Analysis of Mechanical Characteristics of Impeller of Spray Duster Based on ANSYS Workbench

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Abstract. The spray dustless machine is an important environmental protection equipment for harnessing haze. The booster impeller of the spray dustless machine is one of the decisive factors of the booster capacity. The stability of the blade directly determines the reliability of the spray duster. In this paper, ANSYS Workbench is used to analyze the mechanical characteristics of a certain type of spray dustless blade. The results show that: under the rated condition, the maximum equivalent stress of the impeller is 55.6 Mpa, which is far less than the allowable stress of the impeller material 415 Mpa, the maximum deformation of the circumferential position at the bottom of the blade is 1.2mm, and other deformation positions are mainly the outer edge of the blade, which can be optimized later. The interference frequency is far away from the vibration frequency of the first two modes, so resonance will not occur.

Keywords: Spray, Dustfall, Statics Analysis, Modal Analysis.

1. Introduction
With the rapid development of human social and economic level and the rapid improvement of industrialization, air pollution is becoming more and more serious [1, 2]. Now the world pays special attention to haze and expects the government to control air pollution [3, 4]. The most effective dust suppression measure in the short term is spray dustfall, and the spray dustless machine is the most commonly used operation equipment at present [5, 6]. According to the different requirements of operation, the spray range of spray dustless machine is generally within the range of 20-100m [7]. With the increase of spray range, the quality and supercharging ability of spray are also enhanced.

In order to provide enough pressure, the impeller speed is generally 3000r/min. For the supercharged impeller with a diameter of 400mm, the reliability of the impeller is very important. In this paper, a spray dustless machine is used as the research object. The static and mechanical analysis of the impeller of the dustless machine is carried out, and its mechanical properties are evaluated.

2. Analysis Model
The impeller analyzed in this paper is mainly composed of 9 blades and 1 driving shaft, as shown in Figure 1. In this paper, the parametric model of impeller is made by using Creo, and the chamfering and
other mechanical features that have little influence on the analysis results are simplified. The material parameters of impeller are shown in Table 1.

![Impeller model](image)

**Figure 1. Impeller model**

| Modulus of Elasticity/GPa | Poisson’s Ratio | Yield Strength/Mpa | Tensile Strength/Mpa | Density/(kg·m⁻³) |
|-------------------------|----------------|--------------------|----------------------|-----------------|
| 196                     | 0.3            | 415                | 470                  | 7.85x10³        |

3. Static Analysis

3.1. Pretreatment of Static Analysis
ANSYS Workbench not only provides common engineering materials, users can also customize the analysis materials according to their own needs [8]. After importing the model shown in Figure 1 into the analysis software, the analysis materials shown in the table can be established. In ANSYS Workbench, mesh generation methods mainly include automatic mesh generation, tetrahedral mesh generation, hexahedral dominant mesh generation and sweeping method [9]. In this study, the method of automatic mesh generation is adopted, and some parameter control is added to mesh the impeller.

3.2. Application of Working Loads and Constraints
The impeller is mainly affected by centrifugal force and pneumatic force, but the influence of aerodynamic force on the impeller is much smaller than that of centrifugal force, so this study only considers the effect of centrifugal force on the impeller.

In this study, because the interaction between the impeller shaft hole and the shaft is not considered, the working angular velocity load can be directly applied on the model to provide the steady-state inertial force.

The transmission shaft connected with the impeller is also the supporting shaft of the impeller. Under its constraint, the impeller has only the degree of freedom to rotate around the y-axis. In workbench, a cylindrical surface constraint and Y-direction displacement constraint can be used to simulate the working constraint of the impeller. An angular velocity of 297.2 rad/s rotating around the Y-axis of the impeller center is applied to the impeller drive shaft.

3.3. Static Analysis Results
After the calculation, the equivalent stress nephogram, equivalent strain nephogram and total deformation nephogram of the impeller are obtained by post-processing module.

Figure 2 is the equivalent stress nephogram of the impeller. It can be seen from the nephogram that the stress of the impeller mainly appears in the middle of the blade X direction, and the maximum
equivalent stress appears at the top of the blade, with the maximum value of 55.6Mpa, which is far less than the allowable stress 415Mpa of the impeller material. Under the rated working conditions, the blade can maintain stable operation.

Figure 2. Equivalent stress cloud picture

Figure 3 is the equivalent strain nephogram of the impeller. It can be seen from the nephogram that the main strain of the impeller occurs in the middle of the impeller, and the maximum strain appears at the top of the impeller.

Figure 3. Equivalent strain nephogram

Figure 4 is the total deformation nephogram of the impeller. It can be seen from the nephogram that the maximum deformation at the circumferential position of the blade bottom is 1.2mm, and other deformation positions are mainly at the outer edge of the blade. Combined with the equivalent stress nephogram, the equivalent stress of the impeller is smaller, but the total deformation increases, which is caused by the larger blade area. The reasonable optimization can be carried out to reduce the total deformation.

Figure 4. Total deformation nephogram
4. Modal Analysis

4.1. Modal Analysis Preprocessing
Modal analysis is a common method to study the dynamic characteristics, vibration analysis and dynamic optimization design of mechanical structures. Mode is the inherent characteristic of mechanical structure, each structure has multiple modes, and each mode has corresponding vibration frequency and mode [10].

Compared with the modal analysis without prestress, the prestressed modal analysis considers the static analysis results and the prestress of elements and nodes, which is closer to the actual working state of the impeller, makes the modal analysis results more accurate and reflects the modal vibration mode more real.

In this study, the loads and constraints used in static analysis and the results of static analysis are used as the analysis conditions of prestressed modal analysis.

4.2. Modal Analysis Preprocessing
With the increase of the order, the error of modal analysis results will become larger. According to the actual working conditions, the block Lanczos method is used to extract only the first four modes of the impeller, and the vibration frequency range of the first four modes is 26.7-425/Hz. The analysis results are shown in Table 2.

| Order | Frequency /Hz |
|-------|---------------|
| 1     | 26.7          |
| 2     | 88.9          |
| 3     | 224           |
| 4     | 425           |

Table 2. First four modal vibration frequencies of impeller

Figure 5 is the first-order modal nephogram of the impeller. It can be seen from the nephogram that there is a large deformation at the edge of each blade, the maximum value is 19mm, and the driving shaft also has a certain deformation.

Figure 6 is the second-order modal nephogram of the impeller. From the nephogram, it can be seen that some blades have increased deformation, and the deformation position is symmetrical, and the maximum value is 36.3mm.
Figure 6. Second order modal shape cloud diagram

Figure 7 is the third-order modal nephogram of the impeller. It can be seen from the nephogram that there is a large deformation at the edge of each blade, the maximum value is 29.5mm, and the driving shaft also has a certain deformation.

Figure 7. Third mode shape nephogram

Figure 8 the fourth-order modal shape nephogram of the impeller. It can be seen from the graph that part of the blades have increased deformation, and the deformation position is symmetrical, and the maximum value is 67.8mm.

Figure 8. Fourth mode shape nephogram

When the impeller is working, the vibration is related to the impeller speed, that is, \( n = 60F \), where \( n \) is the speed, r/min; \( F \) is the interference frequency, Hz. The rated speed of the impeller is 2840r/min, and the interference frequency is 47.3 Hz. The interference frequency is far away from the vibration frequency of the first two modes, so the resonance phenomenon will not occur.
5. Conclusion
Impeller is an important part of spray duster. In this paper, ANSYS Workbench is used to analyze the mechanical characteristics of the impeller of a spray dustless machine, and the following conclusions are obtained.

(1) Under rated conditions, the maximum equivalent stress of impeller is 55.6 MPa, which is much lower than the permissible stress of impeller material 415 MPa. Under rated conditions, the blades can maintain stable operation.

(2) Under rated conditions, the maximum deformation of the circumferential position at the bottom of the blade is 1.2mm. The other deformation positions are mainly the outer edge of the blade, which can be optimized to some extent in the future.

(3) The rated speed of impeller is 2840r/min. The interference frequency is far away from the vibration frequency of the first two modes and no resonance will occur.

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