An Experiment Method of Choosing Structure of shrouded power turbine blade

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Abstract: The turbine blade presents various failure modes in service. The stress concentration located near the shroud can result in fracture failure, thus the structural optimization of the shroud is the main focus for mechanical engineers. Stress concentration is difficult to accurately evaluate by calculation and needs to be verified by experiment. Three-dimensional photoelastic test is an important method of program preference. This paper conducts three-dimensional photoelastic tests on shrouded turbine blades with different structures to select structures with minimum concentrated stress. It is shown in the experiment results that the stress fringe pattern clearly shows the stress distribution trend and stress concentration area of the blades, which shows the quality of design intuitively. It shows that photoelastic test can provide a reliable test basis for the design and model selection of small aeroengine shrouded turbine blades. The advantage of this method is that it is a fast, economical and intuitive method of program preference. The method has been successfully applied in a self-developed small aeroengine shrouded turbine blades.

1. Introduction
The turbine is the core component of the aeroengine. The mechanical failure is prone to occur on the turbine blade due to large load and high speed. Thus, the strength assessment of the turbine blade is an essential part of the turbine development process. In modern advanced aeroengines, turbine blades are generally shrouded, which can reduce air leakage at the tip of the blade and improve the efficiency. The friction generated between the adjacent integral shroud can absorb the vibration energy and has an effect of vibration reduction[1-4]. In the open literature of the last decade, the research on the structural strength of shrouded turbine blade is mainly using finite element method, and there is very little experimental verification, which undoubtedly has a great security risk. As the speed of small aeroengines increases, the blades are subjected to larger centrifugal load, and stress concentrations are more likely to occur at weaker points of tip, which can lead to fracture separation between the integral shroud and blade body. Therefore, in the design and development process of the shrouded turbine blade, how to accurately obtain the stress distribution characteristics in the large centrifugal load environment is an important issue that designers are extremely concerned about. Three-dimensional photoelastic test is an effective method to solve this complex problem[5-6]. In the present research, three-dimensional photoelastic test is applied to analyze the stress distribution of shrouded turbine blades, and basic experimental data is provided for for optimizing the structure of the blades.

2. Three-dimensional photoelastic test of the shrouded turbine blades
For the photoelastic test, the photoelastic model of the shrouded turbine blade similar to the real object based on the similarity principle is prepared firstly, and then the stress fringe pattern is obtained by...
stress-freezing loading, and finally the stress and distribution trend of the blade are recorded under the polarizer. The test was carried out in accordance with the three-dimensional photoelastic test method and was divided into three steps, including model making, model stress-freezing loading and stress stripes reading.

2.1. Production of photoelastic models

Two well-designed blade shapes are selected for the research, and a better blade shape will be selected based on the experimental data of the photoelastic test. Since both blade shapes are relatively small, the models are magnified five times according to the similarity principle in order to facilitate model machining and test results observation. The material of the models is cured epoxy resin. The process for the fabrication of the models is as following: firstly, the liquid resin is prepared by adding 35 wt% of maleic anhydride to epoxy resin (BYD-128); secondly, the liquid resin is poured into a mold by a vacuum casting machine; thirdly, the models are obtained after curing at 60°C for 240 h; finally, the photoelastic models of the shrouded turbine blades are fabricated by numerical control milling technology. The physical map of the two models is shown in Fig.1, the model number processed according to design scheme 1 is 1#, and the model number processed by scheme 2 is 2#.

![Fig.1 Physical map of two shrouded turbine blade models](image1)

2.2. Stress-freezing of photoelastic model

The lifting module of model loading device and the calibration module of the disc are selected in the loading of the shrouded turbine blade. The temperature control module of the model hybrid loading device is chosen in the stress-freezing. The blade adopts a serrated shroud, and the shroud fixture according to the shape of the shroud is shown in Fig.2. The assembled model loading device is shown in Fig.3. The test load is 88.2 N.

![Fig.2 (a) and (b) are physical maps of the shroud fixture1# and 2#](image2)
Fig. 3 Power shrouded turbine blade loading device

The temperature control module of the model hybrid loading device and the model stress-freezing are started. The model load is 88.2 N. The stress-freezing temperature control curve of the blade is shown in Fig. 4. Firstly, the temperature is raised to 80 °C at a rate of 20 °C/h, and then raised to 120 °C at a rate of 2 °C/h, and kept at constant temperature for 24 h. Afterwards, the temperature is raised to 156 °C at a rate of 2 °C/h, and kept at constant temperature for 24 h. Finally, the temperature is lowered to 80 °C at a speed of 1 °C/h, and then the module is automatically shut off and the temperature is naturally cooled to room temperature. At this time, the deformation and stress information are memorized in the model.

Fig. 4 The stress-freezing temperature control curve

2.3. Reading and analysis of stress stripes in photoelastic model

Fig. 5 (a) and (b) are the stress stripes pattern of the shrouded blades 1# and 2#

The photoelastic device is used to read the stress stripe series of the model after the stress-freezing. Fig. 5 is the stress stripes pattern of the two blades obtained by the photoelastic device. It can be seen from the
figure that the stress stripes grain of the blades are clear and there is no obvious “cloud” phenomenon. The stress distribution tends to decrease from the blade edge to the blade center.

The stress stripe series of the blade 1# is significantly higher than that of the blade 2#, which is intuitively reflected that the stress value of the blade 2# is much lower than that of the blade 1#. The stress amplitudes of the blades 1# and 2# obtained by the stress stripe treatment method[12] are 2.315 Mpa and 0.825 Mpa, respectively. The stress concentration is near the junction of the blade shroud and the tip which is indicated in the figure. From the test results, the design of the shrouded blade 2# is obviously better than 1#.

3. Comparison of photoelastic test results and strain test results

In order to verify the accuracy of the photoelastic test, four strain gauges are attached to the representative area to compare the two test results. The position of the strain gauges is shown in Fig.6, and the strain test site is shown in Fig.7.

![Fig.6 Schematic diagram of Strain gauge](image1)

![Fig.7 Strain test site map](image2)

![Fig.8 (a) and (b) are the comparison of photoelastic test results and strain test results for blades 1# and 2#](image3)

The comparison of photoelastic test results and strain test results of two kinds of blades is shown in Fig.8. It can be seen from the figure that the magnitude and trend of two test results are preferably consistent. The stress values of points S1 and S3 at the edges of the two blades are significantly higher than the stress values at the center points S2 and S4. In general, the stress values of the blade 2# is about 40% of the blade 1#. The results show that the design of the shrouded blade 2# is more satisfactory than the shrouded blade 1# in terms of stress caused by the same load.

| Table 1 Comparison of two test results of shrouded blade 1# |
|---------------------------------|
| Measuring point | S1 | S2 | S3 | S4 |
| Results of photoelastic test (MPa) | 2.315 | 0.118 | 1.537 | 0.358 |
| Results of strain test (MPa) | 2.002 | 0.120 | 1.428 | 0.336 |
| Error (%) | 13.52 | 1.69 | 7.09 | 6.15 |
Table 2 Comparison of two test results of shrouded blade 2#

| Measuring point | S1  | S2  | S3  | S4  |
|-----------------|-----|-----|-----|-----|
| Results of photoelastic test/MPa | 0.825 | 0.170 | 0.713 | 0.170 |
| Results of strain test/MPa | 0.765 | 0.150 | 0.623 | 0.160 |
| Error % | 7.27 | 11.76 | 12.62 | 5.88 |

The comparison of the specific data of the two test results is given in Tables 1 and 2. It can be seen from the tables that the maximum errors of the shrouded blades 1# and 2# photoelastic tests are respectively 13.52% and 12.62% compared with the strain test results. The error comes from many aspects, including dimensional error caused by processing, subjective interpretation of interference stripe error and stripe value calibration error caused by material performance dispersion. These results show that the photoelastic test meets the accuracy requirements.

4. Conclusion

In this paper, two kinds of power shrouded turbine blades are made by self-developed new aeroengine casting molding machine and general vacuum casting process. Three-dimensional photoelastic test of small aeroengine power turbine blades is conducted by using new test methods and techniques. The test results show that the stress stripes obtained by stress-freezing of the blades are clear and there is no “cloud” phenomenon. The test results intuitively reflect the stress difference values and the stress concentration of each part of the blades. The stress distribution tends to decrease from the blade edge to the blade center. The stress amplitudes of the two types of blades obtained by the photoelastic test are 2.315 Mpa and 0.825 Mpa, respectively. Finally, the paper uses the strain test results to verify the effectiveness of the photoelastic test, and the maximum test error is 13.52 %. The experimental results of this paper provide a reliable basis for blade selection and improvement and have a good reference value for the design of shrouded turbine blades.

References

[1] Tang Feng, Meng guang. Contact Analysis of Shrouded Turbine Blade[J]. Noise and Vibration Control.2005,8(4),5-7.
[2] Tang Feng, Hu Boan. Vibration Characteristic Analysis of Shrouded Turbine Blades [J]. Journal of Mechanical Strength. 2007,29(5),831-834.
[3] Ren Xingming, Lu Na, Yue Cong. Dynamic Characteristics of Flexible Shrouded Blades inAero-engines[J].Journal of Northwestern Polytechnical University,2013,31(6),926-930.
[4] Nan Guofang, Ren Xingming, He Shangwen. Damped vibration characteristics of blades with tips of an aero-engine [J]. Journal of Vibration and Shock, 2009, 28(7), 135-138.
[5] Guo Tiancai, Deng Wangqun, Xia Qing. An Experiment Method of Measuring Stress Distribution of Turbine Blade Tenon[J]. Mechanical Science and Technology for Aerospace Engineering, 2014,33 (8) ,1277-1280.
[6] Guo Tiancai, Deng Wangqun, Mei Qing. Experiment Study on Influence of slight Change in Arc Radius on the Tenon Stress for Turbine Blade [J]. Mechanical Science and Technology for Aerospace Engineering,2016,35(9),1466-1469.
[7] Guo Tiancai, Xu Youliang, Wen Hua. A three-dimensional photoelastic testing method[P]. China, 201510611513.0, 2015-9-23.
[8] Guo Tiancai, Mei Qing, Xu Youliang. Development of the vacuum casting machine for new aeroengine [J]. Chinese Journal of Vacuum Science and technology. 2017,37(5):471-474
[9] Guo Tiancai, Mei Qing, Xu Youliang. Novel Fabrication Technique of Photoelastic Modelby vacuum casting [J]. Chinese Journal of Vacuum Science and technology. 2016,36(5),551-555.
[10] Wen Hua, Guo Tiancai, Xu Hua. Model loading device[P]. China, ZL201110365872.4, 2013-06-05.
[11] Guo Tiancai, Mei Qing, Su Nanyang. Model hybrid loading device[P]. China, ZL201410191906.7, 2016-5-23.

[12] Guo Tiancai, Liao Xuejun, Liu Feichun. A processing method for the value of model stress stripe series[P]. China, ZL201410211514.1, 2016-4-20.