Design and Aeroelastic Stability Test of Five-Blades Froude Scaled Model Rotor

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ABSTRACT

This paper presents the design of a helicopter froude scaled model rotor with variable damping condition, which is 2.4 meters in diameter. Rotor aeroelastic stability test under different damping conditions in hover has been finished using this model rotor. Two-steps method for mode damping identification in the test has been validated which firstly adopt transfer function in rotating system to identify the mode frequencies, and then combine Fourier Series Moving Block (FSMB) and Hilbert Transform Method with digital filtering to identify the mode damping. This method can synchronously give attention to both mode frequency and mode damping accuracy. It is clear in physics and widely applicable.

INTRODUCTION

Rotor aeroelastic stability is one of the most important part in rotor dynamics investigations, which relates to the safety of helicopter. The damping condition affects helicopter aeroelastic stability margin directly. The benefits for identifying mode damping accurately not only can avoid the unstable phenomenon, but also can reduce rotor weight and loads caused by excessive damping requirement. So it is a key technique in helicopter industry all the time. Many researches in theory and experiment had been carried out for rotor aeroelastic stability test and damping identification. There are many traditional methods in this aspect, such as Half Power Method, Logarithmic Decrement, Random Decrement Method, Ibrahim and Sparse Time domain method, and so on. The moving block method developed by Hammond in 1975 has been used widely. Bousman and Winkler had analysis and taken the numerical simulation experiment in how to identify the damping with interfering by FFT-MB in 1981. Tasker and Chopra studied the influence factors for FFTMB, including noise, window functions ,and so on. Smith and Wereley developed Fourier Series Based Moving Block method (FSMB) in 1998, and identified lag mode damping of flexible beam composite blade with viscoelastic damping layer based on FSMB. Agneni and Crema identified the mode damping in time domain using Hilbert Damping Analysis firstly in 1989. However, the frequency and the damping identification accuracy could not be considered synchronously in those methods. The two-steps method for mode damping identification that gives attention to both frequency and damping identification accuracy has been developed in this research. It uses transfer function to identify mode frequencies then use FSMB and Hilbert method to identify mode damping which can overcome the large time-consuming in FFTMB method. Otherwise, a froude scaled model rotor is...
designed based on a reference full scaled rotor, which can vary the damping condition via assembling different number of viscoelastic damper. Using this model rotor, experimental investigation on rotor aeroelastic stability in hover has been finished, and the effectiveness of this method has been validated.

**MODEL ROTOR DESIGN**

**Design principles**

Froude scaled model rotor is very suitable for investigation on aeroelastic stability because the equilibrium position of which could be consistent with the full scaled rotor. Froude number, advanced ratio and lock number is selected to scale the referenced rotor and other parameters are compromised in this research. Design principles for model rotor are as follows:

a) For the blade: make froude number, advanced ratio and Lock number similar firstly, and dynamic similar in the typical airfoil section (except the blade root and blade tip), that means the distribution of the mass, stiffness, center of gravity in chordwise, and the blade shape are similar.

b) For the hub: make the first order flap and lag frequency similar mostly, and the geometry similar;

c) For the swashplate: satisfy the requirements of the froude scaled model rotor control range just enough.

**Rotor general parameters**

The general parameters of the model rotor are as follow:

- Rotor Diameter: 2.4 m
- Blade Number: 5
- Normal rotating speed: 721 Rev/Min
- Maximum rotating speed: 865 Rev/Min
- Rotor tip speed: 90.6 m/s
- Blade chord: 75 mm

**Design method and results**

The model rotor consists of blades, articulated hub with five arms and swashplate assembly. The small torsion-shear damper can be installed on each arm and damping condition can be adjustable via changing the number of damper. The blade has double load paths consisted of composite skin made of glass fibre and metal beam. The fillings in blade root consist of foam and compound material. The mass and stiffness distribution along span are consistent with froude number scaled requirement of the reference blade. The blade structure is seen as figure 1.

![Figure 1 Structure of the blade](image)

**AEROELASTIC STABILITY TEST**

**Test method**

In the aeroelastic stability test, force is generated via oscillating the swashplate nonrotating ring excited by a hydraulic actuator. The force then passes to swashplate rotating ring, then to pitch link, at last to the blade. The exciting force causes the blade pitch angle varying periodically, also the blade vibrating out of plane and in plane.
The method in this paper developed for Damping Identification in aeroelastic stability test includes two major steps as follow.

The first step is frequency identification of rotating blade. We identify the mode frequencies of rotating blade based on Transfer Function [10] which is used in common in nonrotating system. First, acquire the exciting signal in nonrotating system and the blade response in rotating system synchronously by network based on advanced computer and control technique. Second, make use of the kinematic relation of the swashplate to transform the exciting signal from fixed coordinate to rotating coordinate. Third, resample the exciting signal and the blade response in rotating coordinate according to the analytic frequency. Last of all, compute the transfer function of the resampling exciting and response signal and estimate the modal frequency synthetically by Amplitude-Frequency Curve, Phase-Frequency Curve, Correlation Coefficient-Frequency Curve.

The second step is damping identification of rotating blade. Fix the exciting frequency to the exact rotating blade frequency acquired in the first step. After the blade response reaching a steady state, stop the exciting abruptly and acquire the transient signal of the rotating blade. We combine the digital filter and FSMB/Hilbert to identify the envelope of the transient free vibration signal, then we can identify the rotating blade damping based on the damping model.

**Optimal exciting amplitude**

Unlike hingeless rotor, the loads of the articulated model rotor is small and the Signal-to-Noise is much lower. As a result, it is difficult to excite the chord mode response under small exciting amplitude. So we increase the exciting amplitude step by step but restricted by the blade strength limit. Along with the increase of the exciting amplitude, the blade chord mode response become clearer and clearer. At last, we select the optimal exciting amplitude, on the one hand, which bring enough Signal-to-Noise, on the other hand, which can ensure the security of the experiment.

![Figure 5: Chord Mode and 1/rev Response vs. Exciting Amplitude](image)

**Major test conditions**

The testing conditions include varying the rotor collective pitch, varying the rotor rotating speed and varying the rotor damping state. We select four rotor rotating speeds (505Rev/Min, 656Rev/Min, 721Rev/Min, 764Rev/Min) and three rotor damping conditions, which correspond assembling one elastomeric damper, assembling two elastomeric dampers and no damper.
Table 1 Stability Test Conditions

<table>
<thead>
<tr>
<th>Rotating Speed</th>
<th>Collective Pitch</th>
<th>Exciting Amplitude</th>
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<td>Zero 505</td>
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Typical test results

Figure 6 presents the 1st Chord Mode Frequency Test Results Based on Transfer Function under three damping conditions. The single peak is very clear from the Amplitude-Frequency Curve, furthermore the Phase-Frequency Curve and Correlation Coefficient-Frequency Curve are well-regulated.

Figure 7 presents a typical result based on combining the digital filtering and FSMB/Hilbert for mode damping identification.

SUMMARY AND CONCLUSIONS

A froude scaled model rotor with viscoelastic dampers has been designed in this paper for the need of the aeroelastic...
stability investigation. Rotor aeroelastic stability test based on the five blades froude scaled model rotor has been finished also. The two steps method for rotor damping identification developed has been proved very effective. This technique extends the range of damping identification. It is adapted for the case of nonlinear damping and heavy damping, solves the problem of 1/rev rotor speed signal interfering and overcome the conflict encountered in the traditional Moving-Block technique which can’t give attention to mode frequency precision and mode damping precision synchronously:

a) For mode frequency identification: the network control and synchronized sampling the strain signal of the rotation and nonrotating system were adopted. The frequency identification method of the rotating rotor system based on transfer function has been established, and it is clear in physics to interpretation easily;

b) For mode damping identification: The application of the digital filtering improved the Signal-to-Noise ratio and solved the problem of 1/rev rotor speed signal interfering. And the two-steps method for mode damping identification has been established by combining the digital filtering , frequency indentation, FSMB and Hilbert method overcome the conflict encountered in the traditional Moving-Block technique which can’t give attention to modal frequency precision and modal damping precision synchronously:

c) For the design of model rotor: Based on the characteristic of varying the damping condition, it lays a foundation of deep investigation for aeroelastic stability.

REFERENCES


