Analysis of Dynamic Properties for Double-swing Anti-galloping device Used in Long-span Section over Han River in 1000 kV UHV AC Jingmen-wuhan Transmission Line

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Abstract. The anti-galloping combination mode of “double-swing anti-galloping device + cable cleat rotary spacer” is the anti-galloping scheme which is frequently used at present. In order to enhance the anti-galloping capability of Long-span Section over Han River in 1000 kV UHV AC Jingmen-wuhan Transmission line, this text will research the influence of pendulum’s theoretical length on dynamic properties for the double-swing anti-galloping device, which is widely used in the ultra-high voltage line. Theoretical analysis shows that total mass rate of anti-galloping devices, including double-swing anti-galloping device as well as cable cleat rotary spacer, should reach 6.5%, and the pendulum’s theoretical length should be 650mm, then the theoretical anti-galloping capability of whole system became optimized.

1. Introduction

The ice-coating galloping of power transmission line is a kind of wind-induced vibration disaster of low frequency (0.1-5Hz) and large amplitude (about 20-300 times as large as conductor diameter)\textsuperscript{[1]}.

From the statistical data of power transmission line galloping of our country, the galloping distribution shows obvious regional characteristics, i.e. there is a long “galloping belt” from Hunan Province on the south and to Jilin Province on the north; wherein, the plain areas in Hubei Province and Henan Province are easy occurrence areas of galloping in our country, and they are also acknowledged strong galloping areas.

From January 24, 2018 to January 31, 2018, the middle and eastern regions of our country experienced two low-temperature rainy, snowy and freezing weather processes with severe cold degree, long duration, large precipitation and wide influential scope in succession. Affected by this, power transmission lines in Hubei Province, Anhui Province, Jiangxi Province and Hunan Province

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{a.png}
\caption{(a) Conductor Falling and Strand Breaking}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{b.png}
\caption{(b) Device Damage}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{c.png}
\caption{Figure 1. Damages Caused by Galloping}
\end{figure}
suffered from severe rainy, snowy and freezing disasters, and totaling 135 lines of 110kV and above underwent galloping; wherein, the quantity of lines of tower collapse accident due to galloping reached 12, and most of them were 500kV lines which were put into operation before 2006. However, most of lines in the same regions which have undergone anti-galloping design, governance and reconstruction resisted the impact of this disaster successfully, with light damage or even most of places didn’t undergo galloping. From this, it can be known that the typical galloping prevention and control measures have rationality and effectiveness, and they can be used to weaken or even avoid huge threaten to lines due to ice-coating galloping under extreme weather conditions.

In order to enhance the anti-galloping capability of Long-span Section over Han River in 1000 kV UHV AC Jingmen-wuhan Transmission line, this text will research the influence of pendulum’s theoretical length on dynamic properties for the double-swing anti-galloping device, which is widely used in the ultra-high voltage line. This Report will conduct optimization design targeting pendulum bob mass distribution and theoretical pendulum length of double-swing anti-galloping device, so as to provide reasonable and effective design scheme for the Long-span Section over Han River, and to provide reference for proposal and formulation of anti-galloping design scheme of other lines, thus providing scientific basis and effective guarantee to enhance anti-galloping and galloping suppression capabilities of power grid.

2. Design Situation
Long-span section over Han River in 1000 kV UHV AC Jingmen-wuhan transmission line is designed to locate at the junction of Shayang County in Jingmen, Hubei Province and Zhongxiang City, the crossing point belongs to the first terrace of the Hanjiang River, with flat terrain and open terrain. According to the latest diagram of newly released [2] refs, it can be known that this section, and 10 km range nearby, are all in the level 2 galloping area.

The detailed design parameters of the conductor are as shown in the Table below.

Table 1. Design Parameters of Long-span Section over Han River in 1000 kV UHV AC Jingmen-wuhan transmission line

| Design Parameter                        | Valuing                        |
|----------------------------------------|--------------------------------|
| Span                                   | 1,220m                         |
| Conductor                              | 6×JLHA1/EST-640/170            |
| Tension                                | 550mm                          |
| Maximum Design Wind Speed              | 30m/s                          |
| Maximum Design Ice Thickness           | 25mm                           |

3. Modelling and Analyzing
The modelling based on curved beam theory can fully embody the bending resistance, torsion resistance and 3D stress coupling characteristics of the large cross section conductor\[3; 4\]. The dynamics equation set describing j-step modality of each freedom degree is shown as below.

\[ M_j \begin{pmatrix} x_j^* \\ y_j^* \\ z_j^* \end{pmatrix} + K_j \begin{pmatrix} x_j \\ y_j \\ z_j \end{pmatrix} + C_j \begin{pmatrix} y_j^* \\ z_j^* \end{pmatrix} = f_{nl,j}(x_j, y_j, \theta_j) \]

(1)

In the formula, this thesis will analyze the 3rd-5th step of modalities which are frequently seen in the long-span conductor galloping, so the modality marks are \( j = 3, 4 \) and 5; and \( M, K \) and \( C \) are respectively system mass, rigidity and damping matrix; \( f_{nl,j} \), \( f(x, y, \theta) \) respectively refers to non-linear item of each freedom degree.
\[
M_j = \begin{bmatrix}
m_{j,11} & m_{j,22} & m_{j,33} \\
m_{j,22} & m_{j,22} & m_{j,23} \\
m_{j,31} & m_{j,32} & m_{j,33}
\end{bmatrix}
\quad \text{and} \quad
K_j = \begin{bmatrix}
k_{j,11} & k_{j,22} & k_{j,33} \\
k_{j,22} & k_{j,22} & k_{j,33} \\
k_{j,31} & k_{j,32} & k_{j,33}
\end{bmatrix}
\quad \text{and} \quad
C_j = \begin{bmatrix}
c_{j,11} & c_{j,22} & c_{j,33} \\
c_{j,22} & c_{j,22} & c_{j,33} \\
c_{j,31} & c_{j,32} & c_{j,33}
\end{bmatrix}
\]

In the formula, \(m_{ij}, k_{ij}\) and \(c_{ij}\) respectively refer to mass, rigidity and damping coefficient of different freedom degrees under various step modalities.

According to the “galloping stability mechanism”\(^{[5-8]}\), the core judgment conditions lies in the Routh-Hurwitz stability criterion, and the characteristic polynomial of the formula (1) can be written as below:

\[
f_j(\lambda) = \left|M \lambda^2 + C \lambda + K\right|
\]

The expansion equation is:

\[
f_j(\lambda) = \lambda^6 + \lambda^5 a_1 + \lambda^4 a_2 + \lambda^3 a_3 + \lambda^2 a_4 + \lambda a_5 + a_6
\]

From the Routh-Hurwitz stability criterion, we can know that the condition of system stability is:

\[
\Delta_i = a_i > 0; \Delta = \begin{vmatrix} a_1 & 1 \\ a_1 & a_2 \end{vmatrix} > 0; \Delta = \begin{vmatrix} a_1 & 1 & 0 \\ a_2 & a_2 & a_1 \end{vmatrix} > 0; \Delta = \begin{vmatrix} a_1 & 1 & 0 & 0 \\ a_2 & a_2 & a_1 & 1 \\ a_1 & a_2 & a_1 & a_2 \end{vmatrix} > 0; \Delta = a_4 \Delta_6 > 0;
\]

Conversely, if some item among \(\Delta_1, \Delta_2, \ldots, \Delta_6\) is not positive, it means that the system is of linear instability.

4. Analysis of Dynamic Properties

4.1. Analysis on Vibration Prevention of Pneumatic Parameters

Select the crescent ice-coating which is frequently seen in the ice-coating galloping of long-span conductor.

![Angle of Attack (°)](angle_of_attack.png)  
Figure 2. Curve of Pneumatic Resistance Coefficients of Different Ice-coating Thicknesses along with Change of Angle of Attack

![Angle of Attack (°)](angle_of_attack.png)  
Figure 3. Curve of Pneumatic Lift Force Coefficients of Different Ice-coating Thicknesses along with Change of Angle of Attack
Figure 4. Curve of Pneumatic Torque Coefficients of Different Ice-coating Thicknesses along with Change of Angle of Attack

Affected by such eccentric ice-coating, after the conductor suffers from wind function, there will be a certain pneumatic lift force, resistance and torque. After utilizing mature flow field numerical simulation software, the change of pneumatic coefficient formed on the 6×JLHA1/EST-640/170 conductor with crescent eccentric ice-coating under different ice-coating thicknesses along with the angle of attack is as shown in the following group of Figures.

4.2. Analysis on Examples and Optimization Design Scheme

According to Anti-galloping Design Standard[^9^, ^10^], the overall mass of double-swing anti-galloping device in single span is not more than 7%, and the weight of single bob is 9kg. Distribution schemes and theoretical pendulum lengths which different spans and total mass ratios of double-swing anti-galloping device correspond to. Different schemes are numbered here to facilitate the statement of the subsequent calculation analysis.

| Total Mass Ratio | Quantity of Double-swing Anti-galloping Devices | Distribution Scheme | Theoretical Pendulum Length/mm | Scheme No. |
|------------------|-----------------------------------------------|---------------------|--------------------------------|------------|
| 5.5%             | 40                                            | 10-10-10-10         | 450                            | 1.1        |
|                  |                                               |                     | 550                            | 1.2        |
|                  |                                               |                     | 650                            | 1.3        |
| 6.5%             | 48                                            | 12-12-12-12         | 450                            | 2.1        |
|                  |                                               |                     | 550                            | 2.2        |
|                  |                                               |                     | 650                            | 2.3        |

Utilizing the stability theory criterion, substitute parameters which represent above mentioned schemes, value taking situations of structural parameters of lines mentioned in Table, thus obtaining the stability change situations of lines at different ice-coating situations and wind speeds in different installation schemes of various double-swing anti-galloping devices.

From the below Figures, it can be known that, after the three gears of conductors are added with double-swing anti-galloping devices, the galloping wind speeds are all increased slightly, and the instability intervals under various ice-coating thicknesses are changed, and most of them show the tendency of shrinkage; Compared with total mass, quantity and other relevant factors, the theoretical pendulum length has relatively weak influence on galloping characteristics of each gear of conductor; however, increasing the pendulum length will also obviously improve the anti-galloping capability of three gears of conductors.
5. Summary
The anti-galloping scheme of the Long-span section over Han River in 1000 kV UHV AC Jingmen- wuhan transmission line recommended by this thesis refers to the scheme of “cable cleat rotary spacer + double-swing anti-galloping device”; in which, see relevant standards for installation and layout modes; the percentage of the total mass of double-swing anti-galloping device shall reach 6.5%, and the theoretical pendulum length is selected as 650mm; then the theoretical anti-galloping capability shown by the conductor – anti-galloping device system is the best.

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Figure 5. Galloping characteristics of lines without any anti-galloping device

Figure 6. Galloping Characteristics of Lines with different anti-galloping devices
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