Static Characteristics Analysis and Research on the Energy-Storage Flywheel Rotor Based on Finite Element

Xiu-hua ZHANG 1,2,*, Kang-jie SONG 2, Jiang PU 1, Ya-feng SU 2 and Zhi-guo FENG 2

1School of Mechatronics Engineering of GuiZhou MinZU University, Guiyang 550025, China
2School of Mechanical Engineering of Guizhou University, Guiyang 550025, China
E-mail: 756845681@qq.com

Abstract: The energy-storage flywheel system has been becoming a kind of energy storage device with broad application prospect. It has the advantages of high energy storage density, high power, high efficiency, short charging time, long life, etc. In order to prevent energy storage flywheel system components deformation or failure under high speed, the static characteristic analyses on the flywheel rotor were done respectively under two types of the permanent magnet don’t act on the rotor internal wall and the permanent magnet acts on the rotor internal wall, the deformation, equivalent stress, tangential stress, radial stress of the rotor were researched. The work can provides certain reference for the structure design, optimization design of the flywheel system.

1 Introduction

The energy-storage flywheel system is a device to realize energy conversion and storage by physical methods[1]. The kinetic energy of the flywheel is increased and stored when the flywheel speed is increased; the kinetic energy of the flywheel is decreased and released when the flywheel speed is decreased, so the flywheel can be used to reduce the speed fluctuation of the mechanical operation process. The mechanical vibration of flywheel will be intensified when acted by the unbalanced forces, external dynamic load etc. This makes some parts easy to wear, fatigue and shortened life spans, even will cause the excessive deformation of flywheel components, and then whole system cleft, causing serious accidents[2-6]. Therefore, it is necessary to analyze deeply the energy-storage flywheel system, studying its stress and deformation under working conditions, so as to take protective measures.

In this paper, the static characteristics of the rotor of energy-storage flywheel system being designed were analyzed by finite element method, and the distribution of equivalent stress,
circumferential stress and radial stress of the flywheel rotor were studied, which can provide certain reference for the structure design, optimization design of the flywheel system.

2 Finite element model of outer rotor of flywheel

When stress analysis is carried out on the flywheel rotor model, the axial symmetry of the structure is taken into account and a quarter of the circumference is taken for analysis. The finite element model is shown in figure 1, and the main properties of the outer rotor material \(^7\) are shown in table 1.

| Material  | Elasticity Modulus | Density   | Poisson's ratio | Yield strength |
|-----------|-------------------|-----------|-----------------|----------------|
| 30CrMnSi  | E=200GPa          | 7750kg/m\(^3\) | 0.3             | 885MPa         |

![Figure 1. A quarter of flywheel rotor model](image1)

![Figure 2. Assembly diagram of rotor and permanent magnet](image2)

3 Calculation and Addition of Load

(1) Centrifugal load

The outer rotor is a rotating body, which bears centrifugal load when it rotates, and the rotating speed is set at 6000RPM for stress analysis.

(2) Inner wall pressure of outer rotor

The permanent magnets (each piece length \(L_1 = 80\) mm) are installed on the outer rotor inner wall (length in axial \(L = 400\) mm), shown in figure 2, the permanent magnet outer radius \(r_1\) is 266 mm, inner radius \(r_2\) is 214 mm, every piece of permanent magnet is 25° circumference of Angle. The centrifugal force generated by the permanent magnet acts on the inner wall of the outer rotor with a form of external load.

The working area of each permanent magnet is:

\[
S = 2\pi \times r_1 \times L \times \frac{25}{360} \approx 7.6 \times 10^{-3} \text{m}^2
\]  

(1)

The volume of each permanent magnet is:

\[
V = \pi (r_1^2 - r_2^2) \times L_1 \times \frac{25}{360} \approx 9.2 \times 10^{-5} \text{m}^3
\]  

(2)

The mass of each permanent magnet is (Permanent magnet density is 7800 kg/m\(^3\)):

\[
M = \rho V \approx 0.72\text{kg}
\]  

(3)

When the rotating speed is 6000RPM, the centrifugal force generated by each permanent magnet is \(F = M\omega^2 R\), in which:
\[ \omega = \frac{2 \times \pi \times 6000}{60} = 628 \text{ rad/s} \quad (4) \]

\[ \bar{R} = \frac{r_1 + r_2}{2} = 220 \text{ mm} \quad (5) \]

Then the centrifugal force generated by each permanent magnet is: \[ F = 6.2 \times 10^4 \text{ N} \]

And then the pressure acting on the inner wall of the outer rotor is:

\[ P = \frac{F}{S} \approx 8.2 \text{ MPa} \quad (6) \]

4 Static simulation analysis results

4.1 The permanent magnet don’t act on the rotor internal wall

The boundary conditions is shown in figure 3. The fixed constraints on both ends are added, and the rotation speed are at 6000rpm.

![Figure 3. Boundary conditions](image)

The static analysis results are shown in figure 4:

(a) Overall deformation of rotor

(b) Equivalent stress distribution of rotor

(c) Circular stress distribution of rotor

(d) Radial stress distribution of rotor
Figure 4. The static analysis results in which permanent magnets do not act on the inner wall.

It can be seen from figure 4 that the maximum deformation of the rotor is about 0.395mm at the upper end. The equivalent stress is distributed in 10.58~609.58 Mpa, and the annular stress is distributed in -80.12~644.72 Mpa. The distribution of the two is not much different, here is the stress concentration. Radial stress is distributed in -138~134.95MPa, part is compressive stress, part is tensile stress.

4.2 the permanent magnet act on the rotor internal wall

The boundary conditions is shown in figure 5. In other words, 8Mpa pressure was added to the inner wall of the rotor on the basis of figure 3.

Figure 5. The internal pressure produced by the permanent magnet.

The static analysis results are shown in figure 6:

(a) Overall deformation of rotor       (b) Equivalent stress distribution of rotor

(c) Circular stress distribution of rotor     (d) Radial stress distribution of rotor

Figure 6. The static analysis results in which permanent magnets act on the inner wall.
It can be seen from figure 6 that the maximum deformation of the rotor is about 0.399 mm at the upper end. The equivalent stress is distributed in 10.569 – 605.09 MPa, and the annular stress is distributed in -81.82 – 639.7 MPa. The distribution of the two is not much different, here is the stress concentration. Radial stress is distributed in -201.64 – 144.48 MPa, part is compressive stress, part is tensile stress.

5 conclusion

When the flywheel is rotating at high speed, the centrifugal stress acted on the flywheel cannot be neglected. In this paper, finite element stress analysis of flywheel rotor at 6000 rpm is performed. By comparison, the maximum displacement deformation is concentrated at the upper end of the flywheel, and the maximum deformation is 0.399 mm. The maximum equivalent stress is 609.58 MPa, the maximum annular stress is 644.72 MPa and the maximum radial stress is 144.48 MPa. When design the flywheel rotor, the strength of the stress concentration of the rotor should be considered and proper rotor material should be selected. The research results have certain guiding significance for structure design, optimization design of the flywheel system.

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Acknowledgments

1. Guizhou Science and Technology Support Program([2016]2002);
2. Guizhou University introduced talent project ([2015]-51).