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Design and Simulation of a 120kVA Single-phase HTS Transformer

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Introduction

A 120kVA single-phase HTS transformer operated in liquid nitrogen of 77 K with primary/secondary voltages of 6000/400 V is designed and simulated in a two-dimensional axisymmetric model. The primary and secondary windings are solenoid and double pancakes connected in parallel respectively. The magnetic field distribution, current distribution and characteristics of AC loss of windings are solved by simulation.

Main parameters of the HTS transformer

Table. I. MAIN DESIGNED PARAMETERS OF THE HTS TRANSFORMER

Parameters	Designed value	Parameters	Designed value
Voltage(primary/secondary)	6000V/400V	Radius(inner/outer)	274mm/282mm
Current(primary/secondary)	20A/300A	Secondary winding	
Iron core		Winding type	Double pancake
Radius	150mm	Number of pancakes	13
Magnetic flux density	1.65T	Turns of each pancake	18
Primary winding		Radius(inner/outer)	220mm/234mm
Winding type	Solenoid	Height	172mm
Number of layers	8	Total length of the coils	830m
Number of turns	272(34/layer)	% impedance	3.27

Numerical Model

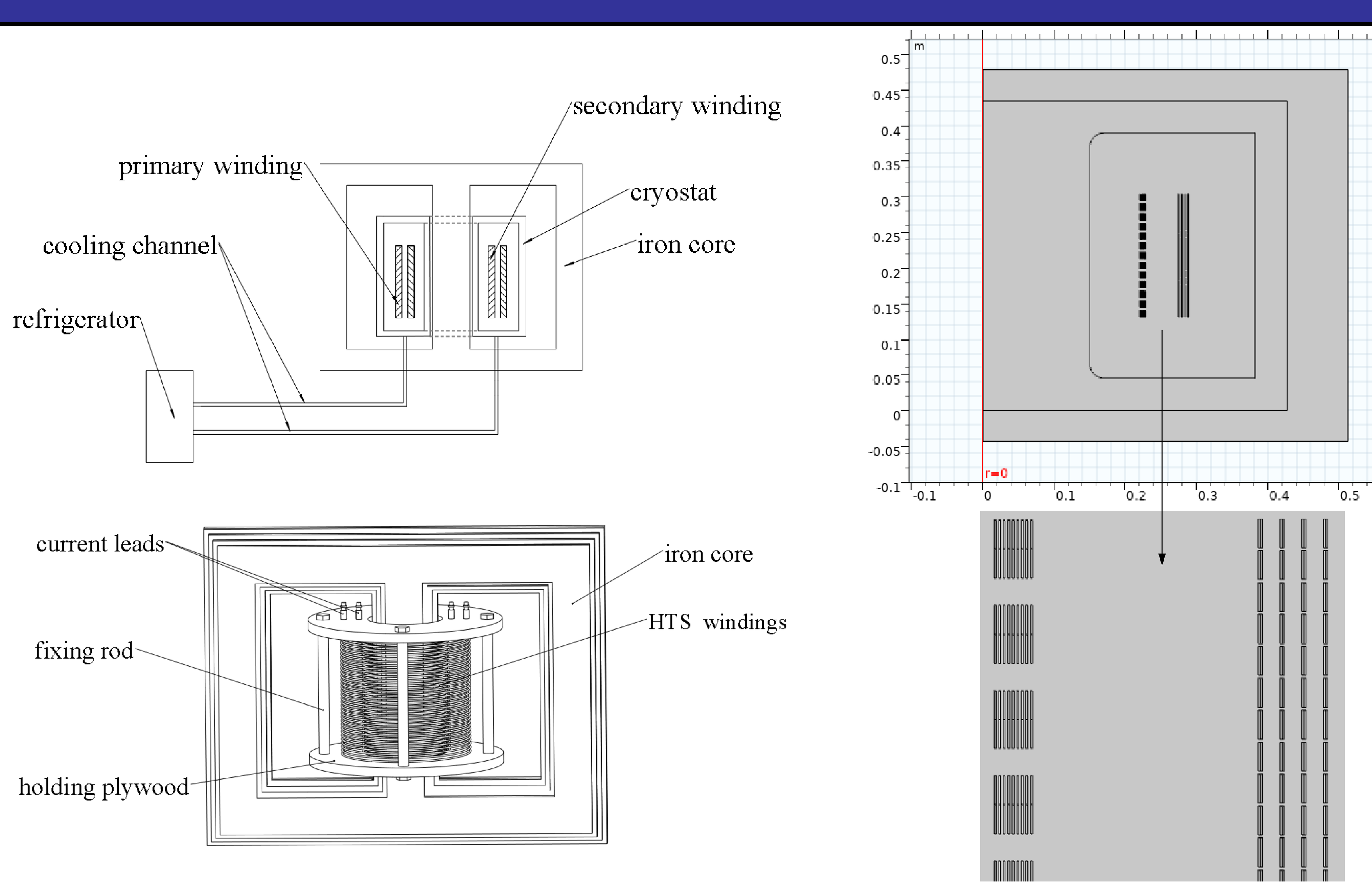

Fig. 3 Main structure of the HTS transformer

2D H-formulation:

$$\begin{bmatrix} \dfrac{\partial\left(E_c\left(\dfrac{\frac{\partial H_y}{\partial x}-\frac{\partial H_x}{\partial y}}{J_c}\right)^n\right)}{\partial y} \\ -\dfrac{\partial\left(E_c\left(\dfrac{\frac{\partial H_y}{\partial x}-\frac{\partial H_x}{\partial y}}{J_c}\right)^n\right)}{\partial y} \end{bmatrix} = -\mu \begin{bmatrix} \dfrac{\partial H_x}{\partial t} \\ \dfrac{\partial H_y}{\partial t} \end{bmatrix}$$

H_x : component of the magnetic field in the X direction
H_y : component of the magnetic field in the Y direction
E_c : electric field criterion, E_c=1μV/cm
J_c : the critical current density

Numerical Results

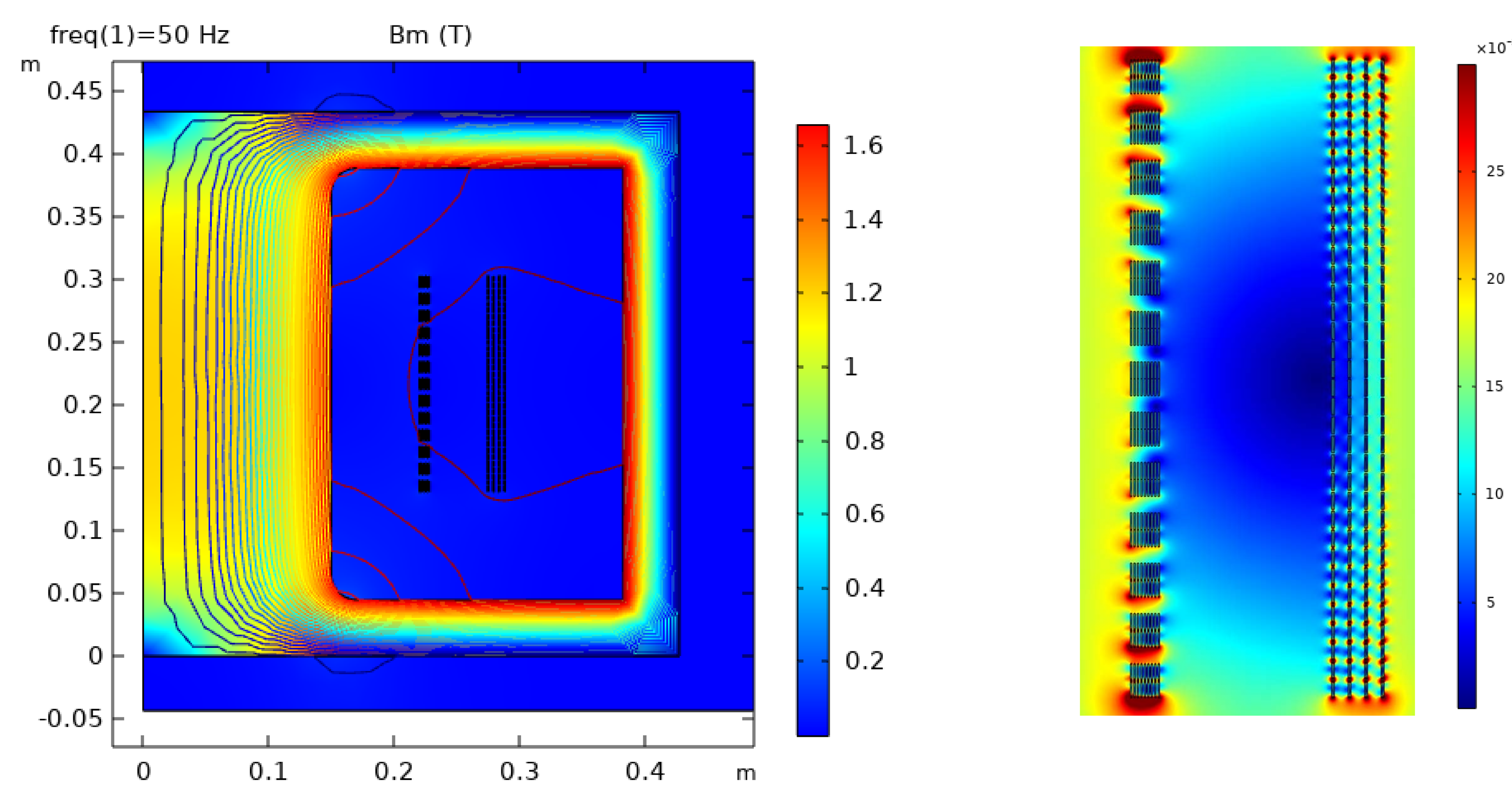

Fig. 4 Distribution of magnetic flux density of the HTS transformer

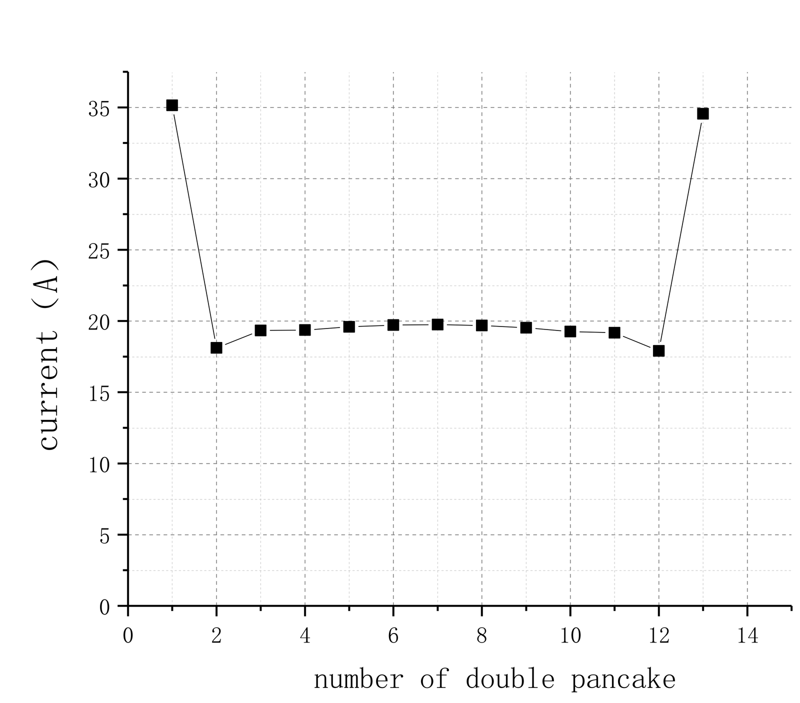

Fig. 5 Current distribution of double pancakes in secondary winding at rated operation

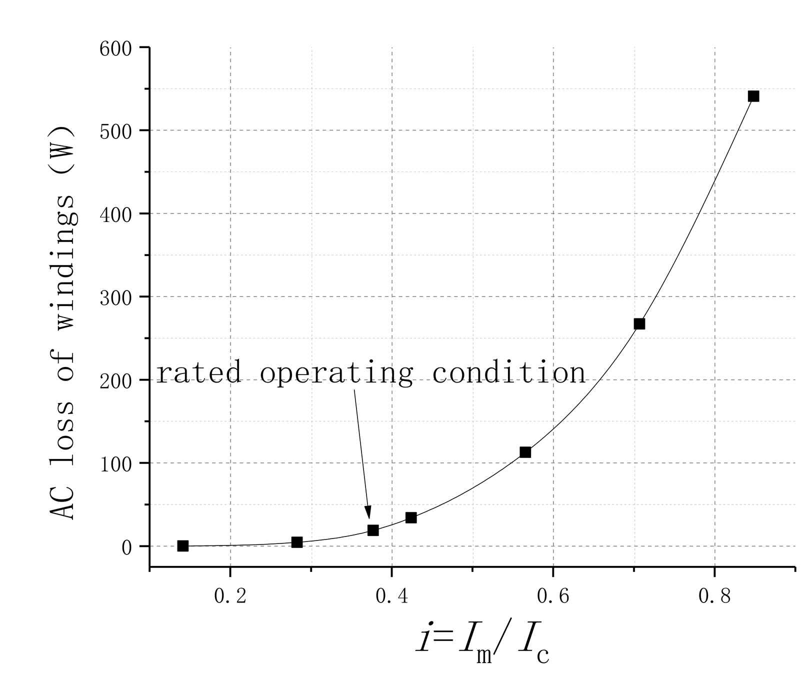

Fig. 6 Simulated AC loss at different values of transport current

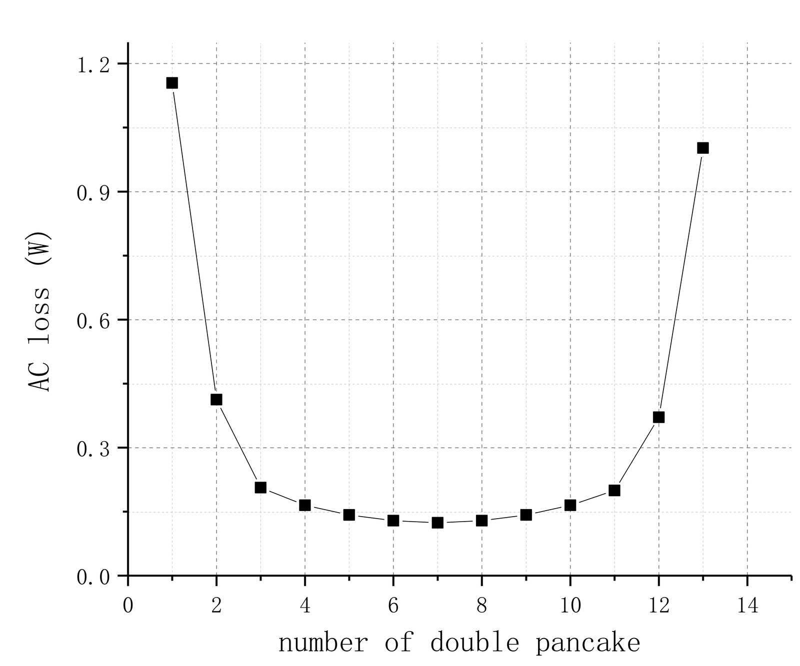

Fig. 7 AC loss Distribution of double pancakes in secondary winding at rated operation

Most of the magnetic field is confined in the iron core, and the leakage magnetic field around the HTS windings is mainly concentrated at the upper and lower ends, which leads to smaller leakage reactance and critical current, resulting in larger current and AC losses distributed to them.

Conclusion

- The leakage magnetic field around the HTS windings is mainly concentrated at the upper and lower ends.
- The unevenly distributed leakage magnetic field makes the double pancakes at the upper and lower ends bear larger current and AC losses than the other double pancakes.
- The simulation model provides a reference for the design and manufacture of HTS transformer.