Support structure load mitigation of a large offshore wind turbine using a semi-active magnetorheological damper

Rasoul Shirzadeh, Martin Kühn

ForWind – Center for Wind Energy Research, Oldenburg, Germany

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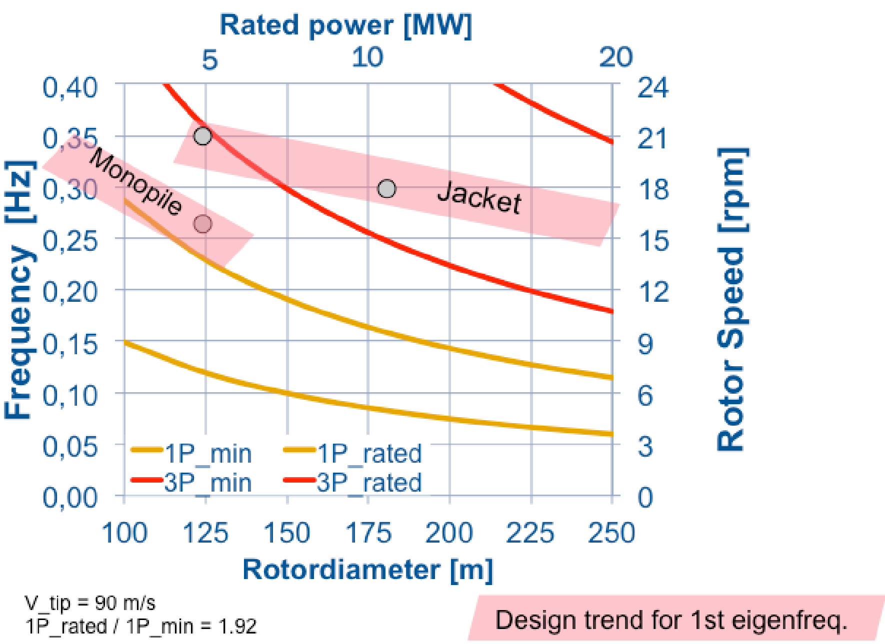
Support by:

Introduction

- The rotor diameter and the tower height sizes are pushing the engineering limits!
- Direct upscaling of support structure from 5 MW reference wind turbine → rotor-tower resonance problem

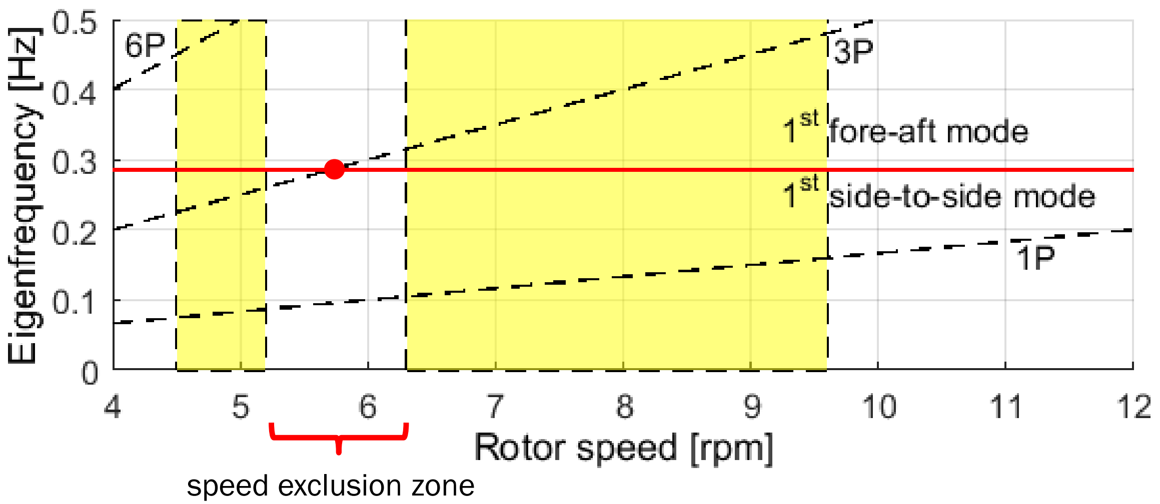


- Monopile foundations are limited up to 6-8 MW class
- Jacket structure is the most economic option for large wind turbines
- A strong and severe 3P resonance is expected for WTs with jacket foundation

Support by:

Campbell diagram

INNWIND.EU 10MW Reference Wind Turbine

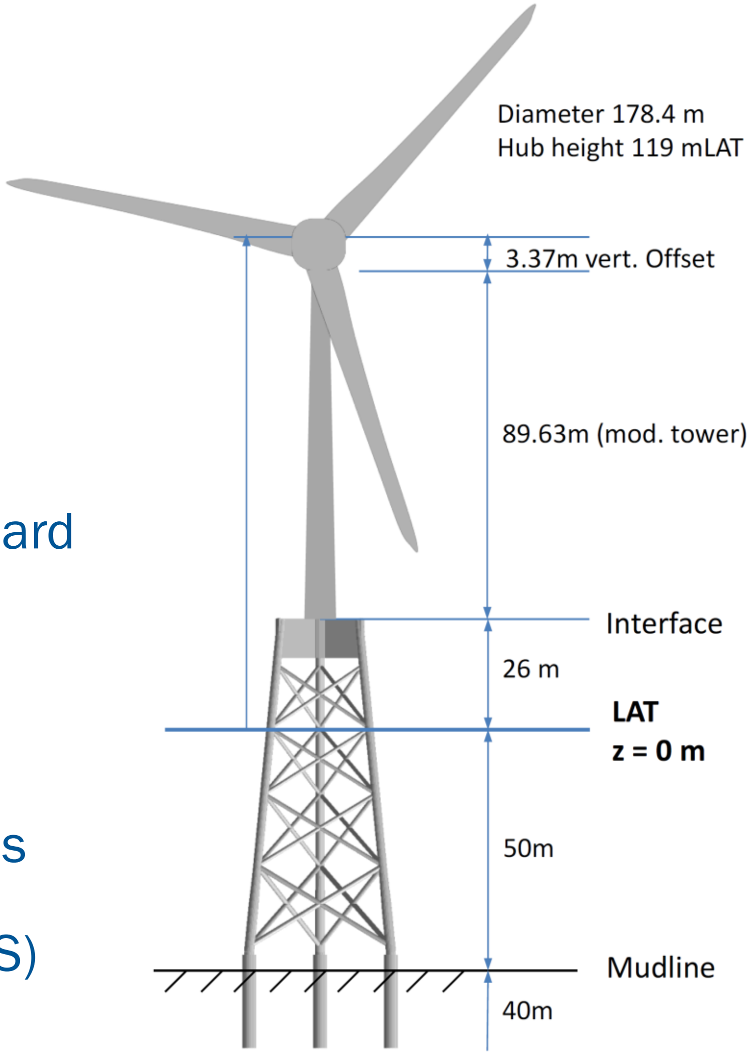


- Coincidence of the 3P mode and the first fundamental mode at 5.7 rpm → dynamic excitation
- Solution: mitigation via control strategy using an exclusion zone between 5.2 and 6.3 rpm

Support by: SEVENTH FRAMEWORK PROGRAMME

Numerical simulations

- OWT type: INNWIND.EU 10MW
- Aeroelastic simulations: DNV GL Bladed software
- Foundation: 4-leged jacket structure
- DLC 1.2 according to IEC61400-1 standard for operational condition
- Wind-wave misalignment: 0°
- 10 min simulations with 6 random seeds
- Post-processing: Fatigue Limit State (FLS)



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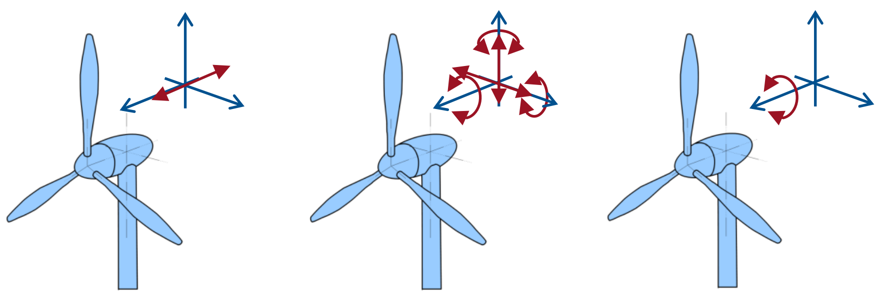
Load mitigation strategies

- Structural control and regulation

e.g.: active tower damping (collective pitch control, individual pitch control, generator torque, active idling)

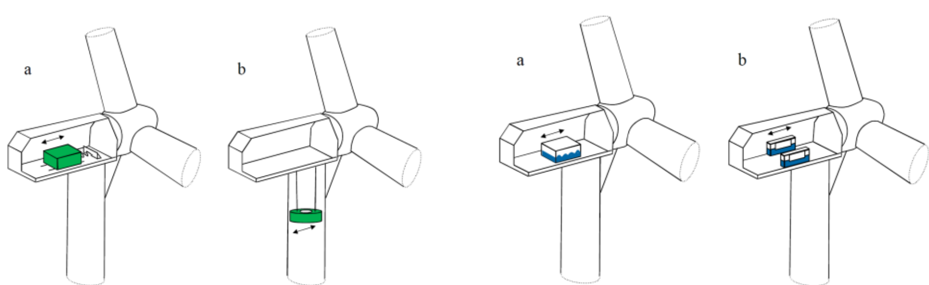


collective pitch

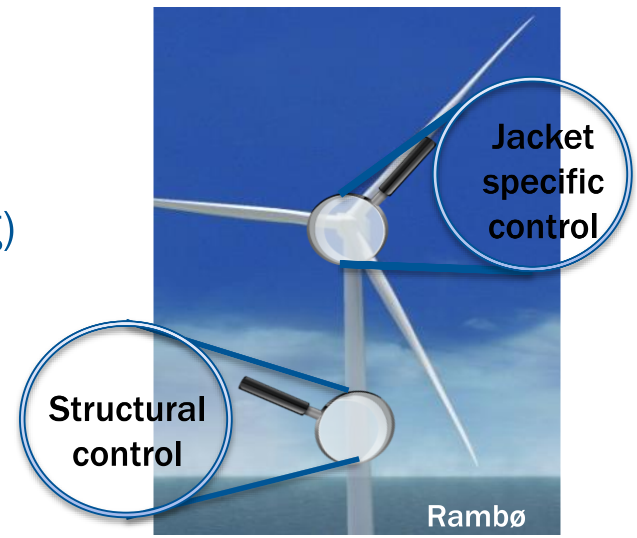
individual pitch

generator torque

- Damping devices, e.g. passive or (semi)-active



[O. Altay et al, RWTH Aachen, EURODYN 2014]



Interface loads

Support by:

Semi-active Magneto-rheological (MR) damper

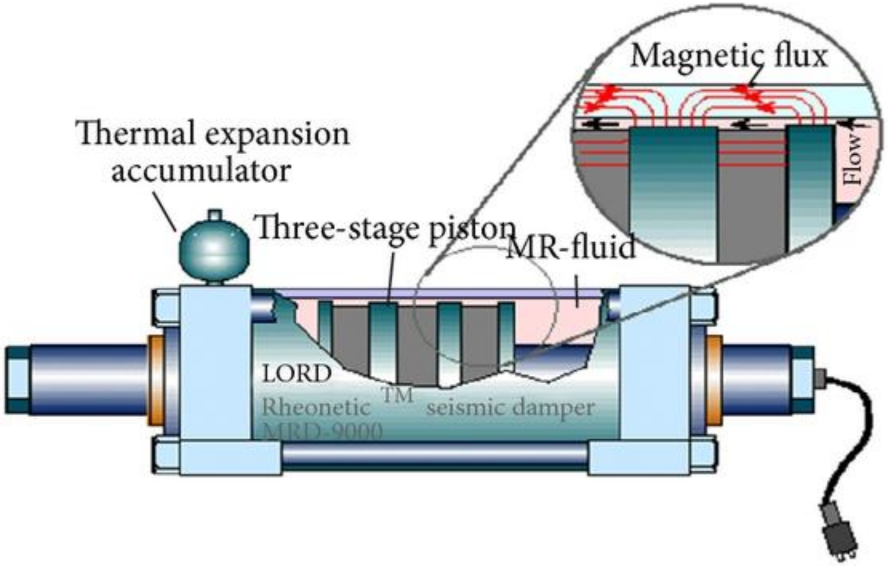
Main characteristics:

- requires low power sources, i.e. only several watts are needed to generate damper force as big as 3 kN.
- fast response time, i.e. less than a few milliseconds,
- can be easily controlled
- quite stable within a broad temperature

range between -40 to 150°C

20 t MR damper

- Inside diameter: 20.3 cm
- Stroke: 8 cm
- Length: 1 m
- Mass: 250 kg



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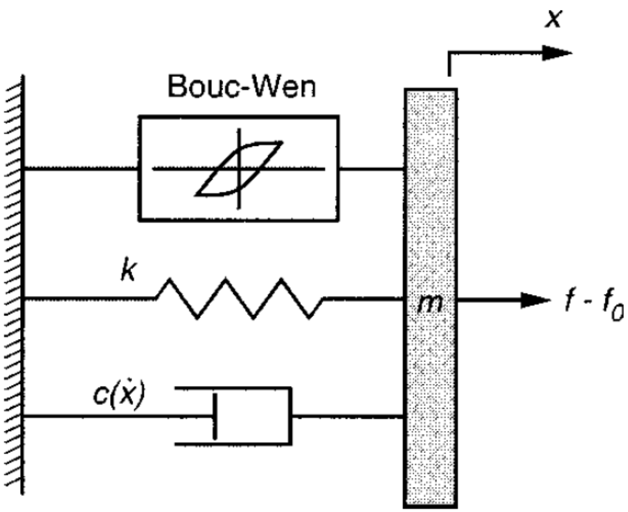
Semi-active MR damper modeling

Yang's model for MR dampers

$$f - f_0 = m\ddot{x} + c(\dot{x})\dot{x} \ + k\dot{x} + \alpha z$$

$$\dot{z} = -\gamma|\dot{x}|z|z|^{n-1} - \beta\dot{x}|z|^{n} + A\dot{x}$$

$$c(\dot{x}) = a_1 \ e^{-(a_2 \ |\dot{x}|)^{p}}$$



m: equivalent mass of the MR fluid which accounts inertia effects,
k: accumulator stiffness,
f_0: damper friction force resulted from seals and measurement bias,
$c(\dot{x})$: post-yield damping coefficient,
$\gamma.\beta.\alpha$ and A: parameters to adjust the shape of the hysteresis loop,
a_1, a_2 and *p* are positive constants.

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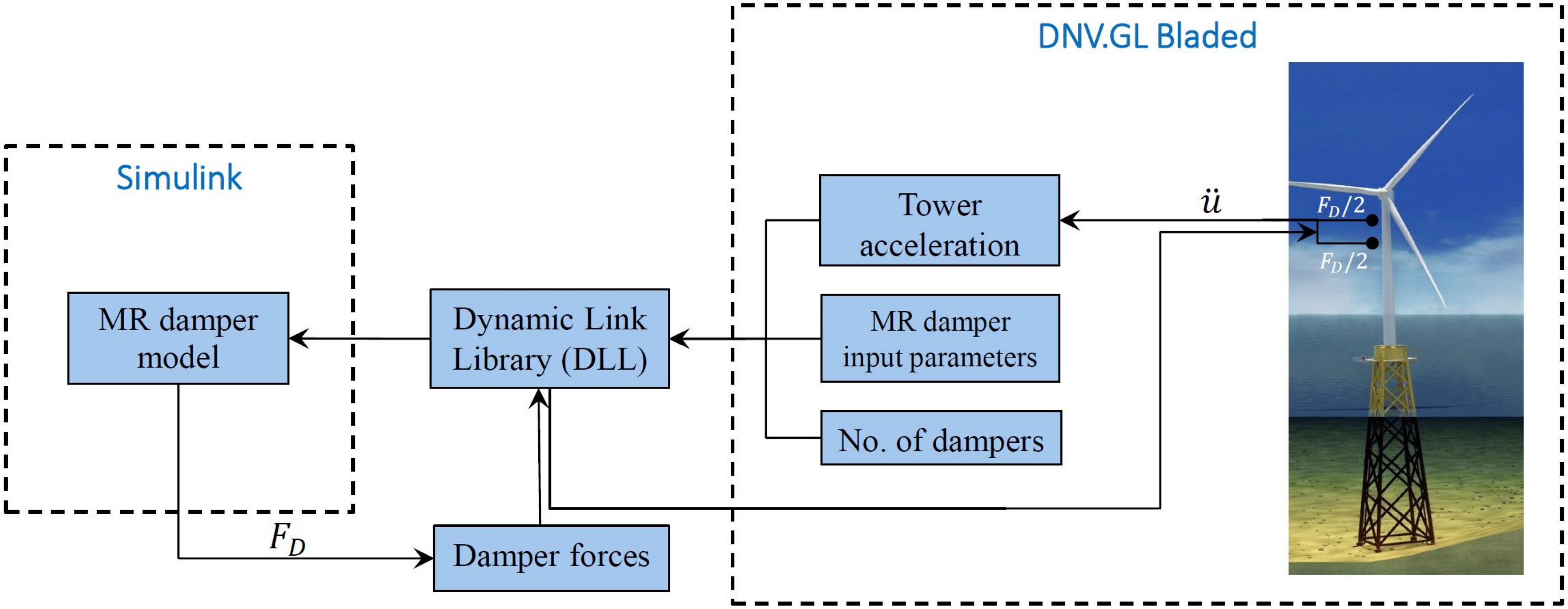
Implementation of semi-active MR damper

Numerical modeling of the MR damper shows the mechanism to calculate the damper forces using the tower accelerations.



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Results

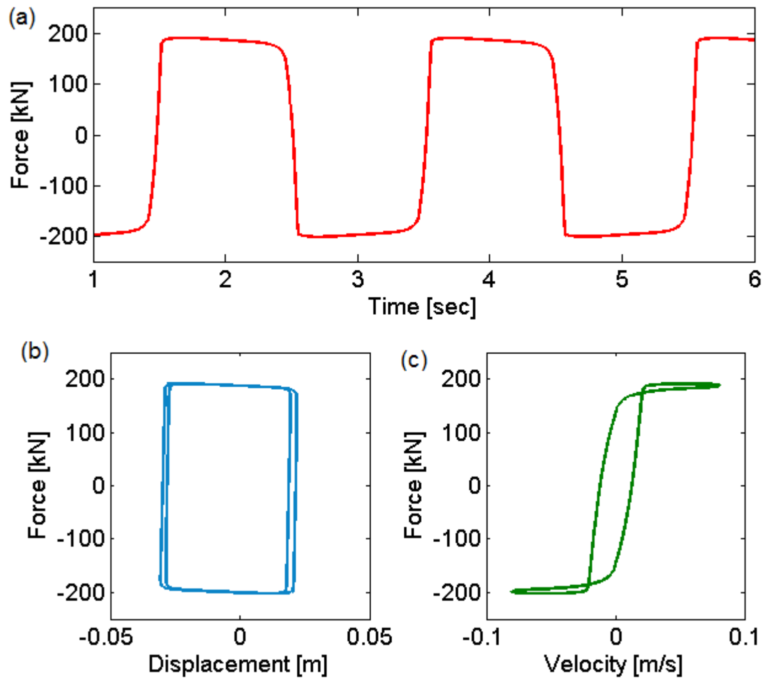
Validation of MR damper model

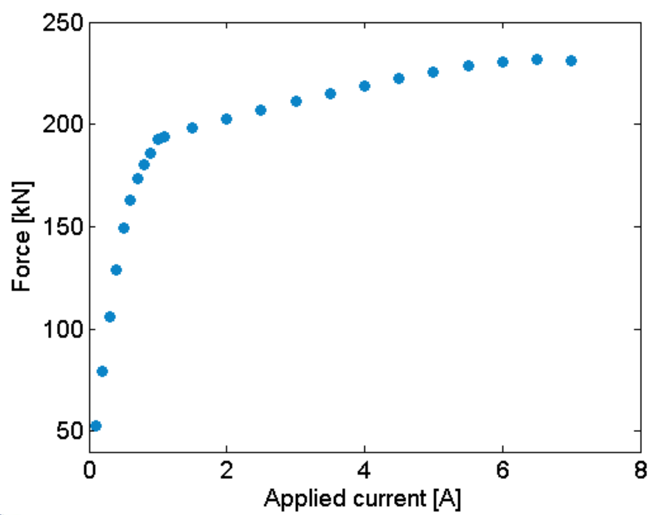
Input:

Sinusoidal displacement excitation with A=1 in and f=0.5 Hz

Output:

Damper force





Damper force vs. applied current

For this study: *i*=2 A

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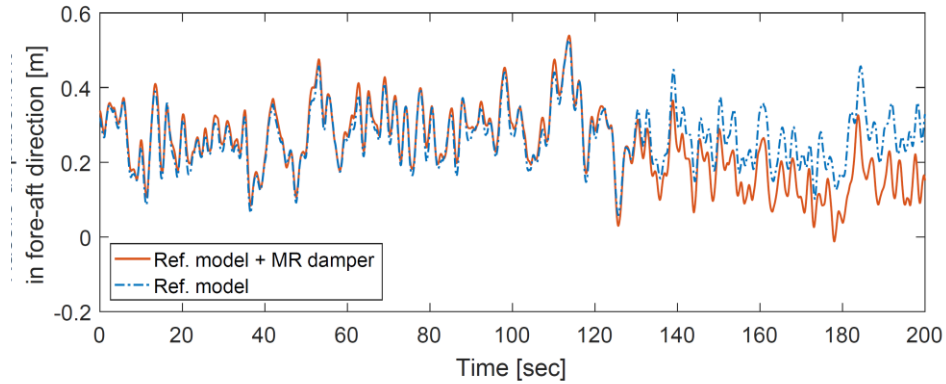
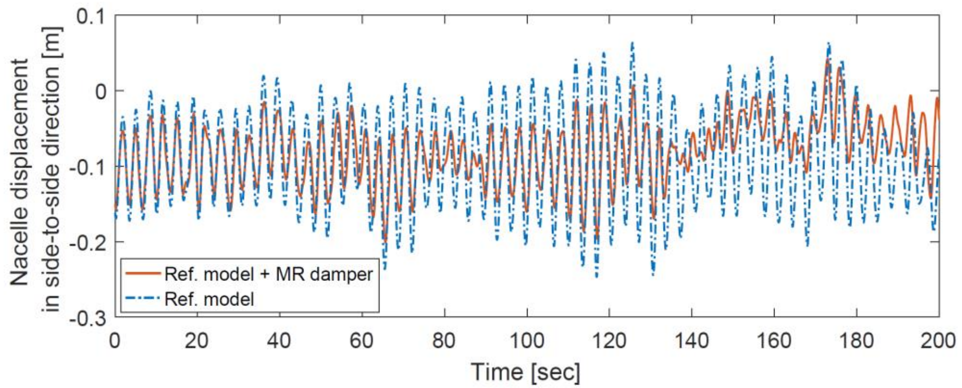
Results

Nacelle displacement with and without MR damper at 22 m/s mean wind speed

fore-aft



side-to-side



- Two MR dampers in 0º and 90º
- Tower top vibrations are dissipated mainly in the sideways direction

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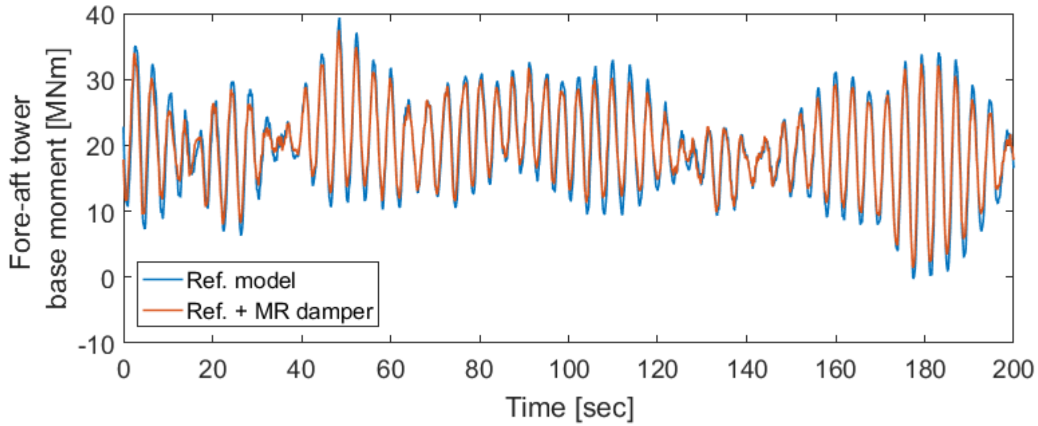
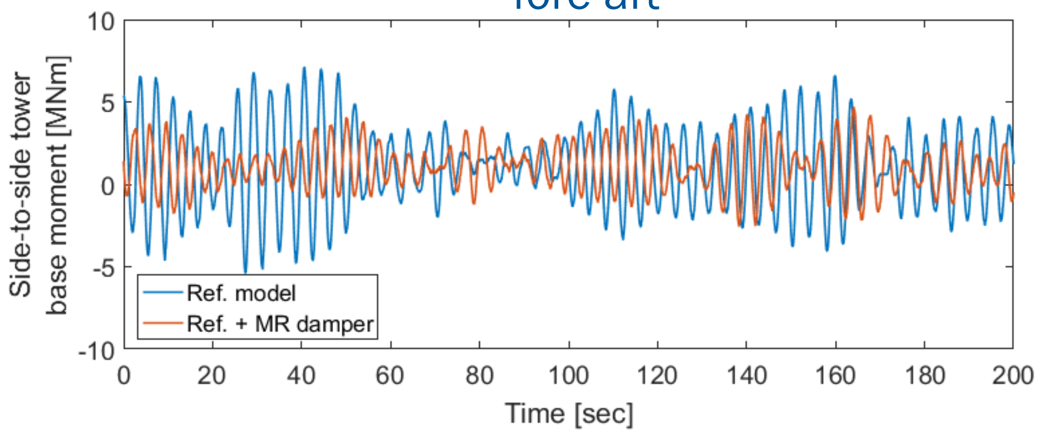
Results

Tower base moment with and without MR damper at 4 m/s mean wind speed



fore-aft



side-to-side

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Conclusions

- The numerical model of a semi-active MR damper is developed to mitigate the structural vibrations at the tower top location

- The preliminary results show that the semi-active damper can effectively alleviate the external loads within the whole operational range

- The integration of the semi-active dampers in the early stage phase of the jacket design could significantly alleviate the interface loads which would result in an optimized and economic jacket structure.

Support by:

Acknowledgment

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Thanks for your attention.

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