Strength analysis of large motor

Dongxin Wang*
College of Electrical and Information, Heilongjiang Bayi Agricultural University, 163319, China
Email of all the authors: wangdongxinkk@163.com
*Corresponding Author: Dongxin Wang; email: wangdongxinkk@163.com; phone: 18245906633.

Abstract: Large motors are widely used in industrial production, mainly playing the role of load operation, equipment cooling and so on, and playing a vital role in the corresponding system, whose safety and reliability determine the stability of the entire industrial production. However, as the large motor is a rotating mechanism with a large volume, it will produce a large moment of inertia when it works at high speed. At this time, the structure between the rotor and bearing, the rotor itself, the rotor ventilation slot and other structures need to ensure a certain mechanical strength. This paper takes a 4500kW large motor as the research object, calculates the strength of rotor core and torsional strength by means of strength calculation, and analyzes the distribution of the internal stress field of the motor due to centrifugal force when it is running at high speed through finite element analysis, determines the location of stress concentration and calculates the strength requirements.

1. Introduction
With the development of industrial production, the large motor, as the main power component in industrial production, has put forward higher requirements for its safety and stability. Especially in recent years, with the development of power electronics technology and frequency conversion technology, the speed of large motor is also getting higher and higher. When the motor is running at high speed, due to its large volume, the resulting high inertia and stress concentration put forward new requirements on the mechanical strength of the motor, including the fit size between the rotor and the shaft, the deformation of the end and the stress concentration of the longitudinal vent on the rotor core. Therefore, it is particularly important to analyze the checking of mechanical strength and the distribution of stress field of large motor under high speed operation.

For rotating machinery, the ability of rotor to convert energy basically determines the performance of the whole machine, so the optimal design of the rotor is the theme part of the design of rotating machinery, and the guarantee of rotor strength is the premise of all work, so the strength check has been paid attention to in engineering design. Over the past 40 years, finite element method has been widely used in engineering and developed into an effective method in numerical analysis and calculation. The three-dimensional solid modeling calculation of rotating machinery with finite element method can better reflect the practical problems, can get more detailed and accurate stress distribution, model deformation, vibration frequency and mode of vibration, and can determine the location of maximum stress or maximum deformation, users can be targeted to optimize the design.

The rotating parts of high-speed motors are subjected to great inertia forces, sometimes tens of
thousands of times the weight of the parts themselves. Therefore, in addition to having to use high strength materials, these components must also have high strength calculation methods to reduce the safety factor used in the design. In the design of motor, strength is understood as the limit to make the motor lose working efficiency when the deformation of the construction exceeds the allowable limit. Therefore, the calculation of stress and deformation of motor components is the most critical problem in the design and calculation of motor strength.

2. Analysis of rotor blade strength

There are three ways of fit between shaft and shaft connecting parts, namely, interference, transition, clearance three kinds of tolerance fit. The hot sleeve fit is a method to achieve the purpose of interference fit by using the principle of heat expansion and cold contraction. There are many parts of the motor when the use of hot sleeve. We call the parts that are assembled on the outside as assemblies, and the parts that receive assemblies that are assembled on their outer surface as bushings. The key of hot sleeve fitting is to correctly choose the fit tolerance between the inner diameter of the kit and the outer diameter of the liner. The kit is heated to an appropriate temperature during assembly, and then put on the liner under the condition that the inner hole of the kit is heated to expand. When cooled, the kit automatically holds onto the lining. Such parts fit, can in practice do not produce any axial stress.

When the assembled part rotates, its centrifugal force is also slightly greater than that of the lining because the radius of the kit is slightly larger than that of the lining. At the same time, in general, the kit is also connected with other parts of the centrifugal force, so the expansion of the inner diameter of the kit deformation is larger than the lining of the outer diameter of the expansion deformation, the higher the speed, the greater the difference between the two deformation. When the difference in deformation due to inertial forces reaches the original fit tolerance, the kit and the liner are out of contact. This release often causes serious damage to the motor. For motor fit safety, it is ok to increase the fit tolerance appropriately. However, excessive improvement is not allowed. When the fit tolerance increases, the normal stress of the contact surface will also increase, which will increase the deformation of the package. When the yield strength of the package exceeds the yield strength of the package, the motor will also be damaged. Therefore, it is necessary to determine the fit tolerance of the hot sleeve of the motor.

2.1. Basic data

In this paper, a 4500kW large motor is taken as the research object to analyze its strength when running at high speed. The specific parameters are as follows:
- Rotate speed, \( n\): 4200 r/min
- The inner diameter of the punch, \( D_b \): 330mm
- The outside diameter of the punch, \( D_o \): 624mm
- The bottom of the channel diameter, \( D_n \): 500mm
- Groove depth, \( h_n \): 62mm
- Minimum distance from keyway to bottom of keyway, \( h_{\text{min}} \): 83.24mm
- Plate material: 50w350
- Tensile strength: 420MPa

2.2. Calculation of transfer torque intensity of rotor blade

Coefficient of stress increase due to keyways and vents:

\[
\beta = \frac{D_o - D_b}{2h_{\text{min}}} = \frac{500 - 330}{2 \times 83.24} = 1.0211
\]

Computing coefficients:
\[ \varepsilon = \frac{h_n}{D_2} = \frac{62}{624} = 0.0994 \]
\[ \alpha = \frac{D_n}{D_2} = 0.66 \]
\[ \zeta = 0.0293 \varepsilon (3 - 6 \varepsilon + 4 \varepsilon^2) + 0.0181(1 + 0.212 \alpha^2)(1 - 2 \varepsilon)^2 = 0.0284 \]

Tangential stress of core inner circle:

\[ \sigma = \zeta \beta D_2^2 \left( \frac{n}{1000} \right)^2 = 195.50 \text{ MPa} \]

Safety factor of rotor core strength:

\[ n = \frac{\sigma_s}{\sigma} = \frac{420}{195.5} = 2.148 \]

Transfer torque calculation:

\[ M = \frac{30N}{\pi l} = \frac{30 \times 4500 \times 1000}{\pi \times 4200} = 10231.39 \text{ N.m} \]

Calculation of maximum shear stress:

\[ \tau_{\max} = \frac{16M}{\pi D^3 \left( 1 - \left( \frac{d}{D} \right)^4 \right)} = \frac{16 \times 10231.39 \times 1000}{\pi \times 330^3 \times \left( 1 - \left( \frac{330}{624} \right)^4 \right)} = 1.57 \text{ MPa} \]

3. High speed centrifugal force calculation of rotor blade

As the rotor punch is a typical periodic symmetric structure, a symmetric period is selected as the analysis and calculation model, and periodic symmetric constraints are adopted in the cut section to ensure the consistency of displacement. A 20-node hexahedral unit and a 10-node tetrahedral unit with 3 degrees of freedom for each node were adopted, namely, SOLID95 unit and SOLID92 unit. In order to prevent rigid body displacement, the displacement degrees of freedom of all nodes in the inner ring are constrained. The calculation only considers the effect of centrifugal force. FIG. 1 Calculation model and FIG. 2 mesh generation by finite element method.
Figure 2. Finite element mesh subdivision diagram

Figure 3. Cloud map of stress distribution of rotor core ventilation slots

Figure 4. The stress distribution nephogram of the local rotor core punch plate
According to the finite element analysis, the stress distribution at the holes on the rotor core is the most concentrated, and the maximum stress of the rotor core ventilation groove is 89.837mpa, as shown in FIG. 3. The maximum punching stress of rotor core is 91.925mpa, and its stress distribution is shown in FIG. 4. The maximum stress of the local rotor core is 97.616mpa, and its stress distribution is shown in Figure 5.

4. Conclusion
This paper analyzes the strength of a 4500kW large motor, analyzes the strength of rotor core and the torsional strength of rotor blade by traditional mechanical calculation method, and obtains the safety factor of rotor core strength, which provides a powerful basis for determining the size of rotor and material selection. The finite element method is used to establish the symmetrical model of rotor blade, and the calculation of high-speed centrifugal force of rotor blade is analyzed. The results show that there is stress concentration at the axial vent of rotor core. Axial ventilation duct is an effective cooling method for large motors, which cannot be omitted in the design. The strength calculation results can effectively help determine the size and position of axial ventilation vents, and provide help for further optimization of large motor design.

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