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Towards the analysis of process fluctuation in wind turbine

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Abstract: *Towards the analysis of process fluctuation in wind turbine.* The basic laws of fluctuation and statistical physics propositions are presented. The analysis of turbulent wind flow characteristics is performed. An example of the correlation of wind speed horizontal and vertical components pulsation is presented. The dependence between the fluctuation laws and entropy is determined.

Key words: wind turbine, turbulent wind flow, process fluctuation, entropy

INTRODUCTION

The fluctuations, i.e. random deviations of physical quantities from their average values, are one of the main characteristics of the processes occurring in wind turbine installations. Quantitative characteristic of fluctuations is based on the methods of statistical physics and probability theory [Małahov 1978].

A measure of the fluctuation quantity is its variance σ_x^2, that is the mean square deviation x from the mean x, $\sigma_x^2 = \overline{(x - \overline{x})}^2 = \overline{x}^2 - \overline{x}^{-2}$, where the line on top denotes the statistical averaging. An equivalent measure of fluctuations is averaged deviation σ_x equal to the square root of the variance or its relative value $\delta_x = \sigma_x / \overline{x}$.

It can be found not only the fluctuations of the quantity x_i, but also the correlation between them Δx_i, Δx_k, defining the mutual influence. Though only for statistically independent variables $\overline{\Delta x_i \Delta x_k} = \overline{\Delta x_i} \times \overline{\Delta x_k} = 0$. The example is correlation of volume and pressure $\overline{\Delta V \Delta p} = -kT$.

Fluctuations are non-equilibrium processes. In general, there is a relationship between the fluctuations of physical quantities in equilibrium and non-equilibrium properties of the system under external disturbance [Monin 1968].

These propositions can be the basis for the study of fluctuations in turbulent flows coming to wind turbine air channel.

MATERIAL AND METHODS

Existing methods of pulsating measurements make it possible to determine for a number of consecutive time points simultaneous speed values u' in the horizontal and w' vertical directions.

Figure 1 shows an example of the correlation graph, which characterizes the relationship between the velocity pulsations u' and w' on the basis of measurements at a height of 1.5 m. The correlation coefficient r_{uw} is 0.65. The initial speed in a horizontal direction – u_o = 0.35 m/s.

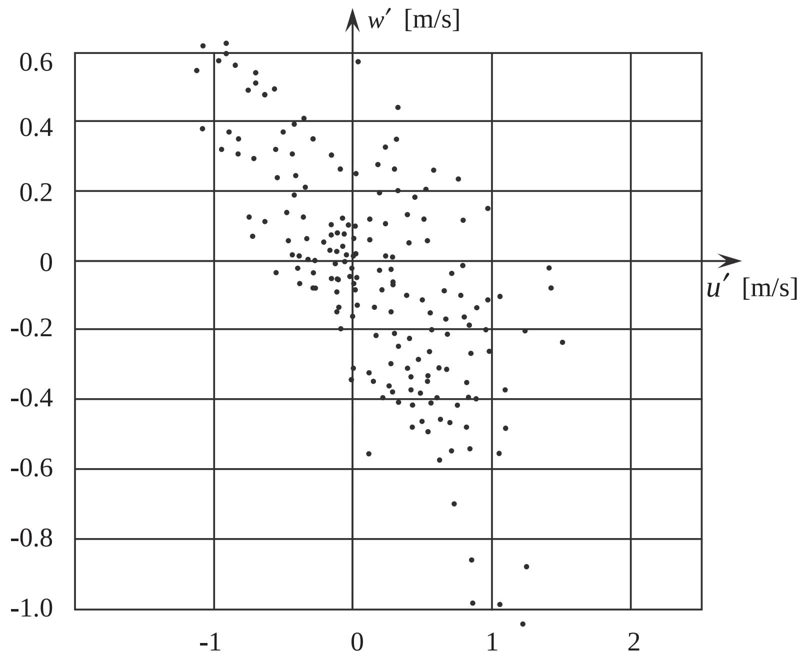

FIGURE 1. An example of the correlation graph for the pulsations of wind speed horizontal and vertical components

RESULTS AND DISCUSSION

Wind flow characteristics change with increasing distance z from the earth surface. When $z >> z_0$ turbulence indicators of at the height z will depend on five variables: z_0, ρ_0, $\frac{g}{T_0}$, u_0 and $\frac{q_0}{c_p \rho_0}$ (where: ρ_0 – density, g – acceleration of gravity, T – temperature, u – speed in the horizontal direction, q – the specific heat flow, c_p – heat capacity at constant pressure). The index "0" indicates that the value of the above parameters apply to the condition $z = z_0$. Since in this case there are four independent dimensions: length, time, mass, and temperature, for the analysis of the phenomenon it can be limited (up to a numerical factor) by a single parameter, namely the dimensionless complex.

As shown in [Monin and Yaglom 1965] the dimensionless complex is the quantity:

$$\zeta = \frac{z}{L} \tag{1}$$

where L – length scale equal:

$$L = -\frac{u_0^3}{\chi \frac{g}{T_0} \frac{q}{c_p \rho_0}} \tag{2}$$

comprising parameters $\frac{g}{T_0}$ and $\frac{q}{c_p \rho_0}$.

Dimensionless Kármán constant χ is introduced in the expression for the purpose of verifying the subsequent calculations so that $L > 0$ under stable thermal stratification, when $q < 0$.

In the analysis of the processes it should be referred to the assessment of the entropy production, which can serve as a quantitative fluctuation measure.

To do this, we must state the main propositions of the thermodynamic theory of fluctuations.

L. Boltzmann having analyzed the relationship between the microscopic environment behavior and the macroscopic thermodynamics laws suggested the relation between entropy and probability [Kondepudi and Prigogine 1998]:

$$\zeta = k \ln W \tag{3}$$

where:
k – Boltzmann constant ($1.38 \cdot 10^{-23}$ J/K);
W – the number of microscopic states corresponding to the macroscopic thermodynamic state.
Value W is called the thermodynamic probability (proposed by M. Planck) because, in contrast to the usual probability, this number is much greater than unity. Thus, Boltzmann introduced the idea of probability in thermodynamics – a controversial idea, the true value can only be determined with the help of the modern theory of unstable dynamical systems.

A. Einstein proposed a formula for the fluctuation probability of thermodynamic variables, applying the idea of the Boltzmann vice versa, while the Boltzmann used the "microscopic" probability at derivation of thermodynamic entropy, Einstein used thermodynamic entropy to deduce the fluctuation probability due to the following relationship:

$$P(\Delta S) = Z e^{\Delta S / k} \tag{4}$$

where:
ΔS – the entropy change associated with the fluctuation relative to equilibrium;
Z – the normalization constant, which provides sum of all probabilities equal to one.

To obtain the fluctuation probability it is necessary to find the associated entropy change. Thus, the main problem is reduced to derivation ΔS in terms of fluctuations δT, δp, etc. On the basis of the propositions of thermodynamics the dependence between the entropy and the fluctuations:

$$\Delta S = -\frac{C_V (\delta T)^2}{2T^2} - \frac{1}{2Tk_T}\frac{(\delta T)^2}{V} - \sum_{i,j}\left(\frac{\partial}{\partial N_j}\frac{\mu_i}{T}\right)\frac{\delta N_i \delta N_j}{2} \tag{5}$$

where N – number of material moles.

This expression can be rewritten in a more explicit form if the derivative if the chemical potential is expressed in terms of the number of moles. For an ideal gas, this can be easily done because the chemical potential for component k equal:

$$\mu_k = \mu_{k0}(T) + RT \ln(p_k / p_0) = \mu_{k0}(T) + RT \ln(N_k RT / V p_0)$$

where p_0 – the standard pressure (usually 1 atm).

After a series of transformations, authors obtain [Kondepudi and Prigogine 1998]:

$$\Delta S = -\frac{C_V(\delta T)^2}{2T^2} - \frac{1}{Tk_T}\frac{(\delta V)^2}{2V} - \sum_i \frac{R(\delta N_i)^2}{2N_i} \tag{7}$$

where:
C_V – mole heat capacity;
N_i – expressed in moles, when multiplied by the Avogadro number we get number of molecules $\tilde{N}_i$ (note that $kN_A = R$).

The calculation of entropy production in the given equations is not difficult.

Finally, we note that the fluctuations are of fundamental importance, limiting the scope of application of thermodynamic concepts of large (containing many particles) systems for which fluctuations are much smaller than fluctuating quantities themselves.

CONCLUSIONS

The analysis of the fluctuations can more deeply reveal the physical nature of the processes occurring in wind turbine and, as a consequence, to clarify the energy performance of the installation.

Quantitative evaluation of the main system characteristics is determined by the value of the entropy production.

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Streszczenie: *Kierunki analizy fluktuacji procesów w silnikach wiatrowych*. Przedstawiono podstawowe prawa fluktuacji i twierdzenia fizyki statystycznej. Wykonano analizę właściwości turbulentnego przepływu wiatrowego. Przedstawiono przykład korelacji pulsacji poziomych i pionowych składowych prędkości wiatru. Określono zależność między prawem fluktuacji i entropii.

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