Journal of Sound and Vibration 366 (2016) 27–43

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Topology optimization of a suction muffler in a fluid machine to maximize energy efficiency and minimize broadband noise

Seungjae Oh [a], Semyung Wang [a,*], Sungman Cho [b]

[a] School of Mechatronics, Gwangju Institute of Science and Technology (GIST), 261 Cheomdan-gwagiro, Buk-gu, Gwangju 500-712, Republic of Korea
[b] Home Appliance Laboratory, LG Electronics Inc., Seoul, Republic of Korea

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form
7 September 2015
Accepted 21 October 2015
Handling Editor: L. Huang
Available online 31 December 2015

ABSTRACT

A suction muffler used in a fluid machine has three functions: noise reduction; minimizing pressure drop and improving energy efficiency using acoustic effects. However, no method of suction muffler design considers all three of these functions concurrently. Therefore, in this study, we attempt to provide an integrated design method of a suction muffler in a fluid machine that considers all three functions. The topology optimization method for acoustic and fluid systems was applied to an integrated design. However, the interaction between fluid and acoustic was not considered. In addition, the acoustic input impedance of a suction muffler was used for a specific acoustical resonance frequency to improve the energy efficiency of a fluid machine. Finally, the sequential optimization method based on physical investigations was proposed to satisfy several design criteria. The proposed method was applied to the suction muffler in refrigerator's compressor.

1. Introduction

A muffler is used to reduce the noise generated by a fluid machine. In addition, a muffler should be designed to minimize pressure drop in suction or exhaust parts in a fluid machine. Recently, research has attempted to increase the energy efficiency of a system using acoustic pressure in a suction muffler [1–5]. Therefore, a muffler can be considered a device that can improve the system energy efficiency while reducing noise.

Studies on noise reduction of muffler have advanced. In representative studies, Barbieri et al. [6–8] studied maximizing transmission loss (TL) using finite element analysis and shape optimization. In addition, Chiu et al. [9–16] predicted the TL of a muffler with various acoustic filters using the transfer matrix method (TMM). Then, the vertical and horizontal lengths of partition walls presented in the interior of the muffler were optimized to maximize the TL at a particular frequency: genetic algorithm (GA) and simulated annealing (SA) were used as optimization algorithms. Lee et al. [17] studied how to make holes in a thin-body structure to reduce the maximum pressure emitted using topology optimization. Recently, Lee et al. [18,19] applied topology optimization to an expansion muffler model. The objective function and constraint in the optimization problem include the TL and the allowable volume of the internal partition walls. Concurrently, optimization was performed by changing the objective function and constraints into the allowable volume of the internal partition walls and the TL; results were verified by measuring the TL. Yoon [20] proposed a way to install fibrous material on the interior

* Corresponding author. Tel.: +82 62 715 2390; fax: +82 62 715 2384.
E-mail address: smwang@gist.ac.kr (S. Wang).

http://dx.doi.org/10.1016/j.jsv.2015.10.022
0022-460X/

partition walls of a muffler using the Delany–Bazley empirical material formulation and topology optimization to reduce the noise at a specific frequency.

A muffler should be designed to minimize pressure drop as well as reduce noise. As a representative study that considers noise and fluid flow in a muffler concurrently, Elnady et al. [21] proposed a method based on the two-port theory. In this method, acoustic and fluid pressure and velocity can be calculated simultaneously. A finite element model was used to analyze the acoustic propagation and fluid behavior of an internal muffler, and topology optimization was applied to make an internal partition by Lee et al. [22]. To simultaneously consider TL and pressure drop as objective functions, a weighted sum technique was used. For simplicity, Stokes flow was used in the fluid model instead of turbulent flow.

Until now, muffler design has been focused on noise reduction and pressure drop induced by fluid flow. There is little research that considers improving the energy efficiency of a fluid machine by utilizing acoustic pressure pulsation with noise reduction and pressure drop. Therefore, in this study, a suction muffler was designed by considering all three of these functions. This is an integrated design of the suction muffler in a fluid machine. Particularly, increasing the energy efficiency of a fluid machine with an acoustic effect is related to having a particular acoustical resonance frequency in the suction muffler. This assertion is explained and verified in detail in Section 3.2.

In this study, a finite element model of an acoustic and fluid system was used to analyze and topology optimization was applied. However, the interaction between fluid and acoustic was not considered. This optimization method has already been validated for acoustic [23–25] and fluid system [26–29] designs. Depending on the application of the system, the size and required performance (i.e., noise control frequency band, target acoustical resonance frequency) of a suction muffler are different. In this study, a suction muffler designed for refrigerator compressor was investigated.

This paper is structured as follows. First, an analysis model is introduced. Next, topology optimization of an acoustic and fluid system is briefly explained. Then, optimization is performed considering the design conditions of a suction muffler. In particular, for a particular acoustical resonance frequency, the input impedance of a suction muffler is introduced and used. Finally, a sequential optimization method is proposed to satisfy several required conditions of a suction muffler. These sequential steps are based on physical insight.

2. Analysis model development

As mentioned earlier, the size and required performance of a suction muffler are different depending on the application of the system. In this paper, a suction muffler designed for a refrigerator compressor was investigated. In addition, the inlet and outlet of the suction muffler are mismatched, as shown in Fig. 1.

2.1. Acoustic model

The governing equation used in an acoustic analysis is the Helmholtz equation, which is shown in Eq. (1):

$$\nabla \cdot \left(\frac{1}{\rho}\nabla p\right) + \frac{\omega^2}{\kappa} p = 0 \tag{1}$$

where p is the acoustic pressure, and $\rho, \omega, \kappa(=\rho c^2)$ are the density, angular frequency and bulk modulus, respectively. c is the speed of sound. When a suction muffler is optimized in terms of acoustics, two factors are typically considered: noise reduction and energy efficiency using acoustic pressure. Noise reduction can be evaluated by the TL, as done in previous studies, and the improvement of energy efficiency by acoustic pressure can be implemented through the acoustic input impedance of the suction muffler. The input impedance is described in more detail in Section 3.2. Thus, the TL and input impedance should be evaluated using the finite element method.

In the acoustic analysis, the inlet position is ② in Fig. 1 and is also the position where the suction valve is installed. In this position, an acoustic wave is generated by the behavior of the suction valve and fluid. This generated acoustic wave propagates the suction muffler. Although fluid is coming from position ①, the acoustic wave is leaving from this location. Therefore, in the acoustic analysis, position ② is considered to be the inlet, and position ① is considered to be the outlet.

For the calculation of the TL and input impedance, two types of boundary conditions were applied. The first boundary conditions are used to evaluate the TL. First, at the inlet of the suction muffler, a plane wave radiation boundary condition with a particular pressure magnitude $(p_0 = 1)$ was set as Eq. (2). Next, at the wall of the suction muffler, an acoustic hard

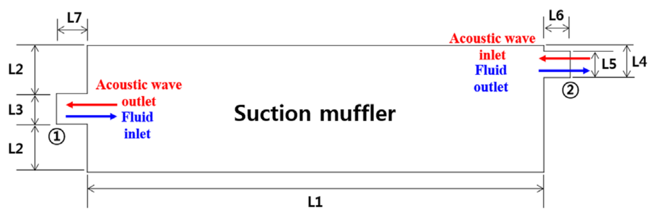

Fig. 1. Suction muffler of a refrigerator compressor ($L1=0.114$, $L2=0.012$, $L3=0.0076$, $L4=0.0080$, $L5=0.0066$, $L6=0.0066$, $L7=0.0076$ [m]).