Thu-Mo-Po4.08-06 [58]

MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Design and Optimization of a HTS Claw-Pole Machine

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Abstract

Abstract—Superconducting (SC) direct-drive wind generators is considered to be the best candidate for the offshore wind energy applications. It is more reliable since it eliminates auxiliary components such as gearbox and using superconductor will de-crease the system weight. In this paper, a 10MW HTS claw-pole machine is designed and optimized. By adopting claw-pole structure, the stationary seal can be realized. This will simplify the cryogenic system and the structure can also be more compact. More-over, the toroidal HTS coils are used in the claw-pole machine and the end-winding can be reduced compared to the regular winding. The operating principle and simplified analytical analysis of the machine are introduced in the paper. Then the optimization of the machine are conducted by the 3D-FEM software. Finally, the performances of this topology are evaluated and the advantages are validated.

Topology introduction

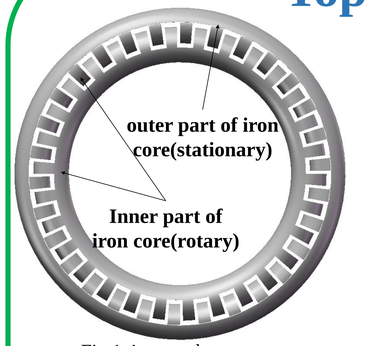

Fig.1. iron teeth structure

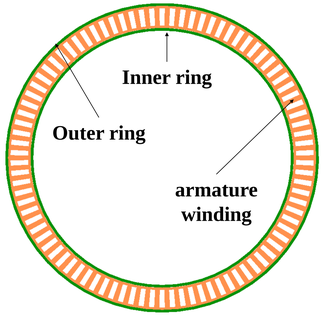

Fig.2. field and armature winding

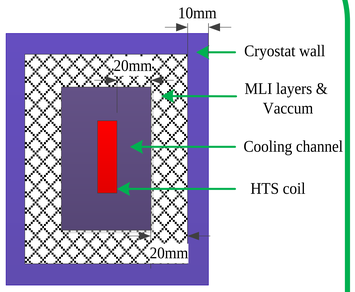

Fig.3. cryogenic system

- Stationary seal – simplify the structure of cryogenic system
- Concentrated winding - shorter end winding & lower loss
- Modular cooling system – independent cooling & increasing cooling efficiency
- Toroidal HTS field winding – shorter end winding & more even cooling

Principle

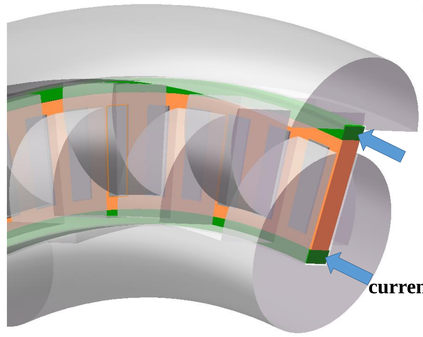

Fig.4. principle of the machine

Two HTS field windings are fed with current and the flux created is led by the claw-pole teeth. With the rotation of the claw-pole teeth, there will be a rotating magneto motive force in the gap.

$$E = 4.44\, fNK_{dp}\phi$$

$$\phi = \frac{2}{\pi} B_{m1}\tau l$$

Claw-pole tooth design

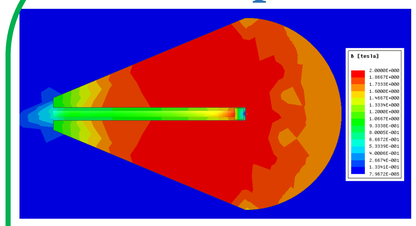

Fig.5. teeth with long effective length

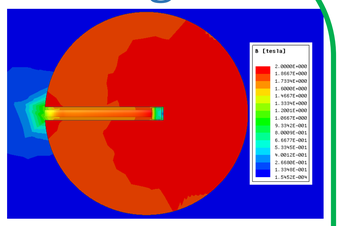

Fig.6. teeth with short effective length

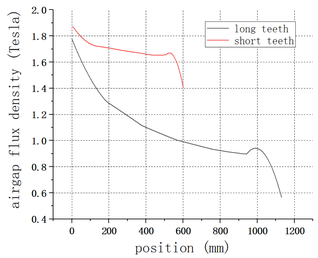

Fig.7. flux distribution in two teeth

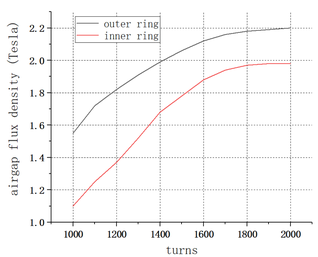

Fig.8. average air gap flux density of inner and outer ring

- Second teeth shape is better
- Inner and outer part are not symmetric

Stator iron teeth

Fig.9. iron inserted into the armature winding

Fig.10. iron pile method

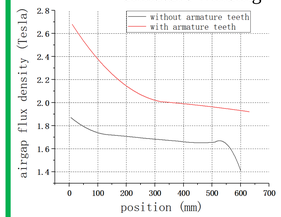

Fig.11. air gap flux density with or without iron teeth

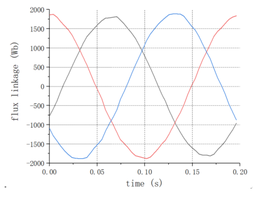

Fig.12. Flux linkage

- Higher air gap flux density
- More copper winding can be inserted
- Field unevenness can not be solved

Performances

TABLE I machine performance

Parameter	unit	value
Torque	MNm	10
Rotating speed	rpm	10
Outer diameter	m	12
Torque ripple	%	28
efficiency	%	96
HTS material	-	YBCO
Active material mass	ton	240
Mass of Iron core	ton	212
Mass of copper	ton	28
Length of HTS material	km	60

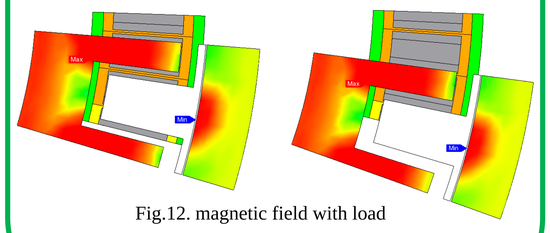

Fig.12. magnetic field with load

- Nearly DC flux in the movement of the machine - low losses

Conclusion

In this paper, a HTS direct drive claw-pole machine is designed and optimized. It solves the problem met in the HTS synchronous machine that the SC field winding has to rotate and the cryogenic system may not have good performance. Then the machine is designed and optimized. Before the 3D FEM, an equivalent 2D simulation is carried out and a performance estimation is given for the reference of the machine design. The claw-pole teeth plays a very important role in the machine since a good shape will largely improve the machine performance such as power rate and efficiency. In the teeth design, the asymmetry of inner and outer part of the flux path is considered and it is solved by adjusting the turns of the inner and outer field winding. Other parameters are also optimized. At last, the performances of the machine is listed. And it still has problems such as field unevenness and the influence it has on the machine needs to be further considered.