Aerodynamic Response of Long-Span Transmission Line Conductors: Wind Tunnel Experiments and Drag Coefficient Analysis

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Abstract. This paper systematically analyzes the mechanical behavior of long-span transmission line conductors under varying wind speeds and directions through wind tunnel experiments. The experiments were conducted using the low-speed recirculating wind tunnel at Shanghai University of Electric Power, simulating wind speeds ranging from 10m/s to 30m/s, covering common wind conditions encountered during actual transmission line operations. The test objects were 1-meter-long aluminum bare stranded wires. By measuring the lift, drag, and torque on the conductors under different wind speeds, aerodynamic characteristic data were obtained. The results indicate that the drag coefficient of the conductors generally increases with wind speed, suggesting a corresponding rise in aerodynamic forces. Variations in drag coefficient patterns among different conductor types may be attributed to differences in geometric shape, material properties, or surface treatments.

Keywords: Conductor Dancing; Constitutive Model; Large Span Tower; Wind tunnel experiment.

1. Introduction

The safe and stable operation of long-span transmission lines is critical for modern power systems and socio-economic activities. Conductor galloping, a common natural phenomenon, poses significant threats to transmission line safety[1]. In-depth research into the mechanisms and characteristics of galloping is essential for improving disaster resistance and reliability[2,3].

Wind tunnel experiments serve as an effective tool for simulating real-world wind load conditions and precisely measuring mechanical responses of conductors under varying wind speeds and directions[4-6]. These experiments provide crucial aerodynamic data, such as lift, drag, and torque, which are vital for understanding the mechanical mechanisms of galloping[7]. The findings from this study will contribute to the development and optimization of galloping early-warning systems, enabling proactive prevention of safety incidents and ensuring the stable operation of long-span transmission lines.

2. Wind Tunnel Experiment Overview

The experiment simulated wind loads on transmission lines at 10–30 m/s, representing conditions from light breezes to near-storm-level winds. Precise measurements of lift, drag, and torque under controlled wind speeds and directions were conducted to evaluate conductor behavior[8,9]. These data are critical for understanding galloping mechanisms and providing scientific support for transmission line design and maintenance[10].

2.1 Experimental Equipment and Specimens

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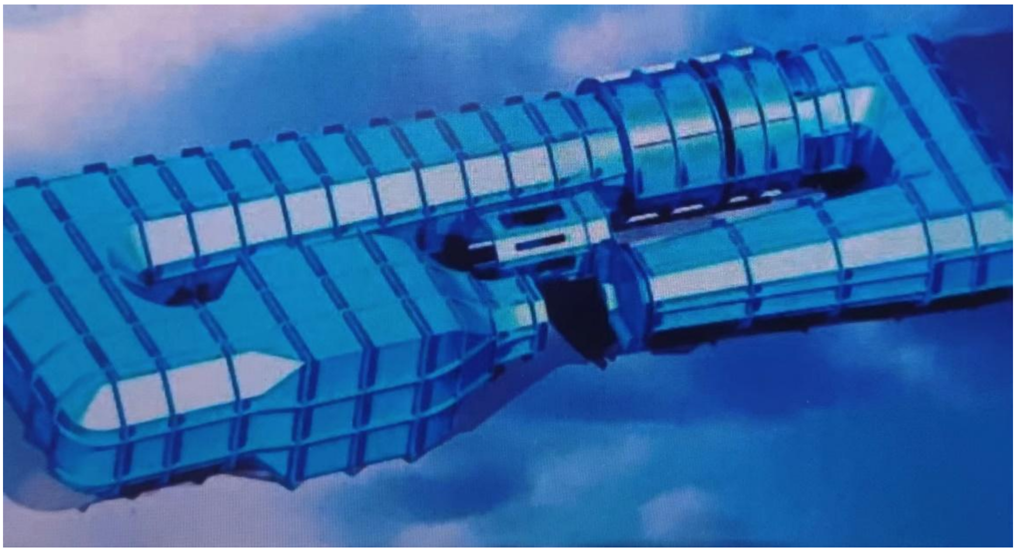

Fig. 1 Low-speed recirculating wind tunnel layout

The test specimens were 1-meter-long aluminum bare stranded wires with diameters of 33.8 mm and 39.9 mm, representing common conductor sizes.[15] The wires were mounted on a force balance using a base plate and flow deflectors to minimize interference from fixture-induced wind loads. Endplates with a 5 mm gap were installed to mitigate edge flow effects.

Fig. 2 Conductor specimen mounting diagram

2.2 Calculation Methods

The ideal gas law pV=nRT was applied to determine air density ρ, assuming standard atmospheric pressure (1.01325×105 Pa) and temperature (0°C). [16]Drag coefficient（CD ） was calculated using:

$$C_{FX} = \frac{F}{\frac{1}{2}\rho v^2 DL} \tag{1}$$

where F is the drag force (N), D is the conductor diameter (m), L is the length (m), and V is the wind speed (m/s).

Fig. 3 Schematic of wind tunnel operation interface

The strain balance device is installed inside the cavity of the conductor model to measure three types of aerodynamic forces: lift, drag, and torque. The arrangement of the conductor is shown in Figures 1-2.[16] To ensure two-dimensional flow around the conductor during testing, smooth-surfaced circular plates are installed at both ends of the conductor model. To fix the conductor model, an aluminum channel with a height of 30 mm is installed below the upper plate. A gap of approximately 5 mm is left between the lower end of the conductor model and the lower plate to ensure sufficient free travel for the torque sensor, thereby guaranteeing that the conductor model does not come into contact with the lower plate during testing.

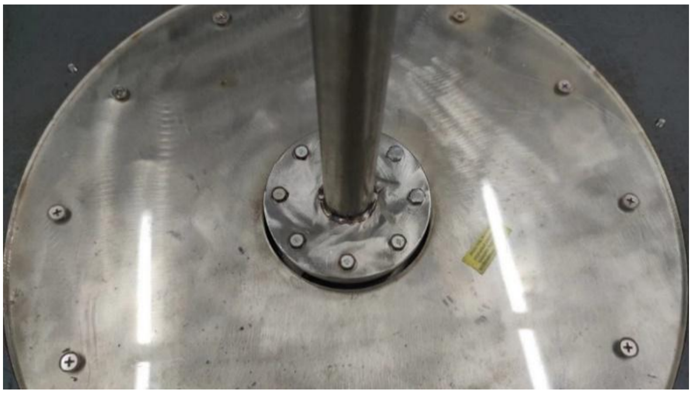

Fig. 4 Lower endplate of conductor support

3. Results and Analysis

Experiments were conducted at 25°C, 1.009 MPa atmospheric pressure, and air density of 1.182 kg/m33. Key findings include:

Drag coefficients (CD) generally increased with wind speed, indicating stronger aerodynamic forces.Variations in CD trends among conductors correlate with geometric and material differences.Measured forces at 10–30 m/s were extrapolated to full-scale spans (1690 m) using scaling formulas.

Table 1. Forces at 10 m/s

Serial Number	Conductor Diameter (m)	Conductor Length (m)	Average Axial Force (Fx) (N)	Aerodynamic Coefficient

1	0.0285	1690	4.591054	0.00048639
2	0.028	1690	5.030173	0.000164837
3	0.0228	1690	3.726000	0.00038488
4	0.0229	1690	4.167068	0.0004977

Table 2. Forces at 20 m/s

Serial Number	Conductor Diameter (m)	Conductor Length (m)	Average Axial Force (Fx) (N)	Aerodynamic Coefficient
1	0.0285	1690	24.772564	0.00059955
2	0.028	1690	25.804929	0.00018635
3	0.0228	1690	23.650453	0.00067971
4	0.0229	1690	24.489069	0.0007314

Table 3. Forces at 30 m/s

Serial Number	Conductor Diameter (m)	Conductor Length (m)	Average Axial Force (Fx) (N)	Aerodynamic Coefficient
1	0.0285	1690	56.535862	0.00060075
2	0.028	1690	57.027592	0.00017476
3	0.0228	1690	54.266302	0.00068979
4	0.0229	1690	59.829899	0.00080356

Data validation confirmed the accuracy of constitutive models. Deformation errors were smaller at higher mounting points due to reduced wind loads. Inner mounting points exhibited lower errors compared to outer ones, consistent with reduced wind exposure.

4. Summary

This chapter systematically analyzed the mechanical behavior of long-span transmission line conductors under varying wind conditions using wind tunnel experiments. The low-speed recirculating wind tunnel provided precise control over wind parameters. Key conclusions include:

（1）Drag coefficients rise with wind speed, reflecting increased aerodynamic forces.

（2）Differences in CD trends highlight the impact of conductor geometry and material properties.

（3）Experimental methodologies and scaling formulas ensure reliable extrapolation to real-world applications.

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