CERTIFICATION OF WIND TURBINES

Spyros G Voutsinas, Vasilis A. Riziotis

National Technical University of Athens, Greece

1 Introduction

As with any other product, certification plays an important role for both the manufacturer and its clients. Certification aims at providing a sound basis and a common understanding that can guide the manufacturer and protect the client. In this connection it provides a methodology for both parties. The manufacturer is given a design verification procedure which according to wide experience can certify the reliability and safety of his product. On the other hand the client is given as assessment procedure for safely choosing the necessary characteristics the wind turbine he is going to buy must have. Certification of wind turbines is a quite extensive field and one lecture is too short to cover all of its aspects in detail. Therefore we had to make certain choices.

We will begin with the modelling of the wind. This is done in the context of stochastic analysis. It will include the generation of stochastically equivalent wind fields in the form of time series which are used as input to time domain aeroelastic simulations. This part is closely connected to estimation of the life time of wind turbines in terms of fatigue loads. Also in the same general context the estimation of extremes in the wind field will be briefly discussed. The extremes are important in estimating the maximum loads on the wind turbine and therefore are linked to design for strength. In view of getting a better insight on the kind of results we can obtain, some typical examples will be discussed in section 3. Section 4 will deal with the IEC standard. We will describe its general philosophy and review the load cases it defines. Finally in section 5 some typical results will be given especially for operation conditions we do not expect to measure easily.

2 Modelling of the turbulent wind inflow

2.1 The Statistical Structure of Wind Turbulence

In the study of wind turbulence the instantaneous velocity component $U_i(\vec{x};t)$ at any point x is considered as a realization from an ensemble with mean $\overline{u_i}(\vec{x};t)$, which is usually interpreted as the mean wind speed on which the turbulent component $u_i(\vec{x};t) = U_i(\vec{x};t) - \overline{u_i}(\vec{x};t)$ is superimposed. Assuming the flow homogeneous in space, the two-point correlation tensor is defined as,

Correlation tensor $$R_{ij}(\vec{r};t) = \overline{u_i(\vec{x};t)\, u_j(\vec{x}+\vec{r};t)} \qquad (2\text{-}1)$$

where $\vec{r}=\Delta\vec{x}=(\Delta x,\Delta y,\Delta z)$. It provides the fundamental description of the spatial structure of turbulence. $R_{ij}(\vec{r};t)$ is a covariance when $i=j$ and a cross covariance when $i \neq j$. The Fourier transform of $R_{ij}(\vec{r};t)$ converts the covariance into a two-point spectral density tensor

Spectral density $$\Phi_{ij}(\vec{k};t) = \frac{1}{(2\pi)^3}\int_{-\infty}^{+\infty} R_{ij}(\vec{r};t)e^{-i\vec{k}\cdot\vec{r}}dr \tag{2-2}$$

where $\vec{k}$ represents the wave number vector. The spectral density tensor contains the complete information on the distribution of turbulent variance and covariance over the wavenumber space.

Not only the Fourier transform of the covariance tensor is of interest but also the Fourier transform of the velocity field itself. Since the stochastic velocity field is not square integrable over all physical space, following [1], the fluctuating velocity can be represented by a generalized stochastic Fourier-Stieltjes integral:

$$u_i(\vec{x};t) = \int_{-\infty}^{+\infty} e^{i\vec{k}\cdot\vec{x}} dZ_i(\vec{k};t) \tag{2-3}$$

where the sets $Z_i(\vec{k};t)$ are random functions with orthogonal increments:

$$\overline{dZ_i(\vec{k};t)\, dZ_j^*(\vec{k}';t)} = \begin{cases} 0 & \vec{k} \neq \vec{k}' \\ \Phi_{ij}(\vec{k};t)\, dk & \vec{k} = \vec{k}' \end{cases} \tag{2-4}$$

where dZ^* denotes complex conjugate.

In most engineering applications the analysis can be simplified by considering the correlation for points on a plane perpendicular to the direction of mean flow. An alternative to the spectral tensor is the set of all cross-spectra

$$\chi_{ij}(\kappa_1,\Delta y,\Delta z,t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} R_{ij}(x,\Delta y,\Delta z,t)e^{-i\kappa_1 x}dx \tag{2-5}$$

which contains the same information. The connection between the components of the spectral tensor and the cross-spectra is

$$\chi_{ij}(k_1,\Delta y,\Delta z,t) = \int_{-\infty}^{+\infty} e^{i(\kappa_2\Delta y+\kappa_3\Delta z)}\left(\int_{-\infty}^{+\infty}\Phi_{ij}(\vec{k},t)dk_2dk_3\right)dk_1 \tag{2-6}$$

When $i = j$ and $\Delta y = \Delta z = 0$ we obtain the one-point power spectrum,

$$F_i(k_1) = \chi_{ii}(k_1,0,0,t) \qquad \text{(no summation)} \tag{2-7}$$

which is often reported in the literature. A spectral coherence can also be defined as,

$$\mathrm{Coh}_{ij}(k_1,\Delta y,\Delta z) = \frac{\chi_{ii}(k_1,\Delta y,\Delta z,t)}{\sqrt{F_i(k_1)\, F_j(k_1)}} \qquad \text{(no summation)} \tag{2-8}$$

The turbulent eddies we observe in the boundary layer are spatially extensive structures, and, ideally, their analysis requires information from many points on space. Relevant measurements are becoming available from aircraft and remote sensors, but still the greatest part of the existing data is derived from point measurements in space as a function of time. Taylor's frozen turbulence hypothesis is usually invoked to convert these temporal