Simulation of YBCO Tape and Coils in HTS Maglev System

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Abstract. In the process of running high temperature superconducting maglev train，the AC(Alternating Current) loss of superconducting coil is directly related to its safe operation and operating cost. In this paper, the simulation model was built based on the finite element software COMSOL Multiphysics, and mainly simulated and calculated the AC losses of YBCO(Yttrium Barium Copper Oxide) tape and coils. In this model, as the solving object, the singular and infinite long YBCO tape and coils model was solved with H-formulation and the nonlinear characteristic (E-J constitutive law) and anisotrophy (B-J characteristic) were taken into consideration as the theoretical foundation. Then on the basis of the model under maglev suspension system, AC losses under different amplitude and frequence AC currents were calculated. The results shows that under different frequencies and dynamic components, the local maximum AC loss of YBCO tape and coils occurs when the steady-state DC(Direct Current) current is 30A . Then comparing with old maglev suspension system, the new system can greatly reduce the energy consumption and the material cost.

1 Introduction

Maglev is considered a promising way of rail transport system. It has lots of advantages which traditional wheel-rail trains do not have. Maglev trains does not contact tracks during running, so that there is no mechanical friction, which makes the noise greatly reduced. It is generally driven by linear motor, so it has great ability at climbing and small turning radius. In addition, the maglev can construct railways through viaduct, so there is less impact on the surrounding environment and lower cost[1-2].

Currently maglev train uses aluminum coils, so there are resistive losses in the suspension process which makes the electromagnets generate more heat, but also results in a waste of energy. Currently power consumption of suspension system is 0.75 kilowatts per ton. If the resistive losses can be reduced, the maglev train will save more energy[3-4].

Superconducting material can significantly reduce the resistance loss of the conventional normal conducting coils. High-temperature superconducting material is a kind of material working in the liquid nitrogen which lowers the requirements of refrigeration and insulation. High-temperature superconducting maglev is becoming the trend of future transportation development[5-6].

Research on AC loss of high-temperature superconducting maglev, obtaining loss characteristics, so we can design the HTS(High-Temperature Superconductor) suspension electromagnet, what's more, the thermal insulation structure and the power of refrigerator etc. Ultimately, assess the possibility of applying the superconducting material on electromagnetic levitation. So the primary issue of applying high-temperature superconducting material in maglev system is to study the magnitude of AC loss[7-10].

This paper is based on the E-J constitutive law of YBCO and the finite element software COMSOL Multiphysics. Mainly simulate and calculate the AC losses of YBCO tape and coils under different kinds of current inputs. The results shows that under different frequencies and dynamic components, the local maximum AC losses of YBCO tape and coils occurs when the steady-state DC current is 30A[11-13] .

2 Simulation

Fig. 1 and Fig. 3 show the simulation of YBCO tape model and coils model respectively, model parameters and expressions shown in Table 1 and Table 2.

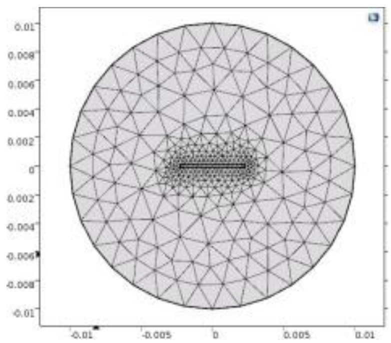

Figure 1. simulation of YBCO tape model

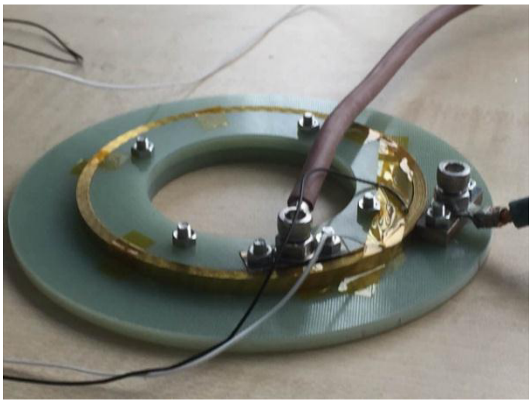

Figure 2. the photo of YBCO coils

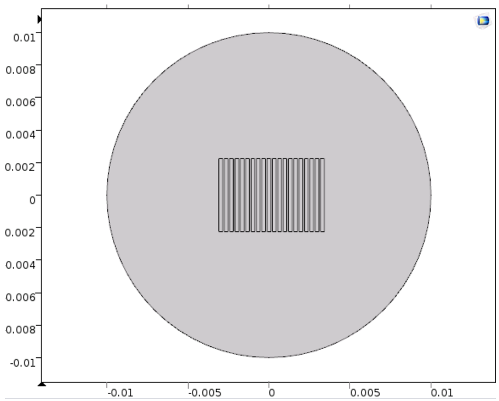

Figure 3. simulation of YBCO coils model

Table 1. Primary parameters

tape width	4.5 mm
tape thickness	0.23 mm
critical current	120 A
critical current density	1.17e8 A/m^2
simulation time	0.1s
distance between turns	0.1mm

Table 2. Primary variables and expressions

variables	expressions	description
J	$\frac{\partial H_y}{\partial x}-\frac{\partial H_x}{\partial y}$	Current density (A/m^2)
E	$\begin{cases}0 & J<J_c \\ E_c(\frac{J-J_c}{J_c})^n & J\geq J_c\end{cases}$	Electric field strength (V/m) E-J constitutive law
Q	$\int_t\int_s E\times J$	AC loss (W/m)
I	$I_d+I_0\sin(wt)$	current applied (A)

This simulation is based on different types of given current to calculate the AC losses of the tape and coils.

3 Results and analysis

3.1. The tape simulation

Current given is $I=I_d+I_\alpha\sin(2\pi ft)$.

AC losses under various parameters are shown below. Among them I_d changes from 10A to 70A with the step of 10A. I_α changes from 5A to 20A with the step of 5A. f changes from 10Hz to 500Hz.

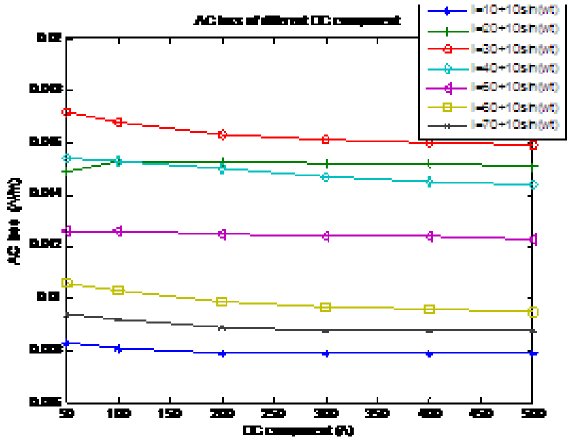

Figure 4. AC losses of different DC components under different frequencies

As can be seen from Fig. 4, with I_α being 10A, the change of frequency makes no significant effect on AC losses in different

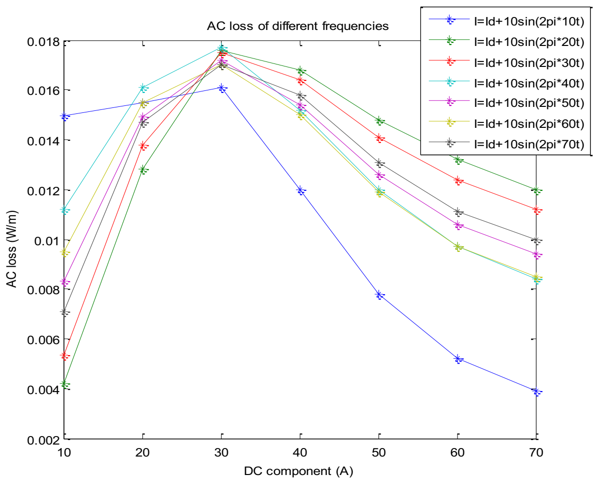

Figure 5. AC losses of 10~70Hz under different DC components

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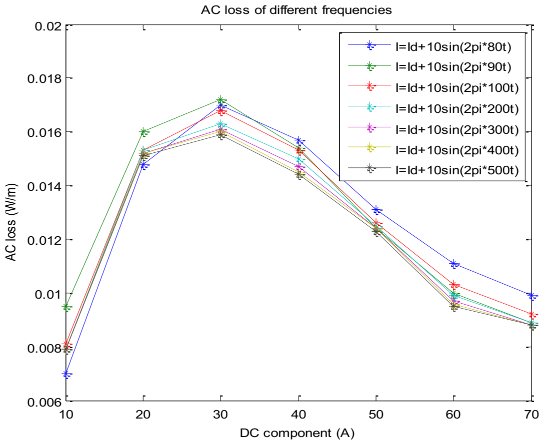


Figure 6. AC losses of 80~500Hz under different DC components

As can be seen from Fig. 5 and Fig. 6, with I_a being 10A, at each frequency, the AC loss occurs local maximum when the DC component is 30A. Thus AC losses can be reduced if avoiding 30A and its neighborhood.

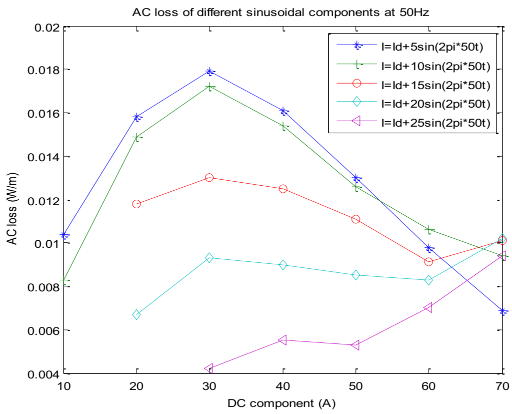


Figure 7. AC losses of different sinusoidal components under different DC components at 50Hz

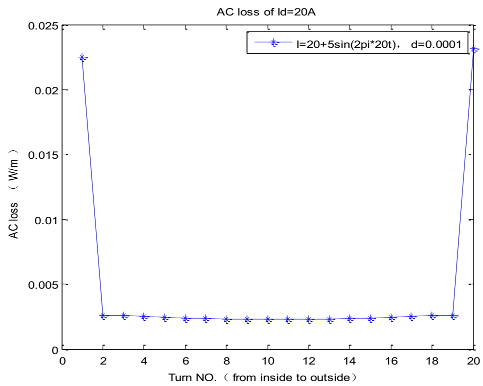
As can be seen from Figure 7, at 50Hz, for different sinusoidal components, the AC loss occurs local maximum when the DC component is 30A. Although there is a rally after 60A, AC losses can be reduced if avoiding 30A and its neighborhood.

3.2 The coils

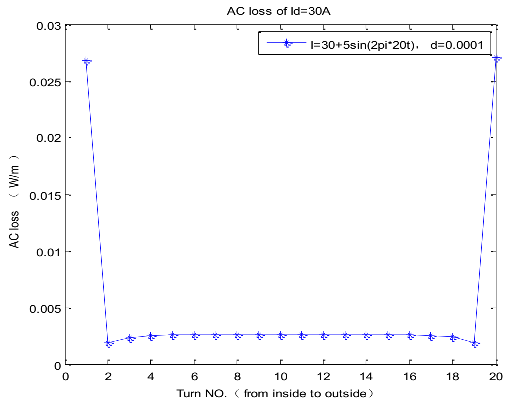
From above, select a set of representative parameters to calculate AC loss of YBCO coils model.

Current given is $I = I_d + I_a \sin(2\pi ft)$

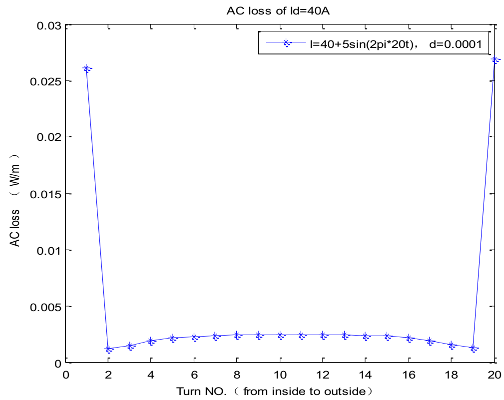
AC losses under various parameters are shown below. Among them I_d changes from 10A to 70A with the step of 10A. I_a = 5A and f = 20Hz.



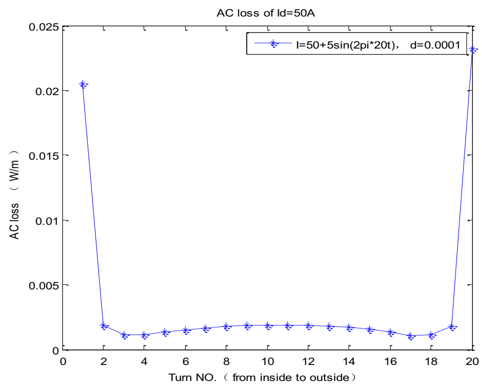
(a)



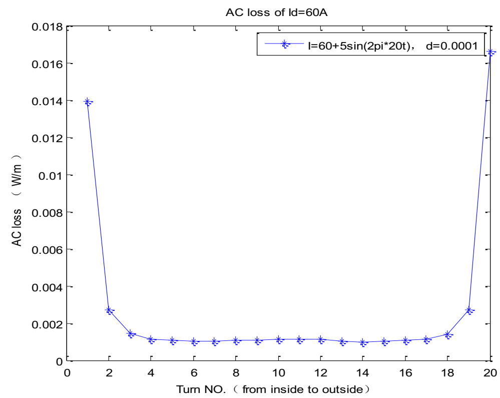
(b)



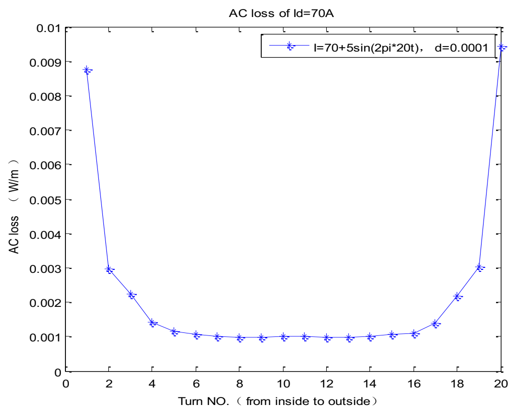
(c)



(d)



(e)



(f)

Figures 8. (a~f) AC losses of 20Hz and I_a = 5A under different DC components from 20A to 70A

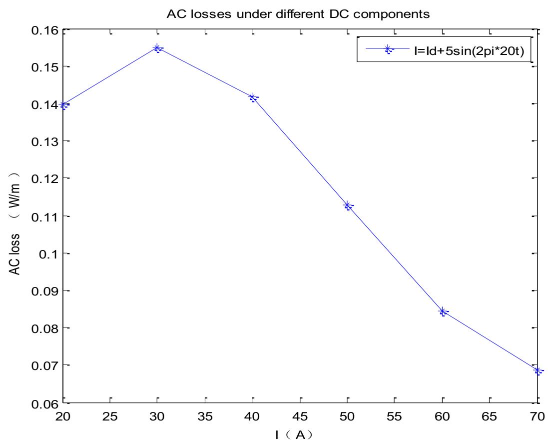


Figure 9. normalized AC losses under different DC components

This normalization means multiplying the corresponding length of every turn of the coils then add them all to obtain the total AC loss.

As can be seen from the simulation above, with I_a being 10A, f being 20Hz, the AC loss occurs local maximum when the DC component is 30A. This result is the same as the simulation of YBCO tape.

4 Conclusion

Equations should be centred and should be numbered with the number on the right-hand side.As for maglev system, saving the cost and reducing energy consumption have always been the objectives to pursue.

Based on the above conclusions, if we improve the DC components of work current from 30A to 50A, the AC loss will drop from 0.0172W/m to 0.0126W/m, a decrease of 26.74%. Meanwhile, with the same magnetic motive force, the coil turns required will reduce by 40%. What' s more, the total reduction of cost will be more than 40% due to the winding accumulation and the low success rate of winding coils. For example, when the DC component of current input is 30A, we need about 400m tape with the market price about 400 yuan / m. Therefore, this improvement will bring very substantial cost savings. Then we turn back to see the energy consumption.

$$E_{new} = (1-26.74\%)\times(1-40\%)E_{old} = 44.0\%E_{old}$$

This improvement will reduce the energy consumption by more than 50%. The new one is only 44% of the old one.

The above conclusions are on the contrary to the traditional cognition that the greater the current is, the greater the AC loss will be. The author was very surprised when firstly found this conclusion, after constantly repeating and verifying this simulation, still got this conclusion. Finally decide to propose this result by this paper to have a discussion with the readers.

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