Study of Vertical Axis Wind Turbine Tower Bending Deformations Using FBG Sensors

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Abstract: This paper presents experimental results of FBG sensors used for SHM of a vertical axis wind turbine tower. Thanks to power spectral density computations, three deformation types are detected, each characterized by a specific frequency.

1. Introduction

Structural Health Monitoring (SHM) is paramount for industrial systems subject to important loads such as wind turbines to prevent structures from mechanical damage. In the literature, sensing solutions based on fiber Bragg grating (FBG) are substantially proposed for horizontal axis wind turbines (HAWT) monitoring [1–8], while the case of vertical axis wind turbines (VAWT), as those produced by Fairwind (Fleurus, Belgium), is not yet addressed. This research provides a study of the bending deformations of a VAWT tower at different imposed rotational speeds, using FBG sensors. After a brief reminder about the FBG theory, the installation process is exposed, followed by the measurements and the outcomes obtained via power spectral density (PSD) computations.

2. Fiber Bragg grating theory

An FBG is created by permanently modifying, in a periodic way, the refractive index in the core of an optical fiber along its propagation axis. This modulation, acting as a distributed mirror, reflects a part of the incident light around the Bragg wavelength λ_B, computed as:

$$\lambda_B = 2 n_{\text{eff}} \Lambda \tag{1}$$

with n_{eff} the effective refractive index of the fiber core and Λ the modulation period. A change of either n_{eff} or Λ implies a shift of λ_B. This property is the principle of temperature, pressure, or strain sensing. A classical FBG at 1550 nm has a sensitivity of 1.2 pm/με (resp. 10 pm/°C) as strain (resp. temperature) sensor.

3. Sensor installation

A picture of a VAWT designed by Fairwind is depicted on Fig. 1a. The main deformation type underwent by the tower of such a VAWT is bending, as represented on Fig. 1b (although the actual bending is much less than the one sketched). The studied machine is the model F100-10, located in Fleurus, Belgium.

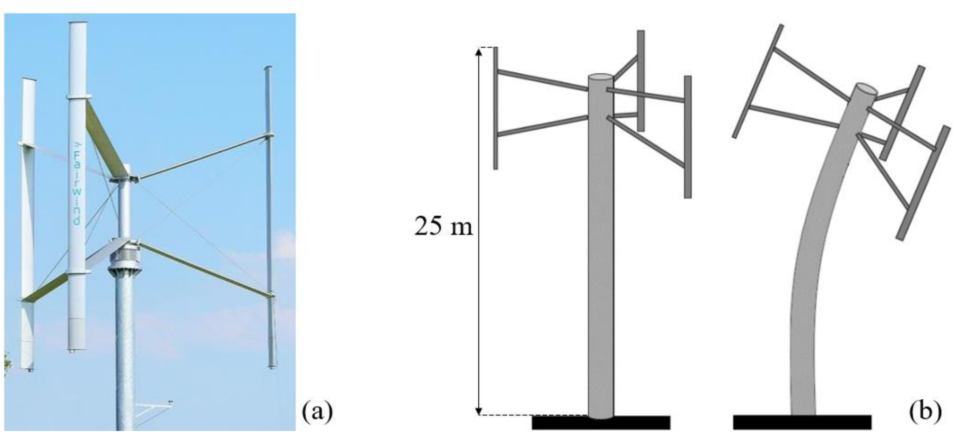
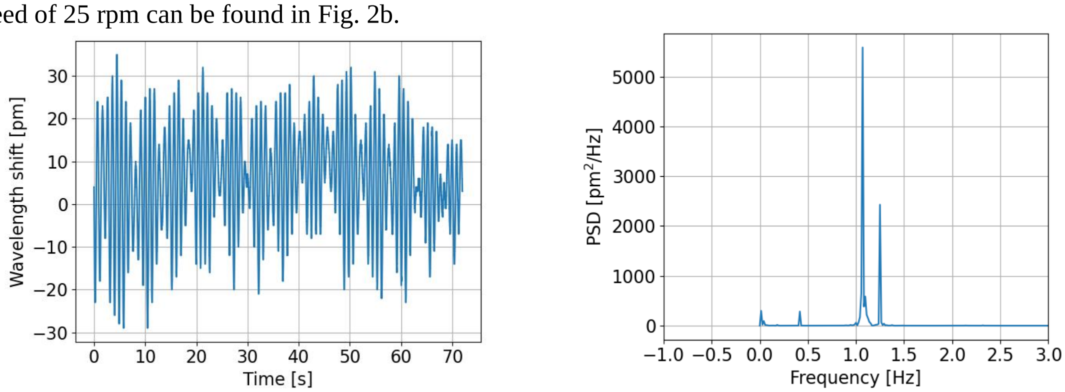


Fig. 1. Vertical axis wind turbine: (a) Picture; (b) Representation of tower bending deformation.

To detect bending, the FBG is vertically placed along the tower, at a 1.5m-height. As this strain sensor is also sensitive to temperature changes, another FBG (inscribed in the same fiber) is not glued to the tower, for a sake of exclusive temperature sensing. This allows for the deduction of the strain contribution of the glued FBG.

4. Results and observations

Measurements were carried out by imposing rotational speeds to the VAWT generator, from 0 to 35 rpm, which is the nominal operational range of the machine. An example of the measured Bragg wavelength shift of the strain sensor as a function of time, for a speed of 25 rpm, is given in Fig. 2a. To determine at which frequencies the tower bending oscillations occur, a power spectral density (PSD) analysis is performed on the temporal signals. The PSD computation for a speed of 25 rpm can be found in Fig. 2b.



(a) (b)

Fig. 2. Results obtained at 20 rpm: (a) Bragg wavelength shift of the strain sensor Vs time; (b) Corresponding PSD computation.

The PSD analysis at all the rotational speeds leads to the conclusion that three bending sources are at stake. First, the wind force applied to the structure creates a bending of the tower. As the wind turbine is composed of three blades, the symmetry repeats thrice per rotation, therefore the wind is responsible for oscillations at a frequency of $(R/60)\cdot 3$ Hz with R the rotational rate in rpm. Secondly, a resonance phenomenon can be observed at a frequency of 1.1 Hz. This value is due to the particular geometry of the considered machine. Thirdly, the structure unbalance causes a tower bending at a frequency of $R/60$ Hz. The higher the rotational speed, the bigger the importance of the unbalance, due to the centrifugal effect.

5. Conclusions

This research demonstrated the ability to determine the bending origins of a VAWT tower. It serves as a solid base for VAWT SHM and holds significant potential as a powerful tool for predictive maintenance of machines. For future works, it would be interesting to investigate the appropriate sensor height along the tower to optimize the sensitivity. Also, other types of deformation like torsion or dilatation could be studied by placing several sensors at different orientations.

6. References

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