Multiple-degree-of-freedom actuation of rotor loads in model testing of floating wind turbines using cable-driven parallel robots

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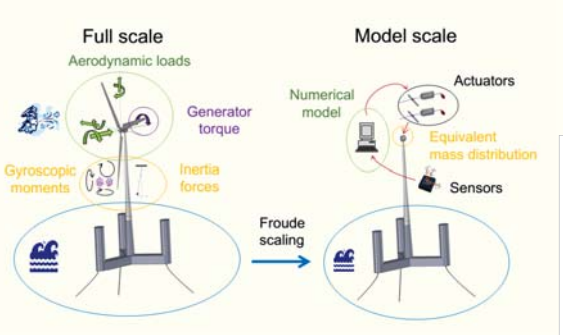


ReaTHM® testing circumvents limitations of hydrodynamic laboratories, and in particular inherent issues of physical wind/wave testing of floating wind turbines. The rotor and wind field are numerical and interact in real tim with the scale model subjected to physical hydrodynamic loads, by means of sensors and actuators.

Actuator requirements:
- Force-based (actuate loads, not motions)
- Multiple-degree-of-freedom (thrust, pitch and yaw moments, gen. torque, hor. shear force)
- Large workspace (follow the structure anywhere it moves)
- High accuracy and bandwidth (up to 3p frequency)

→ Cable-driven parallel robots (set of motor-winch-cable 1DOF actuators)

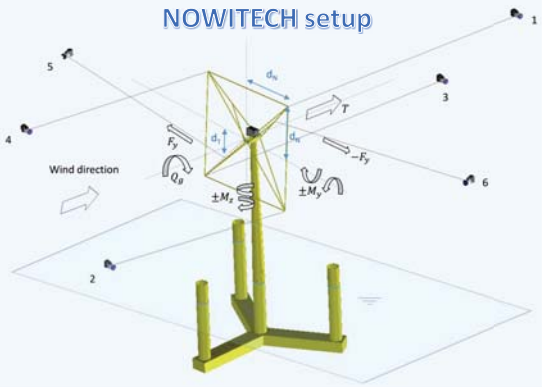
→ Lines should be kept in tension → One more line than actuated load components

1. From where and in which direction should they pull on the structure?
2. How to allocate tensions from rotor loads, and how to control pretension?

$$Line\ tension\ setpoint\ vector = f(motor\ locations, line\ attachment\ point\ locations\ on\ structure, motions, loads\ to\ actuate, pretension)$$

1 Design

NOWITECH setup

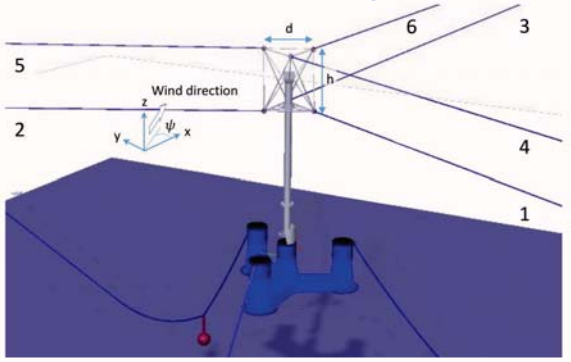


Line nr	Function
1	Thrust force/2 + Pitch moment/2d_N + Pretension
2	Pitch moment/2d_N – Yaw moment/2d_N + Pretension
3	Thrust force/2 – Yaw moment/2d_N + Pretension
4	Pretension
5	Generator torque/2d_T + Shear force/2
6	Generator torque/2d_T – Shear force/2

Similarity with physical rotor: *Intuitive*

VS

LIFES50+ setup



Rotational symmetry: *Flexible*

- Each line contributes to each load component depending on the wind direction ψ
- Pretension is added to all lines

Coefficient line nr i	Load component
$cos\left(\psi+\frac{2i\pi}{3}\right)/3$	Thrust force
$-sin\left(\psi+\frac{2i\pi}{3}\right)/3$	Shear force
$(-1)^{\lfloor\frac{i+2}{3}\rfloor}\frac{2}{3h}sin\left(\psi+\frac{2i\pi}{3}\right)$	Generator torque
$(-1)^{\lfloor\frac{i+2}{3}\rfloor}\frac{2}{3h}cos\left(\psi+\frac{2i\pi}{3}\right)$	Pitch moment
$(-1)^{\lfloor\frac{i+2}{3}\rfloor}\frac{1}{\sqrt{3}d}$	Yaw moment

2 Allocation strategy

Minimize Euclidean norm of line tension setpoint vector: stay close to reference
Convenient

VS

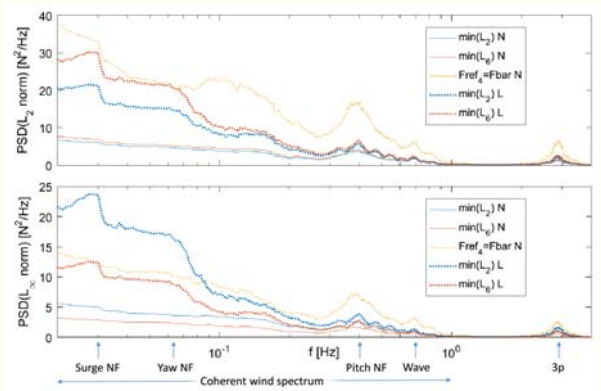
Specify tension on one particular line
Intuitive

VS

Minimize higher-order norm of line tension setpoint vector: stay away from slack and peaks
Performant

Results

Power spectral densities of Euclidean and infinte norms of commanded tension vector at near-cutout condition (25 m/s), from LIFES50+ model tests



1. Line tensions need to adjust for changes in model orientation more with the LIFES50+ setup than with the NOWITECH one
   → Higher line tensions, as a drawback among the many avantages of the LIFES50+ setup

2.
   - The intuitive strategy (setting line 4 to reference tension in NOWITECH setup) gives physical meaning to the cost of much higher tensions
   - Using higher-order norm as minimization objective is significantly more effective in keeping tensions further away from slack and excessively high values than using the Euclidean norm. The tensions still stay close to reference when using higher-order norms. → It should be used
   - The choice of the norm to minimize is less important for the NOWITECH setup

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KPN Hybrid
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References

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