Applied Acoustics 72 (2011) 420–427

Contents lists available at ScienceDirect

Applied Acoustics

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

Reduction of sound radiation by using force radiation modes

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ARTICLE INFO

Article history:
Received 14 April 2010
Received in revised form 5 January 2011
Accepted 13 January 2011

Keywords:
Sound radiation
Radiation modes
Driving force
Eigenvalue/eigenvector decomposition

ABSTRACT

The location of a vibration source within a machine is sometimes found to have a significant effect upon its radiated acoustic power. It is known that a simple reduction of vibration cannot always reduce the radiated acoustic power, so that treatments based on analysis of a structure's vibration modes are not always effective. At the same time, radiation mode analysis is known to be a powerful tool for interpreting sound radiation since those modes are independent of a structure's surface vibration. However, knowledge of the radiation modes alone cannot be used directly to understand the relationship between vibration source location and acoustic power radiation. In this paper, it is shown that the radiation mode concept can be extended to understand the relationship between acoustic power and driving force distribution by considering the product of the structure's mobility matrix and the radiation modes: the resulting functions are here defined to be force radiation modes (f_{rad}-modes). An example is presented in which the acoustic power radiated by a simply-supported, baffled beam is reduced by using guidance provided by the structure's force radiation modes. The results demonstrate that the force radiation modes can be used to guide the reduction of radiated acoustic power by changing the driving force location without the need to perform additional calculations or experiments.

1. Introduction

When machinery is designed, the location of the vibration source is sometimes found to have a significant impact upon the radiated acoustic power. In particular, this is true when a pure tone is prominent: e.g., the pulsating sounds of compressors and hydraulic components in construction machinery, and gear/motor sounds of various types in machinery. To begin with, a machine is usually designed so that it does not resonate. Therefore, these pure tone noises are not always a resonant problem. If there is a resonant problem, it is relatively easy to reduce the noise radiation by applying treatments such as damping materials or by increasing the rigidity of structural components. However, if it is not a resonant problem, treatments for resonance are not useful and reduction of noise becomes difficult. In practice, treatments based on vibration mode analysis are often applied because it is simple. However, it is known that the simple reduction of vibration cannot always reduce the radiated acoustic power [1,2] and that the sound radiation characteristics of a structure must be taken into account. As with the node of a vibration mode, if the node of the sound radiation can be located, it is possible to reduce the sound radiation simply by placing the vibration source at the nodal location.

Radiation mode analysis has been developing since the early 1990s mainly in the field of Active Noise Control [3,4]. It is known to be a powerful tool for interpreting sound radiation since radiation modes are only dependent on geometrical information and are independent of a structure's surface vibration. By calculating the radiation modes, the vibration distribution patterns which radiate sound effectively can be identified. More specifically, when the surface vibration pattern corresponds to the first radiation mode, whose contribution to the acoustic power is the highest, sound is radiated very effectively. In practice, it is possible to focus only on the first few radiation modes and reduce the radiated sound power effectively. Recently, radiation modes analysis has been applied to practical subjects such as the low-frequency sound radiation from a highway bridge [5] and tire/road interaction noise [6]. Since radiation modes are frequency-dependent, it can be said that this style of analysis is more suitable for application to a pure tone noise problem, as dealt with here, rather than broad band noise problems.

Note, however, that knowledge of the radiation modes alone cannot be used directly to understand the relationship between vibration source location and acoustic power radiation. It may be helpful to understand that relation by identifying the dominant vibration modes and radiation modes. However, from a knowledge of radiation modes alone, it is difficult to estimate the influence of source location quantitatively. Therefore, it is necessary to take the

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0003-682X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.apacoust.2011.01.006

structural dynamics information (as available from a finite element model, for example) into account in this process in order to design optimally quiet machinery. According to Tanaka [3], vibration modes can be taken into account as modal coordinates. This method expresses the vibration velocities on the boundary as the product of the modal matrix and the modal velocities. Then, the power modes in which the sound radiation and structure are taken into account are made independent of the modal velocities. However, that process still does not make it easy to understand the relationship between acoustic power and driving force location. Instead, it can be said that once the vibration velocities on the boundary are expressed as the product of the structure's mobility matrix and the driving force distribution, the driving forces can be made independent of both the sound field and the structure. As the result, the acoustic power can be minimized simply by choosing the appropriate location of the driving force (e.g., gears, motors).

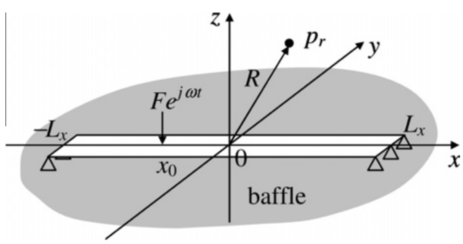

Fig. 1. Calculation model.

In this paper, it is shown that the radiation mode concept can be extended to understand the relationship between the acoustic power and the driving force distribution directly by forming the product of the structure's mobility matrix and the radiation modes to create force radiation modes. An example is presented that involves reduction of the acoustic power radiated by a simply-supported baffled beam by using guidance provided by the structure's force radiation modes. The results demonstrate that the force radiation modes can be used to guide the reduction of radiated acoustic power by changing the driving force location without the need to perform additional calculations or experiments.

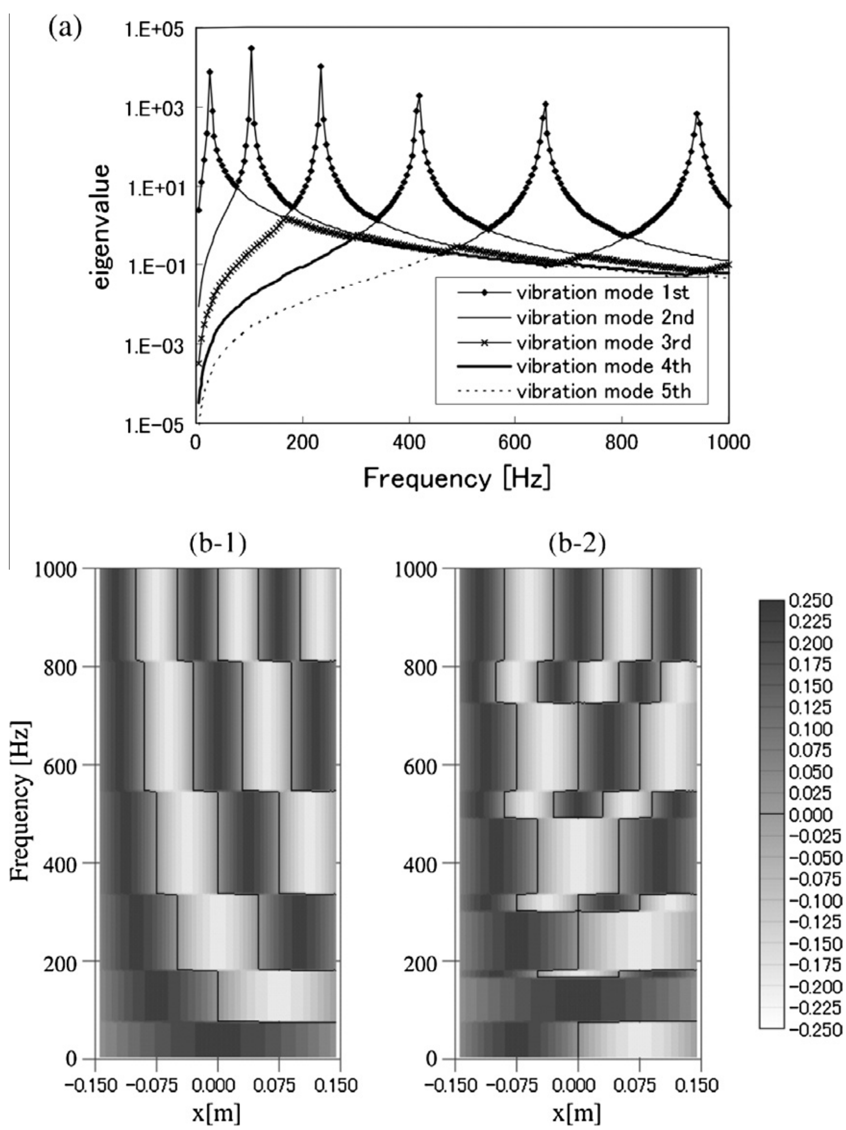

Fig. 2-1. (a) Frequency characteristics of the eigenvalues of the vibration modes. (b-1) Mode shape of the first contributing vibration mode. (b-2) Mode shape of the second contributing vibration mode.