An Experimental Investigation of Dynamic Stability of Bearingless Model Rotor mounting Test Bench

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Introduction

a) The problem of aeromechanical instability of a helicopter on the ground and in hover, commonly referred to as ground and air resonance.

b) Ground or air resonance is a complex phenomenon involving both the rotor and body degrees of freedom in which the rotor lead-lag regressing mode which included substantial body pitch and roll motion may become unstable.
Introduction

a) The bearingless rotor uses the composite material flexbeam replacing flapping hinge and lead-lag hinge and pitching hinge in conventional articulated rotor hub.

b) The flexbeam performs the motions of flapping and lead-lag and pitching by elastic deformation.

c) The greater stiffness and more sophisticated deformation,
   → the stronger flap-lag-torsion coupling motions,
   → the issue of aeromechanical stability is more complex and more prominent.
Test Scheme

a) Select test conditions according to the ground/air resonance speed region of model analysis.

b) Use the frequency scanning sine excitation method.

c) Adopt the method of monitoring the flexbeam profile bending load and test-bed vibration level.
Experimental Model

Overall view of model.

Configuration view of a bearingless rotor.

The rotor dynamic response / aeroelastic stability test-bed
Test Procedures and Data Analysis

- Measuring-point disposal

View of vibration picking point on test-bed.

View of measuring profile of lead-lag bending moment on flexbeam.

The cycle of pitch incentive is implemented by controlling the swashplate.
Test Procedures and Data Analysis

● Test method

Test method of ground resonance: The pitching and rolling and vertical directions of security system on test bench are locked.

Test method of air resonance: The pitching and rolling directions of security system on test bench are locked, but the vertical direction is loosened.
Test Procedures and Data Analysis

- Data analysis

![Graph showing lag-bending responses process of flexbeam](image)

Lag-bending responses process of flexbeam

![Graph showing attenuation mode frequency and damping of flexbeam lag-bending](image)

Vibration responses process of test bench spindle X direction

Attenuation mode frequency and damping of flexbeam lag-bending
Theoretical Modal

\[
\begin{bmatrix} M_{fp} \end{bmatrix}\dddot{X}_{fp} + \begin{bmatrix} C_{fp} \end{bmatrix}\ddot{X}_{fp} + \begin{bmatrix} K_{fp} \end{bmatrix}X_{fp} = \begin{bmatrix} X_{mp}^H \end{bmatrix}^T \sum_{k=1}^{N_b} \left( \begin{bmatrix} F_I^f \end{bmatrix} + \begin{bmatrix} F_{AERO}^f \end{bmatrix} \right)
\]

- **Rotor**

- **Body**

Test measure:

- The amplitude-frequency characteristic and phase-frequency characteristic of dynamic test-bed;
- Effective mass, stiffness, damping and frequency of hub center.
Lead-lag regressive mode damping as a function of rotor speed for ground resonance and air resonance, in fixed coordinate.
# Results and Discussion

## Lead-lag Regressing Mode Damping for Coupling

Mode Damping Values of Comparison and Deviation

### Ground Resonance

<table>
<thead>
<tr>
<th>Rotor speed (r/min)</th>
<th>Damping ratio, %, $\theta_b=0^\circ$</th>
<th>Damping ratio, %, $\theta_b=3^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental value</td>
<td>Calculated value</td>
</tr>
<tr>
<td>850</td>
<td>-6.8</td>
<td>-6.342</td>
</tr>
<tr>
<td>880</td>
<td>-5.6</td>
<td>-5.867</td>
</tr>
<tr>
<td>900</td>
<td>-7.4</td>
<td>-6.848</td>
</tr>
</tbody>
</table>

### Air Resonance

<table>
<thead>
<tr>
<th>Rotor speed (r/min)</th>
<th>Damping ratio, %, $\theta_b=0^\circ$</th>
<th>Damping ratio, %, $\theta_b=2^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental value</td>
<td>Calculated value</td>
</tr>
<tr>
<td>900</td>
<td>-5.3</td>
<td>-5.76</td>
</tr>
<tr>
<td>1032</td>
<td>-5.56</td>
<td>-5.95</td>
</tr>
</tbody>
</table>
Results and Discussion

(1) Correctness of the test incentive method, the concerned lead-lag regressing mode was excited, for all test status.

(2) For ground and air resonance, within the nominal rotor speed, no unstable region, no ground resonance or air resonance occur.

(3) Damping stability margin were greater than 5.0% for all ground resonance tests, more than 4.0% for all air resonance tests.

(4) Compared the attenuation mode damping of test results with the calculated results, the correlation between the experiment and the theory is good.
Conclusion

➢ In view of the new configuration of bearingless rotor, a test method of ground and air resonance in the resonance speed region was proposed, the test principle was described.

➢ The stability test of rotor model scale on test-bed was completed, and information about modal frequencies and damping was obtained.

➢ The reliability and effectiveness of the test and analysis method were verified, that reduced the risk of the traditional experiment.
Thank you!