Study on the Wear of the UB Hanging Plate of the Ground Wire Suspension String Clamp in the Continuous Stable Wind Area

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Abstract. This study focuses on the common wear phenomena on the side of the UB hanging plate of the suspension string clamp in the continuous stable wind area. The force models of the suspension string considering the wind load in three wind speed stages are established, and the formulas for calculating the gravity load and the wind load of the wire are developed, and the expression of the relationship between the contact point pressure (the contact point between the connecting angle steel and the deflected UB hanging plate) and the wind speed and the icing thickness is derived. The results show that the installation clearance between the connecting angle steel and the UB hanging plate is the main structural factor for the wear phenomena, and the side of the UB hanging plate will contact and wear with the connecting angle steel when the wind speed is greater than the critical wind speed. The contact force between the UB hanging plate and the connecting angle steel increases with the increase of the icing thickness, the span and the wind speed, and the influence of the icing thickness on this contact force is more obvious in the case of the occasion with large span and strong wind. This study evaluates the three factors of span, icing thickness and wind speed, which is of guiding significance for the structural optimization of the suspension string in the future.

1. Introduction
Under the continuous stable wind excitation, the transmission lines will have different forms of static and dynamic response. In particular, the disaster caused by wind-induced vibration of conductors has become a major disaster form endangering the safe and stable operation of transmission lines in our country. The length of the ground wire suspension string is short, and the distance between the suspension string and the tower material is generally small. Under the action of the continuous stable wind, the suspension string may collide with the tower material, resulting in the wear of the UB hanging plate and the connecting angle steel [1-2].

The related research on the wear of suspension string clamps in power grid at home and abroad is mostly around the wear phenomenon of the rotating pairs of the suspension string clamps [3-5]. The wear between the UB hanging plate and the connecting angle steel, as a unique wear type of transmission line in strong wind area, is rarely involved in the previous studies. Therefore, starting from the weight of the ground wire and the wind load borne by the suspension string, this paper analyzes the specific structure of the suspension string UB hanging plate, summarizes the main
influencing factors affecting the wear degree, and comprehensively evaluates these influencing factors, so as to provide guidance for the structural optimization in the future.

2. Investigation on the Wear of the UB Hanging Plate of the Suspension String

Through the field investigation of 220 kV transmission line in a windy area in northern China, it is found that the XDU-2A wear-resistant ground wire suspension clamp is used for ZGU double-loop tower in the above area, which is matched with ZH-7 right angle hanging ring and UB-7A hanging plate, and the UB hanging plate is used to connect the suspension string with the connecting angle steel. As shown in figure 1, both the UB hanging plate and the connecting angle steel have varying degrees of wear. The preliminary analysis of the wear reason is that the continuous strong wind leads to the sliding friction and the rigid impact between the suspension string and the connecting angle steel.

![Figure 1. Wear condition of the ground wire UB hanging plate.](image)

Figure 2a shows that the ground wire suspension string is kept straight under the action of gravity when there is no wind. Figure 2b shows that when the ground wire is subjected to a small wind load, the ground wire suspension string has a certain wind deflection angle along the wind direction, and the UB hanging plate is slightly skewed with the suspension clamp, but the UB hanging plate does not contact with the connecting angle steel. Figure 2c shows that as the transverse wind speed continues to increase, the suspension string has a larger wind deflection angle, resulting in line contact between the UB hanging plate and the bottom of the connecting angle steel.

![Figure 2. Deflection of the suspension string varying with the wind speed.](image)
3. Mechanical Analysis of Suspension String of Clamp in Wind Area with Continuous Stability

3.1. Calculation of the Vertical Self-Weight Load of the Suspended Ground Wire

As shown in figure 3, the suspension clamp is connected with the UB hanging plate through a right angle hanging ring, the UB hanging plate is hung on the connecting angle steel through bolts, and the connecting angle steel is fixed on the cross arm of the tower as the base, so the load of the UB hanging plate comes from the self-weight and the wind load of the overhead ground wire.

![Figure 3. Schematic diagram of the working model of the suspension string.](image)

Before the force analysis, the following assumptions are made for the analysis object:

1. the wind load on the ground wire only considers the load in the horizontal direction and ignores the wind load in other directions.
2. the wire is regarded as a soft chain hinged everywhere, and the clamp on the suspension string does not affect the axial tension of the ground wire.
3. the self-weight load and icing load acting on the ground wire all point to the same direction, and the gravity load is evenly distributed along the direction of the wire.
4. the left and right span of the suspension point are the same, and there is no height difference between the adjacent suspension points.

The gravity of the ground wire subjected to the suspension string mainly depends on three parameters: the length of the ground wire borne by the suspension point (each half of the left and right span), the mass parameters of the ground wire and the icing thickness. The length of the ground wire borne by the suspension point can be solved by fitting the ground wire into a parabola. As shown in figure 3, the coordinate system with O as the origin is established. L is the span of two adjacent suspension points, and the unit is m; θ is the suspension angle (the left and right suspension angle are equal). According to the integral calculation of parabola, the length of the ground wire within the range of L can be obtained:

$$l = \frac{L}{2} \left[ \ln \left( \frac{\tan^2 \theta + 1}{\tan \theta} \right) \right]$$

where: l – the length of the ground wire within the L range, the unit is m.

Since the left and right span are the same, the length of the ground wire borne by the suspension point is equal to l. Then according to the mass parameter ρ of the ground wire consumables and the icing load per unit length (ρ’) [6]. We can get:

$$G = l(\rho+\rho')g$$

$$\rho' \approx \lambda b(b+D)$$

In equations (2) and (3):

- G - gravity load of the ground wire borne by the suspension point, the unit is N;
- ρ - mass parameter of the ground wire consumables, the unit is t/km;
3.2. Calculation of the Horizontal Wind Load of the Suspended Ground Wire

When calculating the horizontal wind load, the unit horizontal wind load is calculated first, which refers to the wind force per unit length generated by the horizontal wind on the wire, and its calculation formula is [6]:

$$P = W_0(D + 2b)\alpha \mu_e \mu_f \mu_g \times 10^{-3}$$ (4)

In equation (4):
- $P$ -- unit horizontal wind load of the ground wire, the unit is N/m;
- $W_0$ -- standard value of the reference wind pressure under the designed reference wind speed, $W_0 = \frac{v^2}{1.6}$, the unit is N/mm²;
- $v$ -- wind speed, the unit is m/s;
- $\alpha$ -- wind pressure non-uniformity coefficient. when the wind speed is less than 20 m/s, take $\alpha = 1$, when the wind speed exceeds 20 m/s, take $\alpha = 0.85$;
- $\mu_{uc}$ -- wire shape coefficient, also known as the aerodynamic coefficient, is 1.2 for ice-covered wires and ice-free wires whose outer diameter is less than 17 mm;
- $\mu_f$ -- coefficient of the variation of the wind pressure height, taken as 1;
- $\mu_g$ -- coefficient of the variation of the wind direction, taken as 1;

The horizontal wind load of the ground wire borne by the suspension point is the unit horizontal wind load multiplied by the length of the ground wire borne by the suspension point:

$$F_w = Pl = 12\alpha l(D + 2b)v^2 \times 10^{-5}$$ (5)

In equation (5), $F_w$ means the horizontal wind load of ground wire borne by the suspension point, the unit is N.

3.3. The Influence of the Combined Force of Gravity Load and Horizontal Wind Load on the Suspension String

In order to facilitate installation, the distance between the two connecting angle steels is often slightly larger than the width of the UB hanging plate. This gap leads to the line contact between the UB hanging plate and the connecting angle steel under large horizontal wind load, resulting in different degrees of wear. Therefore, it is necessary to explore the effect of the combined force of the gravity load and the horizontal wind load on the UB hanging plate.

The main dimensions and the force analysis of the UB hanging plate and the connecting angle steel are shown in figure 4. $F_w$ is the horizontal wind load; $F_a$ is the contact force between the bottom of the connecting angle steel and the UB hanging plate; $F_b$ is the force acting on the top of the UB hanging plate in contact with the connecting angle steel; $F_N$ is the support force of the bolt to the UB hanging plate.

The equations of force balance and moment balance for $O$ point are listed as follows:

$$G + F_a \sin \beta = F_N$$ (6)

$$F_w + F_b = F_a \cos \beta$$ (7)

$$F_w(y_1 \cos \beta - x_2) + G\left(\frac{y_2}{2 \cos \beta} - y_1 \sin \beta + x_2 \tan \beta\right) = F_N x_1 + F_b x_2$$ (8)

Solving simultaneous equations (6)-(8):
Figure 4. Main dimensions and force analysis of the UB hanging plate and the connecting angle steel.

\[
F_a = \frac{F_w (y_1 \cos \beta - x_2) + G\left(\frac{y_2}{2 \cos \beta} - y_1 \sin \beta + x_2 \tan \beta\right) + F_w x_2 - Gx_1}{x_1 \sin \beta + x_2 \cos \beta}
\]  \hspace{1cm} (9)

where \(\beta = \arctan(\Delta d / x_2)\). \(\Delta d \approx y_2 - x_1\).

3.4. Analysis of Calculation Results

Taking the ground wire suspension string of the 220 kV Dongyang transmission line in a windy area in northern China as an example, the engineering designed parameters and environmental parameters are shown in table 1.

| Name                      | Description                                                                 |
|---------------------------|-----------------------------------------------------------------------------|
| Line length               | 19.759 km                                                                   |
| Tower                     | Linear Tower: 41 base; angle tower: 9 base                                  |
| Span                      | Maximum span: 730 m; average span: 403 m                                   |
| Ground wire parameters    | Brand: GJ-50; safety factor:3.58; maximum service tension: 15867 N         |
|                           | N; out diameter: 9 mm; mass parameter: 0.42 t/km                           |
| Weather conditions        | Air temperature: -40°C-40°C; maximum wind speed: 30 m/s; maximum icing thickness: 10 mm |
| Suspension string parameters | \(x_1 = 50\) mm, \(x_2 = 37\) mm, \(y_1 = 80\) mm, \(y_2 = 46\) mm         |

According to equations (1)-(9), a MATLAB program is written to calculate the variation rules. Figure 5 shows the curves of the gravity loads varying with the icing thickness under different spans. It can be seen that the gravity load of the ground wire borne by the suspension string increases with the increase of the icing thickness, and the larger the span is, the more obvious the upward trend is. When the span is 730 m and the icing thickness is 10 mm, the maximum gravity load is 7185.32 N.

Figure 6 shows the variations of \(F_a\) under different span, and the two independent variables are wind speed and icing thickness. For the three-layer curved surface in the figure, the span from top to bottom is 730 m, 500 m and 300 m respectively. When the wind speed is 20 m/s, the curved surface has a kink, which is because the wind pressure non-uniformity coefficient (\(\alpha\)) changes from 1 to 0.85.

As can be seen from figure 6, when the icing thickness is 0, the critical wind speed is 15.6 m/s. With the increase of the icing thickness, the critical wind speed decreases, and when the icing thickness is 10 mm, the critical wind speed decreases to 13.2 m/s. The variation rules of critical wind speed are the same under different spans. When the wind speed exceeds the critical wind speed, \(F_a\) increases with the increase of wind speed, icing thickness and span. When environment is at the maximum wind speed of 30 m/s and the maximum span of 730 m, \(F_a\) increases from 5012.29 N to
18454.68 N with the increase of icing thickness, which shows that the icing thickness has an obvious effect on $F_a$ at this time.

![Figure 5. Variation curves of $G$ with the icing thickness under different spans.](image)

![Figure 6. Variations of $F_a$ with the wind speed and the icing thickness under different spans.](image)

4. Conclusion

There are mainly three cases for the suspension string in the environment of the continuous stable wind area: in the case of no wind, the suspension string is in a straight state; in the case of light wind, the suspension string has a small deflection angle, and the side of the UB hanging plate is not in contact with the connecting angle steel; in the case of strong wind, the suspension string deflects to a large extent along the direction of the wind speed, and the side of the UB hanging plate contacts with the connecting angle steel and has a contact force, which leads to wear. This paper studies the relationship between the force of the suspension string and the span, the wind speed and the icing thickness in the case of a strong wind in the continuous stable wind area.

The conclusions are as follows:

1. Since the distance between the two connecting angle steels is slightly larger than the width of the UB hanging plate, when the suspension string deflects in different degrees along the wind direction, it will also lead to the deflection of the UB hanging plate. When the wind speed is large enough, the side of the hanging plate will have line contact with the bottom of the connecting angle steel, so the contact pressure is strong and easy to wear.

2. Only when the wind speed exceeds the critical wind speed, the side of the UB hanging plate of the suspension string will be worn. The greater the icing thickness is, the smaller the critical wind speed is. The variation rules of critical wind speed for different spans are the same.

3. When the wind speed exceeds the critical wind speed, $F_a$ increases with the increase of wind speed, icing thickness and span. In the case of large span and strong wind, the influence of icing thickness on $F_a$ is more obvious.

References

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