Modelling of Flow Past Damper Attached to the Overhead Transmission Line

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Abstract. The paper presents the model of airflow around the conductor of overhead transmission line with the attached vibration damper of Stockbridge type. The analysis was performed for fixed Reynolds number Re = 12000, circular cross-sections of the conductor with the vibration damper. The purpose of the paper is to determine aerodynamic drag and lift coefficients and the frequencies for conductor and damper and also the pressure around them and in their wakes. Based on the analysis, the velocity distribution around the conductor and the damper was found. For analysis the model of RNG $k-\varepsilon$ was used. On the basis of the performed study one can emphasize the need of control of interference of both conductor and attached dampers.

1. Introduction
Due to the vibrations of conductors of overhead transmission lines, the reduction of their vibrations is essential. For this purpose the mechanical dampers are often used. Reduction of vibrations is required especially in the case of turbulent flow that is very common in nature (figure 1) [1]. The wind acting on structures may cause the pressure and suction of static character but also may cause the dynamic effects [2]. The wind load depends on the wind velocity, air density, surroundings of the object, rough of the terrain, shape and the proportion of the elements of the structure. From the point of aerodynamics, the bodies are divided on: streamlined - elongated in the direction of the fluid flow such as cross sections used for wings of aircrafts, and bluff bodies. In the case of bluff bodies the separated wakes are formed, which are the source of detaching vortices, causing problems of vibrations of slender structures, e.g. aeolian vibrations of conductors. The fluid flow around these objects is characterized by numerous physical complex phenomena [3].

2. Mathematical formulation
According to the Reynolds hypothesis, components of velocity and pressure fields can be represented as the sum of the averaged and turbulence components. Hence the equations of motion, taking into account these components, take the following form [4-8]:

$$\frac{D\bar{u}_i}{Dt} = \bar{f}_i - \frac{1}{\rho} \frac{\partial \bar{p}}{\partial x_i} + \frac{1}{\rho} \frac{\partial}{\partial x_j} \left( \bar{\tau}_{ij} + \tau^*_ij \right)$$ (1)

In above equations the stresses mean:
\[ \tau_{ij} = \mu \left( \frac{\partial \bar{v}_i}{\partial x_j} + \frac{\partial \bar{v}_j}{\partial x_i} \right), \quad \tau_{ij}^* = -\rho \bar{v}_i \bar{v}_j \]  

(2)

Stress tensor \( \tau_{ij}^* \) is called the Reynolds stresses and have the turbulent character.

Figure 1. Character of laminar and turbulent flow

In the analysed case the Re-Normalisation Group (RNG \( k - \varepsilon \)) method was used that belongs to the Reynolds-Averaged Navies Stokes (RANS) turbulence models [9-12]. Reynold's turbulence stress tensor is described by the additional equations:

\[ \tau_{ij}^* = \mu_t (\bar{v}_{ij} + \bar{v}_{ji}) - 2 \beta k \delta_{ij}, \quad \mu_t = \frac{c_k \mu k^2}{\varepsilon} \]  

(3)

where: \( k \) - turbulence kinetic energy, \( c_k \) constant, taken in the analysed case 0.0845, \( \varepsilon \) - turbulence kinetic energy dissipation.

3. Numerical analysis and discussion

The wind around the conductor (line) with damper that are modelled as smooth cylinders of circle section was analysed. Diameter of the circles are \( D_1=18 \) mm for the line and \( D_2=40 \) mm for the damper (figure 2). The 'x' direction of the wind is analysed and 'y' component is zero. The unsteady flow for stream simulation around cylinders with fixed Reynolds numbers was used. For improving accuracy of results, 18320 elements were applied. Navier Stokes equations were solved numerically with use of Semi Implicit Method for Pressure Linked Equations (SIMPLE) with sequenced calculations of velocity and pressure's components. The coefficients of subrelaxations were additionally used for stabilizing the calculations process. Second order upwind method for momentum equations was adopted.

The results of numerical analysis for \( \text{Re} = 1.2 \times 10^4 \) and the conductor with damper are shown in figures 3 to 6. The average drag coefficient is: \( C_{D1} = 3.21 \) for the conductor, \( C_{D2} = 5.98 \) for the damper (figure 3a). The amplitude of the lift coefficient is \( CL_{1}=0.78 \) for conductor and \( CL_{2}= 2.30 \) for damper (figure 3b).

The frequency of drag force is approximately twice that of lift force, i.e. for conductor \( f_{c1,1}=0.429 \) Hz and \( f_{c1,2}=0.215 \) Hz, for damper \( f_{c2,1}=0.378 \) Hz and \( f_{c2,2}=0.195 \) Hz (figure 4). The pressure contours around the line and damper and in their wakes are shown in the figure 5. Figure 6 presents the distribution of velocities behind the analyzed system for sections \( x=2*D_1, 5*D_1, 10*D_1 \).

The wind behind the conductor is 0.637 m/s (\( x=3.6, y=0.0 \)) and 0 m/s (\( x=3.6, y=-4.0 \)) behind damper. In the section 5*D_1 minimal velocity is 1.047 m/s (\( x=9.0, y=0.0 \)), and in the section 10*D_1 is 4.332 m/s (\( x=18.0, y=-1.8 \)).
Figure 2. Analysed model

Figure 3. (a) Variation of drag coefficients with time for conductor (cd1_u) and damper (cd2_d) and (b) variation of lift coefficients with time for conductor (cl1_u) and damper (cl2_d) for Re = 1.2 x 10^4
Figure 4. (a) Spectral drag density for conductor (cd1_u) and damper (cd2_d) and (b) spectral lift density for conductor (cl1_u) and damper (cl2_d) for Re = 1.2 x 10^4

Figure 5. Pressure contour for conductor and damper for Re = 1.2 x 10^4

4. Conclusions
The paper presents the model of airflow around the conductor of overhead transmission line with the attached vibration damper of Stockbridge type. Drag and lift coefficients for Reynolds number Re = 1.2 x 10^4 was analyzed. These coefficients were analyzed in the time domain and also power spectra analysis was performed. The average drag coefficient for the damper is bigger than for the conductor. The amplitude of the lift coefficient for line is smaller than for damper. The frequency of drag force is approximately twice that of lift force. In the paper the pressure along the conductor and damper and the distributions of velocity are presented. On the basis of the performed analysis one can emphasize the need of control of interference of both transmission conductors and attached dampers. Further analysis of the shape of dampers may bring benefits in terms of aerodynamic damping.
Figure 6. Velocity distribution behind the analysed system

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