Oscillating Wing Unit (OWU) for Power Generation
– Analysis & System Development

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Current Wind Turbines

Limitation:
Low aerodynamic efficiency particularly at low winds
Objective

To develop a new wind power converter

- High aerodynamic efficiency particularly at low winds (< 5 m/s);
- Simple structures for easy manufacturing;
- Low setting-up and maintenance cost.
Conceptual Design of Oscillating Wing Unit

**Advantages**
- High aerodynamic efficiency particularly at low winds
- Less-constrained structures
- Easy maintenance
The power coefficient:

\[ C_p = \frac{P}{(1/2) \rho V_\infty^3 A_{act}} \]

\[ = 4a_1(1-a_1)^2 \left( \frac{A_1}{A_{act}} \right) + 4(1-2a_1)^3 a_2(1-a_2)^2 \left( \frac{A_2}{A_{act}} \right) \]

\( a_1, a_2 \): the axial interference parameters of Disks 1 & 2

Total Disk Area:

\[ A_{act} = A_1 + A_2 \]
Dynamical Model

The aerodynamic forces in a simplified mechanical model

Velocity and aerodynamic force vectors on the wing #1
Motion Equation

\[
\frac{d^2 \beta}{dt^2} = \frac{1}{2 \tau_1^2} \left( C_{L1} \gamma_1 \cos \delta_1 - C_{L2} \gamma_2 \cos \delta_2 \right) + \frac{1}{2 \tau_1^2} \left( C_{D1} \gamma_1 \sin \delta_1 - C_{D2} \gamma_2 \sin \delta_2 \right) - \frac{1}{2 \tau_2^2} \beta - T_{load}^*
\]

The lift and drag coefficients are calculated based on the lifting-line model by considering the local effective wind velocity of the moving wings.

The power:

\[
P(t) = 4\pi f l q S_w \eta_{mech} \gamma_1 \left| C_{L1} \cos \delta_1 + C_{D1} \sin \delta_1 \right|
\]
Conceptual Design of Medium-Size Oscillator

Table 1. Design Parameters for a Wind Oscillator

<table>
<thead>
<tr>
<th>Components</th>
<th>Design Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single wing mass (kg)</td>
<td>100</td>
</tr>
<tr>
<td>Arm length (m)</td>
<td>8</td>
</tr>
<tr>
<td>Single wing area (m$^2$)</td>
<td>40</td>
</tr>
<tr>
<td>Wing aspect ratio</td>
<td>12</td>
</tr>
<tr>
<td>$\tau$</td>
<td>0.2</td>
</tr>
<tr>
<td>Oswald efficiency</td>
<td>0.8</td>
</tr>
<tr>
<td>Zero-lift AoA (degrees)</td>
<td>0</td>
</tr>
<tr>
<td>Stall AoA (degrees)</td>
<td>12</td>
</tr>
<tr>
<td>Zero-lift drag coefficient for the wing #1</td>
<td>0.05</td>
</tr>
<tr>
<td>Zero-lift drag coefficient for the wing #2</td>
<td>0.05</td>
</tr>
<tr>
<td>Air density (kg/m$^3$)</td>
<td>1.21</td>
</tr>
<tr>
<td>Spring constant 1 (N-s)</td>
<td>30000</td>
</tr>
<tr>
<td>Spring Constant 2 (N-s)</td>
<td>200000</td>
</tr>
<tr>
<td>$l_s$ (m)</td>
<td>0.5</td>
</tr>
<tr>
<td>CL at stall AoA</td>
<td>1.5</td>
</tr>
<tr>
<td>CD at stall AoA</td>
<td>0.2</td>
</tr>
<tr>
<td>Amplitude of AoA control (degrees)</td>
<td>12</td>
</tr>
<tr>
<td>$\eta_{trans}$</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Kinematical Parameters

$\beta(t)$

$\frac{d\beta}{dt}$

AoA
Normal Force on the Wing #1
The Mean Shaft Power as a Function of Oscillation Frequency
Estimated Power Output and Efficiency of Medium-Size Oscillator
Power Scaling

Chart 1: Power vs. Actuator Area for HAWT and OWU

Chart 2: Power Coefficient vs. Actuator Area for HAWT and OWU
Design of Model OWU for Wind Tunnel Testing
Main Parts of Real Model OWU for Wind Tunnel Testing
Design Details: Counter Weight
Design Details: Servo Motors

Image above shows the location of the stepper motors and how they are driving the wing.
Design Details: Optical Encoder

Drawing above shows the optical encoder located at the end of the middle rod.

Image above shows the location of the optical encoder which is located at the end of the middle rod.
Model OWU in Wind Tunnel Test Section
Design Details: Computer Control
Typical RMS Voltage as a Function of Wind Speed at Different AoAs
Typical RMS Voltage as a Function of Wind Speed at Different Arm Angles
Conclusions

• An aerodynamics analysis has been made to evaluate the performance of the wind oscillator.

• A model wind oscillator has been designed and built for wind tunnel testing.

• The model wind oscillator is operational and ready for systematical wind tunnel testing.