RESEARCH ON HYBRID TUNED VIBRATION ABSORBER AND ITS CONTROL PLAN

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The tuned vibration absorber (TVA) can significantly reduce the vibration of the primary system when it is tuned to the excitation frequency. When it is mistuned, the TVA does not work. In recent years, the adaptive tuned vibration absorbers have been studied to broaden the bandwidth of the conventional absorber. An adaptive TVA usually has a variable stiffness element. By adjusting the stiffness, the absorber natural frequency is changed too. Variable mass is also used in some TVA designs. However, we have to make the stiffness (or mass) of the absorber changes over a much wider range if we want to obtain a wider bandwidth, because the natural frequency of the absorber and the TVA stiffness (and mass) are nonlinearly related. In order to solve this problem, a hybrid vibration absorber based on variable mass and variable stiffness is studied, while its control plan is investigated in this paper. Some simulations are carried out to test the performance of the absorber and the control plan. The result shows that the new hybrid vibration absorber can markedly broaden the effective frequency bandwidth of the absorber and reduce the vibration of the primary system.

Keywords: vibration control, adaptive vibration control, tuned vibration absorber, adaptive absorber, absorber control

1. Introduction

The tuned vibration absorber (TVA) [1-3] is a simple device used in vibration control [4-5]. When tuned, the TVA reduces the primary system vibration markedly. However, the effective bandwidth of the conventional TVA is very narrow so that the TVA becomes ineffective when it is mistuned. In order to broaden the TVA bandwidth, adaptive tuned vibration absorber was investigated by many researchers in the past tens of years. In many configurations, the adaptive TVA has a variable stiffness element [6-9]. When the absorber stiffness changes, the natural frequency of the TVA will change too, and then, the TVA bandwidth becomes wider. In other designs of the adaptive TVA variable mass are used [10-12], where the absorber mass is adjusted to change the TVA natural frequency to match the excitation frequency of the primary system. In some applications, the primary system subjects to an excitation whose frequency changes over a very wide range, therefore, we have to make the vibration absorber stiffness (or mass) change over a much wider range because the natural frequency of the absorber and the TVA stiffness (and mass) are nonlinearly related. In practical design, it usually is hard. In order to solve this problem, the hybrid tuned vibration absorber and a control plan are suggested in this paper, some numerical simulations are conducted to test its performance.
2. Hybrid absorber and control plan

The TVA is a mass mounted on the primary system via a spring and a damping, as shown in Figure 1. The motion equation of the primary system and the TVA is as follows:

\[
\begin{align*}
    m_1 \ddot{x}_1 + c_1 \dot{x}_1 + c_2 (\dot{x}_1 - \dot{x}_2) + k_1 x_1 + k_2 (x_1 - x_2) &= F_0 \sin(\omega t) \\
    m_2 \ddot{x}_2 + c_2 (\dot{x}_2 - \dot{x}_1) + k_2 (x_2 - x_1) &= 0
\end{align*}
\]

(1)

where \( k_1 \) and \( m_1 \) are the stiffness and mass of the primary system, respectively; \( k_2 \) and \( m_2 \), the stiffness and mass of the absorber, respectively; \( x_1 \) and \( x_2 \), the displacement of the mass of the primary system and absorber, respectively; \( F_0 \sin(\omega t) \) is the harmonic excitation on the base. Then the amplitude of the primary system satisfies the equation below:

\[
\frac{X_1}{X_{st}}(\omega) = \sqrt{\left[ \frac{-m_2 \omega^2 + 1}{k_2} \right]^2 + \left( \frac{c_2}{k_2} \omega \right)^2}
\]

(2)

while

\[
\Delta = \left\{ \frac{m_1 m_2 \omega^4}{k_1 k_2} - \left[ \frac{m_1 c_1 c_2}{k_1 k_2} + \frac{m_2}{k_1} + \frac{c_2}{k_1} \right] \omega^2 + 1 \right\}^2 + \\
\left\{ - \left[ \frac{m_1 + m_2 (c_1 / c_2 + 1)}{k_1} \right] \omega^2 + \left( 1 + \frac{c_2}{k_2} \right) \left( \frac{c_2}{k_2} \omega \right)^2 \right. \\
\left. \right\}^2
\]

(3)

When hybrid adaptive absorber is designed, variable stiffness and mass element are introduced into the TVA, as shown in Figure 1(b). Then the natural frequency of the absorber can be changed over the range of \( \sqrt{\frac{k_{2\text{min}}}{m_c + m_{v\text{max}}}}, \sqrt{\frac{k_{2\text{max}}}{m_c + m_{v\text{min}}}} \), where \( m_c \) and \( m_v \) are the constant and variable mass of the absorber, respectively.

A control plan is proposed to adjust the absorber stiffness and mass to tune the adaptive absorber. Let:

\[
\begin{align*}
    k_2 &= k_{2\text{min}} + k_{e1}(\omega - \omega_{\text{min}}) \\
    m_2 &= m_c + k_{e2}(\omega - \omega_{\text{min}})
\end{align*}
\]

(4)

where \( k_{e1} \) and \( k_{e2} \) are two coefficients. Then, it can be obtained when:
In this situation, the absorber is tuned.

3. Simulation of the control plan

Some simulations are conducted to test the performance of the control plan. Parameters of the primary system and the hybrid absorber are shown in Table 1. The frequency responses of the primary system are shown in Figure 2. We can see that the vibration of the primary system is significantly suppressed over the frequency band from 5.96 rad/s to 13.42 rad/s by using the hybrid vibration absorber and the control plan proposed in this paper.

Table 1: Parameters of the primary system and hybrid ATVA

<table>
<thead>
<tr>
<th>Parameters of the primary system</th>
<th>Values</th>
<th>Parameters of hybrid adaptive TVA</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_1$</td>
<td>1</td>
<td>$m_c$</td>
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<tr>
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<td>$m_{v\text{min}}$</td>
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<td></td>
<td></td>
<td>$k_{2\text{max}}$</td>
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</tr>
</tbody>
</table>

Figure 2: Frequency responses of the primary system when the control plan is used.

4. Conclusion

The vibration of the primary system is significantly suppressed in frequency range from 5.96 rad/s to 13.42 rad/s by using the hybrid tuned vibration absorber and the control plan. It can be seen that the hybrid TVA has a wider effective bandwidth, meanwhile, the frequency response of the primary system
is smooth over the damping bandwidth. This make the hybrid tuned vibration absorber work stably and improve the performance of the absorber.

Acknowledgments

This study is supported by the National Natural Science Foundation of China (Nos. 51175049) and the Special Fund for Basic Scientific Research of Central Colleges, Chang’an University (300102229303).

REFERENCES