Simulation analysis on vibration characteristics of 220kV vertically arranged double bundled conductors

Zhiqing Xu, Fan Gao, Lihuan Wang, Yaning Ren
Stata Grid Hebei Economic Research Institute, Shijiazhuang 05000, China
Corresponding author’s e-mail:2201700563@neepu.edu.cn

Abstract: In order to analyze the adhesion vibration characteristics of vertically arranged double bundled conductors, the vibration equation of adhesion conductor under the coupling action of aerodynamic force and electromagnetic force is established. Firstly, the electromagnetic force on the conductor with different splitting spacing is simulated by COMSOL software. Then, based on the Runge-Kutta numerical calculation method and the vibration mathematical model, the displacement time history curve and amplitude value of the adhesive wire under different wind speed, span and initial spacing are obtained. Finally, a 220kV laboratory model is built, and the real-time monitoring of the wire vibration data is carried out to verify the accuracy of the mathematical model and simulation results. The results show that the coupling effect of aerodynamic force and electromagnetic force is the main reason for the vibration of the wire. The larger the aerodynamic force and electromagnetic force, the larger the amplitude of the wire.

1. Introduction
Under the coupling of aerodynamic force and electromagnetic force, vertically arranged double bundled conductors are prone to stick vibration. In order to study the adhesion vibration characteristics of conductor, the displacement time history curve of bundled conductor under aerodynamic force was solved in reference [1]. In reference [2], the adhesion process of double bundled conductors under electromagnetic force is simulated. The influence of electromagnetic force on the vibration of double bundle conductor is analyzed in reference [3]. References [1-3] have simulated the vibration process of double bundled conductors, and analyzed the influence of aerodynamic or electromagnetic force on the adhesion vibration. However, the coupling effect of aerodynamic force and electromagnetic force is not considered in the above studies.

2. Establishment of mathematical model for vibration of adhesive wire under coupling action of aerodynamic force and electromagnetic force

2.1. Energy analysis of vibration system of two degree of freedom adhesive conductor
Under the coupling effect of electromagnetic force and aerodynamic force, the initial energy of vertically arranged double bundled conductors can be obtained, and then lead to conductor vibration. The mechanism diagram of bundled conductor adhesion vibration is as follows.
In this paper, it is assumed that the oscillation mode of the conductor in two directions is

\[ u(x,t) = \varphi_1(x) \cdot q_1(t) \]

\[ v(x,t) = \varphi_2(x) \cdot q_2(t) \]

(1)

The kinetic energy expression of the adhesive wire is as follows:

\[ T = \frac{1}{2} m \int_0^L \sin^2 \left( \frac{\pi x}{L} \right) dx \cdot \left[ \ddot{q}_1^2(t) + \ddot{q}_2^2(t) \right] \]

(2)

The strain energy expression of bundled conductor is as follows:

\[ V_e = \int_0^L \left( \frac{1}{2} EA \varepsilon_x^2 \right) \cdot ds \]

(3)

The gravitational potential energy of the vibrating system is expressed as follows:

\[ V_g = mg \int_0^L u(x,t) dx \]

(4)

The expression of dissipation function is as follows:

\[ D = \frac{1}{2} \int_0^L \left( 2m \omega_\xi \ddot{\xi}_y \sin^2 \left( \frac{\pi x}{L} \right) \ddot{q}_1^2 + 2m \omega_z \ddot{\xi}_z \sin^2 \left( \frac{\pi x}{L} \right) \ddot{q}_2^2 \right) dx \]

(5)

The non conservative force expression of vibration system is as follows:

\[ Q_i = \int_0^L \left[ \sin \left( \frac{\pi x}{L} \right) \cdot F_y \right] dx + \int_0^L \left[ \sin \left( \frac{\pi x}{L} \right) \cdot F_D \right] dx \]

(6)

2.2. Establishment of mathematical model for vibration of bonding wire

The mathematical model of the vibration of the glued conductor can be deduced based on the energy method, Lagrange equation and assumed mode method, and the generalized coordinates which can completely define the position of the system are introduced.

\[ \frac{1}{2} m \ddot{q}_1 + \frac{m^2 g^2 L (\pi^2 + 6)}{24T^2} q_1 - \frac{7mg \pi EA}{3TL} q_1^3 + \frac{3 \pi^4 LEA}{16T^4} q_1^5 + \frac{3 \pi^4 LEA}{16T^4} q_2^5 - \frac{7mgEA}{9} q_2^2 + \frac{2mgL}{\pi} m \omega_\xi \ddot{\xi}_y L \dot{q}_1 = \frac{2L}{\pi} Q_{Fy} + \frac{2L}{\pi} Q_{Dy} \]

\[ \frac{1}{2} m \ddot{q}_2 + \frac{3 \pi^4 LEA}{16T^4} q_1^3 q_2 + \frac{3 \pi^4 LEA}{16T^4} q_2^3 - \frac{14mgEA}{9} q_1 q_2 + m \omega_\xi \ddot{\xi}_z L \ddot{q}_2 = \frac{2L}{\pi} Q_{Fx} + \frac{2L}{\pi} Q_{Dx} \]

(7)

3. Simulation of electromagnetic force on vertically arranged double bundled conductors

3.1. Simulation principle and process

First, the stress tensor on the boundary is automatically integrated. Then, the Lorentz force density on the cross section of the conductor is integrated, and the Maxwell stress tensor distribution on the surface
of the bundled conductor is called to draw the flux density model cloud of the bundled conductor. Finally, the area of the surface stress tensor is divided, and the electromagnetic force data of the bundled conductor in X and Y directions are extracted.

3.2. Simulation results of conductor electromagnetic force under different splitting spacing

When the splitting spacing is 400 mm, 100 mm and 50 mm, the magnetic flux density model cloud diagram of the bundled conductor is shown in Fig. 2-4.

When the splitting spacing of the conductor is 400mm, 100mm and 50mm, the magnetic flux density modes of the conductor are 0.031T, 0.034T and 0.038T respectively. The magnetic flux density mode of the conductor increases with the decrease of the splitting distance.

The electromagnetic force of unit length bundled conductor in X and Y directions as follows.
According to figure 5, the electromagnetic force in X direction of unit length bundled conductor fluctuates around 0.0003N/m. The main reason is that all the main flux generates the electromagnetic force in Y direction, and only a small part of leakage flux generates the electromagnetic force in X direction.

According to figure 6, when the splitting spacing of the conductor is 150 mm, 100 mm and 50 mm, the electromagnetic force on the unit length conductor in the Y direction is 6 N/m, 9 N/m and 17 N/m respectively. The smaller the splitting spacing of the conductor, the greater the electromagnetic force on the conductor.

4. Simulation solution and experimental verification of mathematical model

4.1. Solving principle of Runge Kutta method and simulation results of adhesion vibration

In this paper, based on Runge Kutta numerical method, firstly, the order of equation (7) is reduced to \( x_1 = \dot{q}_1, x_2 = \dot{q}_2, x_3 = \dot{q}_3, x_4 = \ddot{q}_2 \). Then, the coefficients are substituted into the reduced formula, and the initial adhesion conditions are set. Finally, the vibration displacement time history curve of the conductor is obtained.

When the wind speed is 10m/s and 30m/s respectively, the span is 100m and 300m respectively, and the initial spacing is 200mm and 400mm respectively, the displacement time history curve of the conductor is as follows.
According to figures 7-8, when the span is 100m and 300m, the maximum vertical displacement at the lowest point of the bonding conductor is 0.448m and 1.047m.

Fig 9. Displacement time history curve of wind speed 10m/s
Fig 10. Displacement time history curve of wind speed 30m/s

According to figures 9-10, when the wind speed is 10m/s and 30m/s, the maximum vertical displacement at the lowest point of the bonding conductor is 0.605m and 1.046m.

Fig 11. Displacement time history curve of initial spacing 200 mm
Fig 12. Displacement time history curve of initial spacing 400 mm

According to figures 11-12, when the initial spacing is 200 mm and 400 mm, the maximum vertical displacement at the lowest point of the bonding conductor is 0.671m and 1.224m.

4.2. Test verification and analysis
In order to verify the accuracy of the mathematical model and simulation results, a 0 ~ 1500A continuously adjustable mobile power supply is used to supply power to the test model of vertically arranged double bundled conductors. The test model uses the transmission line wire vibration monitoring system and inertial combination sensor, and adopts wireless monitoring technology to measure the wire adhesion vibration.

The transmission line monitoring system uses micro meteorological sensors to monitor the temperature, wind speed and other meteorological data of bundled conductors. The sensor records weather, state parameters and real-time vibration data of bundled conductors. By extracting the data from the monitoring system and analyzing the data during the adhesion vibration, the displacement vibration status of the bundled conductor during the adhesion vibration can be obtained.
Tab.1 Comparison of test data and simulation results

| Working condition | Conductor temperature (℃) | Wind Speed (m/s) | Splitting distance (mm) | Amplitude of bonding wire (m) |
|-------------------|---------------------------|------------------|------------------------|-----------------------------|
|                   | Test value                | Simulation value | Error rate(%)          |
| 1                 | 24                        | 10               | 200                    | 0.773                       | 0.671                       | -13.2                      |
| 2                 | 18.8                      | 10               | 400                    | 1.096                       | 1.224                       | 11.7                       |
| 3                 | 20.5                      | 30               | 200                    | 1.042                       | 1.046                       | -3                         |
| 4                 | 19.2                      | 30               | 400                    | 1.56                        | 1.482                       | -5                         |

According to table 1, the error between the simulation value and the test value of the amplitude of the bonding wire under each working condition is not more than 15%. There are two main reasons for the error: (1) the mathematical model assumes that the vertically arranged double bundle conductor is a flexible chain with equal height at both ends, while the actual conductor is a rigid ACSR, and there is horizontal stress between adjacent conductors. (2) The experimental data are easily affected by the environment, such as the error between the measured value of wind speed and the actual value, and the error of the initial spacing due to the different sag, which affect the accuracy of the observation data.

5. Conclusion
1. The vibration of the wire is caused by the coupling of aerodynamic force and electromagnetic force. The influence of electromagnetic force can't be ignored when the bundled conductor vibrates or gallops.
2. In the transmission line safety detection, the mathematical model can be used to predict whether the wire adhesion vibration will occur in advance, which improves the efficiency of operation and maintenance.
3. In the design of transmission line, spacer and shock hammer should be installed for the conductor with large span and large splitting distance.

Reference
[1] He Xiaobao, Yan Bo, Wu Chuan. Numerical simulation of wake induced oscillation of double bundled conductors [J]. Vibration and shock, 2017,36 (04): 59-65 + 98
[2] Zhang Biao, he Xiaoxin, Yu Jianhui. Simulation of adhesion mechanism of 220kV vertical double bundle conductor [J]. Acta electrotechnics Sinica, 2012, 27 (05): 252-259 + 267.
[3] Zhou Linshu, Yan Bo, Zhao Yang. Influence of electromagnetic force on galloping of double bundled conductors [J]. Vibration and shock, 2016, 35 (04): 141-147.
[4] Lou Wenjuan, Yang Lun, pan Xiaotao. Nonlinear dynamics and parameter analysis of iced conductor galloping [J]. Chinese Journal of civil engineering, 2014047 (005): 26-33101.
[5] Xie Xianzhong, Long Hao, Li Dan. Study on nonlinear coupling vibration characteristics between two transmission lines [J]. Journal of dynamics and control, 2015, 13 (003): 170-176.
[6] Xiao Liangcheng, Li Xinmin, Jiang Jun. analysis of aerodynamic characteristics of four split crescent iced conductor [J]. Acta electrotechnics Sinica, 2014,29 (12): 261-267.