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An Innovative Umbrella-type Rotor of Horizontal Axis Wind Turbine to Regulate Power and Reduce Wind Thrust

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Abstract

- Innovative umbrella-type rotor is proposed, aiming at active power regulation and wind thrust reduction.
- Corresponding folding mechanism is designed to refine loads on hub. Truss-frame structure principle is sufficiently used.
- Wind tunnel experiments are conducted to offer supporting data.
- Multi-body dynamic analysis of umbrella-type rotor is conducted.
- Umbrella-type rotor is found to effectively regulate power and wind thrust. The innovative rotor bears lower wind thrust than the pitch regulated type.
- Torques and moments acting on the hub are considerably reduced and bending moment is converted to the tension mode.

Umbrella-type rotor concept

Innovative rotor concept

- Blades is folding upstream at hub.
- Folding axis inclines to blade extension direction, tilting down to the rotor revolution direction.
- Pitching and coning coupled.
- Rotor coning leads to extra wind thrust reduction.

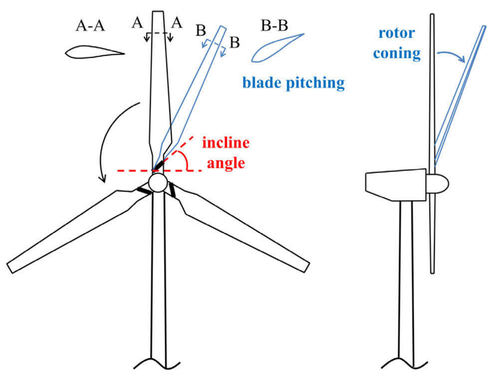


Fig. 1 Concept of innovative umbrella-type rotor

Folding mechanism

- Inclined hinge connects blade and hub.
- Screw rod is fixed on hub center line, driven by the motor.
- Link rod connects blade root and slider with spherical joints.
- Slider is driven to move along the screw rod and blades are folded.
- Bending moment on hub is converted to link rod tension and screw rod compression.
- The patent authorization is in process [1].

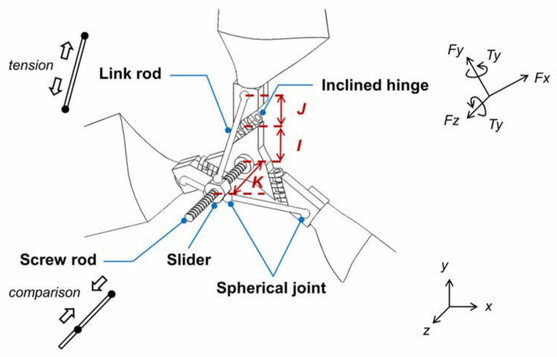


Fig. 2 Schematic diagram of folding mechanism

Wind tunnel experiment

Experiment setup

- Rotor test system: measure rotor mechanical power.
- Rotor is evaluated by Cp (power coefficient) and Ct (thrust coefficient).

Blade profile and tested rotor

- Blade: scaled down "NREL PHASE VI " blade with a length of 0.3 m, pitched at 18.18°.
- Rotor: 3 blades with a diameter of 0.65 m.
- Incline angle: 30°, 45° and 60° and pitch regulated rotor.

Experiment scheme

- Wind speed: 4 m/s; Hinge incline angle: 45°.
  → rotor potential to regulate Cp and Ct.
- Speed: 200 RPM (const.); Power: 0.521 watt (const.); Rotor: incline angle of 30°, 45°, 60° and pitch regulated; Wind speed: increasing from 4 m/s.
  → Fold angle variation along wind speed and Cp regulation sensitivity comparison.
  → Wind thrust comparison between umbrella-type and pitch regulated rotor.

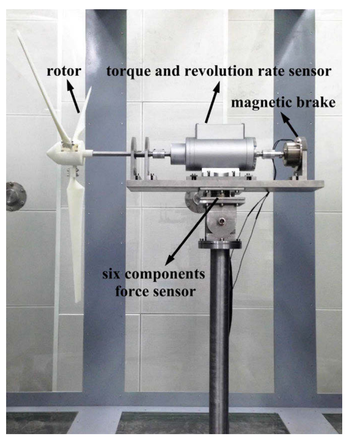


Fig. 3 Rotor test system

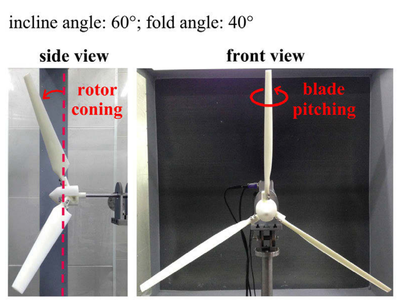


Fig. 4 Tested umbrella-type rotor

Wind tunnel experiment results

Power coefficient and thrust coefficient

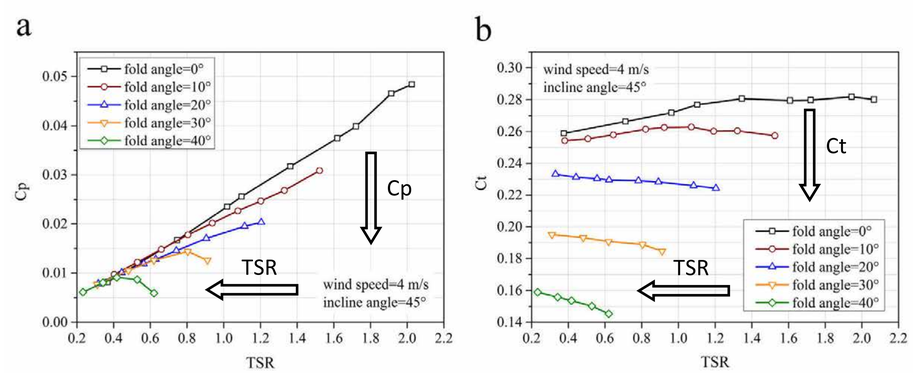


Fig. 5 Umbrella-type rotor performance: (a) Cp variation along TSR and (b) Ct variation along TSR

Wind tunnel experiment results

- Drastic drop of both Cp and Ct, and a shift of TSR to lower range.

→ Potential to reduce power and wind thrust, and to limit speed in high wind speed.

Constant power output and Cp regulation sensitivity

- Under increasing wind speed condition, fold angle adjustment is less in case of larger incline angle to limit power output growth.
- Larger incline angle leads to higher Cp regulation sensitivity.

→ Incline angle magnitude dominates rotor power regulation sensitivity.

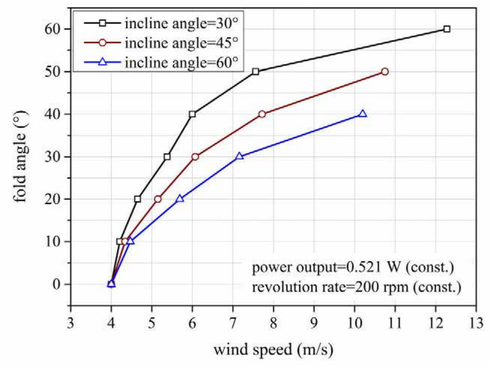


Fig. 6 Fold angle variation along wind speed to maintain constant power

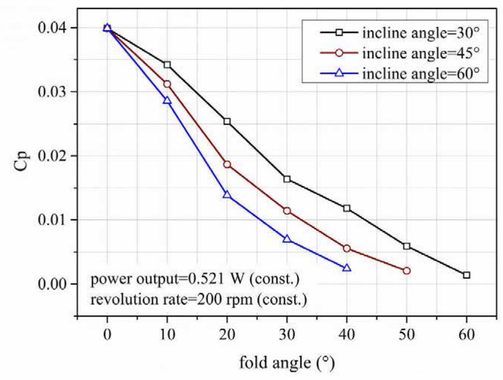


Fig. 7 Umbrella-type rotor Cp regulation sensitivity

Wind thrust comparison

- Under identical power output condition, wind thrust on umbrella-type turbine is less than that on pitch regulated type.
- Smaller incline angle is, less wind thrust the umbrella-type turbine bears.

→ Rotor coning leads to extra wind thrust reduction.

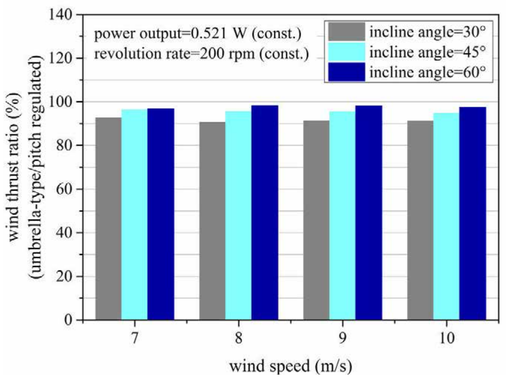


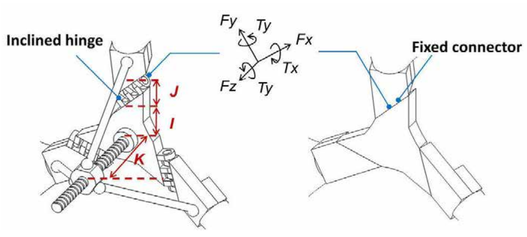
Fig. 8 Wind thrust ratio of umbrella-type to pitch regulated turbine

Case study: rotor multi-body dynamic analysis

- Analyzed rotor consists of 3 "NREL PHASE VI" blades which are pitched at 3°. Rotor hinge incline angle is 45°and fold angle is 20°. Revolution rate is 71.63 RPM and wind speed is 10 m/s. I=0.33 m, J=0.515 m, K=0.54 m.
- Wind loads are calculated using the code developed by the authors. Blade gravities and centrifugal forces are obtained based on data provided in Ref. [2]. The loads are applied to each blade which is divided into 11 elements. The multi-body dynamic analysis is conducted using ADAMS software.

Tab. 1 Force components on inclined hinge and fixed connector

	Fx	*Fy*	*Fz*	*Tx*	*Ty*	*Tz*
Inclined hinge	-6791 N to -4733 N	-5985 N to -5493 N	4775 N to 5579 N	0 Nm	-610 Nm to 71 Nm	-534 Nm to 1361 Nm
Fixed connector	4269 N to 5556 N	4540 N to 5827 N	-258 N	-3362 Nm to -2901 Nm	2862 Nm to 3322 Nm	-8 Nm to 1934 Nm



- Moments on inclined hinge are much less than that on fixed connector.
- Bending is converted to link rod tension which is between 14966 N to 17344 N.

→ The folding mechanism well refines the load distribution on hub.

Conclusions

- An innovative umbrella-type rotor is proposed. Experiment result indicates that innovative rotor is capable in regulating Cp and Ct.
- Constant speed of 200 RPM and power output of 0.521 watt in increasing wind speed are achieved with the umbrella-type rotor models.
- Innovative rotor is more desirable in reducing wind thrust than pitch regulated type. Rotor coning leads to extra wind thrust reduction.
- Incline angle magnitude dominates rotor power regulation sensitivity.
- Folding mechanism for umbrella-type rotor is proposed. Bending moment on hub is reduced and converted to link rod tension mode.

Acknowledgement

- The authors gratefully acknowledge the support of the National Natural Science Foundation of China (No. 51575296).

Reference

[1] Chinese invention patent: 201510917639.0 (authorization in process).
[2] Jonkman JM. "Modeling of the UAE wind turbine for refinement of FAST_AD". NREL (National Renewable Energy Laboratory) technical report, NREL/TP-500-34755; 2003.