Applied Acoustics 113 (2016) 210–220

Contents lists available at ScienceDirect

Applied Acoustics

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

Equalization of acoustic source using multi-pole sources and source strength estimation using inverse method

Reza Madoliat, Nowrouz Mohammad Nouri, Ali Rahrovi *

School of Mechanical Engineering, Iran University of Science & Technology, Tehran, Iran

A R T I C L E I N F O

Article history:
Received 30 October 2015
Received in revised form 23 June 2016
Accepted 29 June 2016
Available online 6 July 2016

Keywords:
Acoustic monopole
Dipole
Inverse method
Quadrupole
Source strength

A B S T R A C T

Sound measured at various points around the environment can be evaluated by a series of multi-pole sources and their acoustic strength can be acquired. In this numerical study, a method, called the inverse method, was examined to achieve this goal. A variety of arrangements of different sources were considered and the acoustic strength of these sources was acquired. Through the application of the mismatch criterion, good conformity was observed between these sound models and the original sound. Furthermore, with regard to results, sound was generated via different source arrangements which showed acceptable agreement with the original sound. Finally, an arrangement named 'sources vertical arrangement' was selected as the best approach.

1. Introduction

Throughout the world, much effort has been devoted to reducing noise in different environments. It should be noted that mechanical components play an important role in noise production. In many cases, one can easily distinguish which part of the machine is the source of noise, but the strength of noise from a known source is not easily measurable. If the strength of a source is known, selecting an effective method for noise reduction may become possible.

Grace [1] investigated the inverse method to study the noise of a plate exposed to gust. Further, he studied this problem for a rectangular wing instead of a plate [2]. Assuming that the number and the position of the sources were given, Nelson and Yoon [3,4] estimated the acoustic strength of several sources using the active control method. They also assumed that the matrix relationship between the strength of the source and the acoustic pressure was given.

Li [5] and Li and Zhou [6] solved the inverse problem for a 3D moving object with an arbitrary shape using Ffowcs Williams Hawkings equation (FW-H). Luo and Li [7] examined the inverse problem for an aero-acoustic resulting from the interaction of the rotor wake/stator. They used the Fredholm integral equation of the first kind. Gérard et al. [8,9] worked on noise produced by a fan. They obtained the distribution of sources of an axial fan both theoretically and experimentally. Presezniak continued Gérard's studies and found the best location for fan noise measurement where least measurement errors are achieved [9].

Trabelsi et al. [10] obtained the distribution of the unsteady rotating forces on the blade of a fan by applying a far-field sound pressure. He concluded that mainly propellers cause the hull pressure induction. Installing receivers on top of the propeller and applying the boundary element method and the inverse method, it would be possible to determine the parameters of the sources. Wijngaarden [11] and Seong et al. [12,13] have made very good efforts in this regard.

In most cases, Blind Source Separation (BSS) technique is expressed by the Cocktail Party example [14]. Blind Source Separation is applied to the cocktail party problem. There is a room in which three people are speaking at the same time. The mixture signals of their voices are recorded simultaneously. Blind Source Separation is a technique that can separate the initial signals from this mixture. If the parameters of the generated sounds are independent statistically, BSS method can separate different sounds. Unlike the behavior shown in different problems, the BSS is not a suitable method for determining the strength of multi-pole acoustic sources because all sources generate sound with a frequency which makes it impossible to statistically identify the generated sounds independently [15].

In this numerical study, a general model has been presented which is not limited to propellers, fans or similar cases. All types of multi-poles are involved in this model and it is not restricted

* Corresponding author at: School of Mechanical Engineering, Iran University of Science & Technology, Narmak, Tehran, Iran.
E-mail address: Ali_rahrovi@iust.ac.ir (A. Rahrovi).

http://dx.doi.org/10.1016/j.apacoust.2016.06.030

to some special types. As an instance, lateral quadrupoles have never been used in any model presented in previous studies. A method is used to maximize the conformity between the real and modeled sounds. This general model is presented for estimating the strength of an acoustic source in different frequencies (monopole, dipole, and longitudinal and lateral quadrupoles). Henceforth, the word 'multi-pole' will be used to refer to monopoles, dipoles and quadrupoles. For this purpose, the inverse method is applied.

To examine the compatibility of the original sound and the model sound, the matched-field inversion (MFI) method has been used. Furthermore, the location of noise generation has been checked to minimize the effects of measurement errors.

2. Method

According to Lighthill, sound production in fluid generally results from the distribution of three kinds of sources [16]. It should be note that these three types of sources are the first three vibratory modes of a sphere. The first mode is called monopole, and the second and the third modes are called dipole and quadrupole, respectively. Higher modes are generated in solid environments, such as compressor housings, as well. However, when their released sound is considered, higher modes can be constructed from these first three modes.

Sound sources can be classified into two main categories: sources that are small compared to the wavelength, and sources that are large compared to the wavelength [16]. Bigger sources with an extensive surface can be decomposed into a number of smaller resources which are called Near-field Equivalent Source Imaging (NESI) [17]. These sources are the first three vibratory modes of a sphere. In this paper, a general framework is presented for source selection and the way their strength is determined as shown in Fig. 1.

$$\nabla^2 p + k^2 p = 0 \tag{1}$$

Helmholtz's equation is the ruling equation for the time-harmonic linear acoustics.

In this equation, k is the wave number and p is the total sound pressure.

$$p = p^i + p^s \tag{2}$$

According to the 'superposition principle', this pressure is the sum of the incident sound pressure (p^i) and the scattered sound pressure (p^s) [12].

Both the incident wave pressure (p^i) and scattered wave pressure (p^s) satisfy Helmholtz equation, but only the scattered wave pressure (p^s) satisfies the Sommerfeld radiation condition. In this paper, we have assumed that sound emitted from multi-pole sources do not hit any surfaces as depicted in Fig. 2; therefore, the scattered part (sound reflection from a hard surface [18]) has not been taken into account. In order to take the scattered portion into account, the boundary element method and its inverse must be employed, which is beyond the scope of this article.

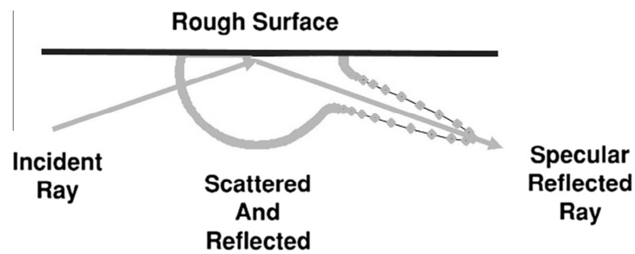

Fig. 2. Sound reflection from a hard surface [18].

Multi-poles are considered to be sound sources that are monopole, dipole and quadrupole. Quadrupoles are divided into two group: longitudinal quadrupole and lateral quadrupole. In Fig. 3, sound is symbolically measured in one point and a monopole, dipole, longitudinal quadrupole and lateral quadrupole sounds are shown.

The mechanism of sound production is shown for each source in Fig. 3. It is worth noting that all sources generate sound at a certain frequency. At this stage, the acoustic pressure is measured at different points in order to find their source strength. In the end, the inverse method is considered that can be used to obtain the source strength.

2.1. Inverse method

First, at various points, sound with pressure (P), which is a function of time and place, is measured.

$$P(x,t) = Re\left\{\sum_j i\rho\omega_j\varphi_j(x)\exp(-i\omega_j t)\right\} \tag{3}$$

Acoustic pressure (P) at each point is equal to Eq. (3) with the mean density of acoustic fluid ρ, angular frequency ω_j and frequency-dependent potential $\varphi_j(x)$ [11].

After the measurement of sound at different points in terms of time, according to Eq. (3), $p(X)$ is computed by applying the Fourier transform to the measured sound at different points.

$$p(X) = i\rho\omega\varphi(X) \tag{4}$$

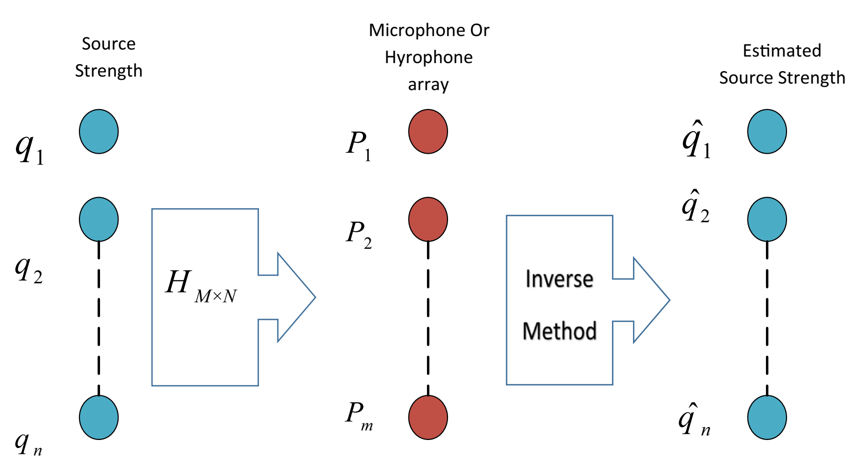

Fig. 1. Block diagram of the system model.