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Aeroelastic measurements on a vertical axis wind turbine

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SUMMARY:
Aerodynamic pressure and acceleration are measured synchronously on a blade of a full scale vertical axis wind turbine during operation using a novel type of aeroelastic measurement device: the WAMB (Wireless Aeroelastic Measurement Belt). The objective is to investigate the aeroelastic behaviour of the blade during the rotation, where the flow might change from attached to separated from the surface of the blade, depending on the azimuthal position. These important variations of the aerodynamic loading might lead to dynamic stall. When coupled to the flexibility of the blades, important vibrations of the turbine are expected. At this stage, convincing preliminary tests have been performed to demonstrate the capability of the WAMB to measure pressure and vibrations on a rotating blade. A future test campaign is planned to perform similar in situ measurements on the wind turbine for different operating conditions, including low tip speed ratios, for which dynamic stall is expected to take place.

Keywords: Vertical axis wind turbine, unsteady aerodynamics, aeroelastic vibration

1. CONTEXT

Vertical Axis Wind Turbines (VAWT) are characterised by important variations of the flow conditions around the revolution of the blades. The flow velocity seen by the blade varies in magnitude and direction over the azimuth. As a result, the static stall angle of the blade can be exceeded for low tip ratios, leading to dynamic stall. The complexity of the flow is reinforced by induced velocities, blade tip effects and shed vorticity from the wake of the tower and wake of the preceding blade (Paraschivoiu, 1988). As a result, complex unsteady aerodynamic loading is experienced by the blades. These blades and the tower being flexible, prohibitive vibrations level can turn out.

This work investigates the aeroelastic behaviour of the blades of a vertical wind turbine. For that purpose, a novel type of measurement device has been developed, validated through wind tunnel tests on a static wing and installed on a full scale turbine during operation. The resulting set of experimental data will be compared to simulations predictions of the aeroelastic tool Qblade developed at TUBerlin[1].

[1] http://fd.tu-berlin.de/en/research/wind-energy/qblade/

2. METHODOLOGY

The WAMB (Wireless Aeroelastic Measurement Belt) is a novel type of instrument developed at University of Liège by the Microsys laboratory. It consists in synchronous pressure and acceleration sensors, packaged on a flexible belt, which enable its installation on curved surfaces (see Fig. 1). The WAMB is wireless, in order to be installed on rotating equipments, such as a wind turbine. The current version of the WAMB is 35cm long with 13 MEMS pressure sensors and a single 3-components accelerometer. The acquisition frequency is set to 60Hz, which is sufficient to capture the fluctuations of the flow around a blade with modal frequencies between 1Hz and 6Hz of a turbine rotating up to 45RPM (0.75Hz).

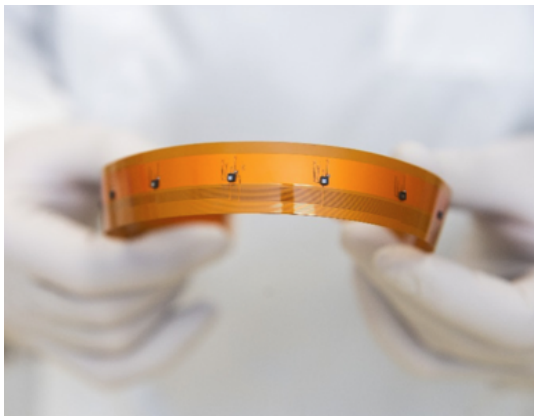

Figure 1. Picture of the WAMB device.

Aerodynamic pressure measurements have been performed on a wing and compared to a conventional pressure scanner (DPMS by Turbulent Flow Instrumentation) in the wind tunnel of ULiège. These tests validated the consistency of the signals measured with the WAMB. They are not presented in this extended abstract for sake of conciseness, but will be presented in the conference paper.

Figure 2. Pictures of the VAWT (left) and the WAMB device installed on one of its blades (right).

3. RESULTS

Preliminary measurements of aerodynamic pressure distribution and acceleration of a blade of a VAWT have been performed with the WAMB. The VAWT developed by the company FAIR-WIND[2] is shown in Fig. 2, together with the WAMB installed on the outer part of the blade, which corresponds to the upper (low pressure) side of the NACA0018 wing.

The resulting aerodynamic pressure are presented in Fig.3 for different azimuthal positions of the blade along the revolution, as defined in Fig. 4. The unsteady (black dots) data correspond to phase-averaged pressure distribution over 30 periods of revolution of the rotor. The lines correspond to the steady pressure distribution computed by XFOIL on the static NACA0018 airfoil profile at 4 different azimuthal positions. For each position, the effective angle of attack (α_{eff}) and wind speed are computed through vectorial combinations of the wind speed and tangent speed of the blade. This comparison between instantaneous/unsteady (black dots) and steady (plain lines) pressure distributions is performed in order to set the 0° of the azimuth.

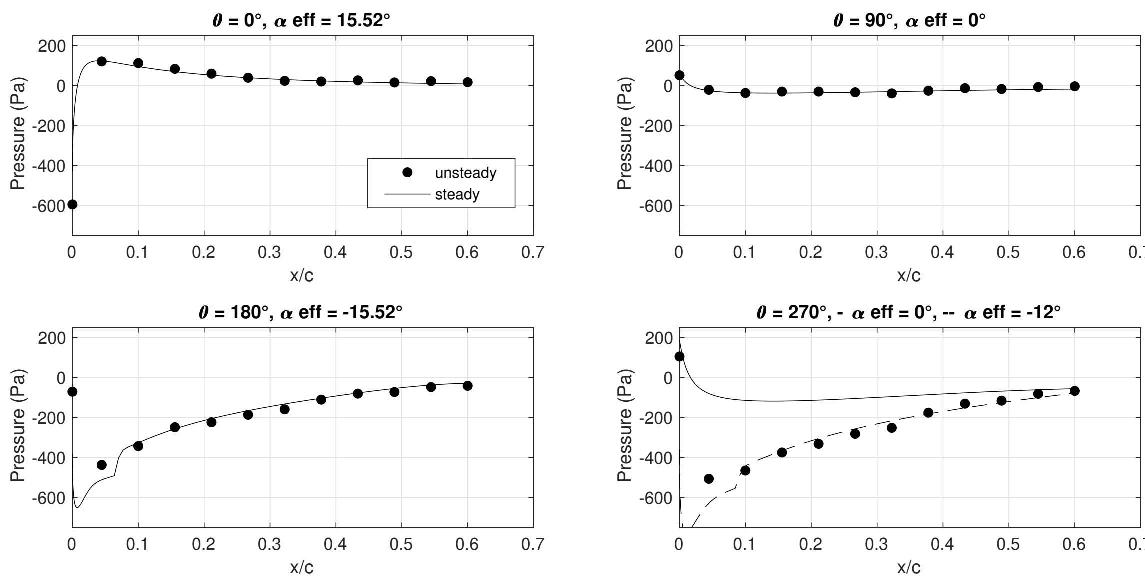

Figure 3. Instantaneous pressure distributions on the blade for selected azimuthal positions.

It is observed that the matching between instantaneous and steady pressure distributions is ensured for $\theta = 0°$, 90° and $\theta = 180°$, while strangely wrong for $\theta = 270°$. This observation is difficult to explain since the effective velocity vector is aligned with the blade velocity, and hence corresponds to $\alpha_{eff} = 0°$. In addition minimal interference with the wake of the blades and the mast is expected at this azimuthal position. In this subplot, the unsteady pressure distribution matches much better the one computed for $\alpha_{eff} = -12°$ (dashed line). Further investigations will be performed for this case.

The vertical, radial and tangential accelerations have been measured synchronously to the pressure taps with the WAMB. The phase-averaged signals are shown over a revolution in Fig. 5. It is observed that the acceleration level is rather low for all three directions. It can be explained by the fact that the turbine was operating at its optimal tip speed ratio, for which the flow remains

[2]www.fairwind.be

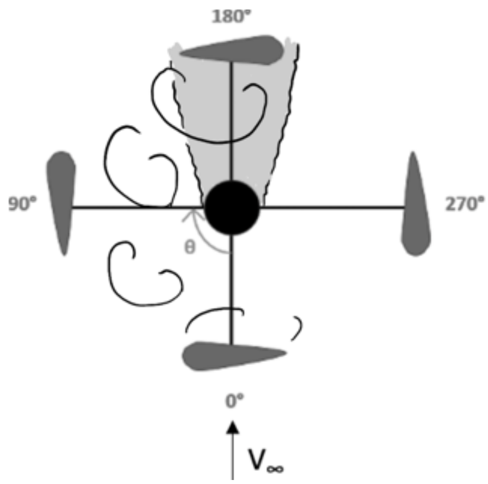

Figure 4. Convention on the azimuthal position of the blade over a revolution.

attached to the surface of the blades. This explanation is corroborated by the pressure distributions presented in Fig. 3 where no flow separation is observed. The acceleration signals show higher frequencies which will be analysed and compared to the modal characteristics of the turbine.

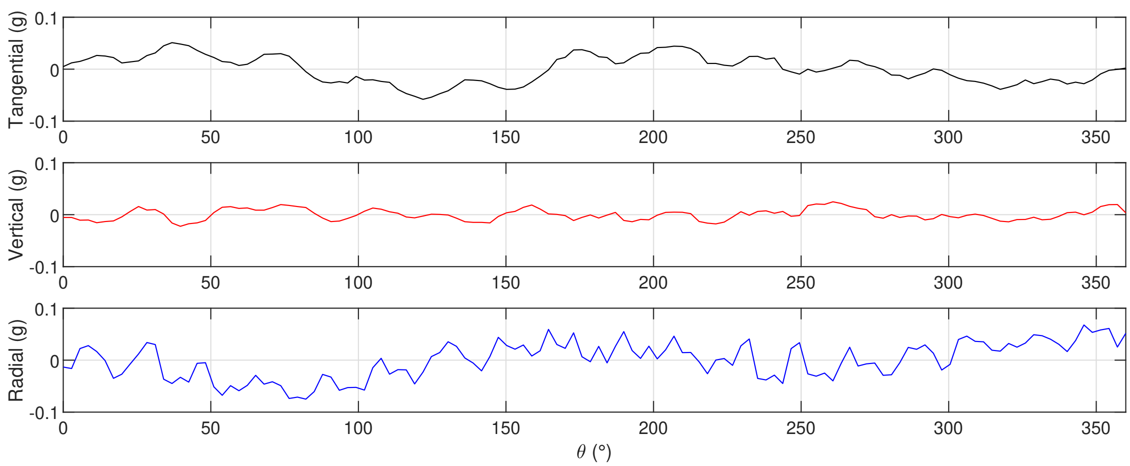

Figure 5. Acceleration signals over a revolution.

4. CONCLUSION

A novel measurement device has been developed and tested (on a fixed wing) in laboratory and in situ on a VAWT during operation. The preliminary set of data shows the potential of the WAMB as a wireless aeroelastic measurement device giving access to time-resolved, synchronous, pressure and acceleration data. A new test campaign is planned in Spring 2023 in order to increase the set of data with different operating conditions of the turbine. A special focus will be given to low tip speed ratios, for which dynamic stall phenomenon is expected to take place. This unique set of experimental data will be compared to numerical predictions of the aeroelastic simulation tool Qblade.

REFERENCES

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