Study on Wind-Induced Vibration of Tension String Shielding Ring for UHVDC Transmission Lines Based on Modal Test

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Abstract. Under the action of natural wind, the shielding ring of tension string of UHVDC transmission line is prone to low frequency vibration, and the long-term vibration may lead to the fatigue damage of the shielding ring, threatening the safe operation of the line. In this paper, the modal test of the shielding ring of the tension string of UHVDC transmission line is carried out by using hammering method, and the natural frequencies and vibration mode shapes of the shielding ring are mastered. Combined with the analysis of the wind speed and wind direction in the engineering site, it is shown that the vortex induced vibration of the shielding ring is caused by the low-speed continuous stable wind along the line.

1. Introduction

UHVDC transmission lines span a wide range of areas and long mileage, and the climate conditions in the areas where they pass are complex and changeable, and the operation conditions of some areas are very harsh. During the operation of the line, there will be various security challenges, among which the wind-induced vibration of fittings caused by continuous wind excitation is one of the important factors affecting the safe operation of the line. The tension insulator string of UHVDC transmission line mostly adopts double side runway shaped shielding ring. The shielding ring is formed by welding after bending round pipe. Under the action of continuous stable wind, vibration often occurs. The shielding ring is connected with the bracket by welding. The long-term vibration will cause the weld fatigue damage, which will lead to the shielding ring falling off and threaten the safe operation of the line. In order to carry out the research on vibration suppression of shielding ring, the test of vibration mode of shielding ring are carried out in this paper, and the natural frequencies and vibration mode shapes of shielding ring are mastered. Then, according to the meteorological conditions of shielding ring vibration in engineering site, the causes of vibration of shielding ring are analyzed[1]-[3].

2. Modal Test of Shielding Ring

2.1. Test Method

Generally speaking, vibration measurement methods can be divided into two categories. The first one is to measure the response level only. This method can not judge whether a large response level is caused by large excitation force or torque or by structural resonance. The second method is to measure the input and output simultaneously. From the physical meaning of the frequency response function mentioned above, if the excitation and response are known, the characteristics of the system can be deduced. In this sense, there are two ways to choose. One is to measure the response of all the points in the structure, that is, the single point excitation method. The other is to excite some points (usually 2~4 points) of the structure at the same time to measure the response of each point, which is
commonly called multi-point excitation method. In this paper, the second method is used to measure the mode of shielding ring[4].

2.2. Connection and Support
In ideal condition, the measured structure is connected with the ground foundation, and the velocity admittance of the connection point is considered to be 0. In fact, because the connection point and the foundation can not be absolutely rigid, only when the admittance value of the foundation structure in the whole frequency range measured by the frequency response function is much smaller than that of the test structure at the connection point, the requirements can be met. Under the actual working condition, the shielding ring is fixed on the connecting hardware, so the shielding ring is fixed on the ground foundation through the bracket during the test.

2.3. Selection of Test Excitation
The hammering method is fast and convenient, and has no additional mass and constraint on the tested part. In order to obtain the straight spectrum characteristics in a wide frequency band, a tuned force hammer is used in this test. It has the advantages of eliminating the additional low frequency interference in the force spectrum caused by the structural resonance of the hammer, reducing the two impacts caused by the rebound of the component, and simplifying the calibration.

2.4. Selection of Sensors
In the modal test of shielding ring, the response of three directions should be measured. If the uniaxial acceleration sensor is used, the measurement data of some measuring points along the axis of the cylinder of the ring body will be missing. Therefore, this paper uses ICP type three-axis acceleration sensor, which can avoid using charge amplifier to adjust the signal. At the same time, one sensor can measure the response in three directions.

Figure 1. Installation of ICP type three-axis acceleration sensor.

2.5. Test Parameters
The test range of the hammer is 25000N. The variable time base sampling method is adopted. The vibration signal sampling frequency is 320Hz and the variable time multiple is 32 (force sampling frequency is 10240Hz). The trigger test is repeated for three times. The force trigger amount is 251.3N (trigger ratio: 0.5%), and the vibration signal sampling points are 16384. Five triaxial accelerometers are used. The test site is shown in Figure 1.

2.6. Model Meshing
The shielding ring used for the test is FP-800N3-6/650, 4000mm in length, 1800mm in width, and 120mm in diameter. Considering that the stiffness of the shielding ring is large and the vibration is mainly low-order vibration, it can be simplified as a ring composed of lines. Each edge is divided into two segments, and the arc of adjacent edge transition is not divided. The sensor is installed on the unit node, as shown in Figure 2.
2.7. Test Result

This test adopts multiple input and multiple output mode to measure the shielding ring mode. For the measured excitation and response data, the frequency response function of the excitation should be calculated to obtain the natural frequency of the shielding ring; then the impulse response function should be calculated, and the vibration mode and damping ratio of the shielding ring can be calculated by using the eigensystem algorithm. The first five natural frequencies and their corresponding damping ratios are extracted, as shown in Table 1. The corresponding vibration modes of each order frequency are shown in Figure 3- Figure 7.

**Table 1. Modal frequency and damping ratio**

| Order | Frequency (Hz) | Damping ratio |
|-------|----------------|---------------|
| 1     | 3.436          | 2.539         |
| 2     | 3.709          | 0.907         |
| 3     | 5.297          | 0.798         |
| 4     | 17.563         | 4.986         |
| 5     | 22.718         | 3.923         |

**Figure 2.** Mesh division of shielding ring and arrangement of test points.

**Figure 3.** The 1st mode shape.

**Figure 4.** The 2nd mode shape.

**Figure 5.** The 3rd mode shape.
3. Cause Analysis of Shield Ring Vibration

3.1. Vortex Induced Vibration
Under the action of a certain flow velocity, the vortex shedding will occur alternately on both sides of the cylindrical structure, and the cylinder will be subject to periodic fluctuating pressure in the flow direction and transverse direction. If the cylinder is elastically supported at this time, the fluctuating pressure will cause the periodic vibration of the cylinder, and the vibration of the cylinder will change its wake structure in turn. This fluid structure interaction is called "vortex induced vibration".

3.2. Vortex Induced Vibration of Shielding Ring
The shielding ring is a cylindrical structure. Under the action of wind, Karman vortex may occur alternately behind the ring cylinder. The frequency of Karman vortex is related to wind speed. When the wind speed is relatively stable, the frequency of Karman vortex will also be relatively stable. In the range of Reynolds number $Re=200-5000$, according to the empirical formula of vortex frequency of cylinder in fluid pointed out by Strouhal, the exciting frequency of wind on cylinder is as follows[5].

$$f = S \frac{V}{D}$$  \hspace{1cm} (1)

Where $f$ is the excitation frequency of the wind on the cylinder, Hz; $S$ is Strouhal number, usually taken as 0.2, $V$ is the wind speed perpendicular to the cylinder direction, m/s; $D$ is the cylinder diameter, m.

When the wind speed and wind direction are appropriate, the direction and frequency of the exciting force generated are equal to a certain natural frequency of the shielding ring, a certain order of continuous vibration will be induced.

3.3. Field Vibration Analysis
According to the field observation, when the shield ring vibration occurs, the wind speed is estimated to be about 2m/s. The vibration mode is pitch vibration around the support point of the ring body plane, and the vibration frequency is close to 4Hz, which is consistent with the second-order modal vibration.

When the shielding ring is subjected to the continuous stable wind in the same direction with the line direction, the two short sides of the shielding ring will be subjected to the vortex excitation force perpendicular to the plane of the ring body, which is similar to the pitching vibration around the support point. When the vibration frequency is 3.709Hz, the corresponding wind speed is $V= f*D/S=2.22$m/s, which is very close to the wind speed observed on site. It can be seen that the vortex induced vibration of the shield ring is caused by the low-speed steady wind along the line.

4. Conclusion
In this paper, the shielding ring modal test platform is built, and the modal test is carried out by hammering method, and the natural frequency and vibration mode of the shielding ring are obtained. Combined with the engineering practice, it is analyzed that the shielding ring of tension string of UHVDC transmission line is vortex induced vibration under the action of continuous wind with wind...
speed of 2m/s, and the frequency is the second-order natural frequency. Long term vibration of shielding ring is easy to lead to fatigue damage. Therefore, attention should be paid to the vibration of shielding ring in line operation and maintenance work, and necessary measures should be taken to restrain it.

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6. References
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