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Lightweight design of Rotor Supporting for Large Permanent Magnet Direct Drive Wind Generator

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ABSTRACT

Under the action of electromagnetic force, mechanical force and gravity, the radial deformation of rotor supporting must meet the design standard while ensuring the lightest mass. At first, the mathematical model of single objective optimization is established. Then, the objective function is optimized by the combination of genetic algorithm and finite element method (GA-FEM). With the help of this method, the optimal design parameters of the rotor supporting are obtained. This paper takes the actual rotor supporting of 7MW prototype as the optimization object. The optimal solution of this structure without the lightweight holes can be obtained by first optimization. And then, the optimal solution of the final structure with the lightweight holes is obtained by the second optimization. The final simulation shows that the stiffness can be met while reducing the mass by 40%.

Keywords:
Wind generator; Optimization; Mathematical model; Genetic algorithm; Finite element method

INTRODUCTION

Permanent magnet direct drive motor has become the most promising solution for wind generation because of its advantages of high power density, high efficiency, high reliability and low maintenance cost. However, with the increase of the motor power grade, the excessive volume and weight of the motor are obstacles to its manufacture, assembly, transportation and installation [1]. The large permanent magnet direct drive wind generators are large in volume and mass. The main reason is that they not only include effective materials that produce electromagnetic torque, but also include structural materials that transmit torque. In order to overcome the torque load without plastic deformation or fracture, and ensure that the deformation at the air gap of the generator does not exceed the allowable value. The size and mass of structural are greatly increased for its Stiffness and strength requirements.

Rotor supporting is one of the key factors to determine the weight of generator [2]. In the specific construction design stage of wind generator, when it comes to the design of every component, the designers often depend on their experiences, lack theoretical guidance, and often for safety reasons to choose some structural dimensions. Therefore, the design is conservative. This design method based on subjective experience directly leads to the increase of rotor supporting. Aiming at the optimization of rotor supporting of 7MW prototype. Firstly, the optimization model is established in this paper. The minimum mass of the rotor supporting is selected as the optimization objective. And the deformation of the rotor yoke satisfying the design standard is taken as the constraint condition, when the rotor supporting is under the action of electromagnetic force, mechanical force and gravity. Then, the finite element model is parameterized and the analytical solution is transformed into numerical solution. At last, the optimal solution is obtained through the data exchange between the genetic algorithm and finite element method. This method also provides reference for the optimization design of other large structures in large permanent magnet direct drive wind generator.

STRUCTURE OF 7MW PMDD GENERATOR

The rotor supporting of the 7MW prototype is a large structure which is used to install electromagnetic materials. In addition to ensure that materials should have sufficient strength to overcome the effect of torque load without plastic deformation or fracture.

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The rotor supporting should have enough stiffness to ensure that the deformation amount of the Generator air gap does not exceed a certain value. The rotor supporting adapts disc structure which is welded to the steel shaft as a whole. There are several lightweight holes in the rotor disc for reducing the weight. And there are stiffeners on the back of the supporting plate for strengthening the support stiffness.

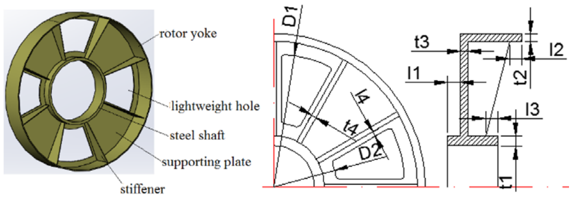

Figure 1. Rotor supporting structure

As shown in Fig. 1. Where:

D_1 = Outside diameter of the lightweight hole
D_2 = Inner diameter of the lightweight hole
l_1 = Distance between the supporting plate and the steel shaft
l_2 = Upper side length of the stiffener
l_3 = Lower side length of the stiffener
l_4 = Distance between the stiffener and the lightweight hole
t_1 = Thickness of the steel shaft
t_2 = Thickness of the rotor yoke
t_3 = Thickness of the supporting plate
t_4 = Thickness of the stiffener
n_1 = Number of the stiffener
n_2 = Number of the lightweight hole

The selection of these parameters directly affects the weight of rotor supporting and mechanical stiffness and strength. Therefore, the purpose of this paper is to determine the most reasonable dimensions of the parameters shown in Figure 1 under the premise of ensuring that the stiffness and strength of the rotor supporting is adequate and the mass is minimum. The rotor supporting determined by this design method can meet the requirements of stiffness and strength under the condition of the lightest weight. Compared with the traditional design method based on experience and conservatism, this method is more scientific and is a lightweight design method for large structural which can be applied in engineering.

OPTIMIZATION PROCEDURE

Optimization model

The least weight of rotor supporting is selected as the optimal objective. And then the radical deformation of the rotor yoke which meet the design criterion is taken as the constraint condition when the rotor supporting under the action of electromagnetic force, mechanical force and gravity. Radical deformation is usually set to 5% of the gap length. Taking the structural dimension in Fig. 1 as design variables, the optimization mathematical model can be established [3,4]:

$$M_{\min} = f\left(l_1, l_2, l_3, l_4, t_1, t_2, t_3, t_4, D_1, D_2, n_1, n_2\right) \quad \text{s.t.} \quad \mathrm{RMS} \le 5\%\xi \tag{1}$$

Where:

M_{min} = Mass of the rotor supporting
RMS = Air gap deformation quantity of the rotor yoke under the action of electromagnetic force and gravity
ξ = Air gap length, which is equal to 7mm through the electromagnetic scheme.

The value range of each design variable is as follows.

$0.2835m \le l_1 \le 0.347m$ $\quad$ $0.1395m \le l_2 \le 0.171m$

$0.0981m \le l_3 \le 0.1296m$ $\quad$ $0.09m \le l_4 \le 0.121m$

$0.1125m \le t_1 \le 0.144m$ $\quad$ $0.0405m \le t_2 \le 0.048m$

$0.045m \le t_3 \le 0.0605m$ $\quad$ $0.018m \le t_4 \le 0.0215m$

$6.025m \le D_1 \le 7.3m$ $\quad$ $3.2m \le D_2 \le 3.825m$

$n_1 = 6,8,10,12$ $\quad$ $n_2 = 3,6$

Parameterized finite element model

The biggest difference between the study of this paper and the traditional optimal design method is to establish the mathematical model of constraint conditions by using finite element instead of analytical method. The air gap deformation of the rotor yoke is taken as the constraint condition in this paper. If the traditional optimization method is used, the analytical expression of the air gap deformation of the rotor supporting under the action of electromagnetic force, mechanical force and gravity must be established according to the theory of material mechanics and elastic mechanics, which is very difficult for complex geometry. Therefore, the radial deformation of the rotor yoke is calculated by finite element method.

For any optimization problem, it is necessary to find the optimal solution from many groups of feasible solutions. Therefore, the established finite element model is not a finite element model with a set of design variable, but can be modified according to the assignment of design variables which is based on the ANSYS Parametric Design Language (APDL) of the finite element model [5]. The design variable is parameterized. Consequently, the value of the design variable can be changed by reading the external data file. Therefore, in this paper, the finite element analysis model of rotor supporting parameterization which include modelling, solving and post - processing should be established by using APDL at first. The parameterized finite element analysis flow is as follows.

Step 1: The design variable data file is read.

Step 2: The finite element model is established.

Step 3: Air gap deformation and rotor supporting volume are calculated.

Step 4: The calculation result of the air gap deformation and rotor supporting volume are saved as data file.

Process of GA-FEM

Fig. 2 is used to explain the optimization process of GA-FEM. Genetic algorithm is written in MATLAB language, and finite element calculation is written in APDL [6,9]. The optimization process is as follows.

Step 1: The value range of the design variables are input according to the design requirement.

Step 2: The initial population is generated, and fitness calculations and statistics of it are performed.

Step 3: The new population is generated and decoded through genetic operators such as selection, crossover and mutation. And the fitness calculations and statistics of it are also performed through this method.

Step 4: The individuals of the new and old populations are compared and survival of the fittest.

Step 5: The population periodically update and evolve. If the new population meets the optimization termination condition, the step 6 is executed. Else, the procedure returns to step 3.

Step 6: The optimal scheme is obtained, the iteration optimization is terminated, the parameter optimization is finished, and the optimization results are output.

OPTIMIZATION RESULT

The number and size of the lightweight holes changes with the quantity and rigidity of the stiffener. Therefore, the rotor supporting with no lightweight holes but with stiffeners is optimized first in the process of optimizing the rotor supporting. After determining the optimal rotor supporting with no lightweight holes, based on which, the structure with lightweight holes is optimized. Because the axial direction of the rotor supporting after

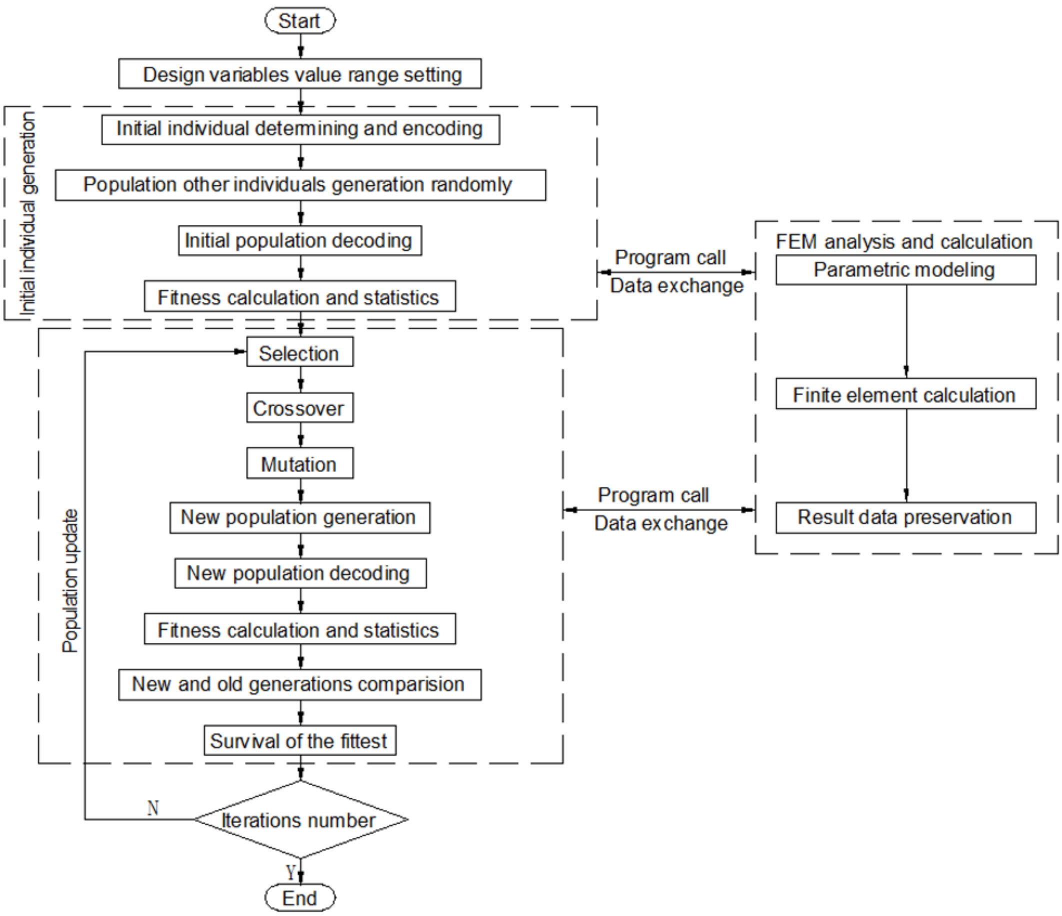

Figure 2. GA-FEM flow chart

installation is parallel to the ground and the structure is nonlinear, the deformation of the rotor supporting is non-uniform under the electromagnetic force, mechanical force and gravity, and the maximum deformation position is changeable according to the structure of the rotor supporting. The deformation of initial structure with no lightweight holes under the action of electromagnetic force, mechanical force and gravity is shown in Fig. 3. The maximum deformation is at the rotor yoke which is 0.101mm, and the allowable deformation is 0.35mm. Therefore, the initial structure can be further optimized.

The rotor supporting is optimized on the bases of initial structure through GA-FEM. And the deformation result of first optimization is shown in Fig. 4. The maximum deformation is 0.132mm which is still less than the allowable value. This indicates that the material of the rotor supporting has not been effectively utilized. So the rotor supporting should be further optimized through machining lightweight holes.

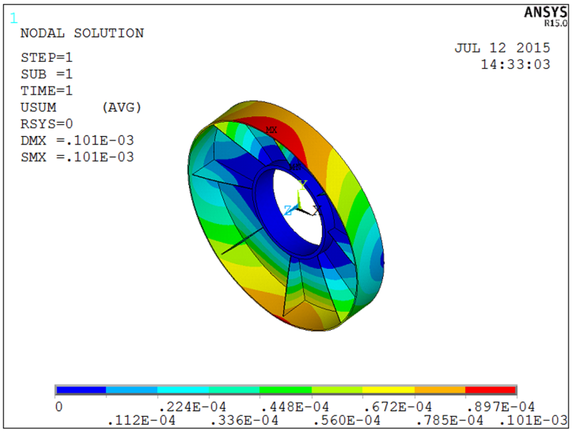

Figure 3. Initial structure deformation

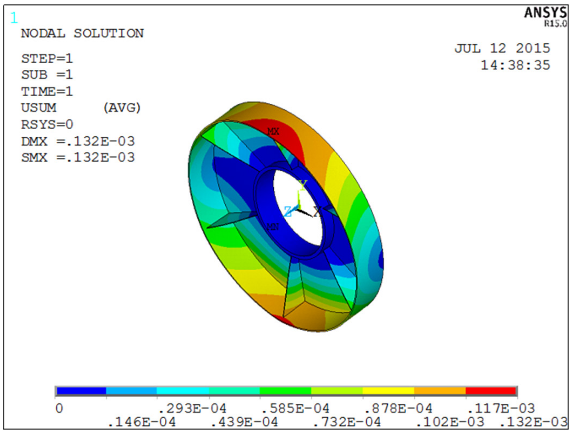

Figure 4. First optimization deformation

As shown in Table 1, the mass of the rotor supporting decreases from 32000kg to 28600kg after first optimization. The evolutionary process of genetic algorithm during first optimization is shown in Fig. 5.

Table 1. Comparison of results before and after optimization

Design variables	Initial structure	First optimization	Maximum
l_1	315mm	343mm	343mm
l_2	155mm	154mm	154mm
l_3	109mm	109mm	109mm
l_4			107mm
t_1	125mm	115m	115mm
t_2	42mm	41mm	41mm
t_3	50mm	45mm	45mm
t_4	20mm	19mm	19mm
D_1			6900mm
D_2			3235mm
n_1	8	6	6
n_2			6
Deformation	0.101mm	0.132mm	0.305mm
Mass	32000kg	28600kg	19000kg

When the population evolves to the 8th generation, the optimization results have become stable, which indicates that the selection of the genetic generation for 10 can meet the requirements of convergence of the optimization results.

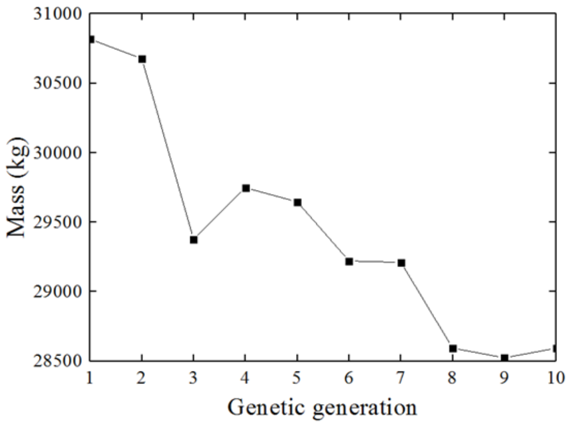

Figure 5. Evolutionary process of first optimization

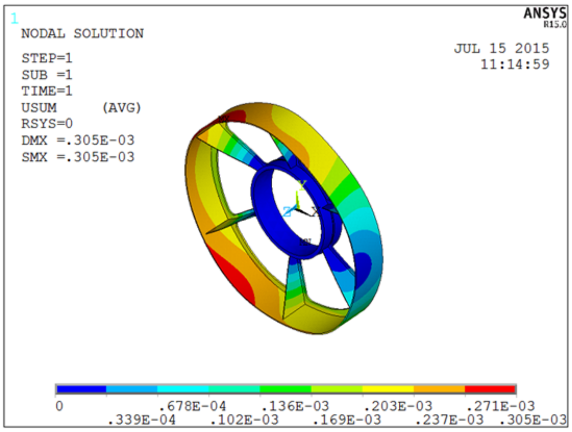

Figure 6. Deformation after second optimization

On the bases of first optimization, the rotor supporting is further optimized to reduce the mass by machining lightweight holes. The number and size of the lightweight holes is optimized during second optimization. The deformation of second optimization is shown in Fig. 6. The maximum deformation value is 0.305mm, which is less than 0.35mm, but very close to the allowable value. Therefore, the design of rotor supporting structure is reasonable. And the mass of the rotor supporting is reduced from 32000kg to 19000kg after two optimization, with the weight loss 40%.

CONCLUSION

The optimization method of combining the genetic algorithm with finite element method which is used to determine the dimension parameters of the structure can be applied to the design of the actual rotor supporting, and it can ensure that the designed rotor supporting satisfies the rigidity and strength with the lightest weight and smallest volume. Because of the more efficient data exchange between the MATLAB and ANSYS, the analysis result is more accurate than the traditional method.

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References

1. A.S. McDonald, M.A Mueller, H. Polinder. Structural mass in direct drive permanent magnet electrical generator. IET Renewable Power Generation 2 (2008) 3–15.
2. T. M. Jahns. The expanding role of PM machines in direct–drive applications, 2011 International Conference on Electrical Machines and Systems. (2011) 1–8.
3. Wang J, Luo S.M., Su Deyu. Multi–objective optimal design of cycloid speed reducer based on genetic algorithm. Mechanism and Machine Theory 102 (2016) 139–148.
4. Wu Z.Y, Qu R.H, Li J., et al., Lightweight Design of Rotor Supporting Structure of Large PM Wind Generator Based on Response Surface Model. 2015 18th International Conference on Electrical Machines and Systems (ICEMS), pp. 705–709, 2015.
5. Gui S.G., Optimal design of product structure based on ANSYS APDL. Modular Machine Tool & Automatic Manufacturing Technique 07 (2010) 92–96.
6. Wu Z.Y, Qu R.H, Li J., et al. Structure optimization of rotor supporting of permanent magnet direct drive synchronous generators for large wind turbine based on genetic algorithm and finite element method. 2015 IEEE International Electric Machines & Drives Conference (IEMDC), vol. 2, no. 1, pp. 1755–1760, 2015.
7. N. Taran and M. Ardebili. Efficiency optimization of an axial flux permanent magnet synchronous generator for low speed wind power applications. 2014 22nd Iranian Conference on Electrical Engineering (ICEE), pp. 539–544, 2014.
8. A. Mahmoudi, S. Kahourzade, N.A. Rahim, et al., Design, analysis and prototyping of an axial flux permanent magnet motor based on Genetic Algorithm and Finite–Element Analysis. IEEE Transactions on Magnetics, vol. 49, no. 4, pp. 1479–1492, 2013.
9. M.J. Navardi, B. Babaghorbani, A. Ketabi. Efficiency improvement and torque ripple minimization of switched reluctance motor using FEM and seeker optimization algorithm. Energy Conversion and Managem– ent, 78 (2013) 237–244.