Vibration Analysis of FR-2 Damper Based on ANSYS

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Keywords: FR-2 damper, Aeolian vibration, ANSYS.

Abstract. The finite element model of FR-2 damper is established, and its natural frequency is gained by calculating. The finite element model of the wire is established, and the first-order natural frequency and mode shape are gained by calculating. The feasibility of the model is verified by comparison with theoretical calculation results. The aeolian vibration of the single-wire system and the FR-2 damper-wire system were simulated and their results were compared. The concept of vibration suppression rate was proposed to measure the suppression effect of the damper on the wire vibration.

Introduction

Aeolian vibration is the main reason of that, the fatigue damage of overhead transmission lines, damage of towers and the abrasion of towers. How to control the aeolian vibration is an important issue for extra-high voltage transmission[1-4]. Damper is a component what is the most widely used to control aeolian vibration[5]. Compared with traditional damper, FR-2 damper can be used in wider range and its affection of controlling vibration is better. But there is only a little research of FR-2 damper.

There are a lot of researches of damper by many scholars from home and abroad. Jingpeng Hou used the Lagrange equation to establish the equation of motion of the system and establish a mathematical model of damper. The results are compared with the experimental results to verify the correctness of the mathematical model [6]. Yu Wang used ANSYS to analyze the dynamic characteristics of the damper [7]. Shuhui Yu used MATLAB software to analyze the installation position of damper and the influence of different damper on the vibration of transmission lines [8]. Jun Wang used the lumped mass model to study how to calculate power consumption of damper. He plotted the power curve, and further studied the influence of various structural parameters of damper on the power characteristics [9]. G. Diana obtained the force and moment of the damper during the vibration process, which can provide reference for damper design of the overhead line [10]. O. Barry gave a nonlinear model of damper, and he derived the expressions of the mode shape and nonlinear natural frequency of the anti-vibration hammer. He also verified the correctness of the model through experiments [11].

Finite Element Analysis of FR-2 Damper

Damper is a component what is the most widely used to control aeolian vibration[5]. The head of the series of FR damper is a tuning fork structure, the left and right part is not symmertrical. The relevant parameters of the FR-2 damper are shown in Fig. 1 and Table 1.

Figure 1. The structure of FR-2 damper.
Table 1. The main parameters of FR-2 damper.

<table>
<thead>
<tr>
<th>type</th>
<th>$a$(mm)</th>
<th>$h$(mm)</th>
<th>$L_1$(mm)</th>
<th>$L_2$(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR-2</td>
<td>50</td>
<td>80</td>
<td>118</td>
<td>138</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$m_1$(kg)</th>
<th>$m_2$(kg)</th>
<th>$J_1$(kg·m²)</th>
<th>$J_2$(kg·m²)</th>
<th>$L$(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>1.2</td>
<td>0.081</td>
<td>0.0875</td>
<td>420</td>
</tr>
</tbody>
</table>

The connection between the FR-2 damper and the wire connection and the left and right halves of the FR-2 damper can be regarded as a rigid connection. Therefore, vibrations of the left and right halves of the FR-2 damper are independent and do not affect each other. In order to simplify the calculation, FR-2 damper is divided into two parts for modeling and analysis. Because the vibration of damper is mainly in a plane, it is not necessary to establish a three-dimensional model. The wire is simulated by BEAM3 and the head of damper is simulated by MASS21. Through the analysis of the finite element model of the damper, four natural frequencies of FR-2 damper are gained, they are 8.5618Hz, 53.584Hz, 22.589Hz and 141.39Hz. At the same time, the four mode of the FR-2 damper is shown in Fig. 2 – Fig. 5.

![First-order vibration mode of FR-2 damper.](image1)

![Second-order vibration mode of FR-2 damper.](image2)

![Third-order vibration mode of FR-2 damper.](image3)

![Fourth-order vibration mode of FR-2 damper.](image4)

**Finite Element Analysis of Single-wire System**

**Modal Analysis of Single-wire Systems**

LINK10 is always used to simulate wire. But in this paper, the stiffness of wire is considered. BEAM3 is used to simulate wire. Shape-finding analysis is used to find the true shape of the wire. Fig. 6 shows the finite element model of the wire established in this paper.
Through the modal analysis of the wire, the first-order natural frequency of the wire is gained. It is 0.021244 Hz. And the first-order mode is shown in Fig. 7.

![Figure 6. Finite element model of wire.](image1)
![Figure 7. First order mode of the wire.](image2)

The natural frequency of a single-wire system is theoretically calculated by using Eq. (1)

\[
\omega_v = \frac{2k\pi}{l} \sqrt{\frac{H}{m}}, k = 1, 2, 3, \ldots
\]  

(1)

The natural frequency of the single-wire system is calculated to be 0.021295 Hz. By comparing with theoretical calculation results, the error is small enough. So it can verify correctness of the finite element model of the single-wire system.

**Simulation of aeolian vibration of single-wire system**

By using the Eq. (2) and Eq. (3), the upper and lower alternating forces of Karman vortex on the wire are simplified to local harmonic force of the extended wire.

\[
F_L = \frac{1}{2} C_L \rho D V^2 \sin \omega_v t[12]
\]

(2)

\[
\omega_v = 2\pi f_v[12]
\]

(3)

\(F_L\) is uniformly distributed force. Concentrated force is used instead of uniformly distributed force. When there are enough nodes, the error is small and can be ignored. The wire model after applying force is shown in Fig. 8.

![Figure 8. Aeolian vibration of single-wire system loading diagram.](image3)

Harmonic response analysis was performed using the reduction method. Five wind speeds were selected for simulation of vibration of single-wire. Among them, 0.6m/s and 10m/s are the starting and ending wind speeds of aeolian vibration. The other three wind speeds are wind speeds that can cause the vibration frequency of the wire to be the natural frequency of the damper. The resulting image is shown in Figure 9-13.
By analyzing the image, it can be found that the amplitude of the wire decreases as the wind speed rises. As the wind speed increases, the vibration frequency of wire rises away from the low-order natural frequency which greatly affects the vibration of wire, so that amplitude of the wire decreases as the wind speed increases.

**Effect of FR-2 Damper in the Vibration of the Wire**

FR-2 damper-wire system model is established. Limiting the rotational freedom of the connection between damper and wire and the connection between the left and right parts of damper in the z direction. The finite element model of the wire-damper system is shown in Fig. 14 and Fig. 15.
By calculating, the aeolian vibration image is gained. Comparing the aeolian vibration image of the single-wire system and the wire-damper system, the effect of damper on aeolian vibration of wire can be visually seen. The vibration comparison of the single-wire system and the wire-damper system is shown in Fig. 16-Fig. 20.

![Figure 14. Finite element model of the FR-2 damper-wire system.](image1)

![Figure 15. Partial enlargement of the finite element model of the FR-2 damper-wire system.](image2)

![Figure 16. Comparison of aeolian vibration at 0.6m/s wind speed.](image3)

![Figure 17. Comparison of aeolian vibration at 0.749m/s wind speed.](image4)

![Figure 18. Comparison of aeolian vibration at 1.977m/s wind speed.](image5)
As shown in the images, it can be seen that the damper has a significant suppression effect on the wire aeolian vibration. However, it is impossible to visually see the degree of suppression of the wire aeolian vibration by the damper only through the image. In order to further study the vibration characteristics of damper, the parameter $K$ is introduced to measure the degree of suppression of damper on the wire aeolian vibration, which is called the suppression rate of damper to the wire vibration. The formula for calculating the parameter $K$ is as follows:

$$K = \frac{\sum (A_i - a_i)}{\sum A_i}$$

(4)

Values of the parameters $K$ under different wind speeds are calculated as shown in Table 2:

<table>
<thead>
<tr>
<th>Wind speed (m/s)</th>
<th>0.6</th>
<th>0.749</th>
<th>1.977</th>
<th>4.689</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K$</td>
<td>0.33177</td>
<td>0.39558</td>
<td>0.37846</td>
<td>0.37114</td>
<td>0.34072</td>
</tr>
</tbody>
</table>

It can be seen from the above table that when the vibration frequency caused by the wind is near the natural frequency of the damper, the damper suppresses the wire aeolian vibration to the greatest extent.

Conclusions

In this paper, the ANSYS software is used to analyze the damper with the finite element method. The analysis results can be concluded as follows:

1) The FR-2 damper has the fourth-order natural frequency and the fourth-order natural vibration mode. The fourth-order natural frequencies are 8.5618 Hz, 53.584 Hz, 22.589 Hz, and 141.39 Hz, respectively.

2) The wire studied in this paper was analyzed by ANSYS, concluded the first-order natural frequency of the wire is 0.012124 Hz. The first-order natural frequency of the wire obtained by theoretical calculation is 0.021294 Hz, and the error is 0.24% by comparison. The small error can be neglected, which proves the correctness of the wire model established in this paper.

3) By analyzing the aeolian vibration of the single-wire system, it is found that the amplitude of the wire decreases with the increase of wind speed within a certain wind speed range. This is because the Steroha shedding frequency also increases away from the low-order natural frequencies that have a large influence on the vibration of the wire when the wind speed increases.
(4) After comparing the aeolian vibration of the single-wire system and the wire-damper system at different wind speeds, and the suppression effect of damper on the wire aeolian vibration is parameterized as the vibration suppression rate $K$. When the wind speeds are $0.6 \text{ m/s}$, $0.749 \text{ m/s}$, $1.977 \text{ m/s}$, $4.689 \text{ m/s}$, and $10 \text{ m/s}$, the $K$ values are $0.33177$, $0.39558$, $0.37846$, $0.37114$, and $0.34072$, respectively. The vibration suppression effect is better when the vibration frequency caused by the wind is close to the natural frequency of the damper.

Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (51608195) and the Fundamental Research Funds for the Central Universities (2018MS122).

References


