A design support multibody tool for assessing the dynamic capabilities of a wind tunnel 6DoF/HIL setup

Marco Belloli*, **Hermes Giberti, Enrico Fiore**

Dipartimento di Meccanica, Politecnico di Milano

Via La Masa 1, 20156, Milano, Italy. Ph:+39 0223998486, Mob:+39 3772855518

**marco.belloli@polimi.it*

Abstract

Within the H2020 funded project LIFES50+, the Department of Mechanical Engineering of Politecnico di Milano, is finalizing the design and building the 6-Degree-Of-Freedom (6-DoF)/ Hardware-In-The-Loop robotic setup (HIL) [1] to perform wind tunnel tests on floating offshore wind turbines (FOWT) [2], at Politecnico di Milano Wind Tunnel [3]. Due to geometric and dynamic constraints, the best suited machine for this peculiar application is represented by a parallel kinematic manipulator "Hexaslide". This work presents an integrated FEM/multibody tool for assisting the correct design of the robot. This is carried out with the multibody software ADAMS coupled with AdWiMo (which implements FAST/Aerodyn [4]) for assessing the effect of the robot's flexibility on the imposed motion of the wind turbine at the base of the tower, due to wind and wave loads. Simulations of the OC4 floating system [5] were run in ADAMS/ADWIMO (Aerodyn) and then compared to FAST output. The methodology is herein presented, along with some results about the wind rated condition.

Figure 1: Coupled flexible multibody model the robot and the FOWT.

1 The Robot

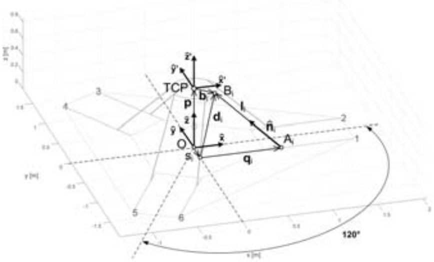

Figure 2: Hexaslide kinematics.

Hexapod, the PoliMi Hexaslide robot, is composed of a mobile platform connected to six linear guides by means of six links of fixed length, so that six independent kinematic chains belonging to the PUS family can be identified. With reference to Fig.2, the six linear guides are organized into three couples of parallel transmission units, each one out of phase by 120° with respect to the z axis. Given the TCP position $\mathbf{p}$ and the mobile platform orientation, $\Theta = \{\alpha, \beta, \gamma\}$, it is possible to find each slider position q_i by performing the inverse kinematics analysis. For the i-th kinematic chain it is possible to write:

$$\mathbf{l}_i = \mathbf{d}_i + q_i\hat{\mathbf{u}}_i \qquad \text{with} \qquad \mathbf{d}_i = \mathbf{p} + [R]\mathbf{b}'_i - \mathbf{s}_i \tag{1}$$

The [R] matrix is the rotational matrix used to switch from the mobile frame to the fixed one, and it is function of the platform orientation Θ. After some simple mathematical passages it's easy to recognize that:

$$q_i = \mathbf{d}_i^T\hat{\mathbf{u}}_i \pm \sqrt{\mathbf{d}_i^T(\hat{\mathbf{u}}_i\hat{\mathbf{u}}_i^T - [I])\mathbf{d}_i + l_i^2} \tag{2}$$

2 Multibody model

Due to the flexibility of the robot and of the wind turbine, they can't be regarded as two distinct entities. Thus it is necessary to develop a coupled FEM/flexible multibody model in order to design the system "robot + wind turbine" sufficiently rigid, not to interfere with the dynamic phenomena being investigated in the wind tunnel. Regarding the robot, the only source of flexibility is assumed to be the slender links. The mobile platform can be considered reasonably rigid.

3 Methodology

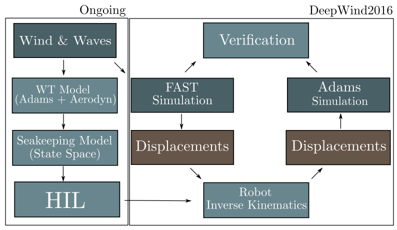

Figure 3: Numerical methodology.

In Fig. 3 the methodological approach is reported. As it can bee seen, the final target is also building a numerical tool that can be used for assessing the wind tunnel HIL implementation, that will rely on state space modelling of the seakeeping equations, due to the real-time characteristics of the application [6] (*"Ongoing"*, Fig.3) . In this work, results are reported regarding the *DeepWind 2016* section of the methodological scheme of Fig.3.

4 Numerical results and conclusion

In Fig. 4 a comparison between the ADMAS/ADWIMO output and FAST is reported, with regard to surge displacements at rated condition, where good agreement can be seen. Furthermore, Fig. 5 shows how the the natural frequencies of the system "robot+wind turbine" are well above the frequency range that will be investigated in the wind tunnel. This numerical tool is useful for a correct design of the robot, whose dynamic response is required to be at higher frequency then the range in which physical phenomena are expected to occur (e.g higher than sum-frequency second order hydrodynamics, [7], [8]).

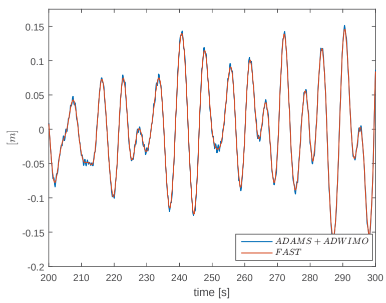

Figure 4: Comparison of the Surge response time histories (up-scaled).

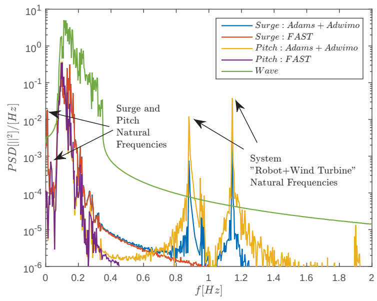

Figure 5: PSDs comparison: ADAMS+ADWIMO(Aerodyn) Vs FAST.

References

[1] Bayati I., Belloli M., Ferrari D., Fossati F., Giberti H., *"Design of a 6-DoF Robotic Platform for Wind Tunnel Tests of Floating Wind Turbines"*, Energy Procedia, pp. 313-323, 2014.

[2] Bayati I., Belloli M., Facchinetti A., Giappino S.,*"Wind Tunnel Tests on Floating Offshore Wind Turbines: A Proposal For Hardware-In-The-Loop Approach To Validate Numerical Codes"*.Wind Engineering, vol.37, N.6, 2013.

[3] Diana G., De Ponte S., Falco M., Zasso A., *"A new Large Wind Tunnel For Civil Environmental And Aeronauitcal Application"*, Journal of Wind Enegineering and Industrial Aerodynamics, 74-76, 553-565, 1998.

[4] Jonkman J.,*"Dynamics Modeling and Loads Analysis of an Offshore Floating Wind Turbine"*, PhD Thesis, 2007.

[5] Jonkman J., *"Definition of the Semisubmersible Floating System for Phase II of OC4"*, NREL/TP-5000-60601, 2014.

[6] Perez T., Fossen T., *"Practical aspects of frequency-domain identification of dynamic models of marine structures from hydrodynamic data"*. Ocean Engineering, Vol 38, pp. 426435, 2011.

[7] I.Bayati, S.Gueydon, M.Belloli, *Study of the effect of water depth on potential flow solution of the OC4 Semisubmersible Floating Offshore Wind Turbine, Energy Procedia 80 (2015) 168 176.*

[8] Bayati I., Jonkman J., Robertson A., Platt A., *"The effects of second-order hydrodynamics on a semisubmersible floating offshore wind, turbine"*, J. Phys.: Conf. Ser. 524, 2014.