Experimental analysis of zero-natural-frequency damper for transmission line large cross project based on NES

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Abstract—The operation experience of transmission line large cross project shows that the traditional anti-aerolian-vibration devices had poor adaptability to complex terrain and micro meteorological conditions, and they were difficult to meet the application requirements of super large cross project at this stage. A zero-natural-frequency damper was designed by introducing nonlinear energy sink in this paper, and the solid prototypes were processed. According to the actual design parameters of conductor using in a large cross project, the anti-vibration effect was tested by using the indoor simulation test span. The test results showed that the anti-vibration effect of the scheme based on the zero-natural-frequency damper could meet the needs of practical engineering. The installation of this damper could improve conductors’ and fittings’ adaptability to complex terrain and enhance the wind and anti-vibration ability of transmission line.

1. Introduction
Aerolian vibration of overhead conductors is one of the natural disasters threatening the safety and stability of power grid equipment[1]. After years research of mechanism[2-4], control technology[5] and damper devices, a series of prevention and treatment systems have been formed, such as optimizing line design, anti-vibration device research and development[6], standard detection test, true effect evaluation[7], operation and maintenance anti-accident measures[8]. The prevention and treatment of aerolian vibration in most line sections has been preliminarily solved.

However, the long-term operation experience showed that the existing anti-vibration devices had poor adaptability to complex terrain and micro meteorological conditions, and they were difficult to meet the application needs of super large cross and long span projects at this stage. Nonlinear energy sink (NES) is a new design principle of nonlinear anti-vibration device developed based on linear absorber in recent years. In the theoretical research field, by changing the linear stiffness and damping of the system, Oueini[9] and Zhao[10] achieved the effect of energy transfer by introducing cubic nonlinear stiffness and nonlinear damping respectively. Combining NES theory with vibration suppression technology, Guo[11; 12] proposed a new mechanical appendix to suppress airfoil limit cycle oscillation. By using the harmonic balance method, the dynamic response of wing and anti-vibration device under two-dimensional flutter was clarified, and the suppression effect of NES structure on aeroelastic system vibration under different working conditions was revealed.

In this paper, the anti-vibration technology and design of nonlinear anti-vibration device for large cross project were deeply studied, and the NES was introduced to design the anti-vibration device, zero-natural-frequency damper. According to the actual design conditions of large cross line, the anti-vibration scheme test analysis was carried out, and the proposed scheme based on zero-natural-
frequency dampers was put forward to deeply protect the conductor and fittings, prolong their service life, and improve the wind resistance of transmission line.

2. Principle and design scheme of zero-natural-frequency damper

2.1. Basic principle
The structure details of vibrator system with geometric nonlinear stiffness characteristics is shown in the Fig. 1.

![Fig. 1 Vibrator system with geometric nonlinear stiffness](image)

As shown in Fig. 1, $f$ is the pre tightening force of the pull rope, $l$ is the length of one-sided spring, $f$ is the longitudinal external force, $\Delta s$ is the longitudinal displacement of the mass block, and $\Delta L$ is the axial elongation of the pull rope. According to the constitutive relationship shown in the figure, the above parameters have the following relationship:

$$\frac{1}{2} F - f \frac{\Delta s}{l + \Delta l} = \frac{\Delta s}{l + \Delta l}$$

At the same time, there is also a geometric relationship between the longitudinal displacement of the vibrator and the spring length:

$$l^2 + \Delta s^2 = (l + \Delta l)^2$$

Simultaneous constitutive and geometric relationship equations, eliminate $\Delta L$, and obtain:

$$F = 2 \left( k + \frac{f - kl}{\sqrt{l^2 + \Delta s^2}} \right) \Delta s$$

For the above formula, make Taylor expansion near the origin at $\Delta s \to 0$, and ignoring the higher order terms above cubic term, then:

$$F = 2 \left( k + \frac{f - kl}{\sqrt{l^2 + \Delta s^2}} \right) \Delta s$$

Therefore, the extracted linear stiffness coefficient $k_1$ and cubic stiffness coefficient $k_3$ expressions are:

$$k_1 = \frac{2f}{l}$$

$$k_3 = \frac{kl - f}{l^3}$$

According to the principle of geometric and constitutive relationship between vibrator displacement and stay wire deformation at both ends, the following two conditions should be met:
(1) In the static equilibrium state, the elastic ropes on both sides must be in a straight line, and the vibrator must be located at the midpoint of the connecting line between the fixed points on both sides;

(2) The elastic rope only has axial expansion and does not have bending stiffness.

At this time, the reciprocating motion of the oscillator system near the origin can be regarded as a nonlinear vibration with only cubic stiffness. Since there is no linear stiffness, $k_1$ is 0 and the system natural frequency is 0, the system can be called "zero-natural-frequency damping system".

### 2.2. Damper design

The main idea of structural design should be connecting the above zero-natural-frequency anti-vibration module with cubic stiffness directly to the conductor (see Fig. 2 below).

![Fig. 2 Structural diagram](image)

Referring to the design of traditional damper, the principle prototype structure of zero-natural-frequency damper is shown in the figure below.

![Fig. 3 Design drawing of zero-natural-frequency damper (unit: mm)](image)

According to the existing research conclusions and results, the structure and process of the prototype are optimized and improved. To improve the energy dissipation capacity of viscous damping, antifreeze high-performance damping fluid is added in the prototype trial production process. To meet the high and low temperature resistance (-40~80 °C), methyl silicone oil can be selected as the damping fluid medium.

### 3. Experimental study on anti-vibration effect

The anti-vibration effect evaluation test is carried out on the indoor aeolian vibration test span, with a test span of 55m. Referring to the conductor selection scheme used for a large cross conductor, JL/G1A-400/35 is used for the indoor test, and the test tension is 20% RTS. The anti vibration effect evaluation test of zero-natural-frequency damper is carried out according to the test method, test process and judgment standard required by the industrial standard, Technical requirements and tests for damper[^13^] DL/T 1099-2009 (Standard). The anti-vibration effect evaluation test file is shown in the Fig. 4.
The tension sensor requires that the dynamic bending strain at the clamp outlet and the zero frequency damper clamp outlet shall be less than 120 με (Single peak). The conductor shall be erected on the test gear according to the required tension, and the zero-natural-frequency damper shall be installed 2m away from the gear end. Through the comparative test, the key indexes such as power characteristics, antinode amplitude and maximum dynamic bending strain characteristics of the conductor under different anti vibration schemes shall be obtained, which shall be compared with the traditional FR type anti vibration hammer suitable for the same type of conductor. At the same time, according to the measured conductor power, wind power and other data, Combined with the calculation formula listed in the method, it can be calculated that at 120 με (The maximum protection span of a single anti vibration device under the technical conditions of single peak value).

Through the experimental research on the anti-vibration scheme design of the actual engineering line, the anti-vibration effect evaluation test results of the zero-natural-frequency damper for large cross project were given.

4. Test Results and Discussions

The relevant analysis conclusions and discussions based on test results are as follows:

1) The maximum dynamic bending strain of conductor is controlled at 73 and 109 με, which could meet the technical conditions for anti-vibration requirements of large cross lines.

2) According to the calculation formula listed in the standard and then result data in the figures, the maximum protection span of a single zero-natural-frequency damper is 402m. Compared with the traditional FR type damper, it is obvious that the anti-vibration ability of the zero-natural-frequency damper is better.

3) The power characteristics of the zero-natural-frequency anti vibration device for engineering meet the requirements of relevant standards. It can be used as an auxiliary component of the anti-vibration scheme and cooperate with the damping line to achieve good anti vibration effect.

5. Conclusion

In this paper, the nonlinear anti-vibration device is designed by introducing nonlinear energy sink for transmission line large cross project, and the solid prototype is processed. According to the actual design parameters of a large cross conductor, the anti-vibration effect is tested by using the indoor...
simulation test file. The results show that the anti-vibration scheme based on nonlinear zero-natural-frequency damper can achieve good anti-vibration effect. The anti-vibration scheme designed on this basis can meet the anti-vibration needs of actual large cross projects.

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