POLITECNICO DI MILANO





Design of a 6-DoF Robotic Platform for Wind Tunnel Tests of Floating Wind Turbines

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Hexafloat: Motivation and objectives

Motivation

- Some numerical codes to to simulate FOWT dynamics is been developing from different research groups all over the world.
- These very sophisticated numerical tools require experimental data to validation
- There are a few of full scale data available and in most cases these data are not complete.

Objectives

- This work aims at proposing an approach to test scale models of FOWT complementary to wave basin testing.
- The design of a 6 degrees-of-freedom (DoF) robot, called “HexaFloat”, capable of reproducing the floating motion of a scale FOWT for wind tunnel experiments. This approach gives the chance to investigate the aerodynamics of using aeroelastic FOWT scale models in a 14mx4m civil boundaryl ayer test section

Hexafloat: experimental tool

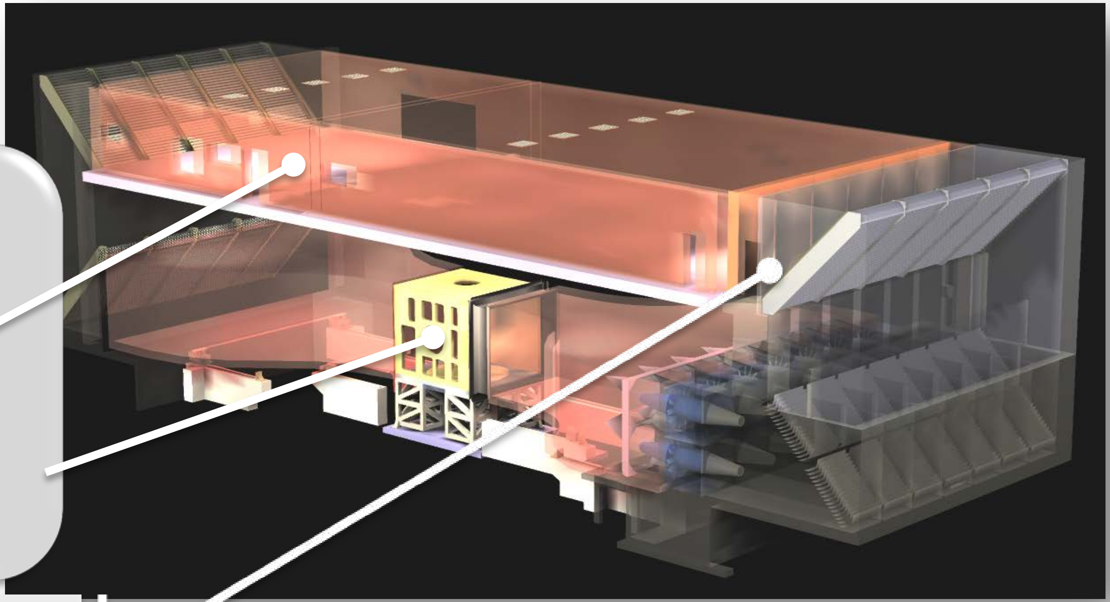
An experimental tool to validate the numerical models to:

- Aero-Hydroelastic and floating codes
- Aerodynamic interaction
- Control strategies

- Known lab conditions
- Aerodynamic parameters (Reynolds Number effects)

- Real time forces measurement
  [rotor, nacelle, tower, blades]
- Wake measurement
- Overall aerodynamic forces measured at the base of the tower
- Dynamic behavior parameters

Politecnico di Milano Wind Tunnel



1.4MW Wind Tunnel

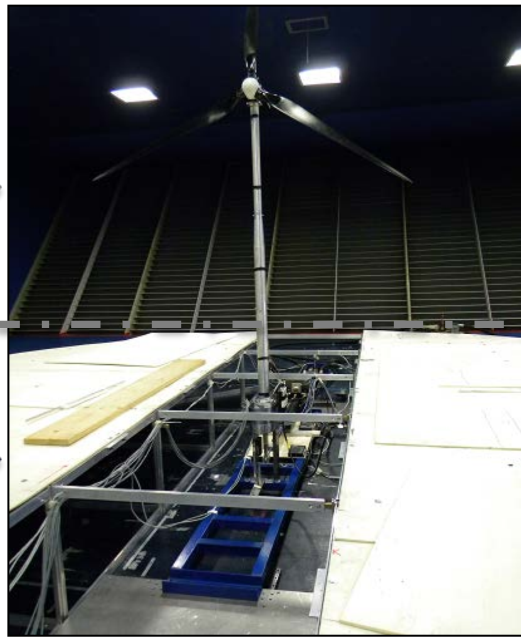
- **13.8x3.8m, 14m/s, civil section**:
  - turbulence < 2%
  - with turbulence generators = 25%
  - 13m turntable
- **4x3.8m, 55m/s, aeronautical section**:
  - turbulence <0.1%
  - open-closed test section

Turbulence (boundary layer) generators

FOWT: HIL approach

Wind

Sea state



Aero

Wind Turbine Scale Model

- Real time force measurement [rotor, nacelle, tower]
- Overall aerodynamic forces measured at the base of the tower

Hardware-In-The-Loop [HIL]

Floater Dynamics Simulation:

- Real time hydro-structure interaction calculated
- Consistent floating platform motion provided

Hydro

Robot requirements

The reference machine is the 5 MW NREL wind turbine
To define the specifications of the robot in terms of Frequencies and displacements
3 reference case have been chosen

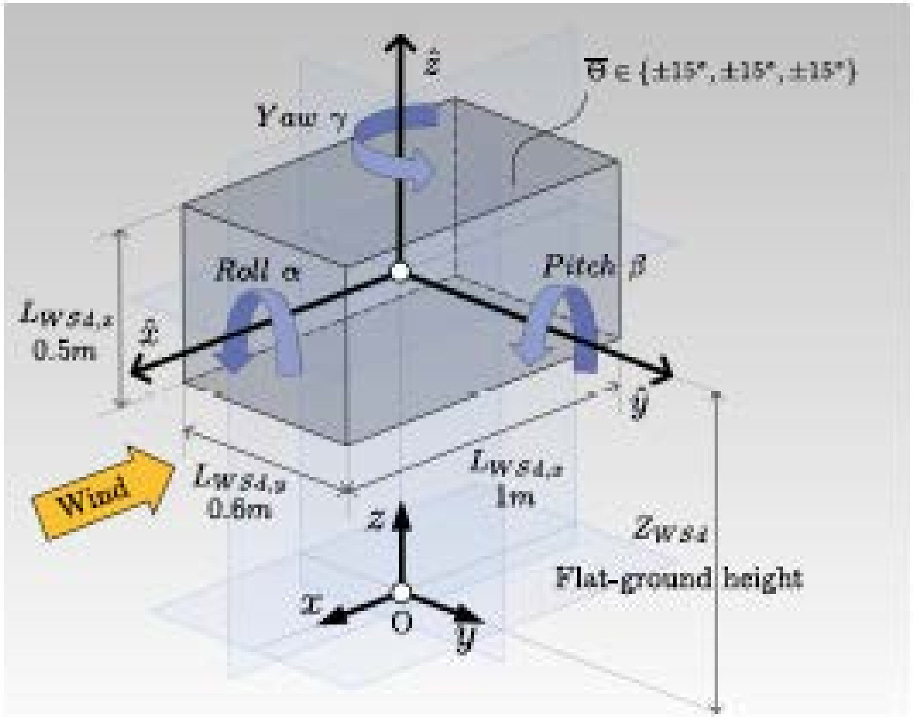
1. MIT/NREL TLP
2. ITI Energy Barge
3. OC3-Hywind

The scale factor is 1/58, driven by the wind tunnel dimensions and BL reproduction

Froude scaling law has been adopted
Reynolds Number could be a problem → Known aerodynamics limits

Robot requirements

	Design		Verification	
Dof	[m]	[Hz]	[m]	[Hz]
Surge	0.5	0.7	0.01	3
Sway	0.3	0.7	0.01	3
Heave	0.25	0.7	0.01	3
	[deg]	[Hz]	[deg]	[Hz]
Roll	15	0.7	3	3
Pitch	15	0.7	3	3
Yaw	15	0.7	3	3



Design process: architecture

Parallel kinematic robots (PKM) have been chosen

The main peculiarities of such robots can be defined as follows:

1. High positioning accuracy
2. High load capability
3. High dynamic performances
4. Components modularity

“Hexaglide” kinematic architecture, also known as 6-PUS architecture with parallel rails.

Advantages

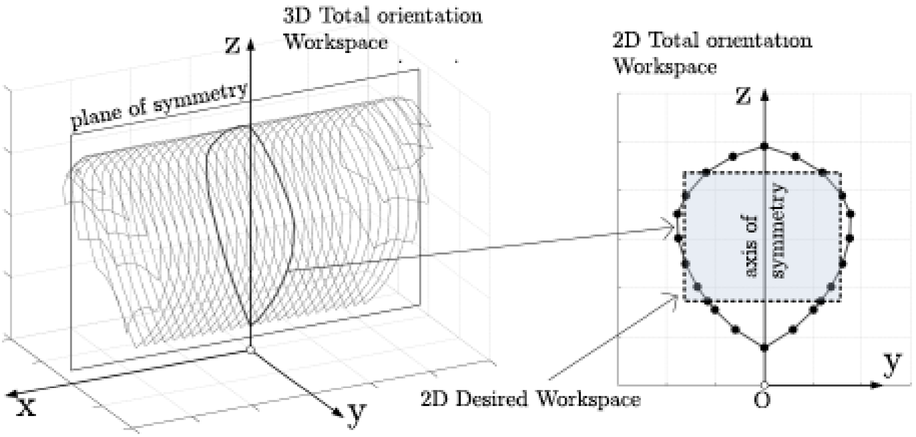
1. low workspace center (TCP):
2. the workspace is characterized by a predominant direction
3. the actuation is placed basically on the ground

Design process: geometric parameters

The Hexaglide robot is characterized by fixed links and parallel rails

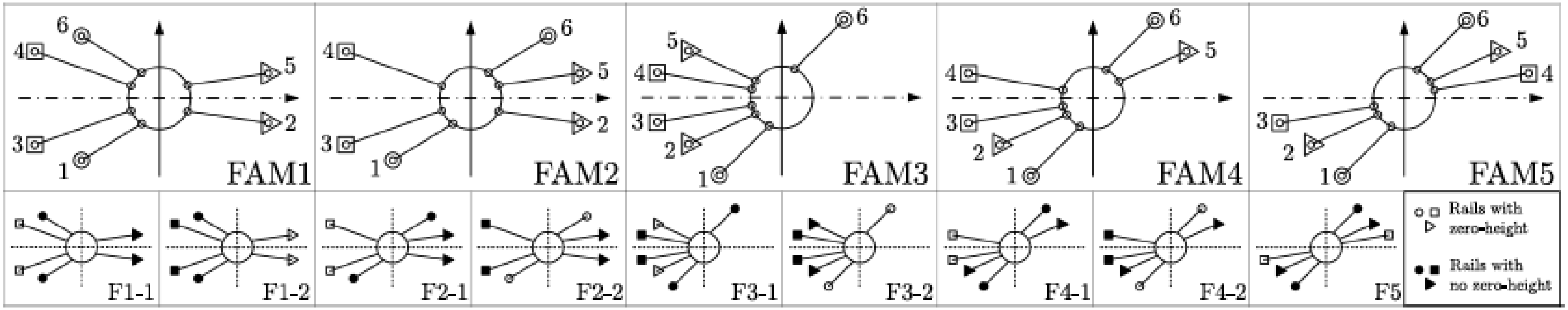
All the other architectural details are determined through a geometric parameterization.

Constrains: orientation workspace symmetric with respect to a vertical plane, parallel to the rails and passing through the longitudinal centerline of the machine

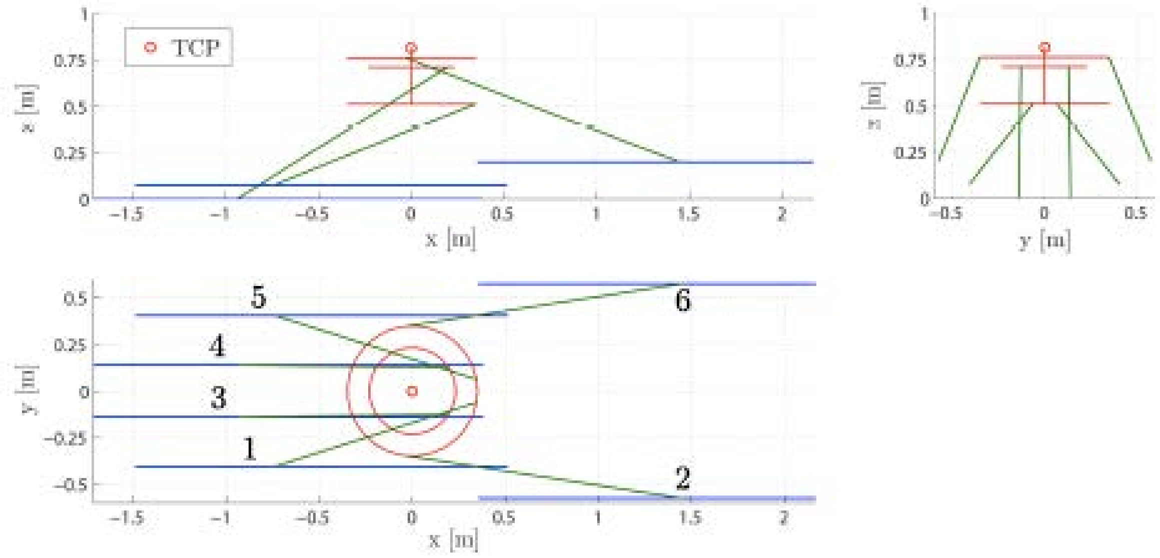


The constrains results in a disposition of the links in pairs with a symmetry with respect to the vertical-longitudinal plane or the central symmetry with respect to the vertical axis passing through the TCP.

Design process: geometric parameters



The considerations and the constrains follow in choosing FAM 1. Symmetry considerations let us define a plane 2D problem



Design process: kinematic syntesis

A multi-objective optimization campaign via genetic has been used to define the dimensions of the manipulator

The target are:

1. Coverage of the workspace
2. Static forces multiplication
3. Interference between the links
4. Interference between the links and the rails
5. Longitudinal size

Two different cost functions have been defined

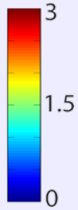
Thresholds have been decided in terms of maximal static force multiplication and minimal link-to-link and link-to-rail distance

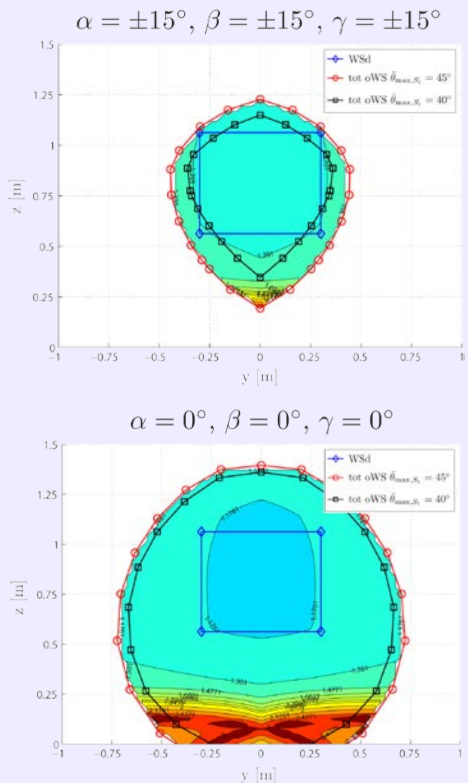
Different Pareto-optimal solutions were obtained and then kineto-statically analyzed and compared.

Design process: kinematic syntesis

Static force multiplication

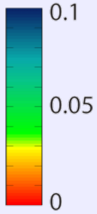
$\log_{10}(\tau_{MAX})$

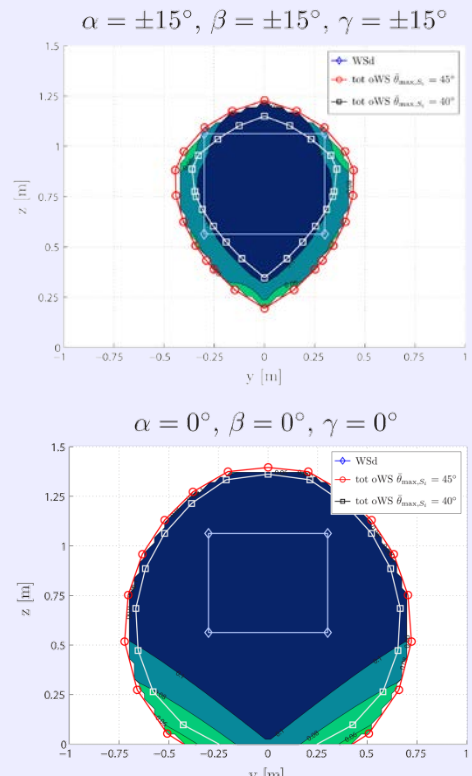




Distance between links

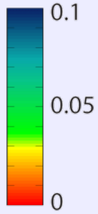
$d(\text{link}\leftrightarrow\text{link})$ [m]

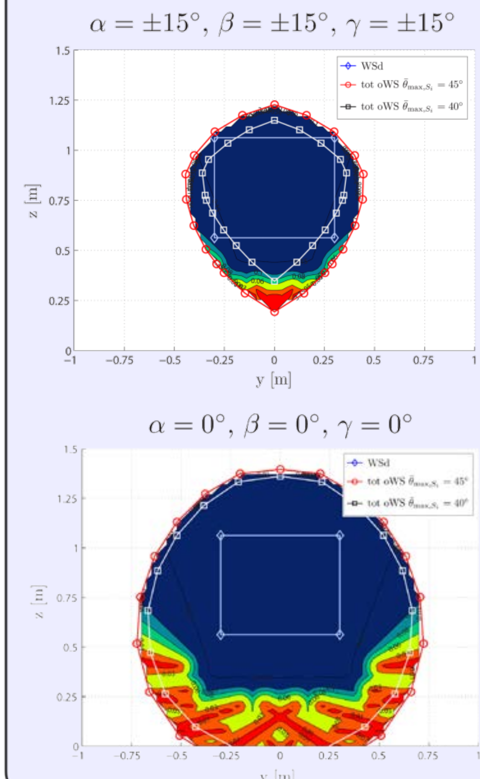




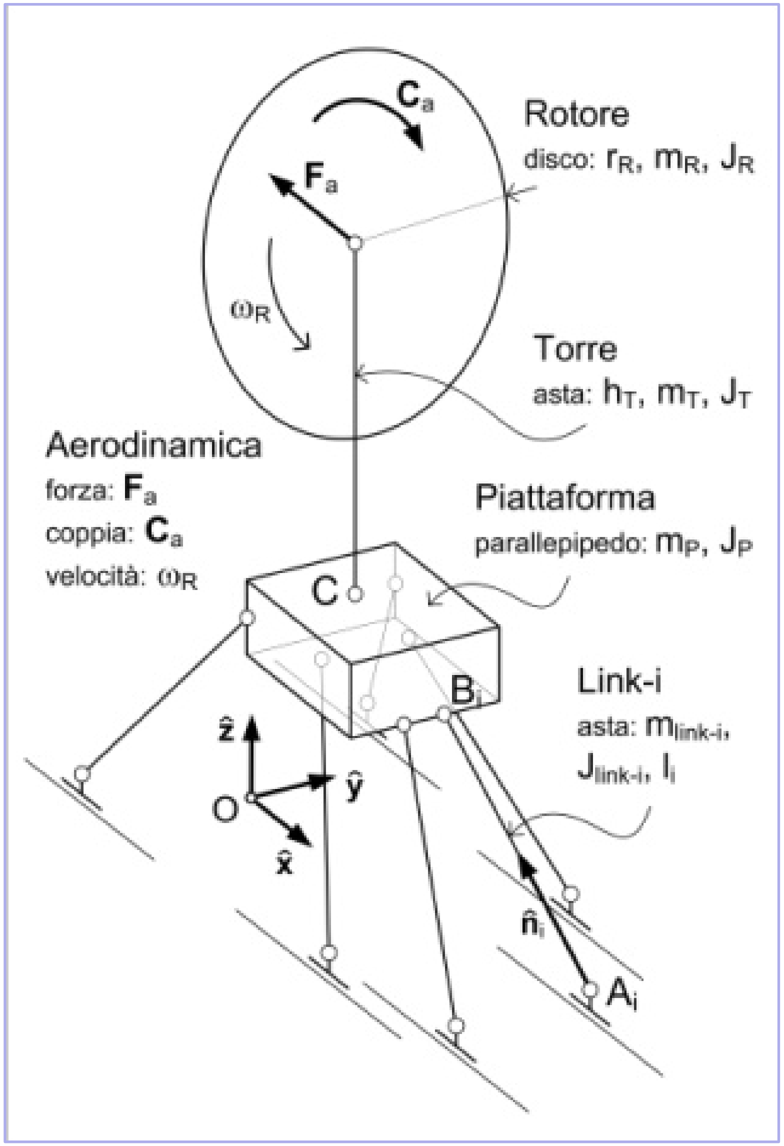
Distance between links and rail

$r(\text{link}\leftrightarrow\text{rail})$ [m]





Design process: Dynamics



Multi-body model to solve the Dynamics
To dimension the joints and the rods of the robot

We impose indipendent sinusoidal motion to each degree of freedom and then compute the forces on each element

This was useful to compare different solutions, considering also other technical issues such as mounting, management and cost-effective aspects.

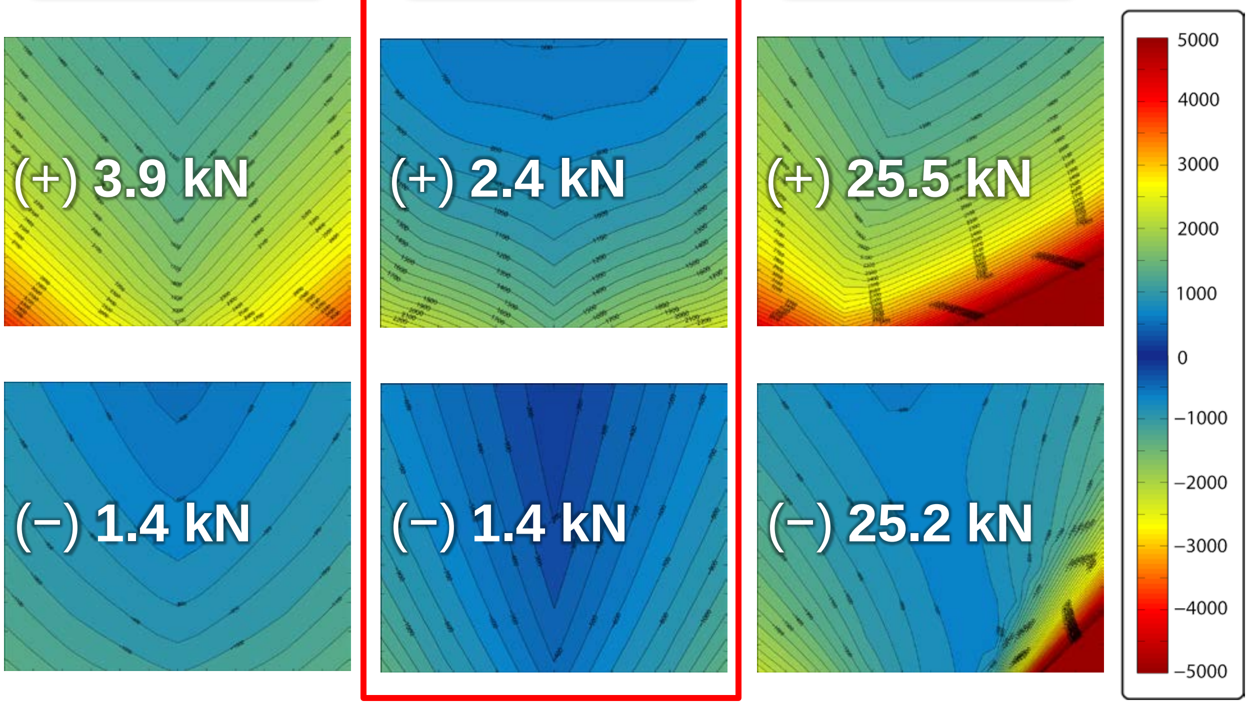
Ball screw and Belt transmissions system were compared on the basis of the dynamic performances

Design process: Dynamics, results

FAM 1-1
Type n. 3
$\bar{\tau}_{MAX} = 50$

FAM 1-1
Type n. 4
$\bar{\tau}_{MAX} = 20$

FAM 3-2
Type n. 1
$\bar{\tau}_{MAX} = 20$

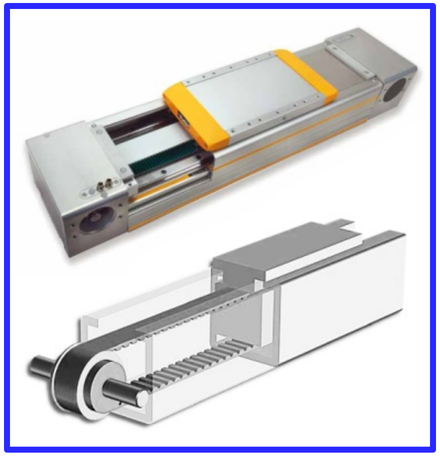


Axial + max
(*on all links*)

Axial – Max
(*on all links*)

Design process: Dynamics, results

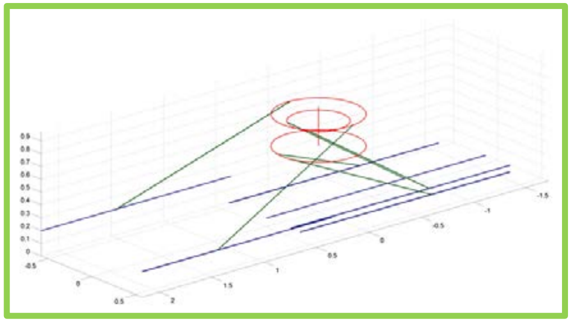
Ball screw: Thomson WH80D



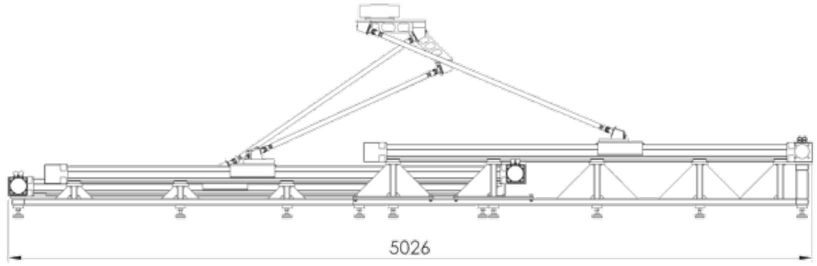
Belt drive: Thomson WH120

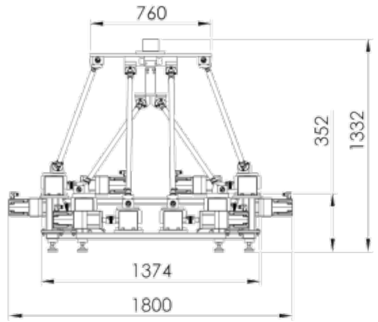
		WM80D	WH120	Fam. 1-1
		$p_h = 50\text{mm}$		ind. 4
$v_{\max}$	[m/s]	2.5	10	2.20
$a_{\max}$	[m/s^2]	20	40	13.02
F_x	[N]	5000	5000	2308
F_y	[N]	3000	4980	709
F_z	[N]	3000	9300	764

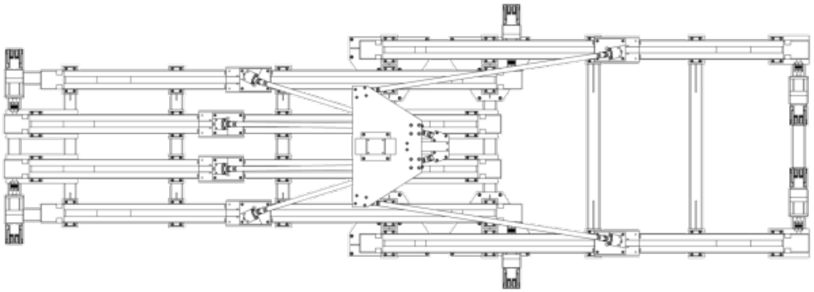
Pareto Optimal solution

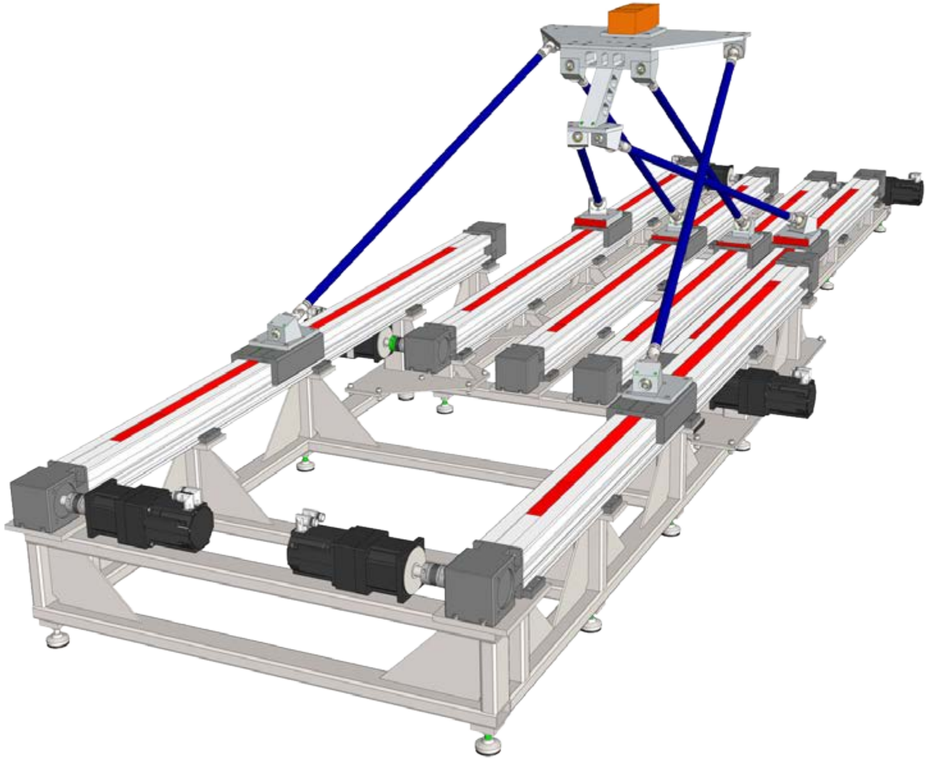


Hexapod Design: final desing







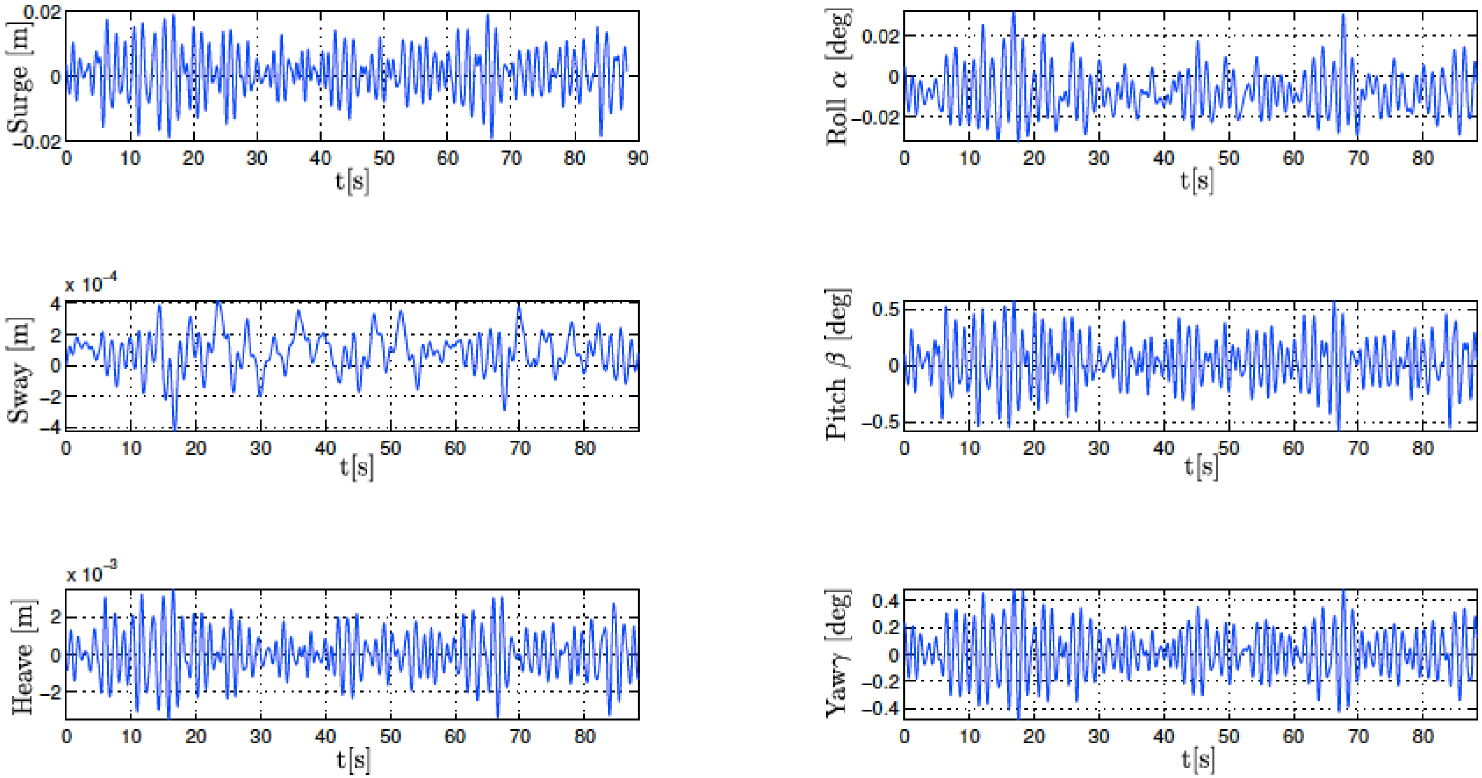


Hexapod design: installation

Hexapod design: verification

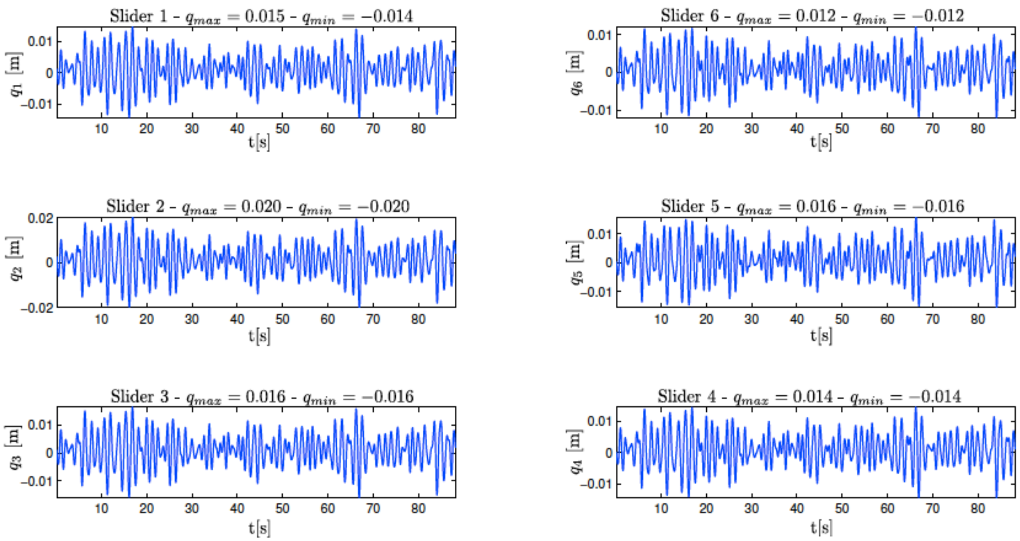
A reference case has been used to test the robot capabilities
OC3 system was performed considering the nominal operational condition
Sea-state: Jonswap spectrum, wave height Hs = 3.66m, pick-period Tp = 9.7 s

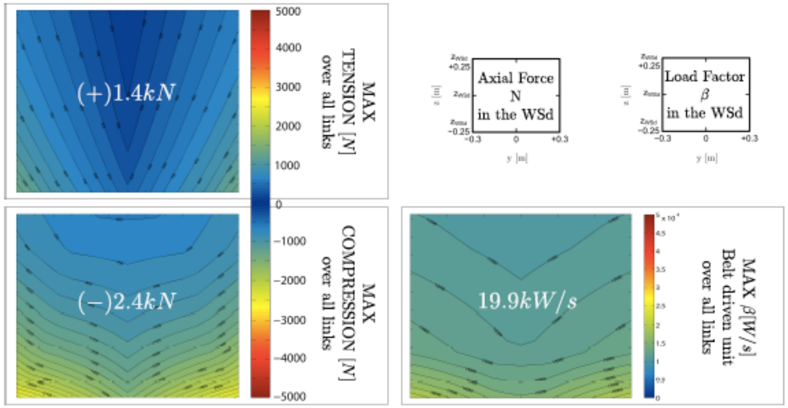
FAST simulation results scaled to 1/58

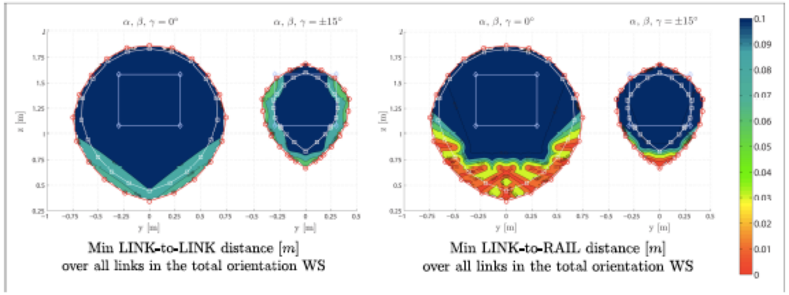


Hexapod design: verification

The selected case gives this output on the robot







Conclusions

I. The desing process of a PKM to aerohydro simulation of FOWT has been presented
II. The machine is designed to be inserted in a HIL test bench in wind tunnel
III. A new concept PKM has been designed using Pareto Optimal kinematic and dynamic solutions
IV. Commercial components
V. Very small vertical dimensions compared to the workspace
VI. The robot will be available at the end of 2014.