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Concept Testing of a Simple Floating Offshore Vertical Axis Wind Turbine

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Department of Wind Energy
EU-FP7: DeepWind project

Objectives:
• To explore technologies for concept
• To develop calculation and design tools
• To evaluate the overall concept

Work Package 7: DeepWind demonstrator: evaluate proof of concept under real field conditions 1kW demonstrator
Overview
1. Design and manufacture of a 1kW concept demonstrator
2. Modal analysis and test setup
3. Testing and database of test results

DeepWind demonstrator in front of old Risø test station
1. Design of a 1kW concept demonstrator

Design considerations:

1. Down-scaled versus small turbine?
2. Test site – field tests and water tank tests!
3. Rotor design – Troposkien, circular, straight with arc
4. Blade design – Profile, chord, 2/3 blades
5. Tube design – material, weight, wall thickness
6. Instrumentation in tube – measurement of movements, weight
7. Generator box design – water tightness, shaft, gimbal joint design
8. Foundation – support for all test components
9. Deployment and maintenance – need of a special sea vessel, safety
1. Design of a 1kW concept demonstrator

Three configurations considered for the DeepWind concept

Second configuration chosen:
1. Turbine connected to generator
2. Generator mounted on gimbal joint
3. Torque arm connected to foundation with met mast
1. Design of a 1kW concept demonstrator

Turbine rotor design

- Type: Darrieus
- Shape: Circular
- Diameter: 2m
- Height: 2m
- Chord: 0.12m
- Profile: SAND 0018/50
- Blade material: Extruded Al
- Blade weight: 2.5kg

Power curve
1. Design of a 1kW concept demonstrator

**Rotor tube**

- **Tube length:** 5.00m
- **Tube diameter:** 0.15m
- **Wall thickness:** 5mm
- **Material:** Extruded Aluminium AW6082 T6
- **Attachments:** Al blade flanges welded on
- **Buoyancy:** Foam with glassfiber cover, dia. 0.40m

![Image of Rotor tube and buoyancy](image-url)
1. Design of a 1kW concept demonstrator

Foundation and generator box
- Legs: Steel 3m
- Feet: Concrete 150kg each
- Torque arm: Steel 5m
- Gimbal joint: Steel
- Generator box: Steel
- Generator: 1kW asynchronous
- Weight: 1.9ton
1. Design of a 1kW concept demonstrator

Instrumentation

Rotor
3D accelerometer at bottom of tube
3D accelerometer at top of tube
Gyro

Met mast
3D sonic anemometer at top
Air temperature sensor
Air pressure sensor

Control system
Electrical power
Rotational speed

ADCP
Water currents
Wave heights

Video from pier
Sterable video camera
## 1. Manufacture of 1kW concept demonstrator

### Manufacture

<table>
<thead>
<tr>
<th>Component</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>Vestas</td>
</tr>
<tr>
<td>Concrete feet</td>
<td>DTU</td>
</tr>
<tr>
<td>Torque arm</td>
<td>Vestas</td>
</tr>
<tr>
<td>Generator box</td>
<td>Aalborg University</td>
</tr>
<tr>
<td>Rotor tube</td>
<td>Vestas</td>
</tr>
<tr>
<td>Blades</td>
<td>WindPowerTree Aps</td>
</tr>
<tr>
<td>Control system</td>
<td>Aalborg University</td>
</tr>
<tr>
<td>Mast</td>
<td>DTU</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>DTU</td>
</tr>
<tr>
<td>Cables</td>
<td>Aalborg University</td>
</tr>
</tbody>
</table>
2. Modal analysis

Modal analysis test setup, mounted upside down

Model of rotor for modal analysis, including blades, tube and generator box
2. Modal analysis

### Eigenfrequencies

**Fixed support versus hinged support**

<table>
<thead>
<tr>
<th>Fixed support frequency [Hz]</th>
<th>Hinged support frequency [Hz]</th>
<th>Mode shape</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.29</td>
<td>4.52</td>
<td>Fore-aft</td>
<td>Blue</td>
</tr>
<tr>
<td>2.33</td>
<td>-</td>
<td>Side-side</td>
<td></td>
</tr>
<tr>
<td>19.73</td>
<td>16.04</td>
<td>2(^{nd}) tube bending side-to-side</td>
<td>Green</td>
</tr>
<tr>
<td>20.41</td>
<td>-</td>
<td>Torsion</td>
<td></td>
</tr>
<tr>
<td>21.45</td>
<td>30.4</td>
<td>2(^{nd}) tube bending fore-aft</td>
<td>Red</td>
</tr>
<tr>
<td>30.12</td>
<td>31.56</td>
<td>1(^{st}) blade flap bending assym.</td>
<td>Azur</td>
</tr>
<tr>
<td>32.58</td>
<td>32.95</td>
<td>1(^{st}) blade flap bending sym.</td>
<td>Purple</td>
</tr>
<tr>
<td>49.34</td>
<td>50.23</td>
<td>1(^{st}) blade edge bending sym.</td>
<td>Black</td>
</tr>
<tr>
<td>62.41</td>
<td>44.16</td>
<td>3(^{rd}) tube bending side-to-side</td>
<td>Lime</td>
</tr>
</tbody>
</table>

### Campbell diagram

![Campbell diagram](image)

### FEM versus modal testing

<table>
<thead>
<tr>
<th>FEM Frequency</th>
<th>Modal test Frequency</th>
<th>Mode shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.78 Hz</td>
<td>2.75 Hz</td>
<td>First bending</td>
</tr>
<tr>
<td>23.61 Hz</td>
<td>21.75 Hz</td>
<td>Second bending</td>
</tr>
<tr>
<td>69.4 Hz</td>
<td>68.25 Hz</td>
<td>Third bending</td>
</tr>
</tbody>
</table>

FEM - Finite Element Method
2. Test setup

Test site at Risø in Roskilde Fjord

Positions of test equipment:
- Mast 50m west of pier
- Yellow sea mark 25m west of mast
- Generator box (raised) south of mast
- ADCP 25m north of mast (not seen)
2. Test setup deployment

Lifting by crane into water next to pier

Lifting by sea vessel (including three air bags with each 250 liter) and transporting to site
2. Test setup inauguration

A new offshore concept is born!

Concept seems to work!

DeepWind project coordinator celebrating a milestone
3. Tests and measurement database

**Testing program**

1. Assurance of no bad vibration modes
2. Brake tests
3. Measurement wind and wave matrix

**Test matrix – winds and waves**

<table>
<thead>
<tr>
<th>Wind and wave matrix</th>
<th>Low wind below 8m/s</th>
<th>Average wind 8m/s to 11m/s</th>
<th>High wind 11m/s to 16m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winds from E, SE and S (low waves)</td>
<td>Case 1</td>
<td>Case 3</td>
<td>Case 5</td>
</tr>
<tr>
<td>Winds from W and NW (high waves)</td>
<td>Case 2</td>
<td>Case 4</td>
<td>Case 6</td>
</tr>
</tbody>
</table>
3. Tests and measurement database

Example of measurements

- Average wind speed 11.4 m/s from west (case 6)
- Blades occasionally hitting wave
3. Tests and measurement database

Example of measurements
- Average wind speed 11.4m/s from west (case 6)
- Blades occasionally hitting wave
Conclusions

Concluding remarks

1. A small DeepWind concept wind turbine was designed and built
2. The rotor was not built as originally designed:
   a) alternative blades were provided 50% heavier
   b) rotor tube 40% heavier
3. Mechanical brake safety tests made successfully
4. A test matrix of combinations of winds and waves was performed successfully
5. The wind turbine have operated smoothly during the tests
6. Friction of rotor very high due to large buoyancy part
7. Further plans:
   a) to start analysis of data from database
   b) to compare measurements with simulations
   c) to test demonstrator in water tank at Marin March 2013
   d) new tests in Roskilde Fjord later in 2013 applying other configurations to the turbine
Thank you for your attention!

…..and thanks to the DeepWind family