CFD Simulation Analysis on Aerodynamic Parameters of Steel Tubular Transmission Tower Body

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Abstract. This paper utilizes the CFD simulation analysis method, calculates and analyzes the distribution characteristics of streaming around the typical steel tubular transmission tower body and the pressure field, researches the change law of wind load force (torque) coefficient along with each main shaft direction o tower body, and then compares it with corresponding wind tunnel test result, and verifies the adaptability of this CFD simulation result. The result shows that the pole member in the upwind direction on the steel tubular tower has obvious disturbance and shielding effect to wind speed distribution around the pole member of downwind direction. The wind direction has obvious influence on the aerodynamic (torque) parameters of tower body, especially the steel tubular - angle steel combined tower body. The above research result provides a certain theoretical support and value taking basis for the wind-resistant design of steel tubular transmission tower body.

Key words: Steel tubular transmission tower; Tower body; Wind load; CFD simulation analysis

1. Introduction
Along with the constant improvement of transmission capacity and voltage class of power transmission line, the load and tower weight of power transmission pole tower are increased constantly. Compared with the angle steel tower, the steel tubular tower is featured by small shape coefficient, large rotating radius, good anti-twisting performance [1, 2], with good technical and economic advantages, applied into large-load and large-span pole towers more and more frequently.

The transmission tower is a wind sensitive structure, and almost each year, there is the strength damage to transmission tower caused by strong breeze [3-4]. To identify the wind load design parameters of iron tower structure of power transmission line exactly, and to enhance the wind-resistant design safety and economy of transmission tower, numerous scholars have implemented wind tunnel test and CFD simulation research on the angle steel power transmission tower, and have analyzed the wind load characteristics [4-11]. However, the research on wind load of round steel tubular transmission tower is limited; wherein, Zou Lianghao et al. [12] have conducted high-frequency dynamometry wind tunnel test to three kinds of typical lattice steel tubular tower rack, researched the calculation method of wind load shape coefficient of lattice tower rack, and have conducted comparison between the wind tunnel test result and the corresponding load standard value. Deng Hongzhou et al. [13] have researched the average wind load and shape coefficient of the model of some steel tubular UHV transmission tower based on the high-frequency dynamometry wind tunnel test, and have obtained the most adverse wind direction angle of transmission tower through analysis. Shen Guohui et al. [14] have discussed the base shear, bending torque and corresponding shape coefficient laws under different landforms of multiple types of round steel tower. The result shows that the shape coefficient measured under the uniform flow shall be corrected. Yang Fengli et al. [15] have adopted the method which combines the wind tunnel test and CFD to obtain the windward and leeward shape coefficients of different steel tubular tower models and the leeward wind load reduction coefficient, and have analyzed the change law of the leeward wind load reduction coefficient along with the wind shield coefficient and height-width ratio. Li Zheng et al. [16] have researched the wind axis shape (resistance) coefficients under different incoming flow air speeds and
wind direction angles of the typical steel tubular - angle steel combined tower body. Through comparison analysis, they have proposed suggestions for the angle wind coefficient and load distribution coefficient of steel tubular – angle steel combined tower body. Yang Zhenyu et al. [17] have implemented high-frequency dynamometry wind tunnel test to the rigid section model of some UHV tower body and cross arm, researched the shape coefficient laws of wind loads of tower body and cross arm, and have compared the test result with corresponding load design standards at home and abroad. From the above information, it can be known that most researches about wind load of steel tubular tower body adopt the technical manner of wind tunnel test. Due to the limit of dimension, the researches about wind tunnel test usually apply the cutoff model after contraction scale, and the difference between the Reynolds number in the test model and the Reynolds number in actual structure is 2-3 orders of magnitudes [2], so the Reynolds number effect cannot be neglected.

This paper utilizes the CFD simulation analysis method, calculates and analyzes the distribution characteristics of streaming around the typical steel tubular transmission tower body and the pressure field, researches the change law of wind load force (torque) coefficient along with each main shaft direction of tower body, and then compares it with corresponding wind tunnel test result, and verifies the adaptability of this CFD simulation result, and the achievement provides theoretical support and value taking basis for the wind-resistant design of steel tubular transmission tower body.

2. Modeling of CFD Simulation Analysis on Tower Body

Model Determination of Tower Body

Through the statistical analysis on the general design of State Grid Corporation of China, geometric parameters of steel tubular transmission tower of UHV engineering and calculation parameters of wind load, the tower body model in this paper is determined coming from some 500kV dual-circuit angle tower. The tower body section between the intermediate cross arm and the lower cross arm of the tower as the research object to implement the simulation analysis on wind load. For the tower body pole member, it is necessary to consider two situations: (1) all of the pole members are made of steel tubular (with steel tubular tower body); (2) the main material of tower body refers to steel tubular member, and the diagonal material refers to angle steel member (steel tubular – angle steel combined tower body).
To conduct comparison and verification with the numerical simulation result, this research conducts wind tunnel tests at the wind speed of 15m/s and 20m/s to the above mentioned steel tubular tower body and the steel tubular – angle steel combined tower body in the HD-2 Wind Tunnel Laboratory of Human University. The selected scale ratios of tower body model are 1:22 and 1:17 respectively, and the test model and dimensional information are as shown in Figure 1.

Setting of CFD Grid Model and Calculation Parameter of Steel Tubular Tower Body

According to the characteristics of geometric model and CFD simulation analysis of steel tubular tower body, and through trial calculation and analysis on comparison with test result, the grid and calculation parameters of CFD simulation analysis model of power transmission tower are shown as below:

1) The calculation domain is set as a cuboid domain, with the length, width and height of 12.5L, 5L (10L) and 4H respectively. Both L and H are length and height of the section model of power transmission tower respectively, and the geometric dimension of the calculation domain is as shown in Figure 2.

Figure 2. Geometric Dimension of Calculation Domain

2) To realize the change of wind attack angle on the premise of no repeat modeling, it is necessary to use the GGI (Generalized Grid Interface) method; the GGI calculation model including three sub-domains is as shown in Figure 3.

Figure 3. Schematic of Calculation Domain Division Based on GGI Grid Interface

3) After comprehensively considering the geometric complexity of power transmission tower structure, difficult degree of grid generation and calculation exactness, it is necessary to fit a complicated geometric boundary by adopting non-structural tetrahedral grid around the tower body and cross arm, and use the blocked structural hexahedral grid far away from the tower body and cross arm to obtain the incoming flow conditions exactly.

4) The maximum dimension of the external calculation sub-domain surround(s) grid is 0.2L, and the minimum grid dimension is 0.05L; the maximum dimension of the internal calculation sub-domain radius2(r2) O-type grid is 0.05L, and the minimum grid dimension is 0.01L; the maximum grid dimension of the non-structural grid of the tetrahedron of internal calculation sub-domain radius1(r1) is 0.01L, and the minimum
grid dimension refers to the steel tubular or the minimum wall thickness of angle steel. The growth rate of grid adopts 1.2 uniformly, so as to reduce the numerical error brought by the sharp change of grid dimension.

(5) Under all working conditions, the k-ω SST model is adopted to simulate turbulence. The spatial dispersion of momentum equation will adopt the second-order windward format, and the turbulence energy k and ω will adopt the first-order windward format for spatial dispersion. The pressure, momentum, k and ω sub-relaxing factors are respectively set as 0.2, 0.3, 0.6 and 0.6.

Method for Analysis on Calculation Data Processing

The numerical simulation data and the wind tunnel test measurement data in this paper are all expressed with the dimensionless force coefficient and moment coefficient. The rules for body axis coordinate system and wind direction angle are as shown in Figure 4. The wind direction angle refers to the included angle between the incoming flow direction and the axial direction of tower body or cross arm, and after defining that the negative direction of Y axis when the wind direction angle is 90° refers to the incoming flow, the resistance which the model suffers from at this time refers to positive value, and both the X-axis right and Z-axis are vertical to the X-Y plane. According to the definition of coordinate system as shown in Figure 4, each dimensionless force coefficient can be worked out according to the formula below:

$$C_i = F_i / \left(0.5 \rho U^2 S \right)$$  \hspace{1cm} (1)

In the formula: i = X, Y and Z, which are three main directions which the body axis coordinate system corresponds to; $$F_i$$ and $$C_i$$ refer to the aerodynamic force (N) along with the i direction and the corresponding aerodynamic coefficient; $$V$$ refers to the average wind speed (m/s) of incoming flow; $$\rho$$ refers to the air density, taking the value of 1.225kg/m$^3$; S refers to the reference area (m$^2$), taking the windward projection area of tower body or cross arm when the wind direction angle is 90°, and the B refers to reference length.

The $$C_{L0}$$ and $$C_{D0}$$ in Figure 4 are the wind axis lifting coefficient and wind axis resistance coefficient of tower body or cross arm model respectively, and the $$C_{R}$$ refers to the coefficient of wind load resultant force which the tower body or cross arm model suffers from. Conduct projection of the body axis resistance coefficient $$C_{X0}$$ and $$C_{Y0}$$ obtained from the calculation with formula (1) along with the coordinate system direction of the wind axis, and then, the calculation formulas for the wind axis resistance coefficient $$C_{D0}$$ and the lifting coefficients $$C_{L0}$$, $$C_{D0}$$ and $$C_{L0}$$ of the model are obtained as below:

$$C_{D0} = -(C_{X0} \cos \theta + C_{Y0} \sin \theta)$$  \hspace{1cm} (2)

$$C_{L0} = -(C_{Y0} \cos \theta - C_{X0} \sin \theta)$$

In the formula: $$\theta$$ refers to the wind direction angle of wind tunnel test, i.e. the included angle between incoming flow direction and the axial direction of tower body or cross arm. According to the formula (2), the calculation formula of the wind load resultant force coefficient $$C_{R0}$$ of tower body or cross arm is shown as below:

$$C_{R0} = \sqrt{C_{X0}^2 + C_{Y0}^2} = \sqrt{C_{D0}^2 + C_{L0}^2}$$  \hspace{1cm} (3)

The angle $$\alpha$$ in Figure 4 refers to the included angle between the transverse wind load coefficient of tower body or cross arm $$C_{X0}$$ and the wind load resultant force coefficient $$C_{R0}$$. 

\[ \text{Figure 4. Definitions of Tower Body Coordinate and Wind Direction Angle} \]
3. CFD Simulation Calculation Result and Analysis

**CFD Simulation Analysis on Shape Coefficient of Steel Tubular Tower Body**

According to above analysis flow, the grid model of typical steel tubular body is established, and then the CFD analysis is conducted. The wind speed of incoming flow is 10m/s, and the calculated wind direction angle is 0-90°, with interval of 15°, as well as the calculation of shape coefficient of each working condition (resistance coefficient) and visualized flow field. Figure 5 gives the diagram of speed and pressure distribution around the section model of steel tubular tower body, and the result shows that the wind speed amplitude value at the windward front edge of main material of tower body is relatively large, and the upwind pole member has obvious disturbance and shielding effect on the wind speed distribution of the downwind pole member. Correspondingly, both the windward and leeward surfaces of main material suffer from relatively large positive pressure and negative pressure.

![CFD Grid Model and Pressure Distribution Cloud Chart of Steel Tubular Tower Body](image)

**Figure 5.** CFD Grid Model and Pressure Distribution Cloud Chart of Steel Tubular Tower Body

![Aerodynamic Coefficient](image)

![Aerodynamic Moment Coefficient](image)

**Figure 6.** Change of Aerodynamic and Moment Coefficients of Steel Tubular Tower Body along with Wind Direction

Figure 6 displays the change law of aerodynamic (moment) coefficients in three directions which the steel tubular tower body suffers from along with the change of direction. The result shows that for the steel tubular tower body model which is researched in this paper, the aerodynamic response in the horizontal direction (x and y directions) shall be greater than the result amplitude value in the vertical direction (z direction), and it shall be dominant. Meanwhile, the wind direction effect is obvious. Take the $C_y$ [as shown in Figure 6(a)] for example, its result distribution shows approximately symmetrical distribution with the 45° wind direction result, and reach the larger values under the wind directions of 15° and 75° respectively. The change of aerodynamic coefficient ($C_x$) in the X direction along with wind direction shows cosine function shape, and the amplitude
value scope is from -0.5 to 0.25 approximately. For the aerodynamic moment, the absolute value of $C_{mx}$ in the horizontal direction is relatively large, taking the larger amplitude value under the 15° and 75° wind directions.

**CFD Simulation Analysis on Shape Coefficient of Steel Tubular - Angle Steel Combined Tower Body**

Figure 7 gives the distribution diagram of speed and pressure around the section model of steel tubular – angle steel combined tower body, similar to the steel tubular tower body, the wind speed amplitude value at the windward front edge of the main material is relatively large. Meanwhile, the air flow disturbance effect of the upwind tower body is also relatively obvious, and compared with the round steel tubular, the air flow separation at the edge of auxiliary material is more obvious. Different from the steel tubular tower body, this paper researches the steel tubular - angle steel combined tower body; besides that the windward and the leeside of main material suffer from relatively positive pressure and negative pressure respectively, its angle steel auxiliary material also suffers from a relatively large pressure.

![Speed Distribution of Tower Body along with 0° Wind Direction](image1)

![Pressure Distribution of Tower Body along with 0° Wind Direction](image2)

**Figure 7.** CFD Grid Model and Pressure Distribution Cloud Chart of Steel Tubular - Angle Steel Combined Tower Body

![Aerodynamic Coefficient](image3)

![Aerodynamic Moment Coefficient](image4)

**Figure 8.** Change Law of Aerodynamic and Moment Coefficients of Steel Tubular - Angle Steel Tubular Combined Tower Body along with Wind Direction

Figure 8 gives the diagram of relationship among changes of aerodynamic (moment) coefficients in three directions which the steel tubular - angle steel combined tower body suffers from along with the change of wind direction. Different from the steel tubular tower body, the changes of amplitude values of aerodynamic coefficients in three directions which the steel tubular - angle steel combined tower suffers from are all relatively obvious; in which, the absolute value of $C_y$ is dominant. However, for aerodynamic moment coefficients, the influence of wind direction on result is relatively small, and the scope of value taking of $C_{mx}$ is from -1.5 to -1.0, while $C_{my}$ and $C_{mz}$ have a tiny change nearby the zero point respectively.
Comparison between CFD Simulation Calculation Result and Wind Tunnel Test

Figure 9(a) - (b) respectively give the comparison between the shape coefficients $C_D$ obtained from simulation of steel tubular tower body and steel tubular – angle steel combined tower body and the wind tunnel test result. The result shows that the wind tunnel test result under two types of wind speeds are coincident basically, which proves that the wind tunnel test and the corresponding data dimensionless method have sufficient reliability and adaptability.

Through comparison with wind tunnel test result, it can be known that the CFD simulation calculated values are around both sides of the test, and the relative deviation of most simulation results and test values is smaller than 30%, especially for the result under the most adverse wind direction, the above mentioned deviation is smaller than 10%.

Figure 9. Comparison between Simulated Shape Coefficients $C_D$ under Different Combinations and Wind Tunnel Test Result

4. Conclusions

Through the CFD simulation analysis on typical steel-power tower body, this paper researches the distribution characteristics of wind speed and pole member pressure around the steel tubular, steel tubular - angle steel combined tower body, discusses the change law of wind load force (torque) coefficient of tower body along with each main shaft direction of tower body, compares it with corresponding wind tunnel test result, and verifies the reliability and adaptability of CFD simulation analysis result of this paper. Main research findings and conclusions are shown as below:

(1) The 50-year-met wind speed is between 20m/s-30m/s in most areas of the simulated Region I and the 100-year-met wind speed is between 20m/s-35m/s. The maximum wind speed appears nearby Bange Meteorological Station. The 50-year-met wind speed and the 100-year-met wind speed are 28.4m/s and 30.0m/s respectively. The 50-year-met wind speed is less than 20m/s in most areas of the simulated Region II, and the 100-year-met wind speed is less than 25m/s. The maximum wind speed appears nearby Xinlong Meteorological Station. The 50-year-met wind speed and the 100-year-met wind speed are 27.4m/s and 28.9m/s respectively.

(2) The wind direction has obvious influence on the aerodynamic (torque) coefficient, especially the steel tubular - angle steel combined tower body, and the absolute value of wind force coefficient in the y direction is dominant.

(3) The shape coefficient calculated from CFD simulation and the result obtained from wind tunnel test are approximate, and for the result under the most adverse wind direction, the deviation of the above mentioned result is smaller than 10%.

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