PO.247

Local structural dynamics identification in offshore wind turbines based on experimental data

Basak Anayurt[1] , Jordi Ollé[2], Jordi Jové[2] and Raúl Benítez[1]
[1]Universitat Politècnica de Catalunya – Barcelona Tech, Department of Automatic control
[2]Alstom Renovables España S.L, R&D department, Transverse Technologies area

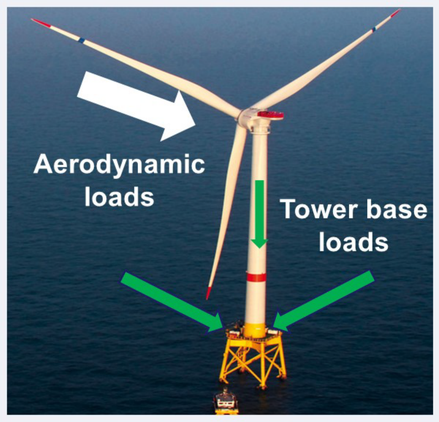
Abstract

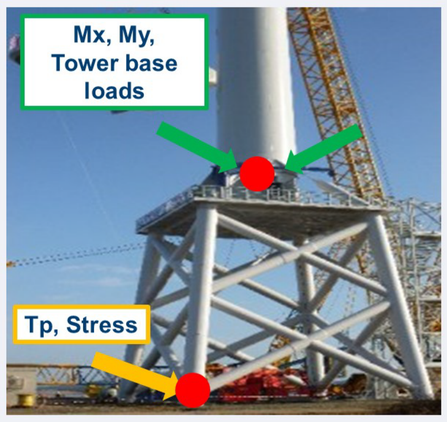
Standard approaches to determine stress in structural components typically use geometrically detailed FEM models including the effect of external loads. Loads are provided by aero-hydro-servo-elastic models, which are geometrically simplified to account for global modes and most relevant non-linarites. However, a common approach for component FEM models assumes a linear and quasi-static w.r.t. global system dynamics. Therefore, whenever they are present, effects such as local dynamics or local non-linearities are not considered during the structural design process. Each new Wind Turbine design is validated by means of a real prototype. In there, main parameters affecting its performance are monitored; strain gages are installed in main sections to characterize reaction loads; and numerically detected critical positions are also instrumented in order to characterize their stress. The present study aims to establish a methodology in order to take advantage of all those experimental data and study whether local dynamics' effects are present or not at component level of real prototypes.

Objectives

- Development of methods and tools intended for the correlation of structural models with experimental data.
- Understanding how to extract useful knowledge from experimental data prototypes by means of advanced time-domain parametric models.
- Building a transversal method for identification of an input-output black box, allowing accurate characterization of local modes eigenfrequencies and associated damping values.

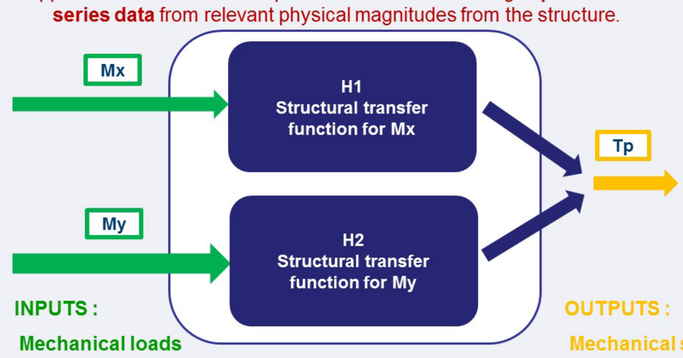
PROTOTYPE UNDER LOADING





REPRESENTATION OF THE STRUCTURAL SYSTEM

Our approach is to model the response of the structure using **experimental time-series data** from relevant physical magnitudes from the structure.



INPUTS : Mechanical loads applied to the tower (perturbation).

OUTPUTS : Mechanical stress at a critical joint of the structure (response)

Methods

(I) Build mathematical representation

(II) Stability Diagram Generation & Processing

(III) Provisional mode selection

(IV) Refine Modal Parameters & Build Final SystemTransfer Function

I Mathematical model

ARMAX is the model class that represents structural signals for the complexity of noise the best.

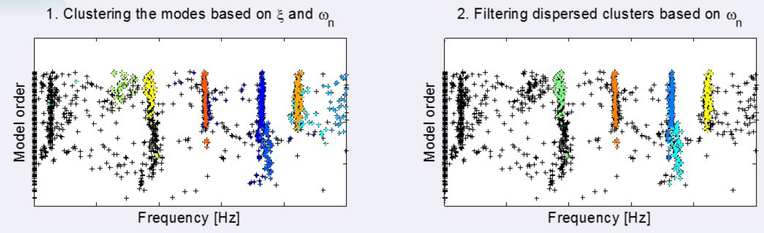
$$Tp_t + a_1 Tp_{t-1} + \ldots + a_{na} Tp_{t-na} = b_0^{Mx} Mx_t + \ldots + b_{nb}^{Mx} Mx_{t-nb} + b_0^{My} My_t + \ldots + b_{nb}^{My} My_{t-nb} + e_t + c_1 e_{t-1} + \ldots + c_{na} e_{t-na}$$

A: auto-regressive (AR) — B: exogenous (EX) — C: Moving average (MA)

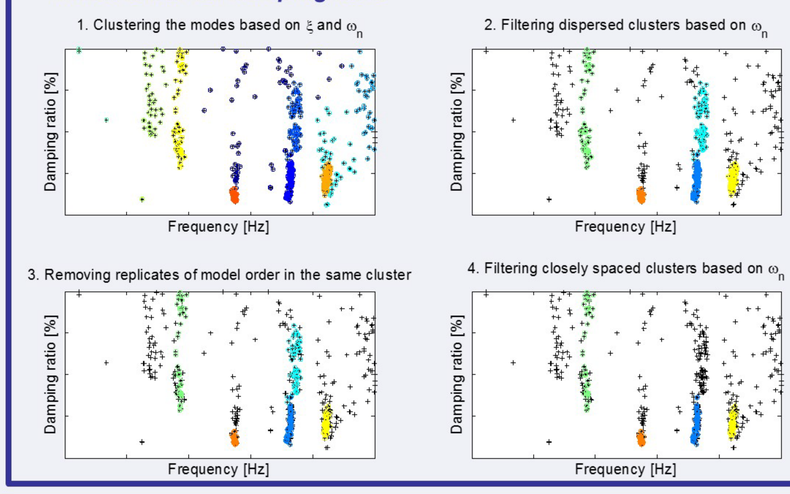
$$Tp(z)A(z) = Mx(z)B_{Mx}(z) + My(z)B_{My}(z) + e(z)C(z) \longrightarrow H_1(z) = \frac{B_{Mx}(z)}{A(z)}, H_2(z) = \frac{B_{My}(z)}{A(z)}$$

II Stability Diagram Generation & Processing

Model order vs. natural frequency

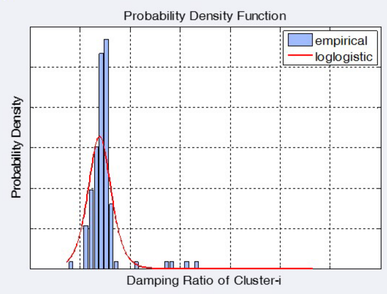


Model order vs. damping ratio

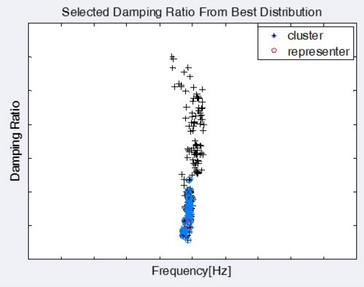


III Provisional Mode Selection

Fitting different distributions to damping ratio within each cluster (best distribution selected with BIC)



Selecting the best one as representer mode of that cluster (highest probability)



IV Refine Modal Parameters & Build Final SystemTransfer Function

- *Create a comparison model CM*

Comparison Model → *modes identified x 2 ≤ na_{BIC}* → Model with highest BIC

Comparison Model → *modes identified x 2 > na_{BIC}* → Model with highest order

- *The distance between identified natural frequencies and the natural frequencies from CM is compared*
  - *If mode has a partner in CM it is kept in structural transfer function*
  - *If not, it is put in the error transfer function*

$$Tp(z) = M(z)\frac{B(z)}{A(z)} + e(z)\frac{C(z)}{A(z)}$$

- *B(z) is re-identified with imposing a Box-Jenkins Model*

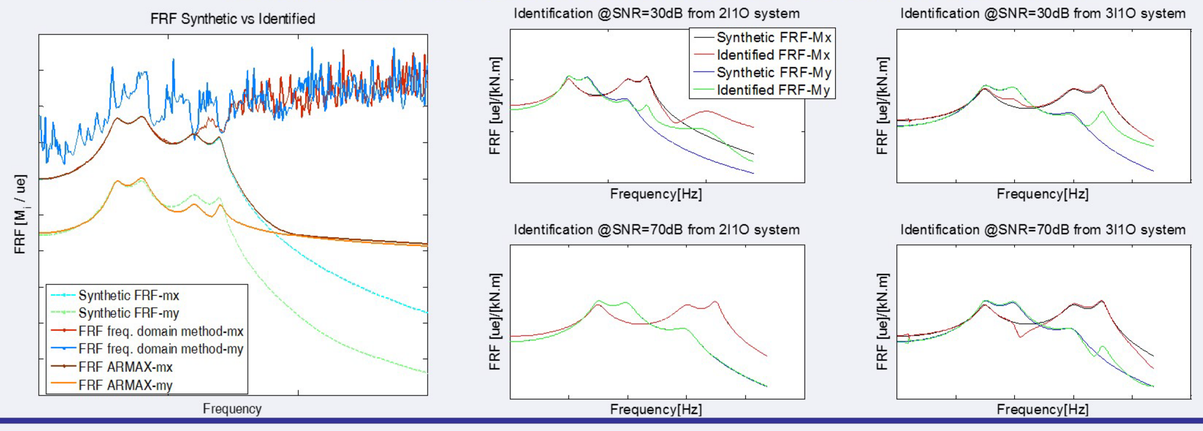
Re-identified: $\frac{B'(z)}{A(z)}$ — Fixed: $\frac{C(z)}{A(z)}$

$$Tp(z) = M(z)\frac{B'(z)}{A(z)} + e(z)\frac{C(z)}{A(z)}$$

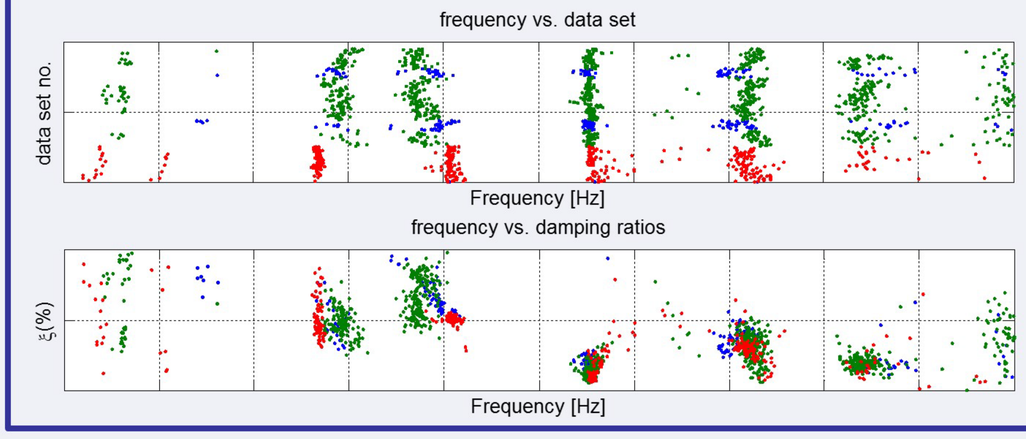
Nomenclature

na	Order of AR polynomia (A)
nb	Order of EX polynomia (B)
nc	Order of MA polynomia (C)
BIC	Bayesian Information Criterion
ω	Frequency
ξ	Damping Ratio
CM	Comparison Model

IDENTIFICATION WITH DATA FROM A SYNTHETIC SYSTEM FOR VALIDATION



IDENTIFICATION WITH DATA FROM OPERATING PROTOTYPE



- ✓ Bringing practical information on design validation and reliability
- ✓ Higher accuracy in modal identification compared to classical methods
- ✓ High accuracy in identification under challenges: high noise, unmeasured inputs
- ✓ Consistent identified modes from different data sets – existent local dynamics
- ✓ Need of user intervention for final decision on phsysical modes
- ✓ Next step : identification of time dependency of modal parameters

References

1. S.D. Fassois, *Identification model-based methods*. In ENCYCLOPEDIA of VIBRATION, SG Braun, DJ Ewins, SS Rao (eds.), Academic Press, 2001.
2. Ljung, L. *System Identification: Theory for the User*, Upper Saddle River, NJ, Prentice-Hal PTR, 1999. See chapter about computing the estimate.
3. C. Fraley, A. E. Raftery *How Many Clusters? Which Clustering Method? Answers Via Model-Based Cluster,* The computer journal, Vol. 41, no.8, 1998.
4. M. Scionti, J.P. Lanslots, *Stabilisation diagrams: Pole identification using fuzzy clustering techniques,*Adv. Eng. Software 36 (11-12) (2004) 768-779.
5. Reynders, E., Houbrechts, J., & De Roeck, G. (2012). Fully automated (operational) modal analysis. *Mechanical Systems and Signal Processing*, *29*, 228250.
6. S.D. Fassois, J.E. Lee, *A Linear Multi-Stage Method For Multivariate ARMAX Process Identification-Part II: Effective Structure/Parameter Estimation and Performance Evaluation,* Report UM-MEAM-90- 05,1990.

EWEA 2015 PARIS — EUROPE'S PREMIER WIND ENERGY EVENT

EWEA 2015 – Paris – 17-20 November 2015