**Parameter Emulation of Superconductive Motor Based on Ansoft Maxwell**

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**Abstract.** Superconductive motor keeps several advantages compared with normal motor, such as stronger power density and less volume. In modern society, the manufacture cost of superconductive motor is quite large. It is better to optimize the superconductive motor carefully before manufacture process, because little designing error may cause big economic loss. The Ansoft Maxwell can be used to emulate the size and performance of the motor by the visual optimal design. The simulated result can help provide reference for motor designing, to decrease the cost and save time. The paper gives the constituent process of motor emulation, to evaluate the changing orderliness of conductive motor.[1]

**Introduction**

In recent year, the superconducting motors are widely used. There is a great deal of research on high temperature superconducting motor in the whole word. In 1995, the U.S. Energy Department had already developed a high temperature superconducting motor of 735kW; In 2001, SIEMENS has developed a 405 kW/1800rpm experimental prototype motor; In 2003, the America Navy decided to cooperate with the American Superconducting Corporation, [1]and developed a 36.5MW/180rpm high temperature superconducting testing-motor in 2006; To our Chinese delight. [2]

**The Simulating Software**

Ansoft Maxwell was developed by Ansoft in 2003, it is the simulation software for electric and magnetic fields, which aim to analyze the physical properties of objects in the dynamic and static conditions by using the finite element analysis. RMxprt has a strong motor design and simulation ability. The advantages are mainly reflected in:

1. the number of operations is fast and the results are accurate.  
2. the amount of computation is large.  
3. it is convenient to change the main parameters of the motor.

**Modeling and Computing Based On RMxprt**

**Design Ideas**

RMxprt is an important part of simulation module in Maxwell. RMxprt can simulate the performance parameters of the motor in a short time. At the same time, the RMxprt can also be able to select, create, and change the material types, [3]to ensure the diversity of practical materials.

**Modeling Steps**

RMxprt can determine the size and performance of the motor in a concise way. After determining the output power, the output voltage, and the relative nominal speed, RMxprt can make the program calculate the operating structure, and obtain the final measurement data.
Outside Permanent Magnet Synchronous Motor (OPMSM)

In this design, we would like to choose the superconducting permanent magnet as the stator. Because the speed of OPMSM is generally high, it can let out a high temperature. Then we can choose the permanent magnet as stator for external cooling. Figure 3-1 shows the structure of OPMSM.

![Figure 1. The structure of OPMSM.](image)

I-Stator outer diameter; II-stator inner diameter; III-Rotor outer diameter; IV-Rotor yoke diameter; V-Permanent magnet thickness; VI-Permanent magnet duty cycle

In addition, motor length is 400 mm; the superposition coefficient is 0.95; the number of the coils in each rotor slot is 20; the material of the stator and rotor are set as silicon steel sheet; the material of permanent magnet is set as yttrium barium copper oxide (YBCO); the output voltage is set to 750 V; the rated power is 500 kW. [6]

The relevant loss data can be obtained after a series of calculating. The detailed data is under below. [4]

Efficiency formula

\[
\sum P = \left( 1 - \frac{\sum P}{P_N + \sum P} \right) \times 100\%
\]  \hspace{1cm} (1)

Among them, \(\sum P\) is the total loss.

The equation for total loss is,

\[
\sum P = P_{Fe} + P_{Feb} + P_{Cul} + P_{Cuf} + P_h + P_{max} + P_{ad}
\]  \hspace{1cm} (2)

Among them, the stator copper loss \(P_{Cul}\) and the excitation loss \(P_{max}\) are the main loss. And the iron loss \(P_{Fe}\) is too small to be ignored. The formula for calculating excitation loss \(P_{Cuf}\) and excitation loss \(P_{Fe}\) is under below respectively.

\[
P_{Cuf} = m \times I_{N}^{2} \times R_{o(x)}
\]  \hspace{1cm} (3)

\[
P_{Fe} = \frac{I_{N}^{2} \times R_{o(x)} + 0.6 \times I_{PN}^{2}}{\eta f}
\]  \hspace{1cm} (4)

In this simulation, the RMxprt uses the YBCO to be the material of the permanent magnet. And we can get the different performance of the motor by changing the magnetization, and to reach our aim finally.

According to the formula (5)

\[
B = \mu_o H + \mu_r M
\]  \hspace{1cm} (5)

\(\mu_o\) is the absolute vacuum permeability (%\(4\pi \times 10^{-7}\)); \(\mu_r\) is relative conductivity; H is magnetic field values; M is magnetization.
From the formula (5), it can be seen that the magnetic properties can be changed by adjusting the magnetic intensity. [4] [5]

![Graph showing the relation between full-load speed and magnetization.](image)

Figure 2. The relation between full-load speed and magnetization.

It is easy to know that if the magnetization \( M \) increase, full load torque would increase gradually. Under the case that if the magnetization \( M \) increased 20 times, the motor torque would increase nearly 3.5 times. However, the incensement of magnetization would greatly sacrifice the motor speed. And the final speed is about 1/4 of the initial speed.

Because the RMxpert module is connected to the external interface to ensure that the output voltage is stable at 750V, the change of current parameters of the permanent magnet motor is small, and the output power is stable at 500 kW, and the current is 136A, the armature current is 34A. Because the no-load speed and full load speed data are approximate, and the performance is consistent, they are not discussed in this paper.

**Inside Permanent Magnet Synchronous Generator (IPMSG)**

Large permanent magnet synchronous generator usually takes the structure of inside permanent magnet, as the Figure 3 shows, with the wind power direct drive system becoming more and more important, In this paper, the RMxpert would begin the simulation and the calculation to it.

![Diagram of IPMSG structure.](image)

Figure 3. The structure of IPMSG.

I-Stator outer diameter; II-stator inner diameter; III-Rotor outer diameter; IV-Rotor yoke diameter; V-Permanent magnet thickness; VI-Permanent magnet duty cycle

The fuselage length of the generator is 400 mm; the stacking factor is 0.95; the control method is AC control; the number of turns of the coil is 12; the rated synchronous speed is 5000 rpm; the output voltage is limited to 730 V; the output maximum power controlled at 550 kW; the

In this simulation experiment, we attempt to change the stator slot number, to observe the relationship between the number of stator slots and the performance of the motor.
For convenience, the number of stator slot is set at 12 poles. The RMxprt changes the magnetization $M$, to observe the change of the output power, efficiency, full load output torque and full load speed. [6][7][8]

![Graph](image)

Figure 4. The relation between output power and magnetization.

The final torque is limited around 1050 N. m, and the output power is controlled at 550 kW. The reason is that 550 kW is the rated output power, and the output power is proportional to the motor torque, thus the torque is controlled at 1050 N. m.

**Analysis**

We can summary from the first motor model, if the magnetic property of the OPMSM magnetic is stronger, the full load speed would be weaker and the full load torque would be bigger in non-linear proportion, under the condition that the excitation current kept stable. In the model of OPMSM, magnetization $M$ increased by 20 times, thus the performance of permanent magnet is also increased by 20 times, the speed drops by 3.555 times and the torque is increased by 3.556 times.

The simulation results of second motor models are similar to the former. Under the condition that the rated motor is 5000 rpm, the higher the magnetization $M$, the stronger the motor performance. From the figure 3-6 and 3-7, the magnetization $M$ increased by 20 times, motor performance increased by 2.77 times, but loses 66.67% of motor efficiency. At the beginning, the output power is 198 kW, then it start to improve in nonlinear way. At last, it is limited at 550 kW because it’s set at first.

**Conclusions**

For the OPMSM, if the armature current and output power was controlled, the higher the magnetization $M$, the stronger the motor torque. Throughout the whole process, magnetization $M$ increased by 20 times, the motor only increased by 3.55 times, and the motor speed dropped.

For the IPMSG, motor speed is the limited condition, when magnetization $M$ increased, the motor torque and output power also increased, And stopped rising after reaching the rated value. From the figure 3-6 and 3-7, the output power and torque only increase about 2.7 times although the magnetization increases 20 times. This shows that the magnetic field increases from 0.6283 T to 12.566 T and tends to saturation, to suppress the output torque to continue to grow.

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