Reliability and environmental sensitivity for vibration-base monitoring of wind-turbines under data and sensors scarcity

Supervisor : Dr. Younes AOUES

Co-supervisor : Pr. Olivier BAREILLE

Over the past few decades, off-shore wind turbines have experienced significant growth due to their ability to harness stronger and more consistent off-shore winds for renewable energy generation [1,2]. The monopile foundation is the most common, accounting for around 80% of existing projects [3]. Ensuring the structural integrity of wind turbine relies heavily on the connection between the MP and transition piece (TP) [4]. Dynamic loads from winds and waves are the primary loads acting on them, which can lead to iterative deterioration and crack initiation, ultimately resulting in fracture. Fatigue damage to the MP-TP connection could cause catastrophic failure. Therefore, early detection of such damage is essential to provide warning signs and prevent complete structural collapse.

Structural health monitoring (SHM) becomes a very important issue in many engineering fields [9]. It aims to avoid any operational breakdown inducing dramatic energy shortage or constructions collapses like in energy supplies when an unforeseen failure occurs. It has also become a key strategy for durability and extended working-life of systems.

Identifying damage through propagative wave-based methods generally involves comparing the baseline data obtained from an undamaged structure with the wave response of a potentially damaged structure [5]. However, this approach faces challenges in practical applications due to potential signal changes caused by various factors beyond damage, such as variations in environmental and operational conditions [6]. Robust compensation methods for these effects are crucial but challenging to develop [7]. Since the past one and half decades, researchers have been experimenting with the idea of utilizing the time-reversal process (TRP) to remove the requirement for the baseline data [8]. In a pristine structure, the TRP makes it possible to reconstruct an input signal at the source transducer by reverse-emitting the response received at another transducer. However, if damage is present, the shape of the reconstructed signal's main mode would deviate from the original input. This dissimilarity, quantified by a damage index (DI), can be used to indicate damage.

Yet, the corresponding new methods and techniques imply a better understanding of the physical phenomena involved with the signature of the system's health. These health-status signals are very sensitive to the actual setting of the system. In vibration-based monitoring applications, some structures exhibit features that are make them more efficient form long distance vibrations' propagation. In addition, the cost-efficiency of the current monitoring strategies implies to cope with distributed and low-tech sensing systems. Therefore, the analysis shall also consider this level of complexity.

Description of the work:

In this work, the damage detection and its evolution in structural components for aging civil engineering structures like monopile foundation will be addressed in view of Structural Health Monitoring issues. Based on the expertise of the hosting research team, in vibration-based analysis, the focus will be put on identifying the proper travelling waves, fitted to specific structural patterns. Actual surrounding environmental conditions and tuning to existing structures are intended to be particularly studied. This is suggesting the monitoring strategies shall adapt to existing structures that were not initially designed to support embedded control components. The research team has also dedicated proficiency in reliability and sensitivity analysis.

Numerical developments will be considered. Simulations of the damage sensitivity for typical structures will be analysed. A numerical method, named Wave Finite Element (WFE) allowing the damage signature analysis will be extended to wind turbines' material structures. The assessment of the structural architecture variability influence on the damage severity evaluation will be analysed. Comparisons real-test cases will be carried out on existing open-access data bases, full accessible to worldwide researchers.

Work plan of the thesis:

The thesis will be conducted through the following milestones:

• Getting started with the existing experimental setup and update of the bibliography: improvement of the setup and specifications tuning, first numerical simulations of time-reversal analysis, first damage-index parametric and non-parametric sensitivity evaluation

• Definition of characteristic scenari to address the bottlenecks of the thesis: evaluation of discontinuous data collection, evaluation of environmental and aging influence on the monitoring reliability

• Development of a dedicated monitoring for distant, large scale and robust monitoring system

• Extraction of design parameters and development: exploration of the design space to define dynamic scenario and adaptative situations for vibration-based, sensors' low density, data low availability and scarcity.

Main topic classification

VI. Sciences de l'ingénieur : Engineering science

VI-2. Prévention des pannes graves d'ingénierie et sûreté des systems : Prevention of serious engineering breakdowns and system safety

Secondary topics classification

V. Energie et environnement / Energy and environment

V-1. Prévention et traitement des pannes de systèmes électriques. Fonctionnement économique : Prevention and treatment of electric system breakdowns. Economic process

VI. Sciences de l'ingénieur : Engineering science

VI-4. Construction intelligente : Intelligent construction

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