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ScienceDirect

Procedia Engineering 176 (2017) 218 – 225

Procedia Engineering

www.elsevier.com/locate/procedia

Dynamics and Vibroacoustics of Machines (DVM2016)

Noise calculation method for industrial premises with bulky equipment at mirror-diffuse sound reflection

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Abstract

The paper presents a method of sound energy characteristics calculation in premises with bulky equipment at mirror-diffuse character of sound reflection from enclosures. At such character of reflection a part of sound energy falling on an enclosure is reflected specularly, and the other part is dissipated under the Lamberts law. Sound pressure levels in reference points of a premise are determined by the sum of direct sound energy emitted by sound sources and energy of mirror and diffuse components of reflected sound field. The numerical method is proposed for calculation of sound energy density and the subsequent determination of sound pressure levels. The method is developed on the basis of the combined design model in which the mirror component of the reflected sound energy is determined by ray-tracing method and the diffuse energy component is calculated by numerical statistical energy method. The equations for determination of density of the direct, mirror-reflected and diffused sound energy are provided and technique of realization of the design model is given. The proposed method takes into account space-planning features of premises, presence of bulky equipment, sound absorption characteristics of enclosures and the nature of sound reflection from surfaces, and provide an opportunity to solve problems of estimating noise in industrial premises. The comparison of the calculated and experimental data obtained for rooms of different sizes and shapes in the absence and presence of bulky equipment confirmed the adequacy of the proposed calculation model for the description of noise field formation in such conditions. It is shown that divergences of calculation and experimental data do not exceed ±2÷3 dB in octave bands with central frequencies equal or more than 250 Hz.

Peer-review under responsibility of the organizing committee of the international conference on Dynamics and Vibroacoustics of Machines

Keywords: noise, calculation method, sound pressure level, energy density, mirror-diffuse reflection

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1877-7058
Peer-review under responsibility of the organizing committee of the international conference on Dynamics and Vibroacoustics of Machines
doi:10.1016/j.proeng.2017.02.291

1. Introduction

It is known that the sound pressure level at any point in the room is determined by the components of direct and reflected sound energy propagating in a confined space. When calculating the direct sound energy, it is necessary to consider the shape and size of the sound source, and the distance from the calculated point. The reflected sound energy is influenced by space-planning parameters of room, sound absorption characteristics of walls and equipment surfaces, the nature of the sound reflected from the surface, location of noise sources, location and dimensions of the equipment in the premises. Typically, industrial facilities do not have a simple geometric shape and there is no sufficiently accurate information about the acoustic characteristics of the surfaces of walls. Besides, a number of other factors increase the uncertainty in the specification of initial and boundary conditions. In such circumstances, the most appropriate methods of solving the problem of sound energy distribution are methods based on statistical energy approach [1] and principles of computer simulation of trajectories and energy rays emitted by the sound source [2].

The choice of a particular method for each situation is largely determined by the nature of sound energy reflection. Sound reflection from the room walls and equipment occurs on complex dependencies, the description of which in general terms is not possible. Therefore, in the calculations we used idealized models with mirror or diffuse components of sound reflection. In developing more reliable calculation methods one can use closer to real, mirror-diffuse sound reflection, in which a part of the sound energy is reflected specularly, and the rest of the reflected energy is scattered diffusely. The calculation model is detailed below.

2. The combined calculation model of the sound field in industrial premises for the mirror-diffuse type of reflection

We propose to use a combined calculation model, where energy distribution of direct sound and specularly reflected energy are determined by the method of ray tracing, and density distribution of diffusely reflected energy is measured by a numerical statistical energy method.

The acoustic energy density at any *i*-th point of the room is determined by the sum of the energy densities of the direct sound and mirror and diffuse components of the reflected energy. Accordingly, the total sound pressure level L_i, [dB], is calculated as

$$L_i = 10\lg[c(\varepsilon_i^{dir} + \varepsilon_i^{mir} + \varepsilon_i^{dif})/I_0], \quad (1)$$

where c is the sound speed in air, [m/s]; ε_i^{dir} is the direct sound energy density, [J/m^3]; ε_i^{mir} and ε_i^{dif} are the energy densities of the mirror and diffuse components of the reflected energy, [J/m^3]; $I_0 = 10^{-12}$ [W/m^2] is the reference sound intensity.

The essence of the proposed combined model is as follows.

A sound source generates a number of sound rays in accordance with its free space pattern. Each of the rays carries a part of the source sound energy. The energy of all rays is equal to the total energy emitted by the source in a unit time, that is, its acoustic power. As the rays travel, they lose energy due to absorption in air and on surfaces of room boundaries or obstacles, which they are meeting. Each ray also loses energy, which is scattered at reflection, i.e. a part of reflected sound energy of the ray is transformed into diffuse component and a part of the energy is reflected specularly back to the room. Then the reflected ray energy is lost again when the ray hits a next obstacle. Each ray is traced until it loses its energy completely due to air and surface absorption and transformation of its mirror component into a diffuse one. Thus all rays emitted by source are traced and direct and mirror reflected sound energy of all rays passing through the reference point are summarized. Energy distribution of rays scattered diffusely is determined by the method based on the statistical energy approach [3] and used by us at noise calculations in industrial premises at diffuse reflection of sound from enclosures [7]. The basic construction principles of calculation methods included in a combined calculation model are considered below.

When calculating the direct sound energy and mirror reflected energy we used an approach, in which the rays have infinitely small spatial angles of propagation. Sound power carried by each *k*-th ray after it has passed from the