Applied Acoustics 111 (2016) 96–104

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Experimental study on variation of acoustical resonance frequency of duct with orifice depending on periodic motion

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ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 29 January 2016
Accepted 23 March 2016
Available online 20 April 2016

Keywords:
Linear compressor
Suction muffler
Periodic motion
Orifice
Impedance

ABSTRACT

Recently, a linear compressor has been actively developed to improve the energy efficiency of home appliances, such as refrigerators. Unlike a reciprocating compressor, the suction part of a linear compressor is periodically moving. Therefore, the suction valve and the muffler constituting the suction part are periodically moving. However, up to now, there has been no research into the characteristics of the sound propagation in a periodically moving acoustic system. Thus, in this study, characteristics of sound propagation in a periodically moving acoustic system were investigated for the first time. Among a variety of acoustic filters used in a suction muffler, the change in the orifice impedance has been observed because this change is considered to be easily affected by periodically moving. Due to difficulty in measuring the orifice impedance in a periodically moving acoustic system, the change in the orifice impedance was predicted from the change in the input impedance of the suction muffler that included orifice. The experiments were carried out while changing the diameter and the pattern of orifice as well as length of the duct. As a result of experiments, the impedance of periodically moving orifice was changed depending on diameter, pattern of orifice and frequency band. Therefore, if periodically moving orifice was used to design a suction muffler in linear compressor or acoustic system, the change in the orifice impedance should be taken into consideration.

1. Introduction

Recently, a linear compressor has been actively developed to improve the energy efficiency of home appliances, such as refrigerators. Unlike a reciprocating compressor, the suction part of a linear compressor is periodically moving [1,2]. Therefore, the suction valve and the muffler constituting the suction part are periodically moving. However, up to now, there has been no research into the characteristics of the sound propagation in a periodically moving acoustic system. If we do not consider the periodic movement of the suction muffler, although it has an influence on the sound propagation, the suction muffler does not work properly in the interesting frequency band. Therefore, in this study, the characteristics of sound propagation in a periodically moving duct were observed experimentally for the first time.

Among a variety of acoustic filters used in a suction muffler, the change in the orifice impedance has been investigated because this change is considered to be easily affected by periodic movement. In general, the impedance of the orifice is represented by the reactance and resistance. The reactance is related to the vibrating mass inside the orifice, and the resistance is related to the viscous dissipation. Many studies focused on orifice impedance have already been conducted [3–6]. Furthermore, orifice impedance with flow has been studied [7–14]. In general, due to the flow condition, the reactance related to the oscillating mass is reduced, and the resistance related to the viscous dissipation increases. However, most of the studies of orifice impedance were carried out under fixed conditions. In other words, orifices are not periodically moving. The change in the orifice impedance has not been investigated as a function of the periodic movement of the orifice designed inside the muffler. Therefore, as mentioned previously, the change in the orifice impedance in a periodically moving duct was observed experimentally for the first time. The experiments were carried out while changing the diameter and the pattern of orifice as well as length of duct.

The configuration of the paper is shown below. First, the objective of this paper is mentioned. Next, the experimental configuration is explained. Finally, the change in the orifice impedance in a periodically moving duct is predicted.

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http://dx.doi.org/10.1016/j.apacoust.2016.03.030
0003-682X/© 2016 Published by Elsevier Ltd.

2. Definition of problem

The greatest feature of the suction part of the linear compressor is the periodic movement. Fig. 1(a) and (b) shows the linear compressor. As shown in Fig. 1(a), the piston can be periodically moved by the linear motor. Additionally, as shown in Fig. 1(b), the suction muffler and valve coupled with the piston can be periodically moved together. That is, the suction muffler of the linear compressor can be periodically moved at the compressor's operating frequency. Conversely, as described previously, the suction mufflers on most compressors, including a reciprocating compressor, are fixed and do not move.

However, when the suction muffler of a linear compressor was designed, the periodic movement was not considered. In other words, this muffler was designed assuming that there was a fixed muffler. However, up to now, there has been no research on the characteristics of sound propagation in a periodically moving acoustic system. Therefore, in this paper, the influence on sound propagation caused by the periodic movement of the suction muffler was investigated.

As a first step in the study of the moving duct, as there are a variety of acoustic filters used in suction mufflers, the variation of orifice impedance was studied because it was considered to be easily affected by the periodic movement. Additionally, the research on the variation of the orifice impedance due to the periodic movement is important because the orifice impedance is primarily used in the design of Helmholtz resonators and perforated tubes.

3. Experiment setup

The experimental study was carried out. To describe the periodically moving suction muffler and valve in a linear compressor, the experiment was designed as shown in Fig. 2.

First, an actual linear compressor was used as the actuator to cause the periodic movement. Because an actual linear compressor was used as the actuator, the operating frequency was not changed. Second, the acoustic source, which was generated from the suction valve, was produced using a speaker. Finally, instead of a suction muffler, a simple duct was used for the experiment. When a voltage is applied to the linear compressor, the compressor can move periodically at 60 Hz. By applying a high voltage to a compressor, the compressor can move at a high speed. However, the operating frequency does not change. Additionally, the speaker and the duct module connected to the linear compressor can be moved periodically at 60 Hz. In this way, the periodical movement of the suction part of linear compressor can be simplified for experimental purposes. Fig. 3 shows the velocity of the speaker and the duct module depending on the input voltage. This value can be obtained from an accelerometer attached to the speaker, as shown in Fig. 5.

As discussed in Section 2, in this paper, the change in orifice impedance was studied because it was predicted to be easily affected by the periodic movement among a variety of acoustic filters. Additionally, the research on the change in the orifice impedance due to the periodic movement is important because the orifice impedance is primarily used in the design of Helmholtz resonators and perforated tubes as the acoustic filter.

Generally, the orifice impedance can be obtained by using the two-microphone method, as illustrated in Fig. 4 and Eq. (1) [14].

$$Z = \rho_0 c_0 \frac{[H_{12} - \cos(kL)]}{j\sin(kL)} \quad (1)$$

ρ_0 and c_0 are the density and the speed of sound in air, respectively. k, L and H_{12} indicate the wave number, the distance and the transfer function between microphones 1 and 2, respectively, as shown in Fig. 4. However, the measurement of the transfer function using a microphone mounted on the periodically moving duct is unstable and dangerous because the microphone can be broken. Therefore, in this study, the variation of the orifice impedance was predicted using an indirect method. Specifically, the acoustical input impedance of the periodically moving duct system was measured instead of directly measuring the orifice impedance. Through the measurement of the input impedance, the change in the orifice impedance could be predicted.

The input impedance was directly measured using a Laser Scanning Vibrometer (LSV) provided by EM4SYS and a microphone. The

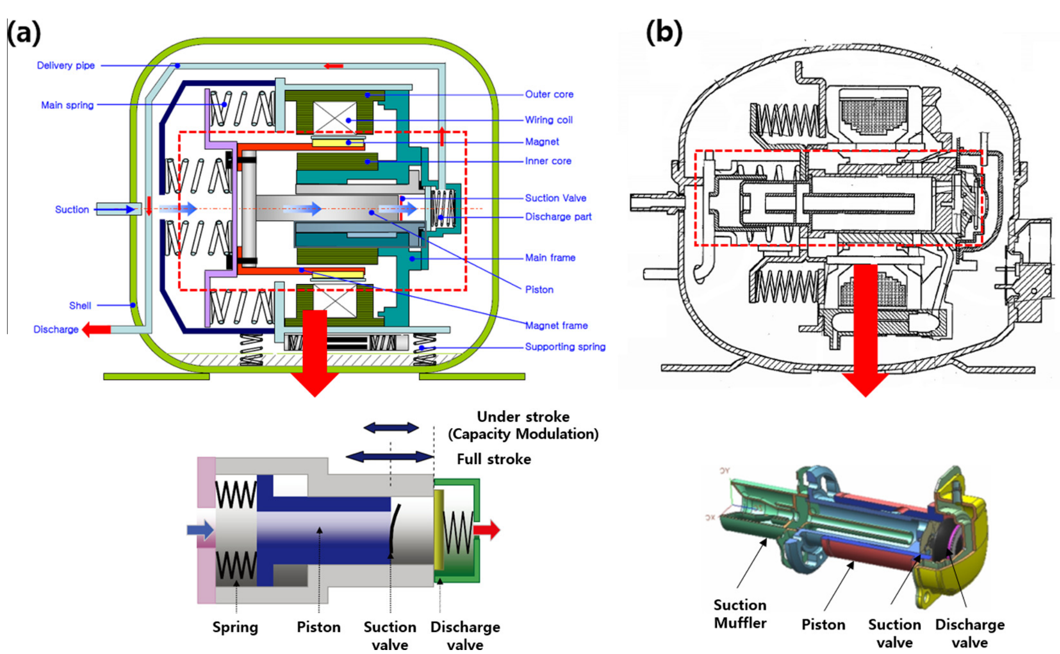

Fig. 1. Schematic diagram of a linear compressor [1,2,15,16], (a) without a suction muffler and (b) with a suction muffler.