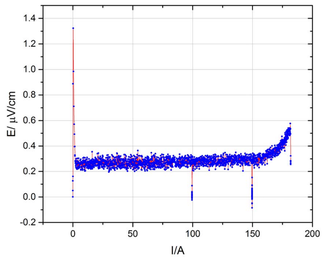
	Item		Value
Winding parameters	Internal diameter / mm		1900
	External diameter / mm		2150
	Height / mm		1204
	Tape width / mm		5.1
	Number of pancake coils		88
	Coil Turns	YBCO	208
		Bi-2223	416
	Air-core inductance/H	YBCO	0.13
		Bi2223	0.35
	Saturated-core Inductance/H	YBCO	0.23
		Bi2223	0.84

	Item		Value
Operation parameters	Magnetomotive force		468000
	Ic/A @72K	YBCO	185
		Bi2223	1150
	Iop/Ic / %	YBCO	86.5
		Bi2223	90.9
	$B_{\parallel max}$/T	YBCO	0.35
		Bi2223	0.51
	$B_{\perp max}$/T	YBCO	0.32
		Bi2223	0.22
Tape Volume	Bi-2223 / m		53120
	YBCO / m		5312

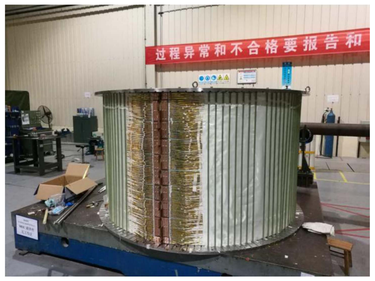
Fabrication and Experiments

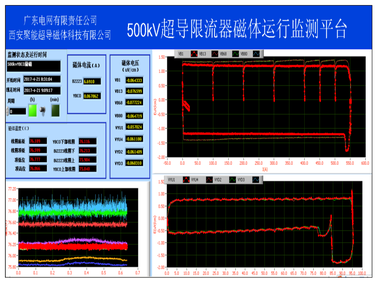
Double pancake coils

Coil critical current test



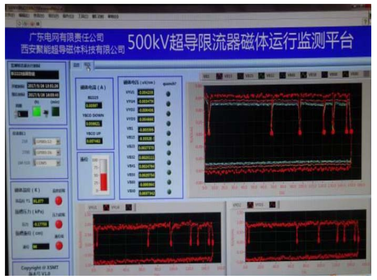
Fabricated winding





Air core coil test result

Assemble of the FCL

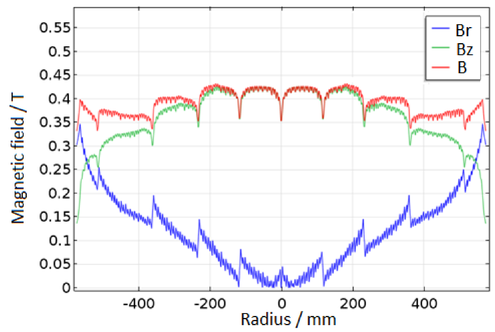


Test with iron core

The steady-state test shows that the developed DC bias winding could operating at 72K (I_{YBCO}=160A and I_{Bi2223}=1050A), which is coincident with design.

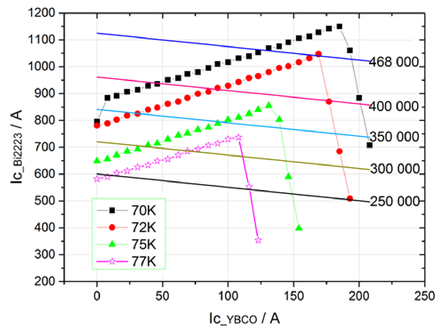
Analysis

Magnet distribution



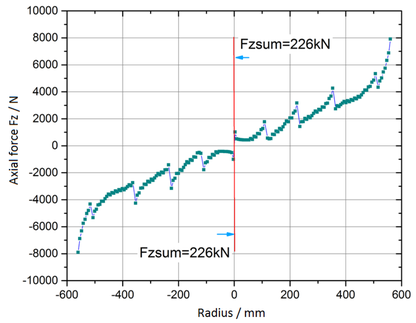
- Operation at rated current: I_{YBCO}=160A, I_{Bi}=1045A.
- Max. parallel magnetic flux density on the winding Bz: 0.43T at inner part when z=0 mm.
- Max. vertical magnetic flux density on the winding Br: 0.39T when z=528mm (on top of the winding).

Operation parameter



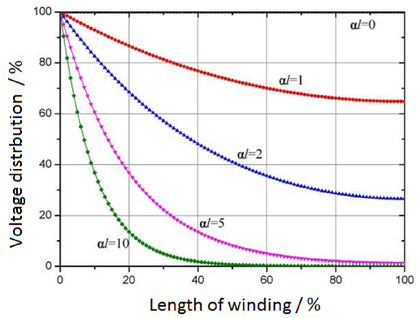
- Operation current at different temperature.
- YBCO windings could reduce the amplitude of vertical magnet flux density Br nearby Bi-2223 winding.
- Reduce Br could enlarge the critical current of Bi-2223 winding.

Force



- Accumulated axial force: Fzsum=226kN (I_{YBCO}=160A, I_{Bi}=1045A).
- 9 G10 bearing rings are used to decentralizing the accumulated axial force.
- Air gap at the bearing rings will affect the magnet field distribution.

Insulation



- Main insulation: 10kV.
- Longitudinal insulation: 75kV.
- Tape Insulation: half folded with 12.5μm Kapton.
- Insulation between coils: G10 sheet.