Numerical Simulation for Optimization of Unsteady Rotating Wind Turbine

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Outline

- **Types of wind turbines**
- **Objective of this research**
- **Numerical Methods**
- **Simulation results**
- **Summary**
### Types of wind turbines

#### Four Categories of Wind Turbines

<table>
<thead>
<tr>
<th>Type</th>
<th>Rotated by Lift</th>
<th>Rotated by Drag</th>
</tr>
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<tbody>
<tr>
<td><strong>VAWT</strong></td>
<td>![Diagram 1]</td>
<td>![Diagram 2]</td>
</tr>
<tr>
<td>Vertical Axis Wind Turbine</td>
<td>Wind</td>
<td>Wind</td>
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<td><strong>HAWT</strong></td>
<td>![Diagram 3]</td>
<td>![Diagram 4]</td>
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1. **Darrieus wind turbines**
   - They are not affected by wind direction.
2. **Savonius wind turbines**
   - The wind direction is easy to change.
3. **Propeller type wind turbines**
   - They have great power generation efficiency.
4. **Dutch type wind turbines**
   - When rotating at a slow speed, the torque is also high.
Objective of This Research

Objective of this research

- In this study, we investigated the characteristics of rotating wind turbines and the time varying rotation in order to investigate the optimum wing shape.
- And I will change five parameters (blade length, wind turbine radius, overlap, gap, blade thickness) to find the optimum shape of wind turbines.

Parameter:
- Length
- Radius
- Overlap
- Gap
- Thickness

Direction: Optimization

Fig.1. Drag-type vertical axis wind turbin

Fig.2. A cross-sectional view of Fig.1
Objective of This Research

Steady rotation
- Wind turbine rotates at constant angular velocity.
- Examining basic characteristics for the design of wind turbines.
- Many studies have been done this research.

Unsteady rotation
- The rotation speed of a wind turbine changes.
- A study on the response of wind speed.
- Examples are small but important.

Activation example
Incompressible Navier-Stokes equations. Fixed on the rotating wind turbine.

Equation of continuity
\[ \frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \]

Incompressible Navier-Stokes equations
\[ \frac{\partial U}{\partial t} + U \frac{\partial U}{\partial X} + V \frac{\partial U}{\partial Y} - \omega^2 X + 2\omega V = -\frac{\partial p}{\partial X} + \frac{1}{Re} \left( \frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2} \right) \]
\[ \frac{\partial V}{\partial t} + U \frac{\partial V}{\partial X} + V \frac{\partial V}{\partial Y} - \omega^2 Y - 2\omega U = -\frac{\partial p}{\partial Y} + \frac{1}{Re} \left( \frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2} \right) \]

In Rotational coordinate system

\((X, Y)\) : Position
\((U, V)\) : Velocity

\(p\) : Pressure
\(t\) : Time
\(\omega\) : Angular velocity
\(Re\) : Reynolds number\((=10^5)\)
Numerical Methods

Fractional-Step method:

\[
\begin{align*}
U^* &= U^n + \Delta t \left\{ -U^n \frac{\partial U^n}{\partial X} - V^n \frac{\partial U^n}{\partial Y} + \omega^2 X - 2\omega V + \frac{1}{\text{Re}} \left( \frac{\partial^2 U^n}{\partial X^2} + \frac{\partial^2 U^n}{\partial Y^2} \right) \right\} \\
V^* &= V^n + \Delta t \left\{ -U^n \frac{\partial V^n}{\partial X} - V^n \frac{\partial V^n}{\partial Y} + \omega^2 Y + 2\omega U + \frac{1}{\text{Re}} \left( \frac{\partial^2 V^n}{\partial X^2} + \frac{\partial^2 V^n}{\partial Y^2} \right) \right\} \\
\frac{\partial^2 p^{n+1}}{\partial X} + \frac{\partial^2 p^{n+1}}{\partial Y^2} &= \frac{1}{\Delta t} \left( \frac{\partial U^*}{\partial X} + \frac{\partial V^*}{\partial Y} \right)\\
U^{n+1} &= U^* - \Delta t \frac{\partial p^{n+1}}{\partial X} \\
V^{n+1} &= V^* - \Delta t \frac{\partial p^{n+1}}{\partial Y}
\end{align*}
\]

Advection term => Third order upwind difference

\[
f \frac{\partial u}{\partial x} \bigg|_{x=x_i} = f \frac{-u_{i+2} + 8(u_{i+1} - u_{i-1}) + u_{i-2}}{12\Delta x} + \frac{|f|\Delta x^3}{12} \frac{u_{i+2} - 4u_{i+1} + 6u_i - 4u_{i-1} + u_{i-2}}{\Delta x^4}
\]

→Numerical stability for non-linear terms
Grid points: 141x141

External side: Uniform flow

On the blade: No-slip

Grid rotates with the wind turbine

**Boundary condition**

<table>
<thead>
<tr>
<th></th>
<th>Distant boundary</th>
<th>Wind turbine blade</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed</td>
<td>$u=0.1$</td>
<td>$u=0.0$</td>
</tr>
<tr>
<td></td>
<td>$v=0.0$</td>
<td>$v=0.0$</td>
</tr>
<tr>
<td>pressure</td>
<td>$\frac{\partial p}{\partial x} = \frac{\partial p}{\partial y} = 0$</td>
<td>Average pressure value near the point</td>
</tr>
</tbody>
</table>

Table.1 Boundary condition
Torque: the force that rotates the rotor

\[ \Delta N = \Delta x_w (p_{in} - p_{out})r \]

Equation of motion of a wind turbine

\[ I \frac{\partial \omega}{\partial t} = N - B \]

$I$: the Moment of inertia
$N$: Torque
$B$: Friction from rotation axis
Numerical Methods

Starting Characteristics

- Initial condition: No wind, turbine is in stationary state
- Wind start to blow → turbine starts to rotate with a delay
- Constant wind speed, the turbine continues to rotate at a constant speed
Simulation results

Vertical axis: torque coefficient (power of the wind turbine) (The bigger the Length1 & Length2 is, the bigger the torque is.)

Fig. 3. Analysis for Length1 & Length2 (Thickness=0.2, Overlap=Gap=0.0)
Simulation results

Vertical axis: torque coefficient (power of the wind turbine) (The bigger the thickness is, the bigger the torque is.)

Fig. 4. Analysis for thickness

Radius = 1

The biggest torque
Simulation results

Vertical axis: torque coefficient (power of the wind turbine)

Radius = 1

Fig. 5. Analysis for Overlap & Gap

Fig. 6. The biggest torque of ①~⑯

Overlap = 0.2
Gap = 0.2

Overlap = 0.3
Gap = 0.3

The biggest torque
Summary

• In this study, we investigated the characteristics of rotating wind turbines and investigated the time varying rotation in order to investigate the optimum wing shape.

• Five parameters (blade length, wind turbine radius, overlap, gap, blade thickness) were changed, and optimum shape was obtained.

• The tendency of simulation results qualitatively agreed with the experimental results for steady rotating wind turbines.
Future research

In order to improve the efficiency of wind turbines, the simulation is carried out in the case where multiple wind turbines are installed close.
Chinese Proverbs

When the wind changes, some people build a wall, and others make a wind turbine.

Don't be afraid of change!

That means, when the environment changes, different people have different attitudes, some people have a passive attitude, refusing all challenges, and some people adapt to the situation.