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Dynamical Analysis and Design of Bearingless Rotor Flexbeam

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Abstract:In helicopter bearingless rotor design, the flexbeam is the key component of rotor system, which plays an importantrole in the blade flapping, lead-lag movement, torsion, and load transfer. Flexbeam must have the minimum torsion stiffness with enough tension strength. In this paper, we first investigated the torsion stiffness of different cross section configurations of the flexbeam through some simple experiments. Then we analyzed a rotor's dynamical characteristics with finite element method and got the rotor's fan plot. After that, we studied the relationship between the frequency changes with the spanwise distribution of mass and stiffness in bearingless rotor. Finally, we analyzed the influence of the flexbeam on dynamical characteristics of the bearingless rotor system, and completed the design of this type of rotor flexbeam.

Key Words : Bearingless Rotor, Flexbeam, Dynamics Analysis, Fan Plot, Rotating Beam

1.Introduction

The typical bearingless rotor structure is a combined structure, which include a composite flexbeam and a torsion tube. The flexbeam generally uses a low torsional stiffness glass fiber, and the torsion tube is built up with ±45 carbon/fibre composites to carry the torsion. This produces beneficial stiffness changes of decrease in torsional stiffness and increase in bending stiffness while keeping the axial stiffness unchanged. The typical examples of this type of rotor are Eurocopter's EC-145 and Sikorsky's RAH-66.

In the course of the development of helicopter rotor structure, the rotor hub structure has a continuous improvement. Unlike any other helicopter rotor system, the analysis of a bearingless rotor system is more involved because of redundancy of load paths at the blade root, along with nonlinear bending-torsion coupling.

During the past twenty years, scholars and engineers have made many efforts on the analysis of the stability of bearingless rotors. Hodges developed the FLAIR code for coupled rotor-body stability of rotorcraft with bearingless blades. The flexbeam was treated as an elastic Euler-Bernoulli beam. Sivaneriand Chopra developed a bearingless

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rotor model, based on finite element method, which included the redundant load paths at the hub. The analysis used 15 DOF elements and solved the finite element equations directly to obtain the blade steady response. Hodges latterly developed the GRASP (General Rotorcraft Aeromechanical S tability Program)to include elastic blade model for general rotor designs, including bearing less rotors.

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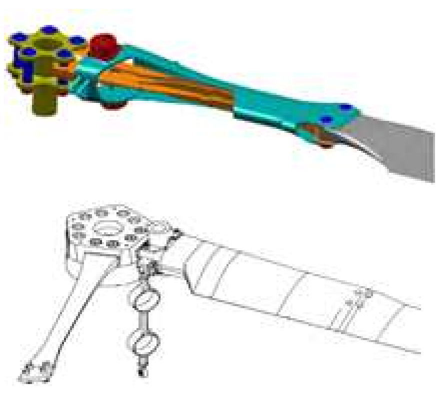


Fig. 1 Rotor Hub Structure of EC-145 and RAH-66

As shown in the Fig.1, the rotor of EC-145 has a non-uniform flexbeam. The bending rigidity of section becomes larger and larger along spanwise, which is to adapt to the requirements of the blade flap. RAH-66's rotor flexbeam has a rectangular section.

2.The Cross Section of the Flexbeam

The torsional stiffness of the flexbeamis associated with the geometric property of the cross section, so we designed an experiment (Fig.2) to study it. In this experiment, nine different cross sections are designed, whose configurations are shown in Fig.3. All of the specimens have the same cross section area of $00mm$

Fig. 2 Torsional Stiffness Test

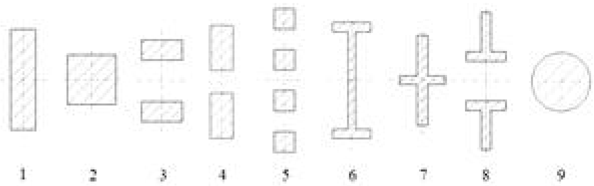


Fig. 3 Cross Sectional Configurations of Specimens

The results of this experiment were shown in Tab1. The torsional stiffness of the circular section (NO.9) was defined as

“1”, and the others weredenoted by the relative values.

Table. 1 The Results of the Torsional Rigidity

Specimens	Relative stiffness
1	0.599
2	0.920
3	0.602
4	0.585
5	0.377
6	0.363
7	0.318
8	0.260
9	1.000

From the results, we can see NO.8 specimen has the minimum torsional stiffness among the nine specimens. This kind of outline will be the best candidate of our design of the flexbeam.

3.Dynamics of Articulated Rotor

In order to determine the design of the flexbeam, the dynamical characteristics of articulated rotor were investigated. In this paper, we used Rayleigh-Ritz method with FEM to study the Euler-Bernoulli rotating beam. The flexbeam is divided into 20 elements with a total of 21 nodes. Each node has two degrees of freedom, which one represents of the vertical displacement, another represents of angular deformation.The beam’s working speed is 58.6rad/s as designed, the distribution of the mass and stiffness of the rotor system are shown in Fig.4.

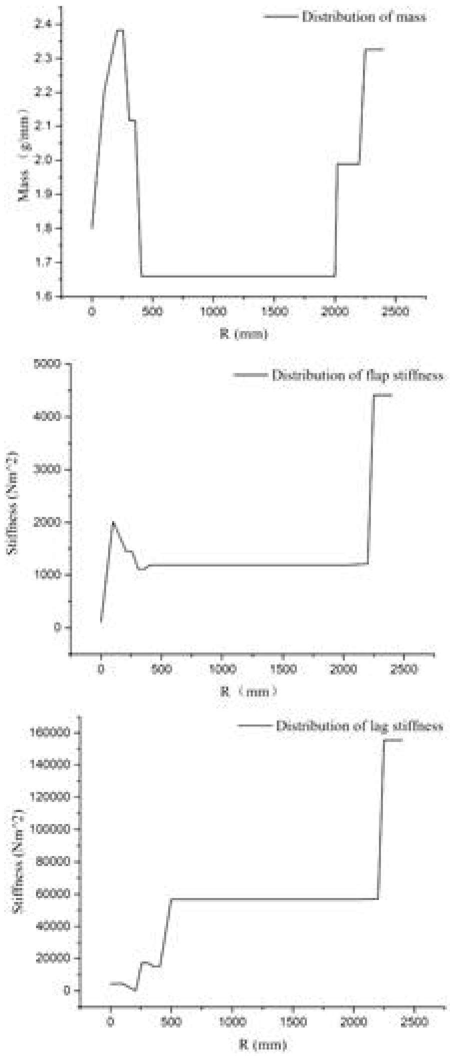


Fig. 4 Distribution of the Mass and Stiffness of the Rotor

The flap and the lead-lag mode shapes from first to fourth are shown in Fig.5.

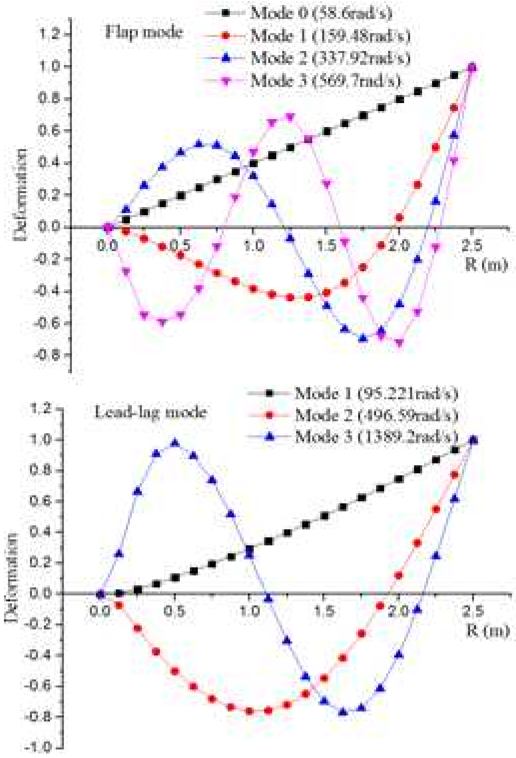


Fig. 5 Flap and lead-lag mode with rotational speed 58.6 ad/s

Fig.6 is the fan plot of this rotor. The rotor speed changes from 0rpm to 800rpm. As it shows, each order flap mode frequency has enough distance from harmonic vibration at working speed(560rpm). The fan plot helps us estimate the rotor's resonance characteristics on different speed that is very important in rotor design.

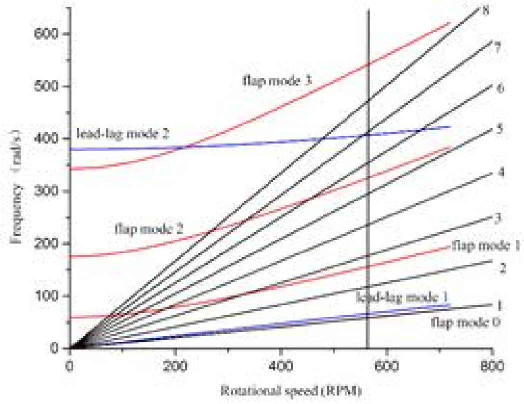
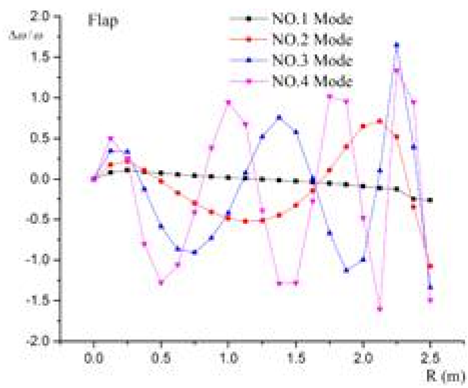


Fig. 6 Fan Plot of the Articulated Rotor in RPM

4.Dynamics of Bearingless Rotor

Theoretical analysis and experimental results both show that the spanwise distribution of mass and stiffness have influences on the dynamical characteristics of the cantilever beam. During the process of the rotor structure design, engineers adjust the flap and lag frequency by changing the distribution of mass and stiffness to meet the dynamical requirements of the rotor. Fig.7 and Fig.8 show the flap and lead-lag frequency changes related to change of mass and stiffness distribution along the spanwise.



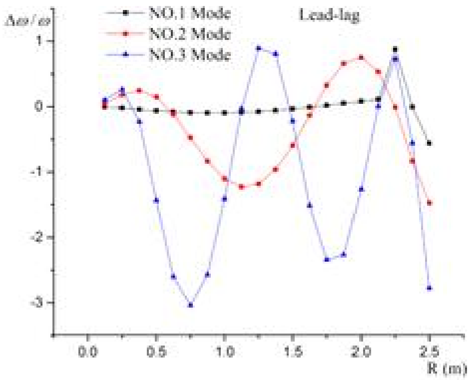


Fig. 7 Frequency Changes with the Change of Mass Distribution Along Spanwise

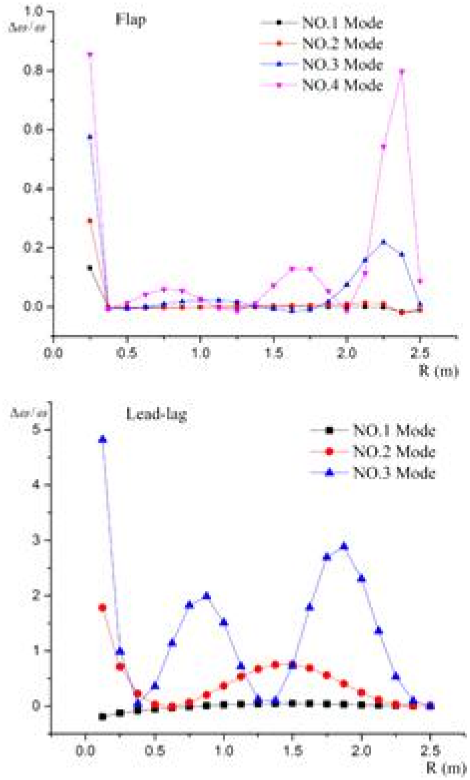


Fig. 8 Frequency Changes with the Change of Stiffness Distribution AlongSpanwise

As it shown in Fig.6, the added mass in root position has little effect on the changes of the frequency, while the stiffness at the root of the flexbeam has noteworthy effects on each mode, which is the main difference between the bearingless rotor and articulated rotor. So we calculate the bearinglessflexbeam using the same model and the same method. Tab.2 shows the frequency changes.

Table. 2 Frequency Changes in Working Speed

Fre.	Articulated		Fre.	Bearingless	
	Flap	Lag		Flap	Lag
M 0	58.6	87.6	M 1	63.7	90.2
M 1	155.3	406.9	M 2	159.5	496.6
M 2	323.7	1125.4	M 3	337.9	1389.2
M 3	539.3	-	M 4	569.7	-

As the data shows, the frequency of each mode has a decrease in bearingless rotor except the 1st lead-lag mode. Because the bearingless flex beam's bending stiffness is much smaller than the blade, the frequency has not changed so much. Fig.9 shows the fan plot.

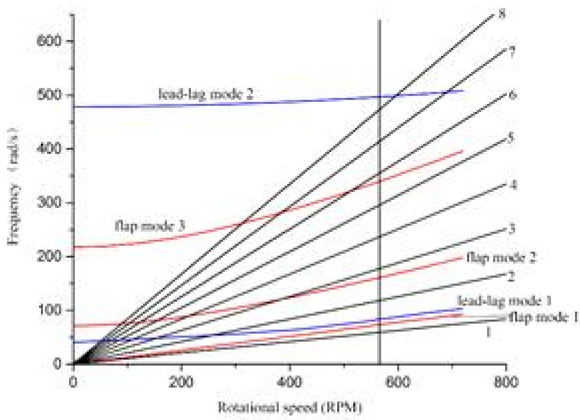


Fig. 9 Fan Plot of the Bearingless Rotor in RPM

From the Fig.9 and Fig.6, we can see that although the frequency hasnot changed so much from articulated rotor to bearingless rotor, but their fan plots are different. We can see that the bearingless rotor is more adaptable in the working speed.

On the basis of the above analysis, we designed a typical bearingless rotor flexbeam, shown in Fig.10. It is a T-section flexbeam and it has a narrowcross-section close to the hub, producing a "quasi-hinge" which allows the blade to flap.

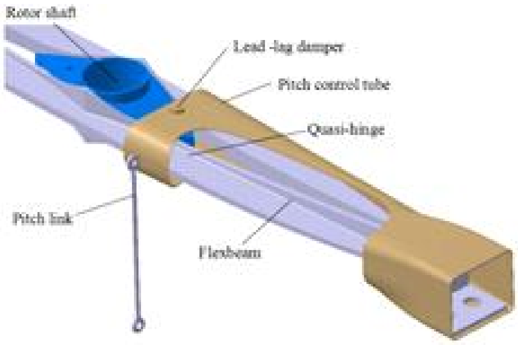


Fig. 10 Typical BearinglessRotor Structures

5. Conclusions

First, the cross section configuration can remarkably affect the flexbeam's torsional stiffness. In our experiment, the doubleside-T shape has the minimum torsional stiffness.

Second, the change of stiffness has different effects on dynamical characteristics with the change of mass, which can be used in frequency adjustment in the flexbeam design.

Third, the change of the stiffness on the root of the rotor can produce enough change of the mode frequency, which can be used to design the flexbeam.

Finally, we can change the cross section configuration of the flexbeam to get a satisfactory design of a bearingless rotor.

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