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# Experimental Measurements of Dynamical Wind Load acting on the Overhead Transmission Line

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*The detailed aim of the study is to determine the distribution of flow velocity, turbulence, the frequency of detaching vortices. These parameters are measured for conductor installed in the wind tunnel and it models the overhead transmission line in wind flow conditions. Knowledge of these parameters are very important from the perspective of response of the conductor on wind load excitations generating the vibrations of the system and the results can be useful in the design process. Measurements are made for constant air velocity, fixed turbulence at the inlet of the tunnel.*

***Keywords***: *wind tunnel, vortex shedding, turbulence, flow velocity distribution, overhead transmission line*

## 1. Introduction.

Wind is a very important load acting on civil engineering structures. Overhead transmission lines are particularly sensitive to wind due to low stiffness and low structural damping. In recent times, the number of wind problems analyzed in wind tunnels has increased significantly.

The time-space distribution of the pressures and velocities and the modeling of the aerodynamic instabilities can be performed in wind tunnel. Galloping or vortex induced vibrations are good examples. Among researchers, Witoszycki developed the use of wind tunnels since 1925's, then in sixties Scanlan and Scruton put the next huge step in applications of this method of research.

One-point probes for the measurement were used in the beginneing of researches and at the present time the multipoint probes for the evaluation of instantaneous values of the velocity field are performed.

Experimental techniques include HWA (Hot Wire Anemometry) [1], LDA (Laser Doppler Anemometry) [2] , UDV (Ultrasonic Doppler Velocimetry) [3] and flow visualization (PIV - Particle Image Velocimetry) [4].

Several investigators [5-8] experimentally studied the problem of turbulence intensity around the bluff body and in the wake. Basic information on the vortex wake structure, stable and unstable regions are provided in works [5-8]. The non isotropic and intermittent character of the turbulence is experimental measured in works [9-12].

In the recent years, the numerical methods has become a very popular and proper method of research of fluid dynamics [13-17]. For turbulence problems some efficient and useful approaches based on the analysis of kinetic energy and dissipation functions are developed [18-20].

The investigations of velocity distribution, turbulence intensity and power spectrum density function of turbulence near the overhead transmission line are analyzed.

## 2.Theoretical foundation

Turbulence energy equation models have been developed to describe the flow history effects [21]. The kinetic energy k is used for experimental analysis of turbulent fluctuation and has the formula:

$$k = \frac{1}{2}\overline{u_i' u_i'} = \frac{1}{2}\left(\overline{u_i'^2} + \overline{v_i'^2} + \overline{w'^2}\right), \tag{1}$$

where u, v, w describe the velocities in directions x, y, z.

Reynolds stress tensor has the form:

$$\tau_{ii} = -\rho\overline{u_i' u_i'} = -2\rho k \ , \tag{2}$$

Including the turbulence kinetic energy and dissipation per unit mass one can write the transport equation using two equations:

$$\rho\frac{\partial k}{\partial t} + \rho U_j\frac{\partial k}{\partial x_j} = \tau_{ij}\frac{\partial U_j}{\partial x_j} - \rho\varepsilon + \frac{\partial\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]}{\partial x_j}, \tag{3}$$

$$\rho\frac{\partial \varepsilon}{\partial t} + \rho U_j\frac{\partial \varepsilon}{\partial x_j} = C_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{ij}\frac{\partial U_j}{\partial x_j} - C_{\varepsilon 2}\rho\frac{\varepsilon^2}{k} + \frac{\partial\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]}{\partial x_j}, \tag{4}$$

where the closure coefficients are:

$$C_{\varepsilon 1} = 1.44, C_{\varepsilon 2} = 1.92, C_\mu = 0.09, \sigma_k = 1.0, \sigma_\varepsilon = 1.3, \tag{5}$$

and eddy viscosity:

$$\mu_t = \frac{\rho C_\mu k^2}{\varepsilon}, \qquad (6)$$

### 3. Experimental facilities and conditions of the measurements

The measurements were prepared in the closed-circuit wind tunnel presented in Fig.1. The intension of the experiments was to measure the flow around the transmission line and in the volume of the tunnel, far from the cable.

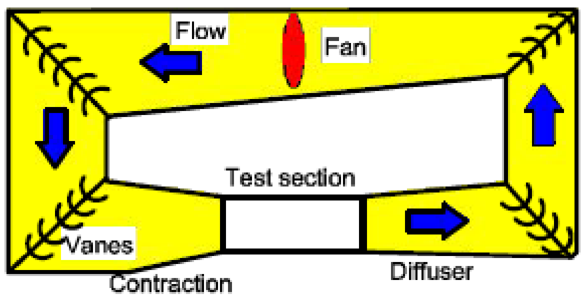


**Figure 1.** Schematic diagram of close-circuit wind tunnel used in the experiments

Dimensions of the tunnel are: 500 x 700 -2000mm, velocity 10 m/s.

#### 3.1. Instruments and calibration of measurement

In the experiments a pitot static tube and constant temperature anemometer (CTA) probe were used. Before measuring the flow around the cable in the wind tunnel is necessary to calibrate the measuring instruments.
Callibration coveres both instruments used in experiments: pitot static tube and constant temperature anemometer.

Pitot static tube is a pressure measurement instrument used to measure fluid flow velocity. This measured pressure is the stagnation pressure of the fluid, also known as the total pressure. According to Bernoulli equation:

$$p_t = p_s + p_d \qquad (7)$$

where $p_t$ is the total pressure, $p_s$ is the static pressure, $p_d$ is the dynamic pressure.

The dynamic pressure can be described as:

$$p_d = \frac{\rho u^2}{2} \qquad (8)$$

where $\rho$ is the air density, u is the air velocity.

In the CTA measurements a turbulent flow is of random nature and a statistical description of the velocity is necessary. The time series are analysed in the time domain and in the frequency domain. Turbulence intensity is define as:

$$Tu = \frac{U_{RMS}}{U_{MEAN}}, \tag{9}$$

Hot wire anemometer, another name of CTA, uses the relationship between the resistance of the wire and the flow speed as it uses 2 micrometres wire electrically heated to some temperature above the ambient and when air flows past the wire it cools the wire.

**Figure 2.** Measurement CTA probe

### 3.2. Measurement tunnel and grids

General view of the system is shown in figure 3.

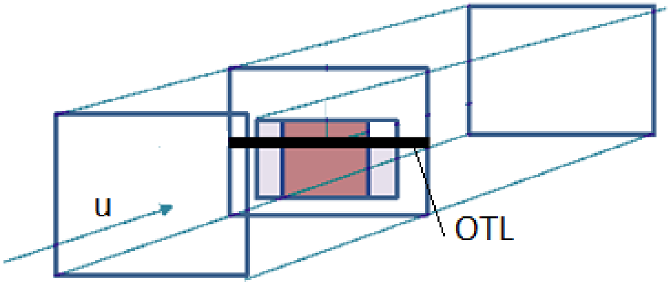


**Figure 3.** Flow inlet against OTL

The measurement probe is mounted to the traverse system that is moving in the predefined distances and connected to the pressure transducer. Location of the probe is set to a defined positionon the two sections: front section and behind section in distance of 10D, where D is the diameter of the transmission line. Measuring program contents the speed, temperature, the barometric pressure and the dynamic pressure. Computer controls the movement of the probe in two directions with the step of 5mm. At each measured point the dynamic pressure is recorded using the pressure gauge.

### 3.3. The inlet velocity deviation

From the figure 4 is seen that the inflow velocity distribution is relatively uniform. The total deviation is not higher than +/ -1% of reference speed V=10 m/s.

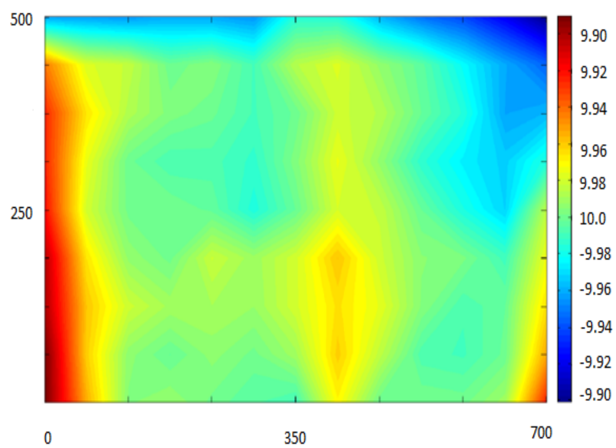


**Figure 4.** Deviation of the inlet velocity

As the turbulence has the influence on the results, it was also measured. In this case the hot-wire anemometer was used. The temperature of the measurement was 20 Celsius degrees.

## 4. Results of the measurements and discussion

The flow in the wind tunnel around the transmission conductor of 700mm length was analysed. Diameter of the conductor is 18mm. The flow around the conductor with fix Reynolds number of 11'911 was performed. For improving accuracy of result, 126 grid points were analysed in front of and behind the conductor for two methods of measurements: PST - Pitot Static Tube (PST), and CTA - Constant Temperature Anemometer. The experiments show the high speed reduce around the conductor.

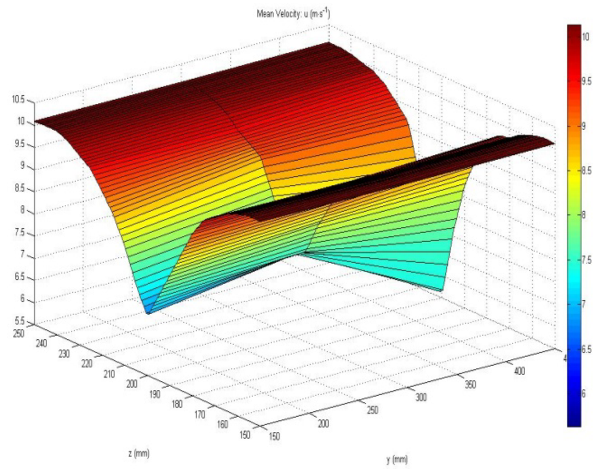


**Figure 5.** 3D PST results of velocity reduction

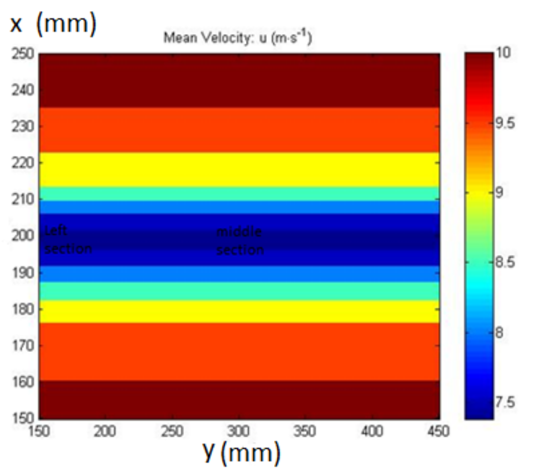


**Figure 6.** PST results of velocity reduction

Figures from 5 to 7 show that the speed is reduced from 10 m/s to 7.40 m/s.

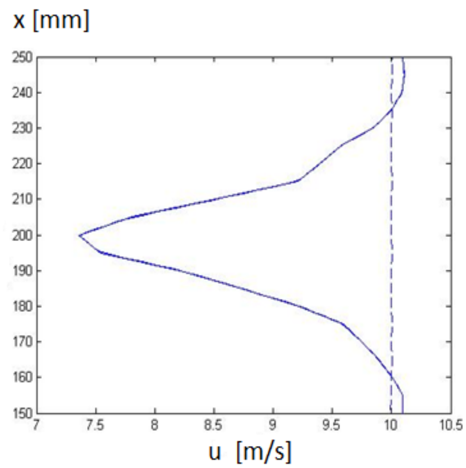


**Figure 7.** Velocity profile in the middle section of the cable from PST measurement.

The results are measured according to grid coordinates presented in figure 8.

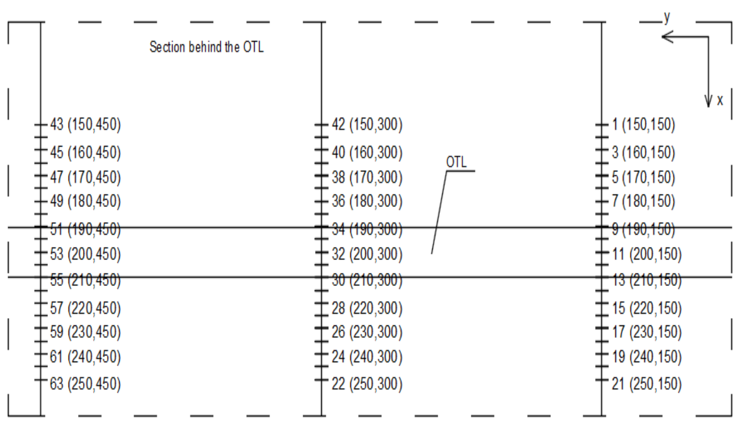


**Figure 8.** Grid coordinates

Distribution of flow velocity behind the OTL in time domain is shown on figure 9. Results present high level of variability of velocity in time domain.

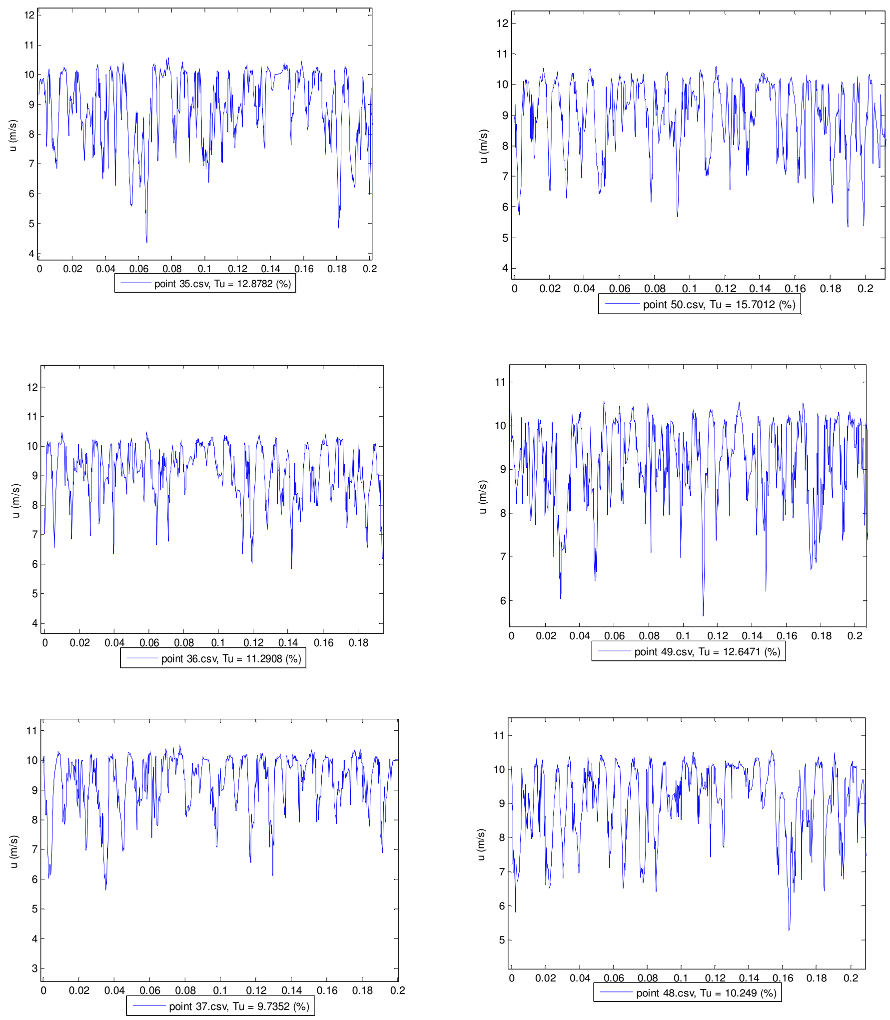


**Figure 9.** Distribution of flow velocity behind the OTL in time domain

Spectral turbulence density is presented in figure 10. Detached vortices frequencies are in the range from 108 Hz to 112 Hz.

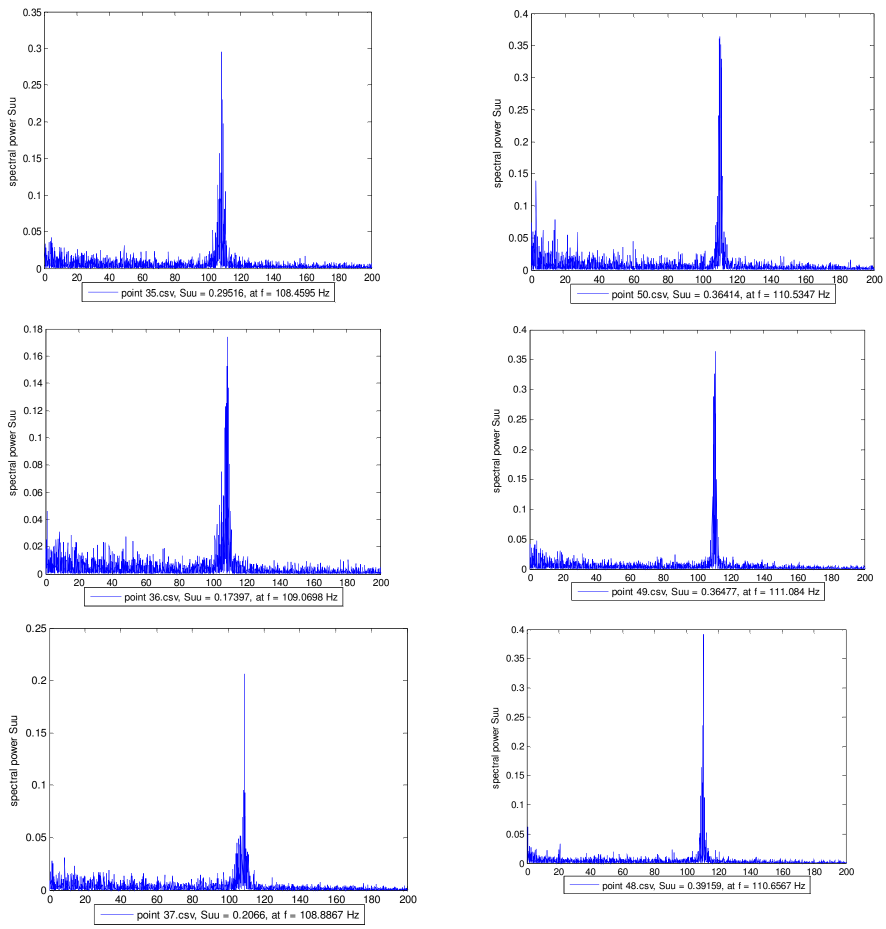


**Figure 10.** Spectral turbulence density behind the OTL

Figure 11 presents the dependence of peak value of turbulence intensity and vertical location of analyzed points in the distance of 10D behind the cable. First case relates to the section in the middle-behind (mPoint) of the cable and second case on the left section (LPoint) behind the cable. Orientation of side sections is shown on figure 6. For both cases the high values of turbulence are achieved in the vortex shedding close to the cable, i.e. turbulence intensity of 15.26 % in the middle section and 20.03 % in the left-side section. In the upper distance from the cable of 50mm equals to 2.78D from the cable axis, the turbulence is still high and reduces to 3.21 % in the middle section and 3.06 % in the left-side section which is much more higher comparing to the inlet turbulence of 0.4 %.

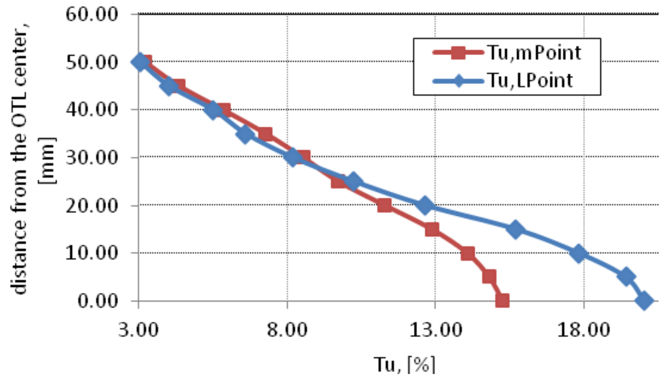


**Figure 11.** Turbulence intensity distribution behind the OTL

Relation between the peaks of spectral turbulence density function Suu and turbulence intensity for middle and left side sections are shown in figure 12. The highest peak value of spectral turbulence density function is 0.3 for turbulence intensity 12.88 % in the middle section, and 0.39 for turbulence intensity 10.25 % in the left section.

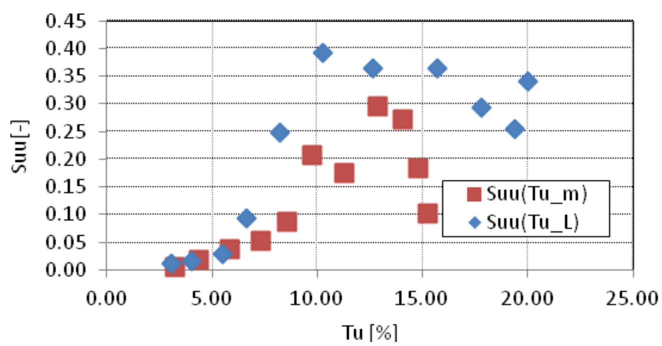


**Figure 12.** Spectral turbulence density against turbulence intensity

Figure 13 presents the relation between spectral turbulence density function Suu and point location behind the cable in the middle and left side sections. Results show that the highest peak value of spectral turbulence density function is achieved in the distance of 0.8D (15mm from the centre of the cable) for middle section and 1.4D (25mm from the centre of the cable) for left section.

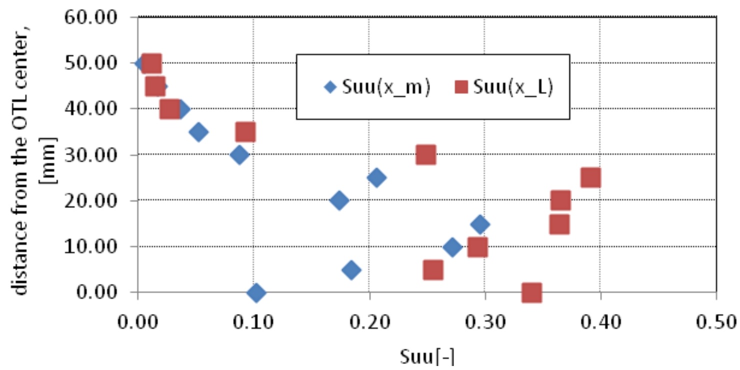


**Figure 13.** Spectral turbulence density distribution behind the OTL

Results on figure 14 show that frequencies of detached vortices for both cases, in the middle and left section, changes with the location of points behind the cable, average values are 108.82 in middle section and 110.62 in the left section.

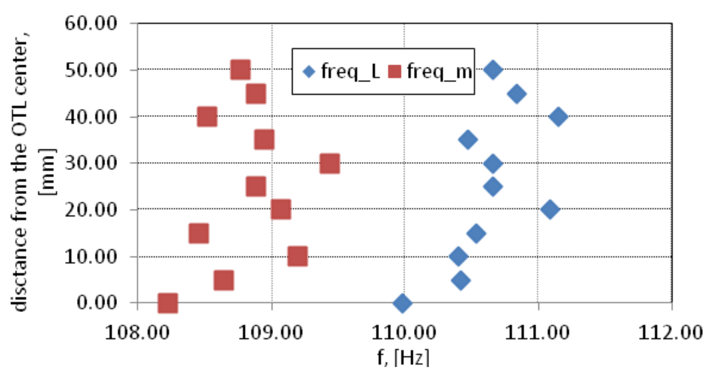


**Figure 14.** Frequencies of detached vortices in wake shedding with distance from the OTL

## 5. Conclusions

In the paper the distribution of flow velocity, turbulence and frequency of detaching vortices were analysed. These parameters were measured for conductor installed in the wind tunnel that models the overhead transmission line in wind flow conditions. Measurements are made for constant air velocity, fixed turbulence at the inlet of the tunnel. The turbulence was kept at very low level in the distance between inlet and measured object, average equal to 0.4%. This allow for comparisment of turbulence intensity that appear due to cable location. The turbulence near the conductor is 20 times bigger then in the inlet.

Knowledge of achieved results are very important from the perspective of response of the conductor on wind load excitations generating the vibrations of the system and the results can be useful in the design process of OTL as well as for BC. The presented experiment is the first part of the research which aim is further description of the flow around the damper located on the conductor and the aerodynamical characteristics of the damper to obtain the maximal vibration reduction of the conductor to improve the durability of the line.

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