The C-Tower Project
A Composite Tower for Offshore Wind Turbines

18 January 2017, Deepwind
Trondheim, Norway

Tjeerd van der Zee (WMC)
Marten Jan de Ruiter (WMC)
Ivo Wieling (Jules Dock Composites)
Contents

- Project introduction
- Deciding on a tower concept
- Flexible composite tower
- Manufacturing
- Conclusions and next phase
Project partners

- Wind2020: co-ordination
- Jules Dock Composites: production expertise
- WMC: composite and tower design knowledge, design and analysis tools, material and full-scale testing
Pros and cons of composite tower

- Weight reduction compared to steel
  - Lower installation costs
- Material may better dampen vibrations
- Opportunities for increasing lifetime
- But:
  - Complex production
  - Reduced stiffness (frequency issues)
  - End-of-life not clear
  - New technology – market is conservative
Project challenge

Design a composite offshore wind turbine tower which is:

- lighter
- more flexible but as strong
- more sustainable
- with better damping characteristics

compared to an equivalent steel tower.
Project goals

- Design a composite offshore wind turbine tower to carry a 10 MW turbine
  - Uses a steel monopile
- Show by software analysis that the concept is feasible (strength and fatigue life)
- Select production techniques for such a design
- Build a (roughly) 1:10-scale prototype and test it
Tower geometry

Reference model:
- DTU 10 MW reference turbine

Tower model using:
- Steel (baseline)
- Composite

Two composite designs:
- Stiff: design has similar eigenfrequencies to steel
- Flexible: design has similar strength to steel, but lower eigenfrequencies
# Eigenfrequencies

<table>
<thead>
<tr>
<th></th>
<th>Stiff</th>
<th>Flexible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top thickness (D 5.5m)</td>
<td>200 mm</td>
<td>10 mm</td>
</tr>
<tr>
<td>Bottom thickness (D 80m)</td>
<td>450 mm</td>
<td>32 mm</td>
</tr>
<tr>
<td>Tower weight</td>
<td>1191 ton</td>
<td>92 ton</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; frequency</td>
<td>0.199 Hz</td>
<td>0.065 Hz</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; frequency</td>
<td>Not relevant</td>
<td>0.217 Hz</td>
</tr>
<tr>
<td>Maximum stress</td>
<td>168.7 MPa</td>
<td>330.2 MPa</td>
</tr>
<tr>
<td>Buckling SF</td>
<td>47.4</td>
<td>&lt;&lt; 1</td>
</tr>
</tbody>
</table>
Optimization

- **Constraints:**
  - 1\textsuperscript{st} side-to-side frequency: below 1P range
  - 2\textsuperscript{nd} side-to-side frequency: over 3P range
  - Idem fore-aft frequencies
  - Buckling safety factor > 1
  - Stresses below critical value

- **Target:** Minimization of tower mass
Environmental conditions

- K13 North Sea location
- 25 m water depth
- Load cases defined according to IEC 61400-3

Source: Upwind Design Basis
Ultimate strength analysis

- Extreme load cases selected
- Parameters in optimization run
  - Wall thickness distribution
  - Fibre orientation
  - Relative thickness of layers
- Full FEM assessment at end of optimization loop
- Result: for a glass fibre reinforced epoxy stresses are below critical values
Fatigue analysis

- Wind-wave directionality plays role in tower loading
  - More aerodynamic damping by rotor for the tower motions when wave direction is aligned with wind
  - Results in large amount of load cases to consider

- Slightly reduced set
  - Maximum of 3 combinations of wave period and wave height per wind speed bin
  - 1824 load cases in total
Fatigue analysis

- Values for Ultimate Tensile Strength (UTS) and Ultimate Compressive Strength (UCS) assumed
- Fatigue Reserve Factors determined at locations at 4 m intervals throughout tower
- 20 year fatigue lifetime possible with UTS = 132.7 MPa; UCS = 92.9 MPa
- All safety factors according to GL Guidelines taken into account
Manufacturing

Filament winding:

- Automation possible
- Consistent and highly controllable
- Angles close to 0 degrees
Manufacturing

- Machine for manufacturing scale model being built now
Conclusions so far

- Calculations show that flexible composite tower is feasible
  - 34% mass reduction compared to steel baseline tower
  - Tower top deflection of less than 3 degrees
- For a real competitive design, an integrated approach including substructure and control strategy is required
Next phase

- Completion of filament winding machine
- Material testing on small test coupons
- Production of the scaled model
- Testing of the scaled model at WMC
Thank you for your attention

Questions?

This research is financially supported by TKI Wind op Zee