Vibration control analysis of active tuned mass damper for large span buildings under simple spectrum excitation

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Abstract. Aiming at the defect that the traditional damper has little anti-vibration control effect, an active frequency-modulated mass damper anti-vibration control method for large-span buildings under simple spectrum excitation was proposed. The anti-vibration matrix of active Tuned mass damper was established, the vibration vector displacement was calculated, the matrix transformation expression was designed, the vibration response value was calculated, the effect of vibration response on anti-vibration displacement was analyzed, then the stability and coordination control of active tuned mass damper were realized. A comparative experiment was presented to verify that the proposed method could increase the amplitude of anti-vibration control of the damper in the application.

1. Introduction
In general, large-span buildings are defined as the buildings whose horizontal span length was greater than 60m, mainly refer to sports venues, literature and art exhibition halls, public halls and other large structures in our daily life. In the modern industrial production activities, they mainly refer to constructions of workshops such as aircraft hangars. Composite structures such as suspension cable and thin shell are usually used in the construction of large span1. Tuned mass damper, as one of the necessary equipment of the building construction industry, its main purpose is to reduce the external forces in the overall architecture of building energy requirements. The device can transmit the vibration energy received by the tissue structure to the auxiliary device of the building in a relatively simple way, then avoid excessive external forces that threaten the stability of the building. Based on the continuous innovation of current construction technology, high-rise buildings are developing towards the direction of high strength and light weight, and the overall damping and stiffness of the frame are reduced, which reduces the service life of long-span buildings.2 The key factor affecting the stability of structures is wind vibration. Referring to the survey data of the construction industry market, more than 60% of the buildings in the construction market are now large-span high-rise buildings, as a result, the following considerations under the numbered musical notation, carry out active tuned mass damper used in large span construction of the design of the vibration control method, through the control the vibration of the organizational structure, to protect the safety of buildings, meet the construction technology, enhance the stability of buildings.

2. Vibration control analysis of active tuned mass damper for large-span buildings under simple spectrum excitation

2.1 Establishment of vibration matrix of 3D active tuned mass damper
The three-dimensional spatial coordinates of the active Tuned mass damper in the application were established, the vibration frequency of the device was adjusted to be the same as the resonance frequency, and the vibration displacement vector was calculated by referring to the positive direction of the device blade and considering the arrangement of the central point. The formula was as follows:

$$r_{ib} = r_i + [d_i', 0, 0][i, j, k]^T \quad (1)$$

In the formula: $r_{ib}$ represented the vibration displacement of the damper; $r_i$ represented the application coordinates of damper in large-span buildings; $d_i$ represented the vertical length of vibration; $i$ represented the spatial abscissa; $j$ represented the spatial ordinate; $k$ represented the space independent vector; $T$ was the vibration frequency. According to the above calculation formula, combined with the theory of simple spectrum excitation, according to the calculation method of virtual work principle, the vibration induced force was converted into the active source force. The vibration motion equation of active tuned mass damper was established. The formula was as follows:

$$\frac{d}{dt} \left[ \frac{\partial [T(q, q') - V(q, q')]}{\partial q'} \right] - \frac{\partial [T(q, q') - V(q, q')]}{\partial q} = Q \quad (2)$$

In the formula: $Q$ represented the vibration trajectory; $\mathcal{F}$ indicated the proposed anti-perk force; $q'$ represented the vibration center; $q'$ represented the moment point of the damper vibration; $V$ represented the inertial coordinates of rest after vibration. According to the above calculation formula, the various forces on the frequency-modulated mass damper in vibration were analyzed, and the matrix transformation from the starting point $(X, Y, Z)$ to the rest point $(x, y, z)$ was expressed as follows:

$$T_w = \begin{bmatrix}
\cos \phi & 0 & -\sin \phi \\
0 & 1 & 0 \\
\sin \phi & 0 & \cos \phi
\end{bmatrix} \quad (3)$$

In the formula: $T_w$ represented as the anti-vibration matrix; $\phi$ expressed as the polarization amplitude. Based on the analysis of mechanical action, the velocity vector was converted to the vibration position vector to reduce the vibration.

### 2.2 Numerical Calculation of Vibration Response under Simple Spectral Excitation

As the vibration amplitude of the damper was limited and the vibration control area was restrained in space, the positive value of the vibration control distance was required to be less than the maximum vibration amplitude. When the stop force was subjected to the maximum allowable vibration displacement, the control force was stopped. The force in this state could be expressed as follows:

$$f_s = k_s \Delta d : \begin{cases}
(d \geq d_{\text{max}}) \land (d \geq 0) \\
(d \leq d_{\text{min}}) \land d \geq 0
\end{cases} \quad (4)$$

In the formula: $f_s$ represented the response force under the action of simple spectral excitation; $k_s$ represented the stiffness matrix of the damper; $\Delta d$ represented the damping coefficient; $d_{\text{max}}$ represented the maximum displacement of vibration; $d_{\text{min}}$ represented the minimum displacement of the vibration. According to the above calculation formula, it was assumed that the rigid body mass of long-span building structure was $G$, the damping elasticity was generated through several damping foundation connections, the dynamic model was simplified, the relative displacement calculation method was introduced, and the curve of displacement transmittance could be drawn under various...
vibration response frequency states by using the harmonic incremental balance method. This was shown in figure 1 below:

![Figure 1. Analysis of anti-vibration displacement of vibration response](image)

R represented the amplitude frequency and the unit of calculation was m²/s. According to the information expressed in Fig 1 above, with the increase of the anti-vibration frequency of the excitation outside the damper, the synchronization of structural displacement transmission changed. When the vibration frequency reached 3.5hz, the peak was reached and the structural response was relatively strong. So the numerical calculation formula of vibration response under the state was expressed as follows:

\[
z (\varepsilon) = a_1 \sin (\omega * t + \phi_1) - b_1 \cos (\omega * t + \phi_1) \tag{5}
\]

In the formula, \( z (\varepsilon) \) represented the response value of anti-vibration control; \( a_1 \) represented the lateral vibration response value; \( b_1 \) represented the longitudinal vibration response value; \( \omega \) represented as vibration parameter; \( t \) represented the vibration response time. According to the calculation formula, the adaptive design requirements of the stiffness and strength of the damper were selected to determine the vibration resistance target of the active frequency modulated mass damper for the long-span building.

2.3 stable and coordinated control of active Tuned mass damper

Based on the calculated damper response value above and clear anti-vibration target, we would use the method of establishing the damper target and the terminal control device to analyze whether the vibration data set has characteristic vibration data or abnormal data, then we established the database, categorized and stored the vibration data with existing features in the database. Based on the theory of simple spectrum excitation, a comprehensive evaluation of the vibration value and the polarization value was carried out.⁵

Combined with the stable and coordinated target selection of anti-vibration control lines and forces, we established the mapping relationship between the path and the target data, and perform real-time correction of the deviation of the vibration value in the data. In accordance with the requirements of anti-vibration control of dampers in long-span building environment, this paper provided the
replication function of multi-polarization data, improved the stability of anti-vibration coordinated control, and realized the research of anti-vibration control of active frequency-modulated mass dampers for long-span buildings under simple spectral excitation.

3. Experimental demonstration analysis
In order to ensure the accuracy of the experimental results and ensure that the whole experiment was carried out in a unified environment, the active frequency modulation mass damper used in a long-span building was selected as the research object of this experiment.

First, we used the traditional damper anti-vibration control method for anti-vibration control, and then the anti-vibration control method designed in this article to implement the same steps of operation, output the anti-vibration damper vibration route, then use the cloud platform was used to process the data. We compared the degree of the same direction between the original data and the output data, and sorted out the experimental data which was divided into the experimental group and the control group. We plotted the results as a comparison curve which was showed in figure 2 below:

![Figure 2. comparison of anti-vibration control](image)

Combined with the information expressed in Fig 2, the anti-vibration control method which was designed in this paper could effectively control the vibration amplitude of the active tuned mass damper in practical application. The amplitude output by the traditional anti-vibration control method could not exclude the influence of external factors, so the control frequency was small. It could be concluded that the vibration resistance control method of active frequency modulated mass damper designed in this paper for large-span buildings under simple spectral excitation could be used to control the vibration amplitude of the damper and realize the vibration resistance control.

4. Conclusion
In this paper, the research on anti-vibration control of active frequency-modulated mass dampers for large-span buildings was carried out from three aspects based on the action of simple spectrum excitation. And the method we proposed could increase the control of the vibration amplitude of the damper, which was verified by our comparative experiment in this paper. This method could guarantee the stability of large-span buildings to a certain extent, and provide new technical support for the development of the municipal engineering industry.

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