Design of a HTS Field Winding Vernier Machine with HTS bulks on Flux Modulation Pole

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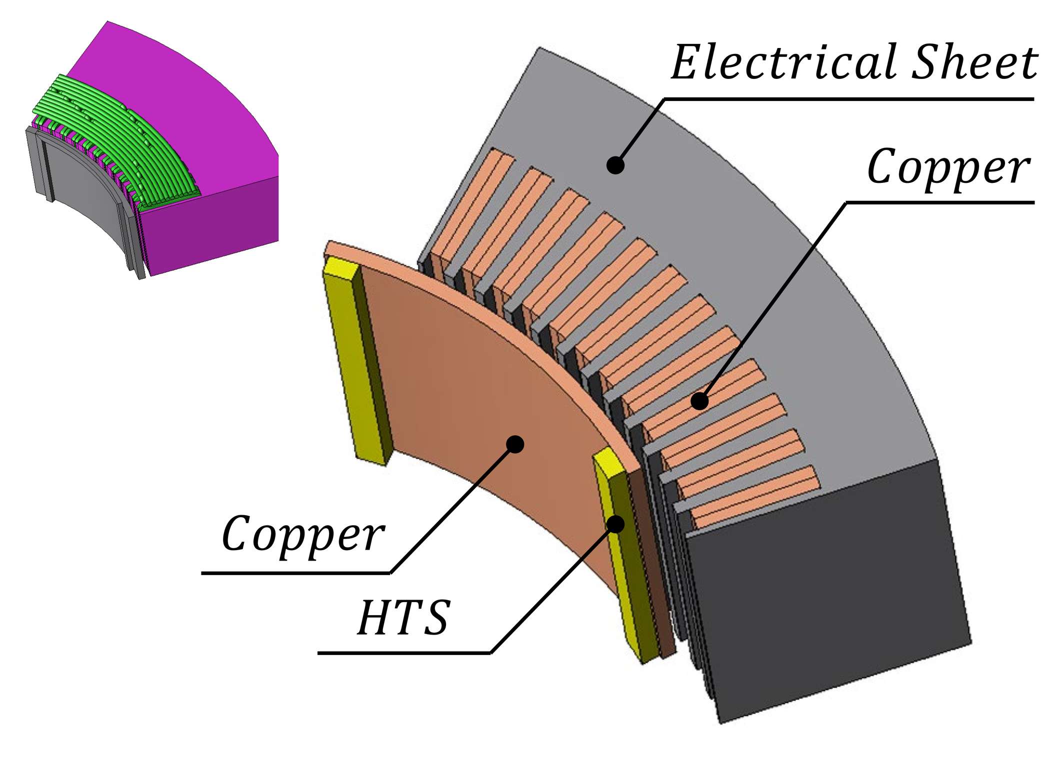
Introduction

- Present Conceptual design of Vernier machine with High Temperature Superconducting (HTS) field winding and HTS bulks on FMP
- 'NI' REBCO HTS Coil is applied on Rotor field winding, Thickness of the Magnetic Damper shell on the rotor has investigated in terms of torque density.
- Investigate the performance of the Air core & iron core topology with considering parametric study of Magnetic force Stress on the Teeth due to the tangential force of the both topology.
- Introduce advantage of the HTS Vernier machine with HTS bulks comparing to the one without HTS bulks and Conventional HTS machines .

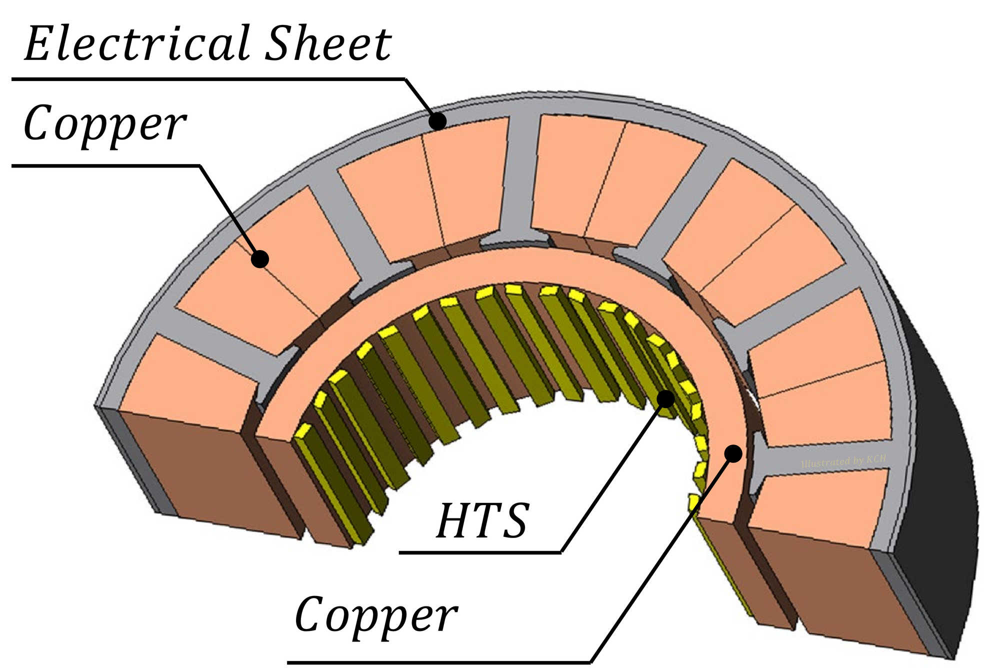
Conclusion

- NI REBCO field winding provides reliable in terms of quench effect, have advantage of cooling effect by eliminating insulation
- YBCO HTS bulks on the Modulating Pole presents flux- shielding(flux concentrating to the flux path) due to the Meissner effect
- HTS Bulks on the FMP shall be protected from AC flux condition which dramatically decrease the critical Flux density
- Concept design of HTS Vernier machine with HTS FMP have advantage in terms of Torque density per mass than 18% and 35 % respectively the conventional HTS machine and HTS Vernier without HTS FMP.

Specification of IPMSM



< Configuration of 'NI' HTS Motor>



<Configuration of 'NI' HTS Vernier Motor'

Major Configuration parameter

Parameter	Unit	Value		
Operating Point	-	15Nm @ 120rpm		
Stator Pole Pair	EA	4	2	
Rotor Pole Pair	EA	4	10	
Stator Slot	-	96	12	
HTS field Winding (Rotor)	mm	1.3 x 0.8		
HTS Bulks	mm	-	-	5.6 x 0.8
Stack length	mm	15.70	18.00	13.30
Damper Shell	mm	3/5		
Armature Current density	A/mm^2	3		
Critical Current	A/mm^2	171		

Design Consideration of HTS machine

- Partially Superconducting(SC) topology –DC field Windings, shielded well by damper shell, AC losses of the SC coils are expected low
- Selecting geometrical parameter and sweep to investigate Airgap Core &

In terms of FEA Consideration

1. Permeability of HTS bulks is set ideally to zero when the bulks is in the superconductor state, when the current, flux, temperature exceed critical point, the material properties shall be changed
2. HTS is highly effected by the operating temperature, which also has effect on the AC loss induced by external field considering 2D FEA

Operating Principle of Vernier

Design using Vernier Effect(Magnetic Gearing effect), Flux Modulation

F_{PM}: *rotor PM MMF distribution*

$$F_{PM}(\theta_m,t)=F_{PM,1}\cos(p_r\theta_m-p_r\omega t-p_r\theta_0)$$

p_r: *number of the rotor pole pairs*

w: *mechanical angular speed*

θ_m: *initial position of the rotor*

p_S: *number of the winding pole pairs*

m: *harmonic order of the winding MMF distribustion*

B_{PM}: *radial flux density distribution by the rotor PMs*

$$B_{PM}(\theta_m,t)=P_0F_{PM,1}\cos(p_r\theta_m-p_r\omega t-p_r\theta_0)+\sum_{j=1,2,3,\dots}^{\infty}\frac{F_{PM,1}}{2}\cos((p_r\pm j)\theta_m-p_r\omega t-p_r\theta_0)$$

F_S: *winding MMF distribution*

$$F_S(\theta_m,t)=\sum_{m=1,4,7,\dots}^{\infty}F_{S,m}\cos(mp_s\theta_m-p_r\omega t)+\sum_{m=2,5,8,\dots}^{\infty}F_{S,m}\cos(mp_s\theta_m+p_r\omega t)$$

B_S: *radial flux density distribution by armature winding*

$$B_S(\theta_m,t)=P_0\sum_{m=1,4,7,\dots}^{\infty}F_{S,m}\cos(mp_s\theta_m+p_r\omega t)+P_0\sum_{m=2,5,8,\dots}^{\infty}F_{S,m}\cos(mp_s\theta_m-p_r\omega t)+\sum_{m=1,4,7,\dots}^{\infty}\sum_{j=1,2,3,\dots}^{\infty}\frac{F_{S,m}P_j}{2}\cos((mp_s\pm j)\theta_m+p_r\omega t)+\sum_{m=2,5,8,\dots}^{\infty}\sum_{j=1,2,3,\dots}^{\infty}\frac{F_{S,m}P_j}{2}\cos((mp_s\pm j)\theta_m-p_r\omega t)$$

Analysis & Results

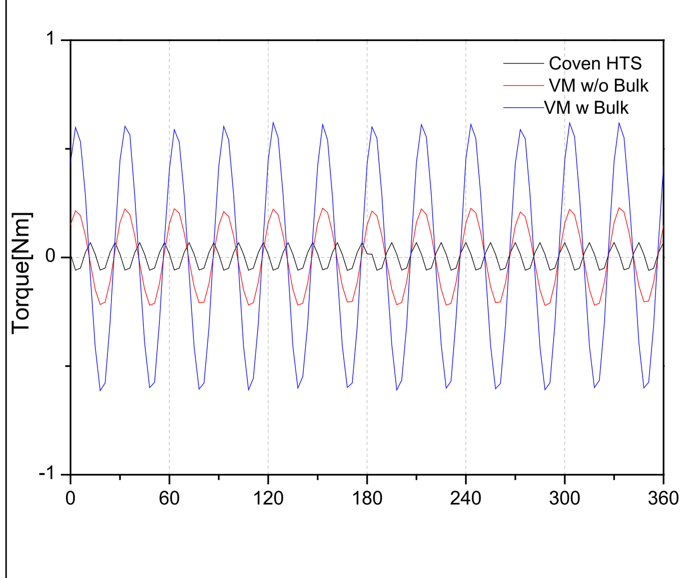
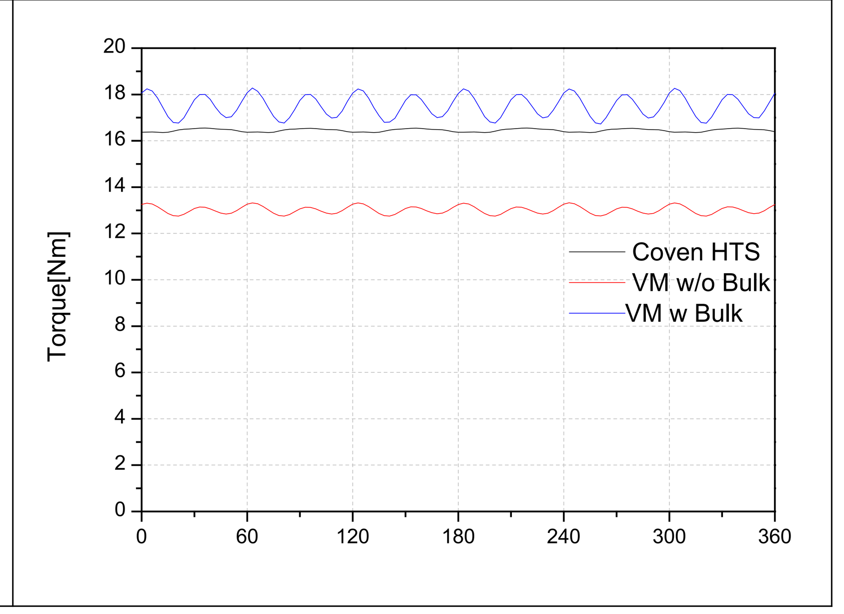
Operating Characteristic by FEM Analysis

HTS material properties (I-V model) - emprical

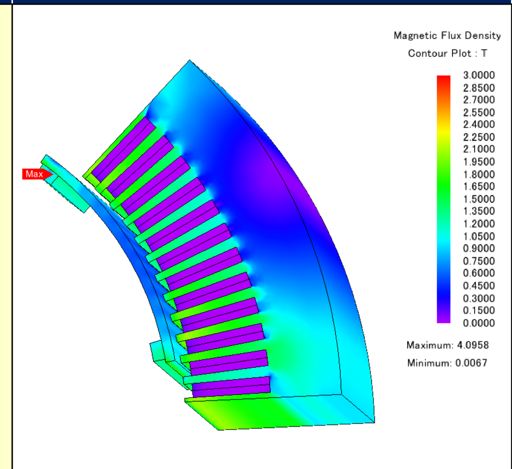
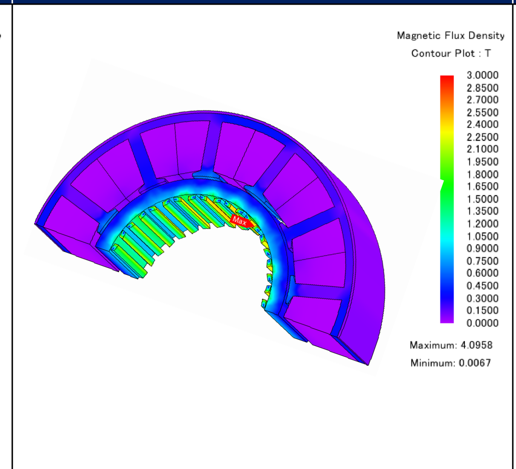
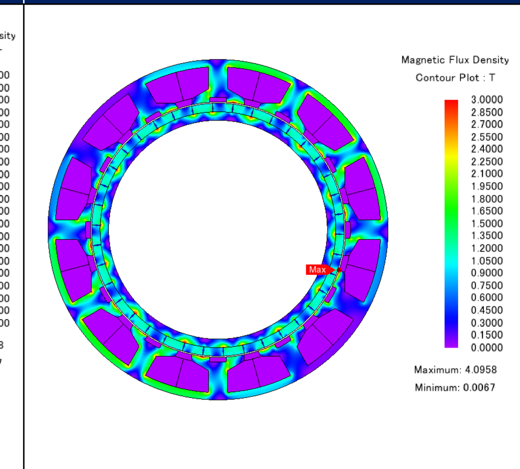
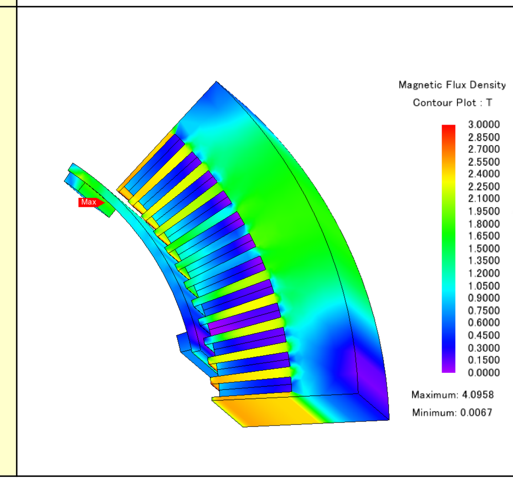
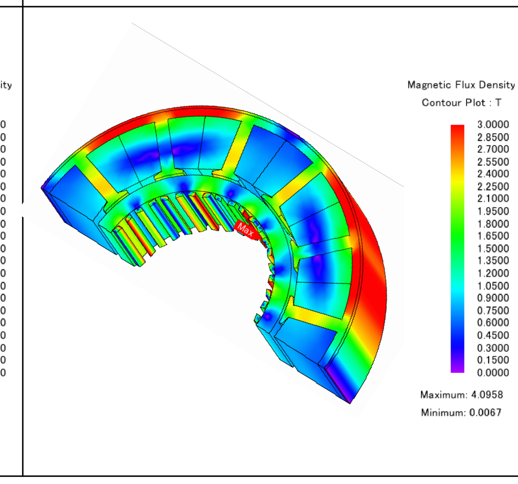
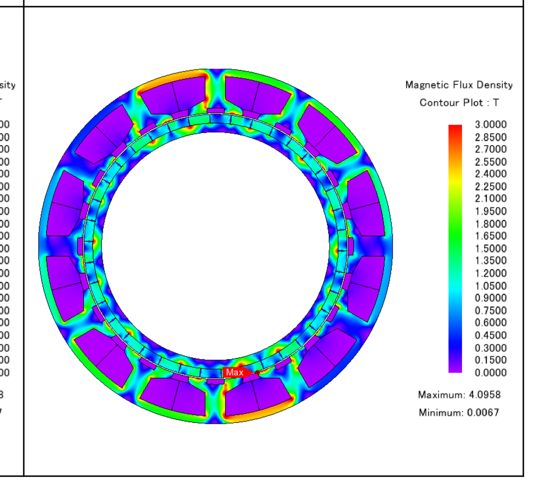
$$E=E_c=\left(\frac{J}{J_c}\right)^n$$

J: *Current density of each element,*
E: *Electric field of each element ,*
J_c: *Critical electric field of each element ,*
E_c: *Critical electric field of each element*

Torque Density : HTS w Bulk > Conventional> HTS Vernier w/o Bulk

Cogging Torque	Rated Torque
	

< Flux Density Distribution of HTS machine >

Item	Conventional	HTS Vernier I	HTS Venier II
No load			
Load			

< Flux Density Distribution of HTS machine >