Marine Corrosivity Effort
December, 2013

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Udel, CEOE - SMSP
Original Objectives

Calibrate the corrosivity of the Lewes, DE wind turbine site with the intention of being able to predict the corrosivity of future sites.

Monitor the real time corrosion of critical wind turbine systems as one component of a condition based maintenance program.
Original Project Goals:

- **a.** Deploy corrosivity test surfaces at a range of heights and distances from the water in the vicinity of the Lewes turbine site.
- **b.** Analyze the corrosivity values as measured above to determine the corrosivity of the atmosphere at the Lewes turbine site as a function of distance from, and height above the water over a 2-Yr period.
- **c.** Evaluate the corrosivity of the present turbine site in comparison to that at other sites along the US Atlantic coastline using plain carbon steel test surfaces.
- **d.** Develop a strategy for condition-based maintenance using electronic sensors for detecting corrosion of real turbine components. *(Not possible due to safety issues)*
Placement of Corrosivity Samples

CEOE Lewes Campus

Site of Wind Turbine

A and B

C and D
Testing

Location B
10 ft back 8 ft high
(Close and Low)
Location B
(MOB Low)
Testing
Location A
(MOB High)
(100 ft back 30 ft high)
Location A
(MOB High)
Testing

Location C
(At Turbine base)
Location C
(At Turbine Base)
Location D
(On Top of Nacelle)
Holder for Samples on top of Nacelle

1. Parts 2 and 3 to be welded together.
2. All parts anodized for corrosion protection prior to installation.
3. Part 1 to be purchased from McMaster Carr. Part 1 to be purchased once pipe size of angle support on top of nacelle is provided. Part 3 Mounting Flange to be machined to match bolt pattern of part 1.
4. The shown assembly should accommodate uprights between 47°-75°.
5. Part 9 (3/8-20 x 2.5) Bolts to be drill in place, at time of installation.
6. We would also recommend a wire rope tether to attach Sample Mounting Frame to the uprights as a fail safe.

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2 Rubber Bumpers 1.5&quot; x 14&quot; Bolted to body.</td>
</tr>
<tr>
<td>11</td>
<td>4 1/4-20 Bolt, Washer, Double Nut</td>
</tr>
<tr>
<td>10</td>
<td>2 3/16&quot; Support, Angle Laminar Support</td>
</tr>
<tr>
<td>9</td>
<td>8 1/4-20 x 2.5&quot; Thru Bolts</td>
</tr>
<tr>
<td>8</td>
<td>2 1-1/4&quot; Sch. 40 Aluminum Pipe, Approx. 48&quot; LG.</td>
</tr>
<tr>
<td>7</td>
<td>4 1&quot; Sch. 40 Aluminum Pipe, Approx. 10&quot; LG.</td>
</tr>
<tr>
<td>6</td>
<td>2 1&quot; Aluminum Female 90° Elbow</td>
</tr>
<tr>
<td>5</td>
<td>2 1&quot; Sch. 40 Aluminum Pipe, Approx. 5&quot; LG.</td>
</tr>
<tr>
<td>4</td>
<td>2 17 Aluminum Female 3/4&quot;</td>
</tr>
<tr>
<td>3</td>
<td>2 1-1/4&quot; Sch. 40 Aluminum Pipe, Approx. 12&quot; LG.</td>
</tr>
<tr>
<td>2</td>
<td>2 3/8&quot; Ti. Mounting Flange</td>
</tr>
<tr>
<td>1</td>
<td>2 Vibration Damping Clamping U-Bolt</td>
</tr>
</tbody>
</table>

NOTES:
1. BREAK ALL SHARP EDGES.
Corrosivity Samples at Location “D” atop the Nacelle (Sept 2\textsuperscript{nd}, 2011)
Thanks to:

Avinash Taware, Gamesa
Jonathan Harp, CHPT
Bob Johns, Wood Group
Rodney McGee, CEOE
Deanna Sewell, CEOE
Sample Cleaning and Weighing Procedure

• Immerse in Conc HCl solution containing the Buffers:
  – Sb$_2$O$_3$ (Antimony Trioxide)
  – SnCl$_2$ (Stannous Chloride)
• For 30 to 45 min at 25 deg C
• Rinse copiously in DI Water
• Dry with Ethanol
• Weigh to nearest 0.001 gm
Cleaned Sample
## Summary of Weight Loss Data Over 24 Mo

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample #</th>
<th>6 Months (Wt Loss (%))</th>
<th>12 Months (Wt Loss (%))</th>
<th>18 Months (Wt Loss (%))</th>
<th>24 Months (Wt Loss (%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOB Low (B)</td>
<td>1</td>
<td>1.119</td>
<td>1.69</td>
<td>2.59</td>
<td>3.84</td>
</tr>
<tr>
<td>(10 ft back 8 ft high)</td>
<td>2</td>
<td>1.108</td>
<td>1.67</td>
<td>2.38</td>
<td>3.98</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.146</td>
<td>1.70</td>
<td>2.75</td>
<td>4.33</td>
</tr>
<tr>
<td>MOB High (A)</td>
<td>1</td>
<td>0.886</td>
<td>1.62</td>
<td>2.31</td>
<td>3.01</td>
</tr>
<tr>
<td>(100 ft back 30 ft high)</td>
<td>2</td>
<td>0.855</td>
<td>1.46</td>
<td>2.19</td>
<td>2.86</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.869</td>
<td>1.62</td>
<td>2.19</td>
<td>2.90</td>
</tr>
<tr>
<td>Turbine Base (C)</td>
<td>1</td>
<td>0.620</td>
<td>1.41</td>
<td>1.96</td>
<td>1.96</td>
</tr>
<tr>
<td>(1150 ft back, 3ft high)</td>
<td>2</td>
<td>0.625</td>
<td>1.39</td>
<td>1.87</td>
<td>2.09</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.645</td>
<td>1.43</td>
<td>1.97</td>
<td>2.16</td>
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<tr>
<td>Turbine Top (D)</td>
<td>1</td>
<td>0.82</td>
<td>1.50</td>
<td>1.76</td>
<td>1.99</td>
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<tr>
<td>(1150 ft back, 100 ft high)</td>
<td>2</td>
<td>0.83</td>
<td>1.46</td>
<td>1.78</td>
<td>2.03</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.86</td>
<td>1.45</td>
<td>1.81</td>
<td>2.07</td>
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</tbody>
</table>
## Summary of Avg. Weight Loss Data Over 24 Mo

<table>
<thead>
<tr>
<th></th>
<th>6 Months</th>
<th></th>
<th>12 Months</th>
<th></th>
<th>18 Months</th>
<th></th>
<th>24 Months</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(gm)</td>
<td>(%)</td>
<td>(gm)</td>
<td>(%)</td>
<td>(gm)</td>
<td>(%)</td>
<td>(gm)</td>
<td>(%)</td>
</tr>
<tr>
<td>MOB Low (B)</td>
<td>2.74</td>
<td>1.12</td>
<td>4.11</td>
<td>1.68</td>
<td>6.26</td>
<td>2.57</td>
<td>9.86</td>
<td>4.05</td>
</tr>
<tr>
<td>MOB High (A)</td>
<td>2.11</td>
<td>0.81</td>
<td>3.79</td>
<td>1.57</td>
<td>5.44</td>
<td>2.23</td>
<td>7.05</td>
<td>2.92</td>
</tr>
<tr>
<td>Turbine Base (C)</td>
<td>1.53</td>
<td>0.63</td>
<td>3.41</td>
<td>1.41</td>
<td>4.74</td>
<td>1.94</td>
<td>5.04</td>
<td>2.07</td>
</tr>
<tr>
<td>Turbine Top (D)</td>
<td><strong>2.04</strong></td>
<td><strong>0.84</strong></td>
<td><strong>3.57</strong></td>
<td><strong>1.47</strong></td>
<td><strong>4.32</strong></td>
<td>1.78</td>
<td><strong>4.95</strong></td>
<td>2.03</td>
</tr>
</tbody>
</table>

### Conclusions:
1. Something on top of the Nacelle (perhaps turbulence from the blades) interferes with corrosion product film formation during the first year of exposure.
2. After the first year of exposure, the effect disappears.
Dexter, Corrosivity: Progress as of 12/2013

June – Aug, 2010  Construct Corrosivity Samples & Holders
Sept, 2010  Deploy 1st 3 Corrosivity Sample Groups
March, 2011  Remove and Analyze 6 Mo Samples
March, 2011  Design Holder for Nacelle Samples
June, 2011  Approval to put Samples on Nacelle

**Summer, 2011**  Gathering Atmospheric Corrosion Data (still on-going)
Summer, 2011  Build Sample Holder for Nacelle
End of Aug, 2011  Mount Samples atop Nacelle at Loc D
End of Aug, 2011  Remove 12 Mo Samples from Locations A, B & C
Early Sept, 2011  Analyze 12 Mo Samples at A, B & C

**Fall, 2011**
1/12 – 3/12  Design Electronic Corrosion Monitors

**Not Possible**

March, 2012  Remove and Analyze 18 Mo Samples + 6 Mo at Site D
Sept, 2012  Remove and Analyze 2Yr Samples + 12 Mo at Site D
March, 2013  Remove and Analyze 18 Mo Samples from Nacelle Site D
Sept, 2013  Remove and Analyze 2 Yr Samples from Nacelle Site D

**Dec, 2013**  Compare to other sites along US East Coast
Dec, 2013  Finish Analysis and Write Final Report
Lightning Over The Lewes Wind Turbine