CONTROL STRATEGIES FOR MECHANICAL VIBRATIONS OF WIND TURBINES

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Mechanical vibrations of Wind Turbines

WT are complex structures with ***several degrees of freedom***

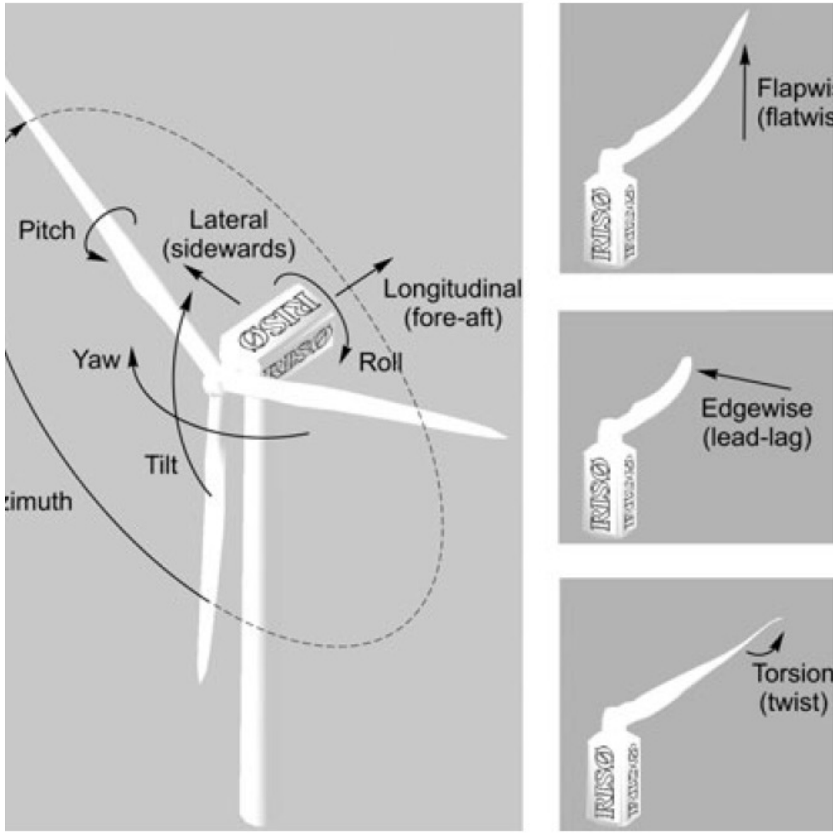
- Tower (fore-aft, lateral)
- Rotor (fore-aft, latereral, yaw, tilt)
- Blade (bending, torsion)

WT vibration mechanism is a ***complex, multicoupling-phenomena:***

- *tower vibrations: coupled wind–rotor–tower system, mechanical transmission twist vibration, and rotor rotation*

Effects of Structural Vibrations on the WT

- Lifetime reduction of the components (blades, main shaft, bearings, generator, gearbox, etc.)
- Fatigue damage
- Possible structural failure (structural resonance)
- Reduction of power production

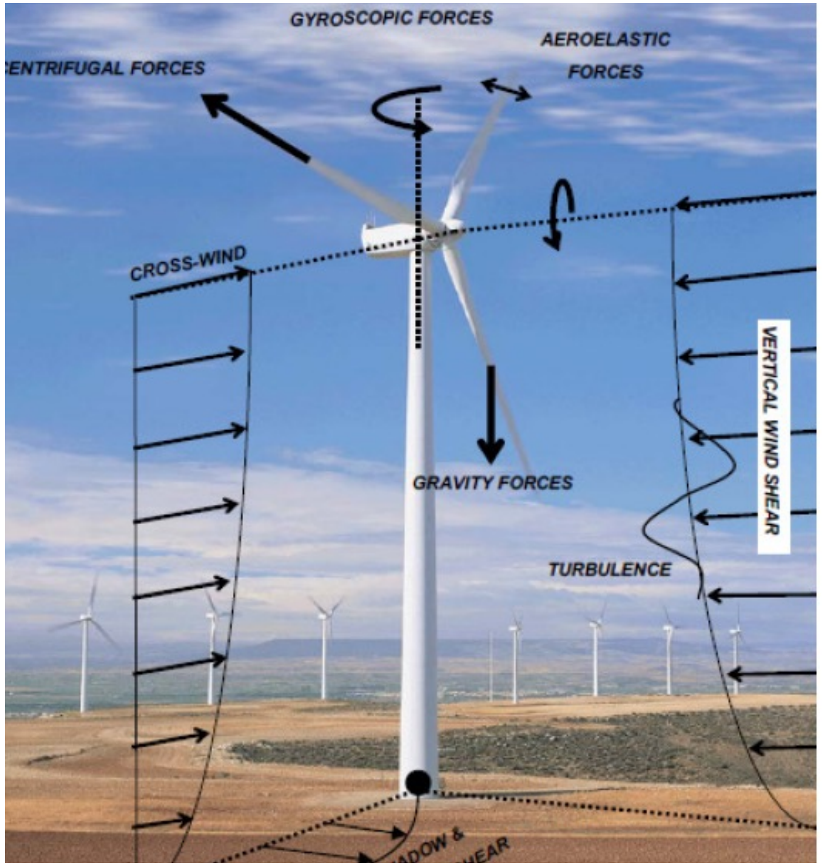


Mechanical Vibrations of Wind Turbines

✓Blade vibrations are the most important and propagate to other components of the structure

✓They are mainly caused by

- induced loads and turbulence
- gravity
- mass and aerodynamic imbalances
- effects of sorrounding WT (wake and tower shadowing)



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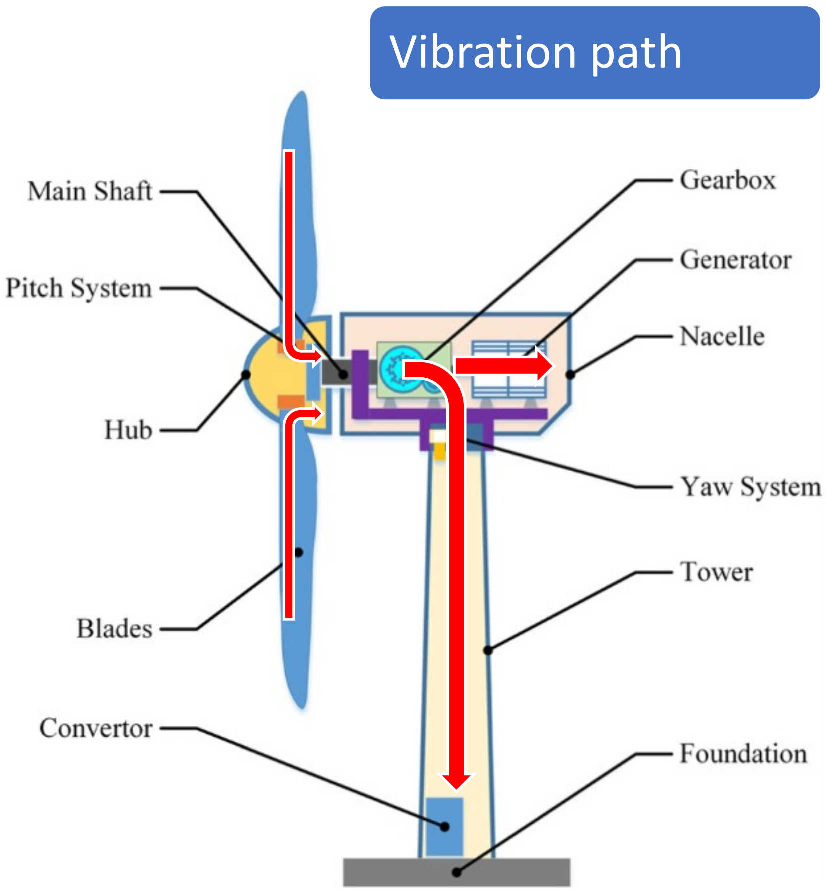


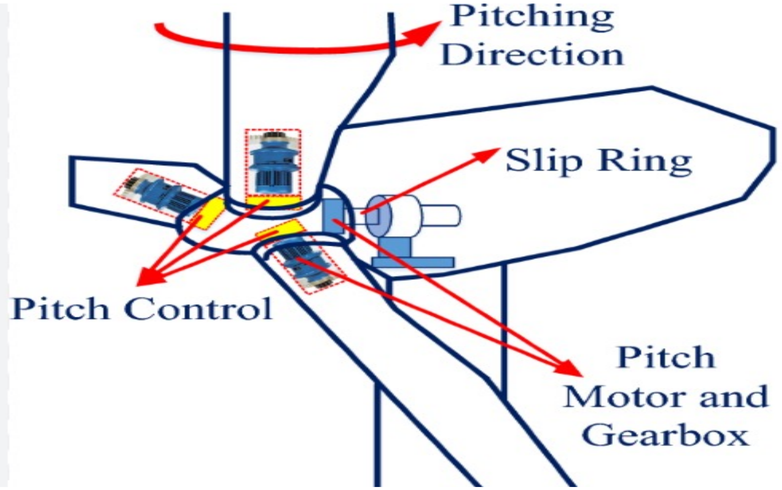
Vibrations control systems

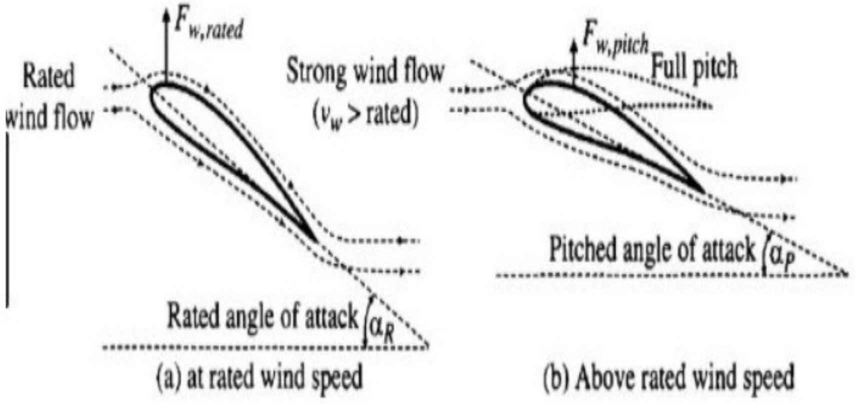
- Advanced Blade Pitch Control
- Flow control
- Tuned mass dampers
- Active tendons
- Piezoelectric materials

Advanced Blade Pitch Control

- ✓ modern wind turbines use the variable speed topology and collective pitch control **to maximize energy production** in the regimes beyond the rated speed
- ✓ advanced blade pitch control methods alleviate blade loads without significative power output reduction

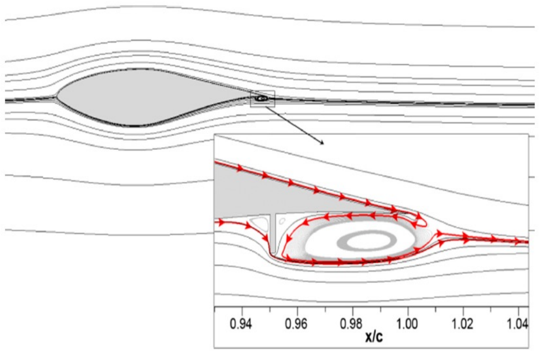
  - Cyclic pitch control reduces effect of gravity loads
  - A tiny increase of blade pitch angle reduces loads over the tower in the far aft direction caused by wind turbulence and thus the tower vibration with little impact on the power generated
  - individual pitch control: 20–40% fatigue load reduction, 20–25% root bending moment reduction

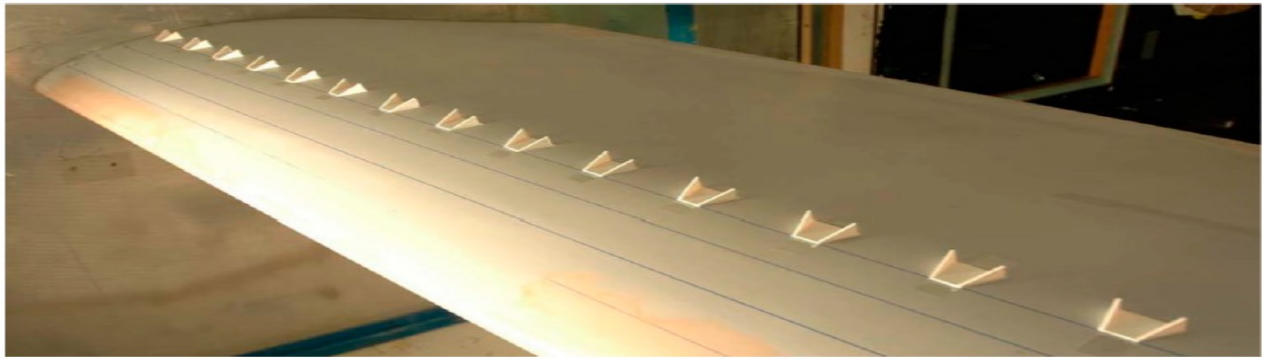




Flow control

- ✓ Distributed actuators and sensors controlled by a microprocessor applied to control loads of wind turbine blades.
- ✓ Flow control reduces drag, increase lift and flow mixing, and contribute to flow-induced noise reduction
- ✓ Most flow control systems originated from the aircraft industry and were adapted to wind turbines:
  - Trailing-Edge Flaps & Micro Flaps
  - Microtabs
  - Miniature Trailing-Edge Effectors (MiTEs)
  - Synthetic Jets
  - Vortex Generators

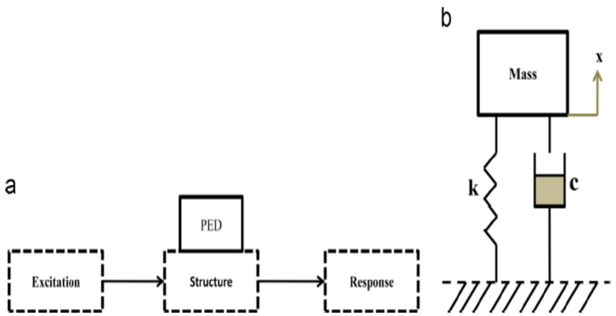




Tuned mass damper (TMD)

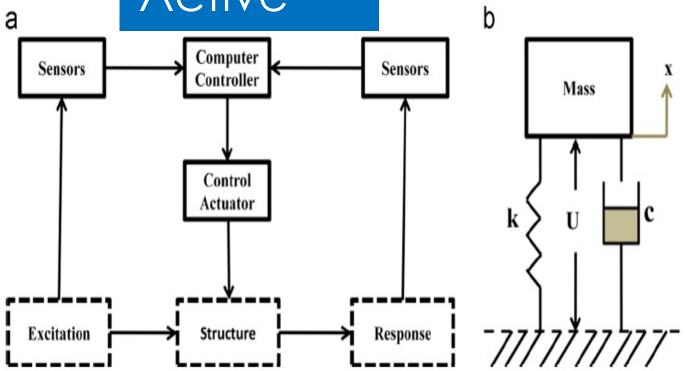
- ✓ Additional mass attached to the main structure (blade, the tower, or the nacelle) using springs and dashpot element
- ✓ Effective and reliable for different civil engineering applications need for tests before extensive use for Wind Energy to evaluate the effects of the additional mass introducing an extra load over the whole structure

Passive



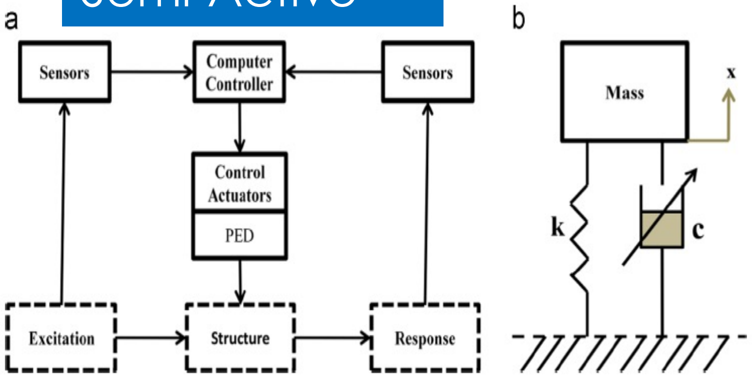
- only springs and dampers
- control forces are developed from the motion of the structure itself
- up to 50% reduction of nacelle sway, tower and blades displacement and for Offshore WTs (Numerical simulations and analytical models)

Active



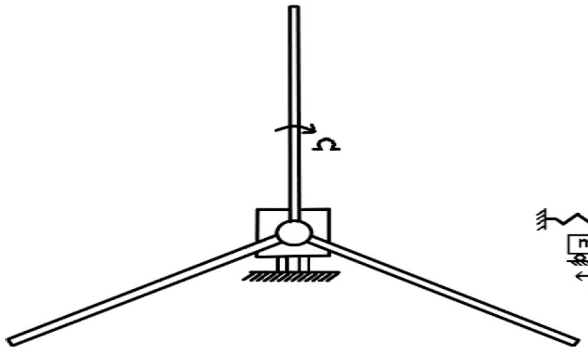
- one or more electro-hydraulic actuators apply torques or forces to mitigate the structural vibration according to a control law (Controller)
- external power supply is required
- main tower base bending moment reduced up to 20% in the extreme cases and around 10% in fatigue (viscous damper systems)

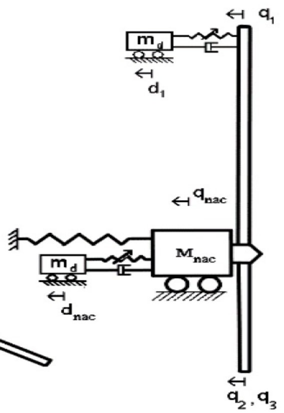
Semi-Active

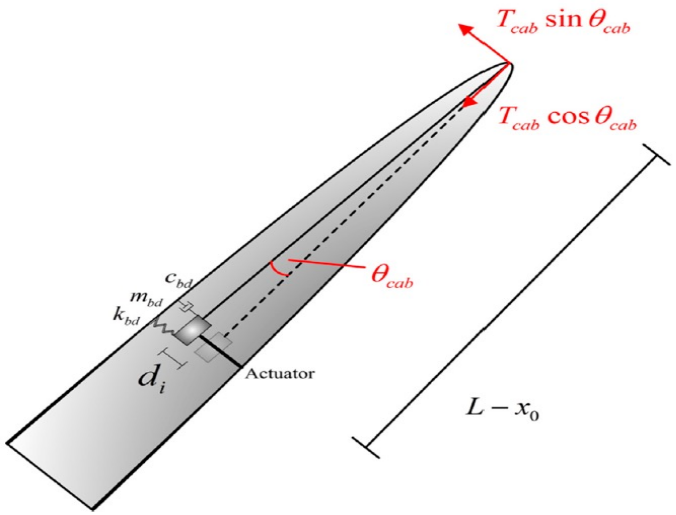


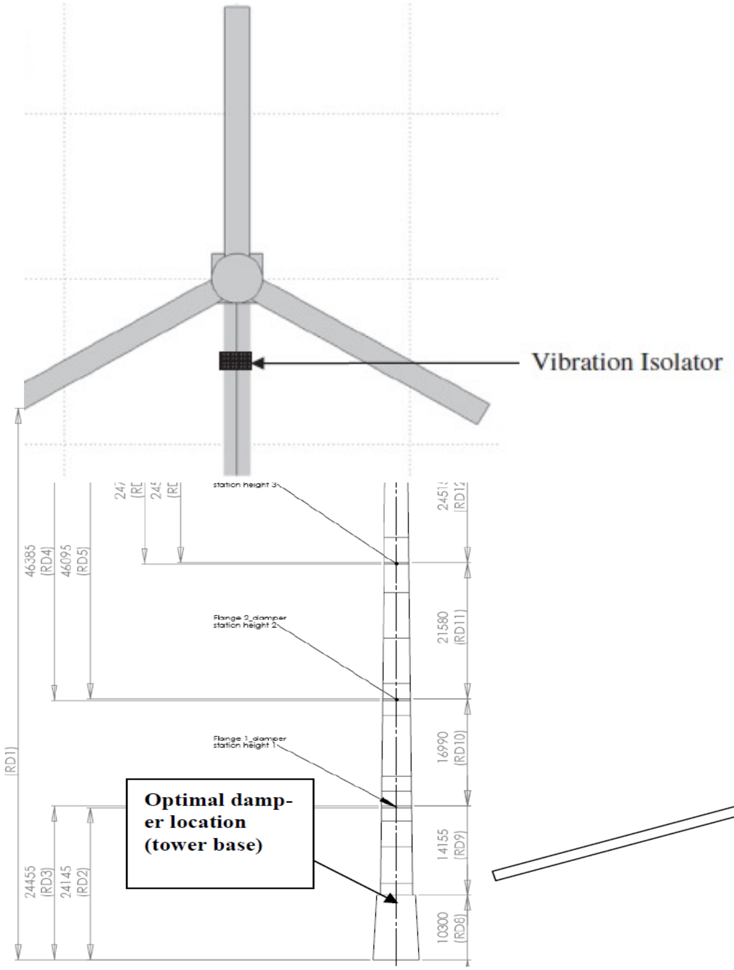
- combining best features of both methods (adjustable force with controllable dumping+ Low Power requirement)
- In-plane vibration control at higher turbulent loadings of wind turbine blades

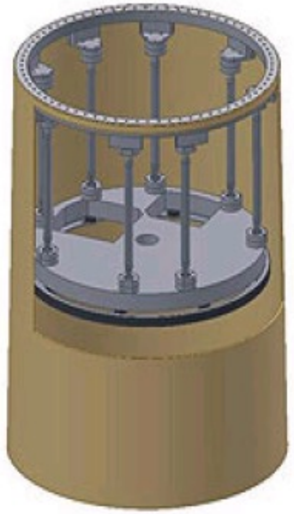
Tuned mass damper (TMD)

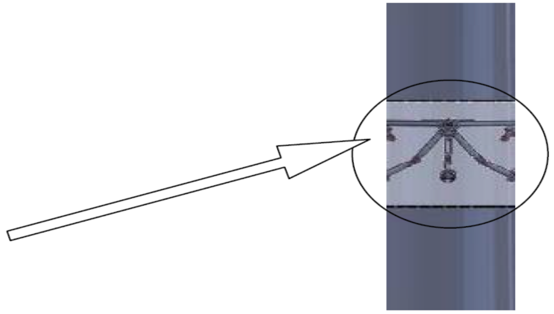












Tuned Liquid Damper (TLD)

- ✓ container partially filled with a fluid that acts like a mass damper, when the structure is excited by external forces, the liquid oscillates reestablishing the system equilibrium
- ✓ Usually installed on top of the tower
- ✓ Active and Semi-Active configurations provide better results than Passive ones
- ✓ Dissipation of low amplitude oscillations unlike TMD

Advantages

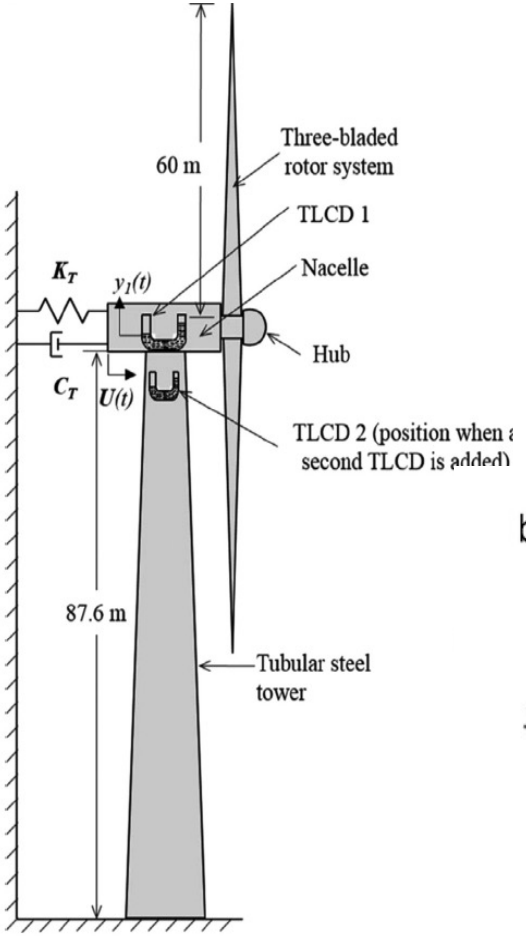
- Reliable and robust over a wide range of excitation levels
- Easy to install(low initial and maintenance costs)
- No need to overcome high slip loads like the TMDs

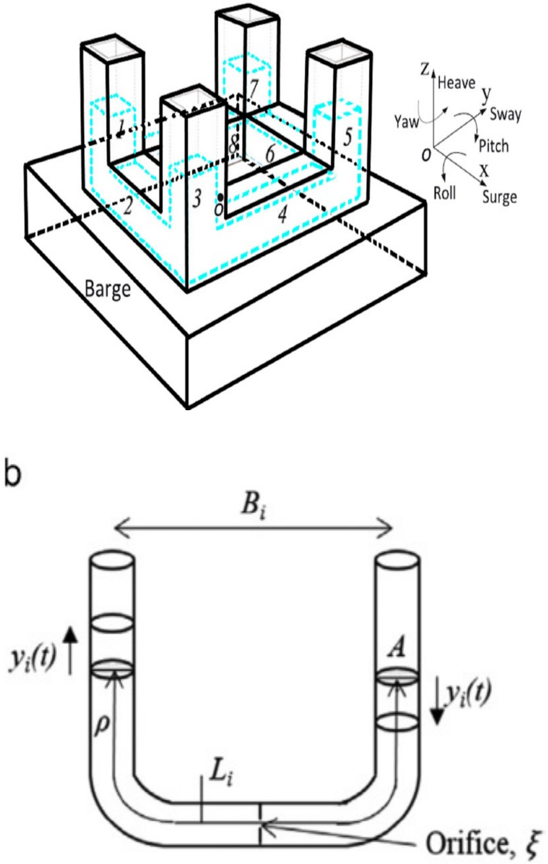
Disadvantage

- Significant mass of the system (1–2%)
- Limited frequency band covered (the device is tuned to the natural frequency of the system)
- The position of these actuators in blades needs further exploration
- More experimental tests are required to validate the vast amount of numerical simulations

Tuned Liquid Damper (TLD)

- ✓ Several shapes available for the container
  - U-shape is the most used
  - Tuned Liquid Column Damper (TLCD) is the most feasible and efficient according to simulations and studies (up to 55%-70% reduction in the peak vibration response occurs on floating offshore wind turbine)



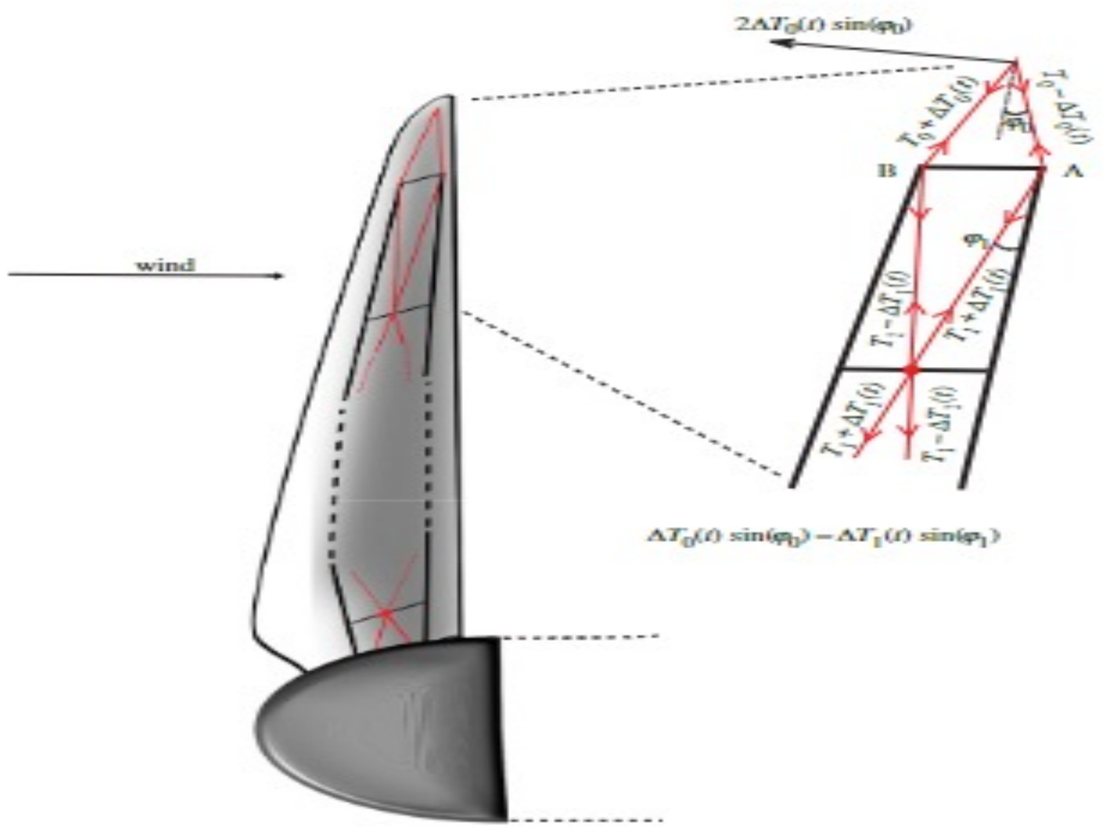


Controlled Liquid Damper (CLD)

- ✓ Semi-active devices using controllable fluids(Electrorheological (ER) and Magnetorheological (MR)) inside the damper
- ✓ The Dumper is equipped with electrical windings to generate a magnetic field, changing the apparent viscosity of the fluid
- ✓ A mathematical model showed a possible 57% reduction of the RMS of tower displacement in low wind speed (5 m/s) installing a TLD (filled with MR liquid); this reduction decreased with an increase in wind speed
- ✓ Advantages:
  - Fast Response
  - Wide range of resistance force applicable
  - Robustness(the fluid is less sensitive to temperature change)
  - Small Power requirement
- ✓ Disadvantages:
  - Additional Mass (up to 8.8% of the total mass of the system)
  - Research and Experiments still on a prototype level

Active tendons

- ✓ A new approach to control wind turbine blade vibrations introducing tendons and actuators inside the blade to reduce vibrational displacement
- ✓ Possible structural implementation complications
- ✓ The system needs experimental testing to provide it's effectiveness



3. Implementation of active vibration blade control based on active tendons. (Online version in colour.)

Piezoelectric materials

- ✓ materials converting mechanical energy into electric energy and viceversa (working as sensors and actuators)
- ✓ extensive literature review showed that piezoelectric materials serve for vibration control of cantilever plates and beams (blades might be assimilated to)
- ✓ Few numerical studies available at the moment about piezoelectric material implementation into the blades
- ✓ The few Numerical results are promising but experimental validation is still needed!!

State of art on vibrations control systems

- ✓ Many vibration control systems showed good potential for wind turbines, based on their application in other fields like aeronautics and civil engineering
- ✓ application of these systems to wind turbines faces multiple challenges (i.e.scaling problems)
- ✓ further efforts are required to prove theireffectiveness and additional experimental validation—especially full scale—is needed for almost all systems

Covered Systems		Stage	Position	Active/Passive
Advanced Blade Pitch control		Full scale	Rotor	Active
Variable rotor diameter		Prototype	Rotor	Active
Flow Control	Trailing-Edge Flaps	Full scale (for traditional one)	Rotor	Active
	Microflaps	Experimental	Rotor	Active
	Microtabs	Experimental	Rotor	Active
	Miniature Trailing-Edge Effectors	Experimental	Rotor	Active
	Synthetic jets	Experimental	Rotor	Active
	Vortex Generators	Experimental	Rotor	Active/Passive
	Plasma actuators	Experimental	Rotor	Active
	Active Twist	Experimental	Rotor	Active/Passive
	Shape Change airfoil	Experimental	Rotor	Active
	Active Flexible wall	Experimental	Rotor	Active
Tuned Dampers (TD)	Tuned mass damper	Experimental	Tower/Nacelle/Rotor	Active/Passive
	Tuned liquid dampers	Experimental	Tower/Nacelle/Rotor	Passive
	Controllable liquid dampers:	Experimental	Tower/Nacelle	Semi active
	Pendulum system	Experimental	Nacelle	Passive
	Tuned rolling balls damper	Prototype	Nacelle	Passive
Active Tendons		Research	Blade	Active
Piezoelectric Actuators		Research	Blade	Active

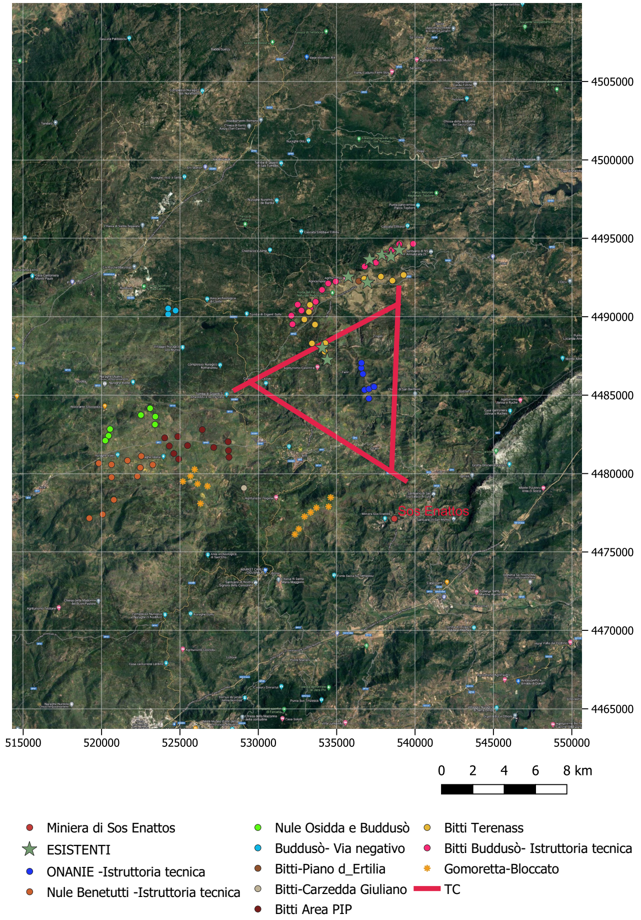
Solutions/research on control system strategies

Companies providing customized solutions on vibration reduction

- Trelleborg (ANTIVIBRATION SOLUTIONS) - https://www.trelleborg.com/en/anti-vibration-solutions/media/blog-stories/benefits-of-anti-vibration-wind-energy-products
- Woelfel - Passive and Active Absorbers - https://www.woelfel.de/en/wind-energy/vibration-reduction.html
- Mecanocaucho - Noise and Vibration solutions, gearbox -
- https://www.mecanocaucho.com/en/windcatalog/
- Anakata Wind Power https://anakatawindpower.com/ - flow control -aeronautical and automotive racing equipment to be installed on the flow control blades
- AMC mechanoaucho (https://www.mecanocaucho.com/en/windcatalog/)- devices for attenuating vibrations of the transmission components
- ALSTOM - DEWEK_10 - Damping devices

Wind Farm mitigation strategy for ET

- ✓ problem of vibrations in the wind sector and devices for their reduction
- ✓ solutions present are currently purely at the research and development or experimental level
- ✓ contact companies that design some of the devices for vibration control and possibility and evaluate alternative solutions to blocking new plant project



Site location	turbine type	overall power [mw]	nominal turbine power [mw]
number of wind turbines	rotor diameter [m]	engine [turns/min]	
tower height [m]	cut_in velocity [m/s]	nominal velocity [m/s]	v_cut off [m/s]
foundation type/soil	enviromental perrmit status	Proponent/ company	web site

survey and classification