LASER DOPPLER VIBROMETRY ON ROTATING WIND TURBINE BLADES

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Abstract: We report a new 1.5 µm laser vibrometry system (based on a precise image tracker) that measures vibrations of rotating blades of wind turbines at ranges up to several hundred metres. After successful tests with a wind turbine scale model, measurements on real wind turbines were recently made and first results will be presented.

Keywords: Laser Vibrometry, Tracking System, Wind Turbine, Wind Power Plant

1. Introduction

The use of wind turbines, and therefore the need to monitor and analyse their performance, are growing steadily. Turbines tend to vibrate strongly, and laser Doppler vibrometry can usefully supplement the existing on-board sensors for monitoring turbine health. Its applications include condition monitoring, fault diagnostics, sound emission inspection, and also validation of turbine simulation models. Early fault detection will protect against catastrophic conditions and sudden breakdowns.

Laser vibrometry allows non-contact measurement of the vibrations of a wind turbine from a distant sensor on the ground [1-3]. For example the vibration characteristics of the whole blade surface can be determined with no need for built-in sensors or attached marks. Desired measurement distances (given the heights of modern wind turbines) are ~ 300 m or more, and 1.5 µm laser sources can satisfy the eye safety requirements.

Wind turbines with large moving blades are difficult targets. Commercial laser Doppler vibrometers (LDVs) are suited to making scans of static objects, or of spinning objects viewed from a point on their spin axis. But we wished to design and develop a system for measurement of the vibration characteristics of rotating turbine blades that move through large angles of view.

2. General System Description

The system has two main parts: a SWIR image-based tracker and an in-house-developed LDV. A fixed camera is mounted at the base of a pan/tilt unit (PTU) that carries the LDV (Figure 1). The camera captures images of the wind turbine and sends these to software that processes the images and builds a model of the rotary motion. With the help of this model, the pan and tilt head is positioned so that the laser beam automatically follows the rotating turbine blades. We pre-define a collection of *measurement points* (particular points on the blade surface) which the beam illuminates in a known sequence. Various scanning strategies are possible, but in this paper we consider a single laser beam that illuminates a single turbine blade for as long as we wish, before we turn attention to another blade; and we re-use the same measurement points for each blade. To achieve synchronisation (i.e. define a reference phase allowing us to trigger the phase of the time signal at any scanned point), we make separate measurements of one reference point with a second LDV. Such a reference may also be provided by an accelerometer fixed on a specific position of the windmill.

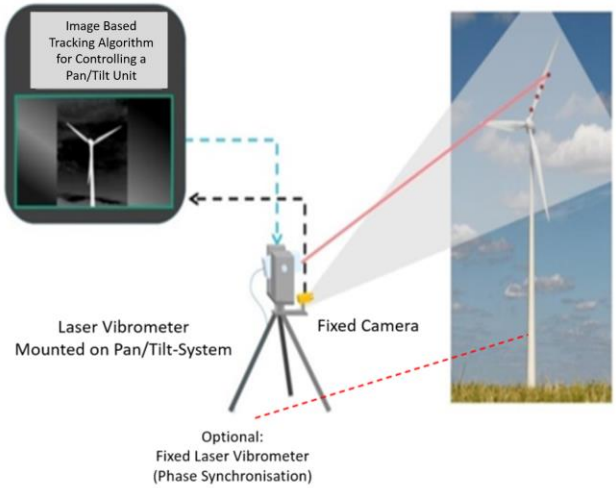

Figure 1. Principal system configuration.

For these wind turbine measurements a new 1.5 µm LDV using a polarisation diversity technique [4] was designed (Figure 2 and Table 1).

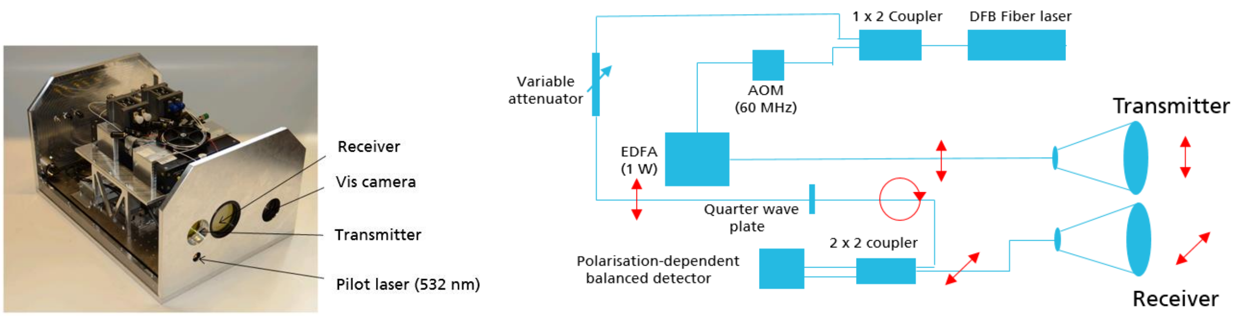

Figure 2. Experimental 1.5 µm laser Doppler vibrometer using polarisation diversity.

Table 1. Parameters of laser Doppler vibrometer

Wavelength	1.56 µm
Output power	up to 1W
Macro Doppler shift (max.)	+/- 60 MHz
Laser divergence	100 µrad
Laser safety class	1M (200 mW), 4 (1 W)

The system has a user interface developed from previous IOSB software. The user can define onscreen the desired set of measurement points on the wind turbine blade. These points are approached radially from the inside to the outside during the experiment, and coloured according to their processing state (Figure 3).

Figure 3. User interface with parameter settings, data acquisition, display and visualisation of the measurement points.

3. Measurements on Dynamic Structures of Wind Turbines

After some test measurements on our outdoor wind turbine scale model, we recorded data for a medium-size wind turbine (Vestas V90) with a rated power of 2.0 MW, a hub height of about 95 m and a rotor diameter of 90 m. The measuring system (LDV on PTU along with the fixed camera) was placed about 335 m from the base point of the wind turbine. Table 2 summarises some important parameters of the turbines, and the consequently expected line-of-sight (LOS) velocities and macro Doppler shifts. Two different data sets are always recorded: the frequency locked loop (FLL) signal related to the macro Doppler shift and the I&Q data of the frequency bandpassed IF signal. Figure 4 displays the estimated and measured macro Doppler shifts for our wind turbine model (left) and the measured wind turbine Vestas V90 (right) during 10 s time duration. The positions for signal pickup are at 20 % from the blade tip to the spinner. The macro Doppler shift variations over time of the real turbine blade are expected to be a combination of the scanning/tracking geometry, the slow mast movement and the blade bending modes. The red curve represents only the scanning/tracking, with the assumption that the blades remain in a fixed plane as they rotate; the other factors will need more detailed attention.

Figure 5 displays, with colour-coded amplitude, the first three vibration modes of the outdoor wind turbine scale model extracted from the demodulated IF signals. First a stationary blade supported on only one end (cantilever) was measured in the laboratory (22 scanning points). Then the same blade was measured when rotating on the outdoor scale model (25 scanning points, but only a part of the whole blade was scanned). In both cases the turbine was excited by a shaker at chosen frequencies, and for phase recognition the data acquisition was synchronised on the excitation frequencies of the shaker. The behaviour of the 1st vibrational mode (lower part left) is not clear.

Table 2. Estimated macro Doppler shifts

Symbol	Parameter	Model wind turbine	Real wind turbine (Vestas V90 – 2.0)	
h_0	Sensor height	1.4 m	1.4 m	
d	Rotor diameter	2 m	90 m	
h	Spinner height	4.15 m	95 m	
R	Range (measuring system – base point of WTG)	7.5 m	250 m	500 m
α_r	Angle between rotor plane normal and horizontal	0°	5°	
T	Revolution period (typ.)	5.1 s	6.2 s	
LOS_{velo}	LOS velocity (max.)	0.43 m/s	15.3 m/s	8.1 m/s
Δf_{macro}	Macro Doppler shift (max.)	+/- 558 kHz	+/- 19.9 MHz	+/- 10.6 MHz

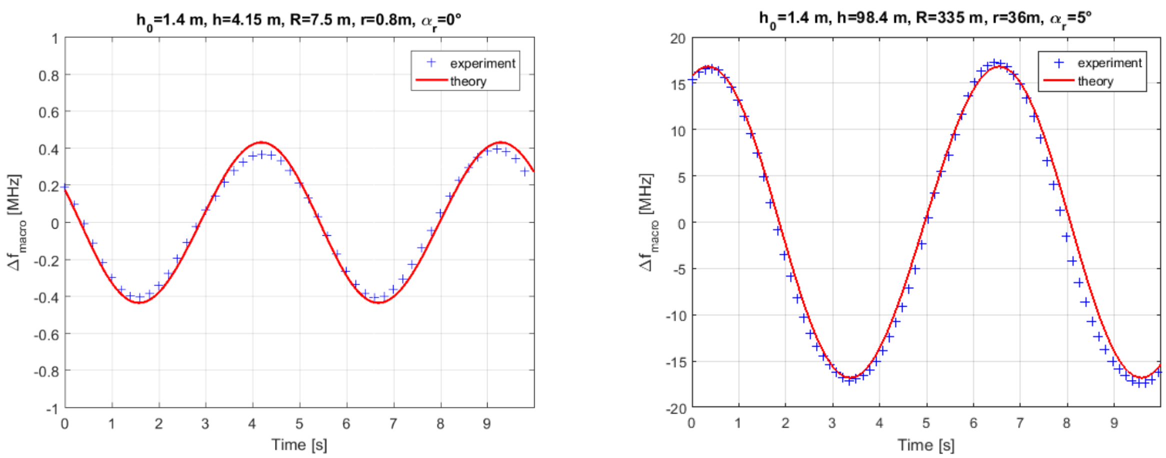

Figure 4. Theoretically estimated (red) and measured (blue) macro Doppler shifts for our wind turbine model (left) and the real wind turbine Vestas V90 (right) during 10 s time duration.

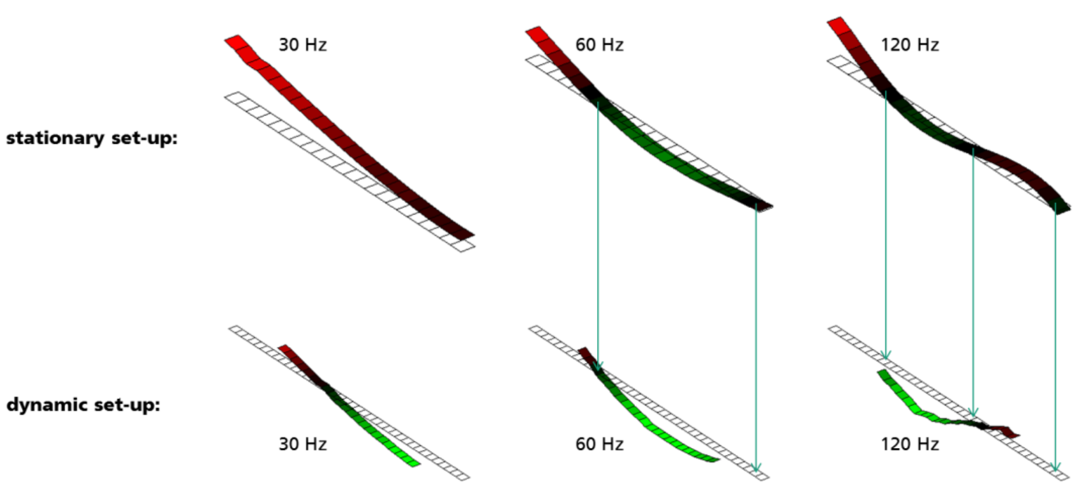

Figure 5. The first three blade vibrational modes of our wind turbine scale model (stationary and during rotation) measured with the laser Doppler vibrometer.

4. ACKNOWLEDGEMENT

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5. References

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