A Study on Structure Parameters of an Offshore Wind Turbine by Excitation Test Using Active Mass Damper

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The seismic load on wind turbine support structure depends on the damping ratios. The values suggested in design codes are different among countries.

- **1\(^{st}\) mode damping ratio**
  - Japan (JSCE) 0.8\%(With gearbox), 0.5\%(Without gearbox)
  - Germany (DIBt) 0.23\%
  - US (AWEA) 1.0\%

- **2\(^{nd}\) mode damping ratio**
  - No measurement so far. No clear description in design codes.
Conventional methods to obtain damping ratios

- Ambient Vibration Analysis
  ⇒ 1\textsuperscript{st} mode is mainly excited by wind

- Human-Power Excitation Test
  ⇒ Not suitable for excitation of higher modes which are usually higher than 2Hz
Objective

- Perform an excitation test using active mass damper up to 2\textsuperscript{nd} mode on an offshore wind turbine tower.

- Identify the natural frequency and damping ratio of 1\textsuperscript{st} and 2\textsuperscript{nd} mode for fore-aft and side-side direction under both pitch-feathering and pitch-fine condition.
Observation Site

Tokyo, 28/07/2014

Observation Site:

- Observation Site: 北緯35度40分54秒，東経140度49分24秒 (世界測地系)
- Wind Turbine: 北緯35度40分54秒，東経140度49分13秒 (世界測地系)
- Observation Tower: 北緯35度40分54秒，東経140度49分24秒 (世界測地系)

Map:

- Observation Site
- Wind Turbine
- Observation Tower
- Ocean Cable
- Distance: 285 meters
Outline of Wind Turbine Facilities

- Anemometer
- AMD controller
- Inside Nacell
- Active Mass Damper (AMD)
Outline of Target Wind Turbine and Measurement

Strain gage height
+75.83m
+38.83m
+10.83m

Accelerometer height
+74.79m
+58.98m
+55.58m
+36.58m

Active Mass Damper

H=70m

Strain gage

10.3m

Accelerometer

side-side (Y)
Fore-aft (X)

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Outline of Excitation Test

weight (x-direction 1.7t, y-direction 1.3t)

x axis excitation (± 0.2m)

y axis excitation (± 0.3m)

Frequency range (0.1 ~ 4.0 Hz)

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Measurement Conditions

Yaw fix, Rotor fix

- **Excitation Direction**
  - Fore-Aft
  - Side-Side

- **Blade Pitch State**
  - Pitch-Feather
  - Pitch-Fine
Ambient vibration analysis is conducted with both pitch-feathering and pitch-fine condition.

1st mode damping ratio is estimated with Random Decrement Method.

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Sinusoidal Vibration Test

- Sinusoidal excitation at several frequencies
- Using measured tower acceleration to calculate
  1. (tower acceleration amplitude)/(excitation force amplitude)
  2. Phase angle
- Estimate resonant frequency $\omega$ and damping ratio $\xi$ from the analytical equation assuming 1 DOF

Excitation Force

$$ F = F_i \sin \omega t $$

Response function

$$ \frac{|a|}{|F|} = \beta^2 \frac{\phi_n(Vib)\phi_n(Acc)}{\sum_i \phi_n(i) m_i \phi_n(i)} \frac{1}{\sqrt{(1 - \beta^2)^2 + (2\xi\beta)^2}} $$

Acceleration Response

$$ a(t) = A \sin(\omega t + \phi) $$

Phase

$$ \theta = \tan^{-1} \left( \frac{2\xi \beta}{1 - \beta^2} \right) $$
Result of Sinusoidal Test in Fore-aft Direction

1st mode

\[ F = 0.351 \text{Hz} \]
\[ \zeta = 0.2\% \]
\[ \omega_1 = 0.351 \text{Hz} \]
\[ \zeta_1 = 0.2\% \]

2nd mode

\[ F = 2.935 \text{Hz} \]
\[ \zeta = 2.5\% \]
\[ \omega_2 = 2.935 \text{Hz} \]
\[ \zeta_2 = 2.5\% \]

- 1st mode damping of 2.4MW was 0.2%
- 2nd mode damping was found to be 2.5%
Free Vibration Result of 1\textsuperscript{st} mode

\[ a(t) = A \exp(-\xi \omega t) \]

**Fore-aft 1\textsuperscript{st}**

- Pitch-feathering
  - \( f_1 = 0.351 \text{Hz}, \ \xi_1 = 0.2\% \)

**Side-side 1\textsuperscript{st}**

- Acceleration
  - \( f_1 = 0.357 \text{Hz}, \ \xi_1 = 1.2\% \)

**Pitch-fine**

- \( f_1 = 0.350 \text{Hz}, \ \xi_1 = 1.0\% \)

- \( f_1 = 0.347 \text{Hz}, \ \xi_1 = 0.3\% \)

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Free Vibration Result of 2\textsuperscript{nd} mode

\[ a(t) = A \exp(-\xi \omega t) \]

**Fore-aft 2\textsuperscript{nd}**

- \( \xi_2 = 2.4\% \)

**Side-side 2\textsuperscript{nd}**

- \( \xi_2 = 3.2\% \)

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Comparison of mode shapes

The mode shapes calculated with FEM model agreed well with measurement data.

<table>
<thead>
<tr>
<th>direction</th>
<th>Measurement</th>
<th>FEM model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fore-aft</td>
<td>1st: 0.351Hz</td>
<td>0.367Hz</td>
</tr>
<tr>
<td></td>
<td>2nd: 2.935Hz</td>
<td>3.223Hz</td>
</tr>
<tr>
<td>Side-side</td>
<td>1st: 0.352Hz</td>
<td>0.365Hz</td>
</tr>
<tr>
<td></td>
<td>2nd: 2.970Hz</td>
<td>3.165Hz</td>
</tr>
</tbody>
</table>
Conclusions

- Damping ratios for 1\textsuperscript{st} and 2\textsuperscript{nd} mode of a wind turbine are identified by sinusoidal excitation test and free vibration tests.

- The structural damping ratio for wind turbine 1\textsuperscript{st} mode is 0.2\%, which is smaller than the conventional value used for middle size wind turbines.

- The structural damping ratio for wind turbine 2\textsuperscript{nd} mode is 2.4\% in the fore-aft direction and is 3.2\% in the side-side direction.

- Damping ratios for wind turbine 1\textsuperscript{st} mode are strongly affected by blade pitch angles.

<table>
<thead>
<tr>
<th>Blade Pitch</th>
<th>Fore-Aft 1\textsuperscript{st}</th>
<th>Fore-Aft 2\textsuperscript{nd}</th>
<th>Side-Side 1\textsuperscript{st}</th>
<th>Side-Side 2\textsuperscript{nd}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free-Vibration test</td>
<td>Feather</td>
<td>0.2%</td>
<td>2.4%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Fine</td>
<td>1.0%</td>
<td>-</td>
<td>0.2%</td>
<td>3.2%</td>
</tr>
</tbody>
</table>