THE EFFECT OF THE IMPEDANCE HEAD ON THE MECHANICAL-ACOUSTICAL RECIPROCAL DEVICE'S PROPERTY

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Mechanical-acoustical reciprocity principle provides a useful method for measuring the low frequency radiation property of an air or underwater sound source in arbitrary surrounding. Mechanical-acoustical reciprocal device is necessary in measurement based on the mechanical-acoustical reciprocity method. But, this kind of reciprocal devices were rare been studied and reported. This paper proposed a kind of mechanical-acoustical reciprocal device with an impedance head, and analyzed the effect of the impedance head on the mechanical-acoustical reciprocal device's property. According to theoretical analysis and experiments confirming, it is found that the impedance head, which used for measuring the response velocity in the direct experiment and the exciting force in the reciprocal experiment, is of vital importance. The different ways of installing the impedance head could change the property of the mechanical-acoustical reciprocal device. This finding provides a guidance on the mechanical-acoustical reciprocal device design, and benefits the application of the mechanical-acoustical reciprocity principle.
Keywords: reciprocity principle, reciprocal device, impedance head

1. Introduction

Measuring the low frequency property of a sound source in arbitrary surrounding is a difficult problem. And reciprocity principle provides an approach to solve it when the sound source could be regard as a monopole[1-3].

In acoustics, reciprocity principle was first proposed by Helmholtz in 1860. Thirteen year later, Rayleigh proposed the general reciprocity principle. He believed that the reciprocity principle exists in all linear, passive, and stable dynamic systems[4]. Ten Wolde is the pioneer applying the reciprocity principle[1-3]. As early as 1970s, he studied the validity of reciprocity principle according to experiments, and applied it to solve engineering problems. One of applications is measuring the volume velocity of a monopole sound source based on the electro-acoustical reciprocity. Besides, Kim estimated the volume velocity of a sound source in a steel box based on the vibro-acoustical reciprocity principle[5].

The authors of this paper studied the technology of measuring the property of an monopole sound source in arbitrary surrounding based on reciprocity principle systematically[6-8]. It's found that the reciprocal device's property has significant influence on the experimental results. In a previous work, the influence of a non-reciprocal loudspeaker which used as a auxiliary loudspeaker in the electro-acoustical reciprocity method was studied, and a modified electro-acoustical reciprocity method was proposed[8].

This paper proposed a kind of mechanical-acoustical reciprocal device with an impedance head. The impedance head is used for measuring the response velocity of the mechanical-acoustical reciprocal device's vibrating plate in the direct experiment, and the exciting force on the vibrating plate in the reciprocal experiment. It is found that the impedance head could change the reciprocal property of the mechanical-acoustical device. The effect of the impedance head on the mechanical-acoustical reciprocal device's property is analyzed according to theoretical analysis and experiments. The finding provides a guidance on the designing of the mechanical-acoustical reciprocal device.

2. Reciprocity principle

In this section, the mechanical-acoustical reciprocity principle and the mechanical-electro reciprocity principle will be introduced[3].

2.1 Mechanical-acoustical reciprocity principle

A classical mechanical-acoustical system is shown in Fig. 1. F_1 and v_1 stand for the exciting force on the structure and the response velocity respectively. Q_1 and P_1 stand for the volume velocity of the omni-directional sound source and sound pressure in the sound field respectively.

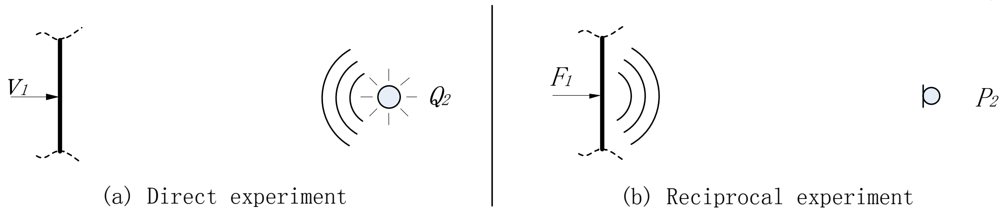

Figure 1: A classical mechanical-acoustical system.

There is a relationship between the four parameters if the entire system is reciprocal:

$$\left(\frac{v_1'}{Q_2'}\right)_{F_1'=0} = \left(\frac{P_2''}{F_1''}\right)_{Q_2''=0} \tag{1}$$

The single dash ("'") in Eq.(1) indicates the direct experiment, and the double dash ("''") indicates the reciprocal experiment.

According to Eq. (1), it is easy to get:

$$Q_2' = \frac{F_1'' \cdot v_1'}{P_2''} \tag{2}$$

Eq.(2) illustrates that the volume velocity of a omni-directional sound source could be measured based on the mechanical-acoustical reciprocity principle when several preconditions are satisfied. First of all, the testing environment must be reciprocal. Then, the sound source under test should be a monopole. And, the directionality of the microphone should be the same with the sound source. Besides, the volume velocity in the reciprocal experiment is zero. Additionally, the mechanical port should be reciprocal. These preconditions are not hard to be satisfied.

However, the reciprocal mechanical-acoustical devices rarely been studied and reported. In this paper, a kind of mechanical-acoustical reciprocal device is proposed, and it's property is checked based on the mechanical-electro reciprocity principle.

2.2 Mechanical-electro reciprocity principle

A classical mechanical-electro system is shown in Fig. 2, which is similar to the mechanical-acoustical system. E_2 and I_2 stand for the open circle voltage and the input current of the loud-speaker respectively.

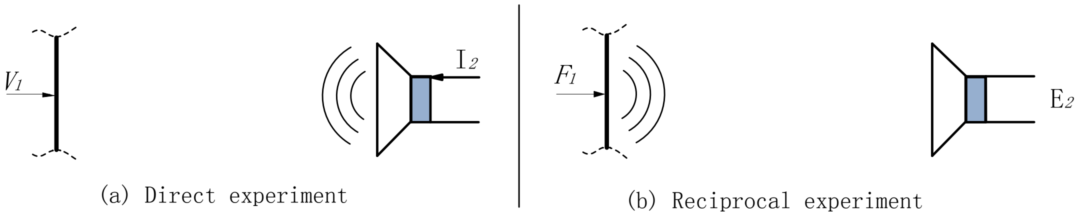

Figure 2: A classical mechanical-electro system.

Similarly, it is easy to get such a relationship if the entire system is reciprocal:

$$\left(\frac{V_1'}{I_2'}\right)_{F_1'=0}=\left(\frac{E_2''}{F_1''}\right)_{I_2''=0} \tag{3}$$

According to Eq. (3), it could be known that all the component of the mechanical-electro system are reciprocal if the transfer function of direct and reciprocal experiments are equal.

3. Reciprocal device design

3.1 Mechanical-acoustical reciprocal device design

A simple mechanical-acoustical device is shown in Fig.2.

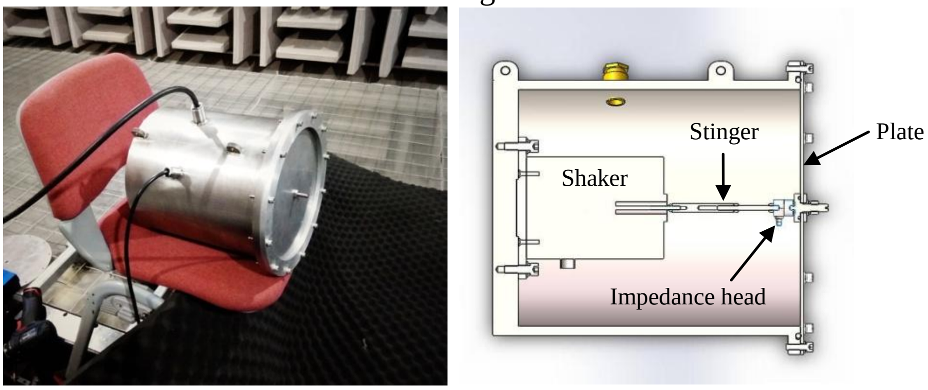

Figure 3: A simple mechanical-acoustical device.

The mechanical-acoustical device consists of four main parts: shaker, stinger, impedance head and a circular plate. They are installed one by one. Actually, only the plate is the mechanical part of the mechanical-acoustical device.

In the direct experiment, the stringer is removed to ensure $F_1'=0$. The plate is excited by sound, and the response velocity is measured by the impedance head. In the reciprocal experiment, the plate is excited by the shaker, and the driving force acting on the plate is measured by the impedance head. It should be pointed out that, in order to measure the driving force accurately, the driving end of the impedance head should be installed together with the plate.

However, the influence of the impedance head's mass on the plate cannot be neglected. In another words, the impedance head could change the inherent characteristic of the plate, for example, the nature frequency. As a result, the device is non-reciprocal.

3.2 Theoretical analysis

Fortunately, an effective method is found to solve the influence of the impedance head on the plate. The key point of this method is that not only the plate but also the impedance head are regarded as the mechanical part of the mechanical-acoustical device.

This method is based on the internal structure of the impedance head. The impedance head contains two piezoelectric element. The piezoelectric element near the driving end is used for measuring force. So, there are two different ways to install the impedance head: the driving end installed together with the stinger, or installed together with the plate.

The mechanical-electro system could be simplified, as shown in Fig. 4. Considering the stinger, there are four different installing way. The influence of the different installing ways of the impedance head and the stinger are listed in Tab. 1.

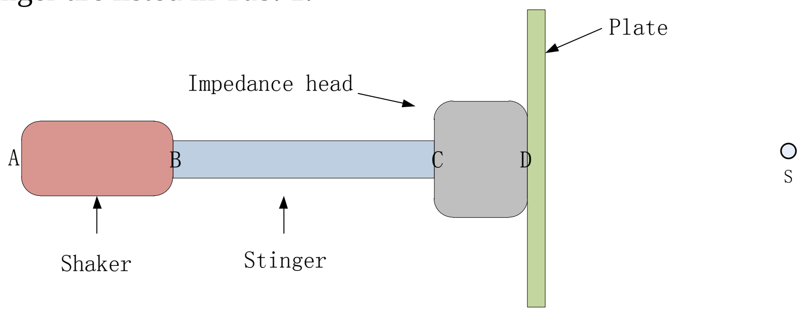

Figure 4: The simplified mechanical-acoustical system

Table 1: The influence of the different installing ways.

Number	Installing way	Direct experiment system	Reciprocal experiment system	Identical or not
1	Direct experiment: the driving end of the impedance head installed at point D; Reciprocal experiment: the stinger is installed.	From point D to point S	From point S to point A	NO
2	Direct experiment: the driving end of the impedance head installed at point D; Reciprocal experiment: the stinger is removed.	From point D to point S	From point S to point C	NO
3	Direct experiment: the driving end of the impedance head installed at point C; Reciprocal experiment: the stinger is installed.	From point C to point S	From point S to point A	NO
4	Direct experiment: the driving end of the impedance head installed at point C; Reciprocal experiment: the stinger is removed.	From point C to point S	From point S to point C	YES

It's found only the fourth setup makes the direct experiment system and the reciprocal experiment system completely consistent. So, it means that the driving end of the impedance head should be installed together with the stinger in the direct experiment, and the stinger should be removed in the reciprocal experiment. In this way, the impedance head could be regarded as a part of the mechanical-acoustical reciprocal device.

3.3 Experiments

Experiments were carried out to verify the correctness of the theoretical analysis. A reciprocal loudspeaker was used to establish a mechanical-electro system. The experiment was carried out in an anechoic room in order to ensure the sound field is reciprocal.

The results of the first installing way are shown in Fig.5. There is a significant difference between the direct transfer function and the reciprocal transfer function.

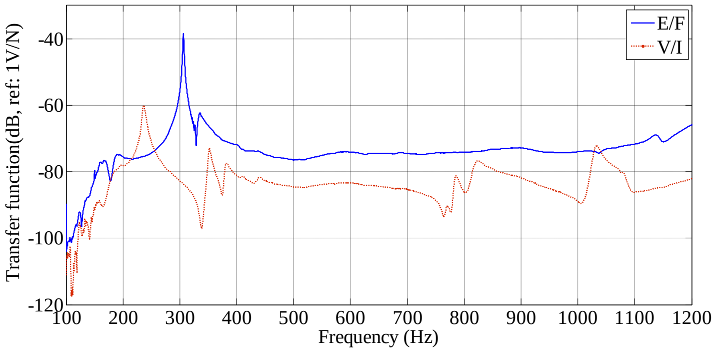

Figure 5: The results of the first installing way.

Then, the experiment was carried out according to the second installing way. The results are shown in Fig.6. Big difference still exists between the two transfer functions.

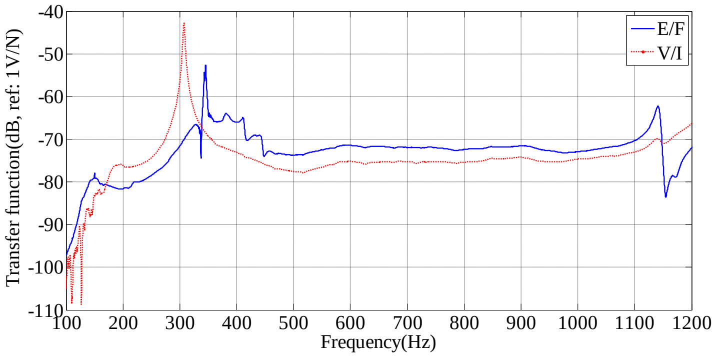

Figure 6: The results of the second installing way.

The fourth installing way is the improvement of the second installing way. The results are shown in Fig.7.

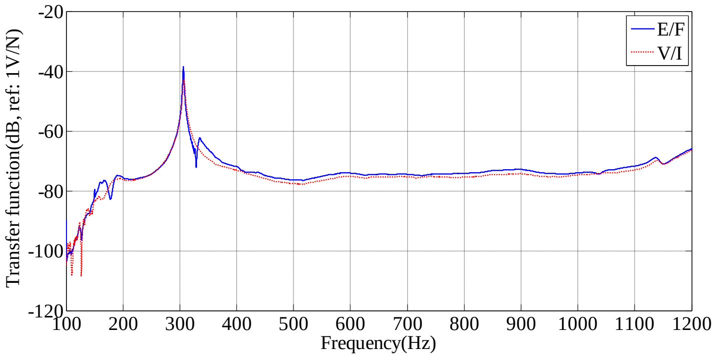

Figure 7: The results of the fourth installing way.

It could be found that, there is a little difference between the direct transfer function and reciprocal transfer function in Fig. 7. So, it's verified the correctness of the theoretical analysis.

4. Conclusion

This paper proposed a new method to establish a mechanical-acoustical reciprocal device, and theoretical analysis and experimental results have proved it. The key point of this method is using the impedance head as part of the mechanical-acoustical reciprocal device's mechanical structure. This finding provides a guidance on the mechanical-acoustical reciprocal device design, and could be used for measuring the property of a sound source in a complex environment.

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