Research on pre-tensioning process of low-pressure turbine shaft assembly for aeroengines considering the rabbet joint structure

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Abstract: Assembly is an important part of aero-engine manufacturing process. Its workload accounts for more than half of the total aircraft generation work. Aero-engine is in extreme service environment. Therefore, higher requirements are put forward for the performance and reliability of its assembly and connection system. In this paper, the influence of the change of the interference of the rabbet joint structure on the stress of the joint surface of the rabbet joint structure, the pressure of the joint surface of the shaft and disk and the pre-tightening force of the bolt is obtained through simulation and analysis. The effect of the pre-tension assembly process on improving the initial tightening state is clarified. A number of pre-tension assembly process experiments under different process parameters are completed and compared. The optimum pretension process parameters can effectively improve the coaxiality of rotor assembly and the uniformity of bolt pretension force.

Keywords: Rabbet joint structure，Simulation, Aero engine assembly，Interference，Pre-drawing process

1 Introduction

The assembly quality of aero-engine is directly related to various service performance indicators, and which almost determines the final quality, manufacturing cost and cycle of the engine. The assembly process is difficult and involves many disciplines, which is one of the key bottlenecks of engine manufacturing in China. Assembly is an important part in the process of aero-engine manufacturing. Its workload accounts for more than half of the total aircraft generation. The control of assembly accuracy is one of the key technologies in aero-engine manufacturing. The aero-engine low-pressure rotor transmits the power of low-pressure turbine to the fan, and the fan rotates to generate thrust, which makes the aircraft generate flight power. The research object of this paper is the bolt connection between the low pressure turbine shaft and the cone wall of the disc drum: the shaft disc and the cone wall is connected

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by the 36 bolts. The connection of the shaft disc and cone wall has features of thin wall ,many connecting bolts, complexl oad (axial load, bending load, torsional load, etc.), high environment temperature and the high speed, which requires high connecting quality. The connecting quality of the shaft and the cone wall is very important to the engine. The connection quality has an important influence on the safety and reliability of the whole engine [1-3].

Bolted connection is a typical non-linear structure. Although a lot of research has been done on bolted connection at home and abroad, it mainly focuses on the sealing connection ,such as pipeline. The research on complex boundary conditions, such as low-pressure rotor connection bolts is still in its infancy. Generally, the bolted connection is neglected and the general manual is used to determine the preload. The connection quality of the rotor can not be guaranteed [4-6]. Cold/hot assembly is often used for the rabbet joint structure interference assembly of rotors, but the mechanism of assembly process is not clear, which leads to lower qualified rate of coaxiality of the rotor after assembly, it can’t guarantee assembly quality, and often leads to poor bonding state of the joint surface, uneven local stiffness of the connection and difficult to predict. In order to ensure the high safety and reliability of aeroengine, the assembly process should be improved on the basis of mechanism research, and the quality and reliability of installation should be improved.

The main connection form of aeroengine rotor/stator is bolt- the rabbet joint structure connection. The main function of the rabbet joint structure is rotor centering, while bolt connection is the key of bearing capacity. When assembling rotor/stator, the assembly quality often fails to meet the standard, and the trial-and-error rate is very high. Aero-engine is in extreme service environment, which requires higher performance and reliability of its assembly and connection system. The stiffness, pressure, uniformity and assembly accuracy of the joints between the rotors are all important factors affecting the service performance. The centring connection between the ends of the rotors is the key and difficult point in the assembly process of the rotors/stators. In actual assembly, the connection stiffness between the rotors, the pressure of the joints and the assembly accuracy of the whole machine are all important factors affecting the service performance. It is difficult to fully play its centring role, and even lead to the overall assembly coaxiality accuracy decline. In this paper, the influence of the change of the interference of the rabbet joint structure on the stress of the joint surface of the rabbet joint structure, the pressure of the joint surface of the shaft and disk and the pre-tightening force of the bolt is obtained through simulation and analysis. The effect of the pre-tension assembly process on improving the initial tightening state is clarified. A number of pre-tension assembly process experiments with different process parameters are completed and compared. For the low-pressure turbine shaft connection of aero-engine, combined with the pre-tensioning assembly process used in the hot-packing process, after the low-pressure turbine shaft-disc heating assembly, pre-tensioning is carried out with appropriate process parameters ,which can improve the initial state of the bolt connection, and effectively improve rotor assembly coaxiality and bolt preload uniformity.

 ISSN 2572-4975 (Print), 2572-4991 (Online)

1.1 Analysis purpose

The main connection forms of low-pressure turbine shaft disk are interference fit of rabbet joint structure and bolt connection. In this connection mode, the rabbet joint structure mainly plays the role of centering, and the bolt connection plays the role of transmitting torque.

The existence of the rabbet joint structure constraints makes the bolt group connection of low-pressure turbine shaft disk different. On the one hand, the restriction of the rabbet joint structure will produce stress on the joint surface, which will lead to the geometric deformation of the disk surface; on the other hand, in the assembly process, the existence of size deviation, shape and position error and installation error will lead to inaccurate positioning between the low-pressure turbine shaft and the cone wall, and uneven stress on the interference surface, which will cause the gap between the joint surface and the deformation of the disk surface. Incorrect positioning and disk deformation will lead to uneven distribution of pre-tightening force and unbalanced mass of rotor disk when bolts are fastened, which will cause vibration in work. The interference of the rabbet joint structure is the key parameter . Therefore, it is necessary to study the influence of the change of the rabbet joint structure interference on the tightening contact state.

1.2 Rabbet joint structure

The rabbet joint structure is a structure used for positioning when the low-pressure turbine shaft and the cone wall are assembled. The low-pressure turbine shaft is first assembled into the rabbet joint structure, and the axis of the shaft and the cone is caused by a certain interference between the hole axes of the stop. Position in the circumferential direction to facilitate the next step of bolt tightening. The mating size of the rabbet joint structure is 238.7 H7/p7, wherein the shaft plate is a concave end and the cone wall is a convex end.

1.3 Finite element analysis of the rabbet joint structure

(1) Establish a low-pressure turbine shaft-cone wall finite element analysis model.

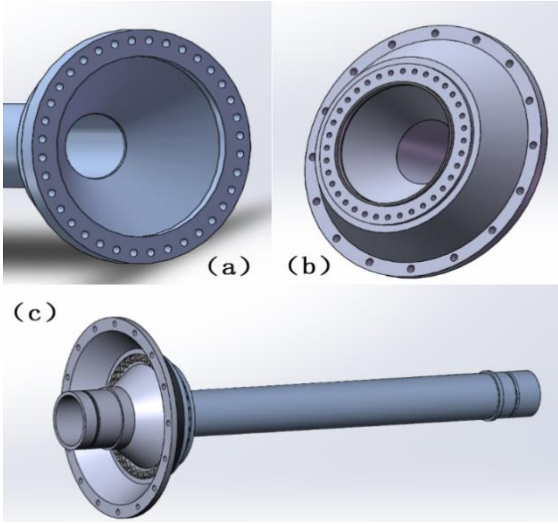

Fig.1. Three-dimensional model

(a) low-pressure turbine shaft; (b) cone wall; (c) the whole structure after assembly

(2) The interference amount of the rabbet joint structure is shown in Tab.1.Other boundary conditions and bolt pre-tightening force were applied. Finally, data processing and analysis were carried out to extract the results of the joint surface stress, combined surface pressure of shaft and disc, bolt pre-tightening force, etc., so as to analyze the influence of interference amount of the rabbet joint structure on the above parameters[7-10].

Table 1. The interference of the rabbet joint structure

groups	1	2	3	4	5	6	7
Interference (mm)	0.00	0.004	0.02	0.04	0.06	0.08	0.096

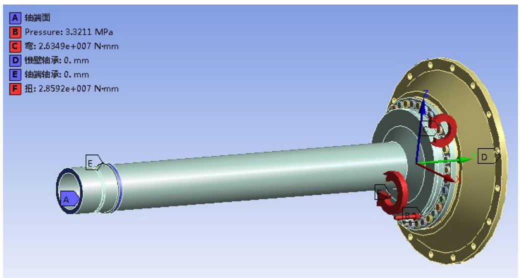

Fig. 2. Finite element analysis model

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(3) Results

The effect of the change in rabbet joint structure interference on the axial load.

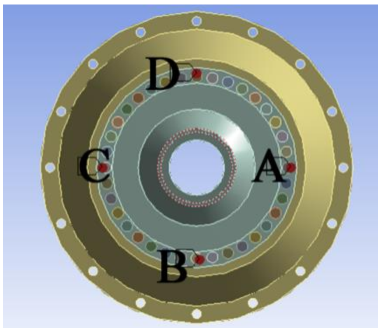

Fig. 3. The position of chosed bolts for analysis

In the state where the working load is loaded, take 4 bolts at A, B, C, and D as shown in Fig.3, where the connection of the A and C bolts is the x-axis (the bending moment is around the x-axis), and the bolts connection between B and D is perpendicular to A and C.

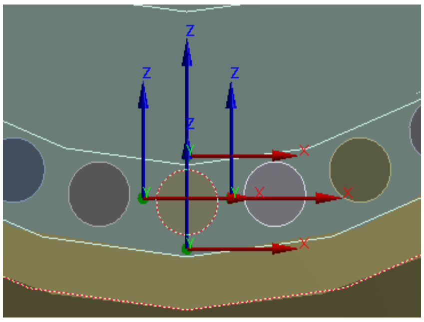

Fig. 4. Force of a bolt joint node

For any bolt, take the intersection of the center line and the vertical bisector of the adjacent bolt as the sample point, take 4 points in the circumferential direction, take the average normal stress and the shear stress value, and draw a curve.

Table 2. Bond surface stress value

Interference (mm)	Average shear stress (MPa)	Average normal stress (MPa)
0.004	11.92593	5.797342
0.01	11.92273	5.851008
0.02	11.88497	6.014063
0.03	11.78777	6.032823
0.04	11.66596	6.05108
0.048	11.43381	6.094819

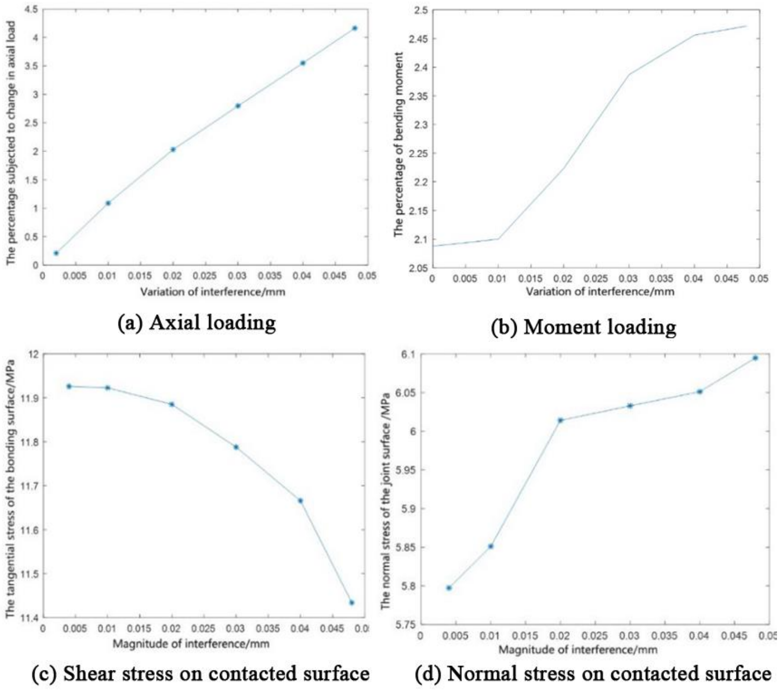

Fig. 5. Results of finite element analysis

With the increase of the interference, the normal stress increases and the shear stress decreases. Under the state of working, the pre-tightening forces of the 4 bolts at A, B,

 ISSN 2572-4975 (Print), 2572-4991 (Online)

C and D as shown in Fig. 3 are extracted, and using the average pre-tightening force value of the 4 bolts to draw the curve [11-12].

Table 3. Average pre-tightening force of bolts

Interference (mm)	Average preload (N)
0.004	45406.55
0.01	45403.84
0.02	45399.93
0.03	45396.23
0.04	45392.78
0.048	45388.09

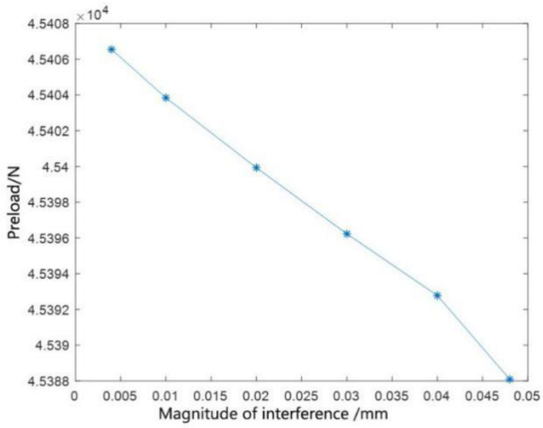

Fig. 6. Influence of interference on bolt preload

Analysis of the above figure shows that under the action of the working load, as the interference increases, the pre-tightening force of the bolt gradually decreases.

2 Pre-drawing process experiment

2.1 Experimental object and experimental equipment

The experimental environment was a special positioning clamping system for low-pressure turbine shaft disc, and a special specimen for low-pressure turbine shaft disc experiment was used. In the experiment, ultrasonic patch bolts, ultrasonic measurement system, copper heater and digital torque wrench were used.

Fig. 7. Ultrasonic measuring system

Fig. 8. Experimental specimen and ultrasonic bolt

2.2 Experimental program

（1）No pre-tension assembly experiment

The hot-packing process is used to heat the temperature of the low-pressure turbine shaft recess to about 100 ° C, push it into the mouth and measure it with a 0.03 mm feeler gauge. If it cannot be inserted in a circle, it means that the joint is assembled successfully. Wait for the door to cool to room temperature (about 15 minutes) and start tightening the bolts.

Tighten the way: D-type ultrasonic bolts are used for tightening. The tightening method is a single-step tightening of the torque method. Use 76Nm as the target torque to tighten with a digital torque wrench. Mark the serial number of all bolts. Test the pre-tightening force for each bolt, as the initial pre-tightening. Force, after all 36 bolts are screwed out, wait 10 minutes until the bolt pre-tightening force is stable, measure the corresponding pre-tightening force of each bolt, and record the final pre-tightening force after 10mins.

（2） Verify pre-tension assembly experiment

The hot-packing process is used to heat the temperature of the low-pressure turbine shaft recess to about 100 ° C, push it into the mouth and measure it with a 0.03 mm

 ISSN 2572-4975 (Print), 2572-4991 (Online)

feeler gauge. If it cannot be inserted in a circle, it means that the joint is assembled successfully.

Number the bolts and the shafts. Starting from 12 o'clock, use a torque wrench to tighten the 18 process bolts in the singular position to 10Nm according to the cross method to complete the pre-tensioning. Use a torque wrench to tighten the bolts in the double-position bolts according to the cross method. The method is tightened to 76Nm, measuring the pre-tightening force of the corresponding bolt, and record it as the initial pre-tightening force; unscrew the process bolt in the singular position, and use a torque wrench to screw the working bolt to 76Nm according to the cross method, and measure the pre-bolt of the corresponding bolt. Tight force, and recorded as the initial preload; check all bolts in time to verify that it reaches 76Nm; wait 10min until the bolt preload is stable, measure the corresponding preload of each bolt, and record it as 10min tight force.

（3） Pretensioned assembly experiments under different process parameters

The experimental scheme is the same as the above experiment, the number of bolts in the pre-drawing process and the corresponding torque should be changed to verify the influence of the pre-drawing process on the evenness of the pre-tightening force of the final bolts with different process parameters.

2.3 Data processing analysis

（1）Experimental data analysis of predrawing contrast of bolts with or without process

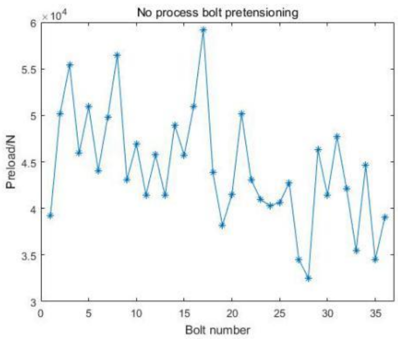

Fig.9. No bolt with pretensioning

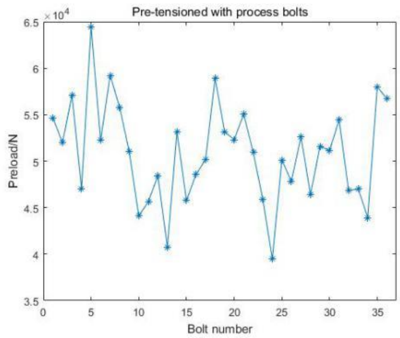

Fig.10. Bolts with pre-tensioning

The average preload of 36 bolts is used as the pre-tightening target value. The final average preload force change is 2329.78N when no pre-tensioning of the process bolt is taken. The average preload force change value after the pre-tensioning assembly process is 1312.69N. Without pre-tensioning, the pre-tensioning force change value of the pre-tensioning is reduced by 56.34%. Therefore, the pre-tensioning of the shaft by the process nut can effectively reduce the influence of the rabbet joint structure on the dispersibility of the pre-tightening force.

（2）Experimental data analysis under different predrawing process parameters

Compare and analyze the uniformity of pre-tightening force of bolts without pre-tensioning process and under different pre-tensioning process parameters:

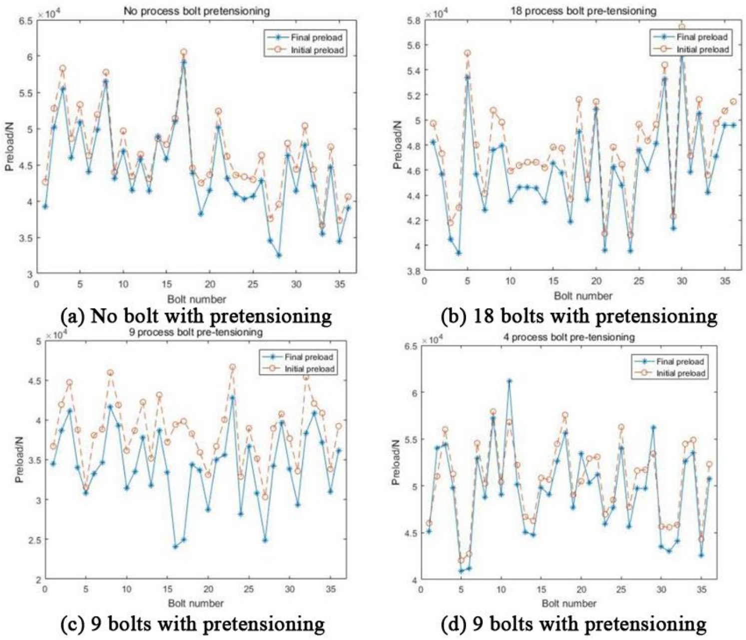

Fig.10. Preload's dispersibility of different number of bolts with pretensioning

Based on the above experimental results, the pretension of process bolts can effectively reduce the dispersion of pretension force of bolt connection, and the more the number of pretension bolts, the smaller the dispersion of pretension force.

Table 4. Pretension test results

Number of pre-tensioned bolts	Pre-pulling torque（Nm）	Final preload force variance
0	--	5.4872E+07
18	10	1.5211E+07
9	18	2.2411 E+07
4	30	2.3741E+07

ISSN 2572-4975 (Print), 2572-4991 (Online)

3 Conclusions

The interference amount of the rabbet joint structure has a certain effect on the pre-tightening force of the bolt, and with the increase of the interference amount, the pre-tightening force of the bolt gradually decreases.

Pretensioning process is adopted to assemble low-pressure turbine shaft disc of aero-engine, which can effectively reduce the influence of the rabbet joint structure on the dispersion of bolt pretightening force.

In the pre-drawing process, the more the number of bolts, the smaller the dispersion of the final pre-tightening force.

Acknowledgement

This work is supported by the Major special basic research projects (No. 2017-VII-0010-0105), Shanghai Sailing Program(No.19YF1452400) and the Fundamental Research Funds for the Central Universities of China (No.DUT18LAB04).

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 ISSN 2572-4975 (Print), 2572-4991 (Online)