Research on Measurement of Loss Factor based on Transient State Decay Method

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Abstract. As an important parameter in application of the Statistical Energy Analysis (SEA), loss factor can measure damping characteristics of a system and determine the ability of vibration energy dissipation. First, the experimental models of steel plate structures are established. And then, the loss factor test is carried out based on transient state decay method. Finally, the variation characteristics of loss factor with medium, thickness and size of structures are explored. The results show that: (1) The loss factor of steel plates has the characteristics that larger at low frequency and small at high frequency, it decreases gradually with the increase of frequency. (2) For the same structure, the loss factor tested in water is greater than the loss factor tested in air. (3) The loss factor increases with the raise of thickness of plates when its cross-sectional dimension is constant.

1. Introduction

The vibration and noise of structures are directly related to the stability and stealth in the work, vibration will lead to fatigue problems of equipment, and noise will have a greater impact on the working environment. It is very important to establish high-precision model for structure design and noise prediction, and accurate damping loss factor is one of the most important factors. Therefore, obtaining the loss factor accurately of structures and master its law is essential to predict the vibration and noise[1-5].

Domestic and foreign scholars generally believe that the main component of noise is the structural acoustic radiation generated by the vibration of equipment, and propose to use the finite element method and the statistical energy method to predict the low-frequency mechanical noise and medium-high frequency mechanical noise. When the statistical energy analysis method is used for noise prediction and evaluation, the key is to obtain the fundamental parameters of structural system,
such as modal density, coupling loss factor and internal loss factor\textsuperscript{[6]}. The common and reliable way to determine structural loss factor is experimental measurement, including steady-state energy flow method, transient state decay method, and so on. The input power needs to calculate accurately by using steady-state energy flow method, this is undoubtedly inconvenient to measure the internal loss factor, and the error is also large. The transient state decay method is suitable for estimating average internal loss factor of the structure and acoustic volume, it doesn’t need to measure input power, the statistical error of experimental results is relatively small\textsuperscript{[7,8]}.

In this paper, the loss factor test is carried out based on transient state decay method, the law of loss factor changing with frequency is analysed, and the effects of changing the test environment and steel structure parameters on the loss factor are discussed. The purpose of this study is to provide parameter input basis for prediction and evaluation of structural noise, and provide preliminary accumulation for loss factor database of steel plate structure.

2. Test principle

Assuming that the acceleration response signal of the structure under excitation is a real function \(a(t)\), the corresponding Hilbert transform is as follows\textsuperscript{[9]}:

\[
\hat{a}(t) = H[a(t)] = a(t) \ast \frac{1}{\pi t} = -\frac{1}{\pi} \int_{-\infty}^{\infty} \frac{a(\tau)}{t-\tau} d\tau
\]

the inverse transformation is:

\[
a(t) = \hat{a}(t) \ast \frac{1}{\pi t} = -\frac{1}{\pi} \int_{-\infty}^{\infty} \hat{a}(\tau) d\tau
\]

Where * represents convolution.

Then the parsing signal of the real function is:

\[
u(t) = a(t) + j\hat{a}(t)
\]

Where the plural expression of \(u(t)\) is:

\[
u(t) = A(t)e^{j\theta(t)}
\]

Where \(A(t) = \sqrt{a(t)^2 + \hat{a}(t)^2}\) is the envelope of the response signal \(a(t)\), and the instantaneous phase is \(\theta(t) = \arctan(\hat{a}(t)/a(t))\). So, the real function can be re-represented as \(a(t) = A(t)\cos(\theta(t))\). The logarithm of the envelope of the response signal is used to obtain the attenuation curve, the absolute value of the slope is the structural damping \(\eta\), the damping ratio \(\zeta = \eta/\omega\) is dividing \(\eta\) by frequency, the damping ratio divided by 2 is the loss factor of structures.

3. Test scheme

3.1. Test model

The test models include three different sizes of steel plates structure, they were tested in air and water respectively. The plates are fixed by elastic rope lifting. The size of the test models is shown in Figure 1.
In the process of testing, the hammer is used to knock the structural parts in different positions, vibration acceleration of plates is collected by using acceleration sensors that placed on the surface of the test model, the acceleration response signal is recorded from knocking plates until the response to minimal. The schematic diagram and data acquisition flow is shown in Figure 2.

![Schematic diagrams of test models](image)

**Figure 1.** Schematic diagrams of the test models (a) 1# plate, (b) 2# plate, (c) 3# plate

**Figure 2.** The schematic diagrams of test mode and data acquisition (a) Schematic diagram of measuring model acceleration, (b) Flow chart of collecting test data

### 3.2. Data Processing and Results

After processing and transforming the collected data, the response signal is obtained. The acceleration curves measured by a certain channel of 1# plate is shown in Figure 3. The attenuation curve and envelope slope of the response signal at 1/3 octave of a 1# plate at 160 Hz are shown in Figure 4.

![Acceleration curve](image)

**Figure 3.** The curve of Acceleration

![Attenuation curve and slope](image)

**Figure 4.** The diagram of response signal attenuation curve and slope
3.2.1. The effect of test environment on loss factor. To explore the impact of the environment in which the structure is on the loss factor, according to the test results, the comparison curves of 1/3 octave loss factor of each plate under different test environments is shown in Figure 5.

![Figure 5](image)

Figure 5. The contrast curves of 1/3 octave loss factor of test models (a) 1# plate, (b) 2# plate, (c) 3# plate

It can be seen from Figure 6 that the loss factor of three different structural size steel plates is on the order of $10^{-3}~10^{-2}$, which is characterized by larger at low frequency and small at high frequency. In the 20~125Hz frequency band, except for the fluctuation of individual frequency points, the loss factor decreases with the increase of frequency. In the 125~5000 Hz band, the fluctuations tend to be flat and gradually decrease. For the same steel plate structure, the loss factor measured in water is greater than the loss factor measured in air in the full frequency band.

3.2.2. The effect of structural parameters on loss factor. To explore the influence of structural parameters on loss factor, the comparison curves of steel loss factors for different structural parameters in the same experimental environment is shown in Figure 6.

![Figure 6](image)

Figure 6. The contrast curves of 1/3 octave loss factor of test models in different testing environment (a) In air, (b) In water

It can be seen from figure 6, that in the same test environment, the loss factor of steel plate with the same cross-section size increases significantly in the whole frequency band with the increase of thickness, especially in water. For the steel plate with the same thickness, the loss factor decreases slightly with the increase of cross-section area, but it is larger than the steel plate with smaller thickness in the whole frequency band.

4. Conclusion

The loss factor test is carried out based on transient state decay method. Finally, the variation characteristics of loss factor with medium, thickness and size of structures are explored. Through the research of this paper, the following main conclusions can be obtained:
(1) The loss factor of three different structural size plates is on the order of $10^{-3}$–$10^{-2}$, which is characterized by large at low frequency and small at high frequency. In the 20~125Hz frequency band, except for the fluctuation of individual frequency points, the loss factor decreases with the increase of frequency. In the 125~5000 Hz band, the fluctuations tend to be flat and gradually decrease.

(2) For the same plate structure, the loss factor measured in water is greater than the loss factor measured in air in the full frequency band.

(3) In the same test environment, the loss factor of plates with the same cross-section size increases significantly in the whole frequency band with the increase of thickness, especially in water. For the plates with the same thickness, the loss factor decreases slightly with the increase of cross-section area, but it is larger than the steel plate with smaller thickness in the whole frequency band.

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