THE THEORY AND PRACTICE OF SOUND POWER MEASUREMENT (THE POWER OF MUSICAL INSTRUMENTS)

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Abstract. The principle of the sound power measurements carried out in anechoic chamber and in reverberation room is shortly described in the paper. The advantages and disadvantages of both methods in practice and some results of the power measurements of musical instruments are shown.

Introduction

The radiated sound power or its spectral distribution is a fundamental physical property of the sound source, and is therefore an important parameter which is widely used for rating and comparing sound sources. Making the sound power measurements, difficulties of principle and of practice arise.

Principle of the Measurements

If any sound source is radiating the changes of the sound energy is described by the following balance-equation:

$$\frac{d}{dt}\int w dV + \int p\bar{v} dS = P - P_e \qquad (1)$$

where $w = \frac{1}{2}\rho v^2 + \frac{1}{2}Kp^2$ denotes the energy density, $p\bar{v}$ the density of energy flow (intensity), P the sound power of the sources and P_e the power absorbed in air.

Equation (1) can be written in the following form:

$$\int \frac{\partial w}{\partial t} dV + \int w\bar{v} dS + \int p\bar{v} dS + P_e = P \qquad (2)$$

By normal sound intensity $w\bar{v} << p\bar{v}$, so $\int w\bar{v} dS$ can be neglected.

The measurement of the sound power P can be reduced to the measurement of $\int p\bar{v} dS$, if $P_e \equiv 0$ and $\int \frac{\partial w}{\partial t} dV \equiv 0$. The latter identity is true only if stationary radiation which means that the elimination of this addition can cause considerable error by sources of impulsive or nonstationary type (e.g. musical instruments).

There are two kinds of general methods being used in practice, namely the measurement carried out in anechoic chamber and in reverberation room [1,2].

Making the measurement in an anechoic chamber the main problem is that sound intensity ($I=p\bar{v}$) cannot be measured directly, because to detect the particle velocity is only possible by extremely high intensities [3].

In practice the sound pressure is measured by a number of microphones placed on a spherical surface around the source. Averaging the microphone signals the power can be calculated:

$$P = r^2\pi \frac{\Sigma p_i^2}{\rho c} \tag{3}$$

where r is the distance between the source and microphone.

The generally used power measurements in anechoic chamber are complicated because of the big number of microphones. It is easier in practice to carry out the measurements in reverberation room, where the sound power radiated into the room is considered being equal to the absorbed power on the wall, which is proportional to the incident intensity and to the wall surface. The power of the source can be expressed as follows:

$$P = \int p\bar{v}dS = \frac{I\bar{\alpha}S}{4} \tag{4}$$

where $\bar{\alpha}$ is the mean value of the absorption coefficient of the wall, S denotes the wall surface.

By the calculation the incident intensity is supposed to be independent of direction. If the point of observation is not too close to the sound source or to any surface of the room, one measurement of the stationary sound pressure is enough for determining the sound power of the source. Then according to eq.(4) and to the well-known Sabine's formula:

$$P = \frac{p_{eff}^2}{4\rho c} \cdot \frac{0.16V}{T} \tag{5}$$

where T is the reverberation time of the room.

The Limits and Accuracy of the Methods

The anechoic chamber method is good for plane waves. Formula (3) can be applied to point sources if the microphones are placed in the far field. In other cases phase differences arise by which the formula is changed. The power can be calculated as follows:

$$P = r^2\pi \frac{\Sigma p_i^2 \cos\psi_i}{\rho c} \tag{6}$$

where ψ_i is the phase difference between p_i and $\bar{v}_i$ (which cannot be measured either).

Although there is a theoretical possibility to determine the particle velocity by measuring the gradient of the pressure [4], but these methods have some disadvantages in practice. If the distance between the source and microphone is big the absorption of air is also to be taken into account. Furthermore, as $\int \frac{\partial w}{\partial t} dV$ is neglected only sources of stationary or of quasi-stationary type can be measured with not too big error. By sources of impulsive or non-stationary type this component is also to be taken into consideration.

In practice the sound field is not diffuse in the reverberation room, that is the sound pressure varies both in space and time even by stationary radiation. But these fluctuations can be averaged by proper measuring methods. If the amplitude fluctuation is commensurable with the travelling time of the sound wave from the source to the wall surface or it is less than the travelling time, eq.(5) is no longer valid. Particularly by sources of impulsive type

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is the method to be revised for taking into consideration the neglected component $\int \frac{\partial w}{\partial t}\, dV$.

Another difficulty is the big quality factor of the resonances of the room which can cause also a considerable error. Let us see what is the effect of the quality factor on the measured sound power! The quality factor of any oscillating system is:

$$Q = \frac{\text{stored energy}}{\text{dissipated energy in one period}}$$

In the case of the reverberation room:

$$Q = \frac{\int w dV}{\int_0^t \int \frac{I\bar{\alpha}}{4}\, dSdt} = \frac{wV}{\frac{IA}{4}\tau} = \frac{wVf}{\frac{IA}{4}} \tag{7}$$

So taking into account the resonances of the room the absorbed power of the wall (P_a) at a resonance frequency can be given by:

$$P_a = \frac{IA}{4} = \frac{wVf}{Q} = \frac{wV}{2\pi}\sigma \tag{8}$$

where σ denotes the width of the resonance curve.

Making a comparison between the sound power values calculated by eq.(5) and by eq.(8) the two values differ in the following factors:
according to eq.(5) to eq.(8)

$$\frac{13.6}{T} \longleftrightarrow \frac{\sigma}{2\pi} \tag{9}$$

Let us take an example! If the frequency is 1000 Hz, the reverberation time is 8.5 s, the mean value of the width of the resonance curve is 0.7 Hz and the factors are

$$1.6 \longleftrightarrow 0.11$$

The greater is the quality factor (or the sharper is the resonance curve) the less is the absorbed power on the wall. It means that the power of the source radiating on a frequency close to the resonance frequency of the room will be calculated by the common method greater than the real power value.

If the source is highly directed the effective surface of the wall seems to decrease as the sound wave propagates mostly in a certain direction. Therefore the calculated sound power will be greater than the real value.

Having taken into account all the advantages and disadvantages of the above-mentioned methods, preference has been given to the reverberation room method in the Acoustic Research Laboratory of the Hungarian Academy of Sciences.

The Reverberation Room Method in Practice
(Measuring the Sound Power of Musical Instruments)

The most complicated sound sources are the musical instruments. The sound of the string and brass instruments can be characterised as follows: complex sound with lined spectra, fluctuating amplitude and frequency.

Because of the lined spectra and the amplitude fluctuation, the distribution of the sound energy density is not uniform in space. Therefore the sound pressure level has been integrated in space by a rotating microphone. For decreasing the "Q-effect" the quality factor of the room was damped at low and middle frequencies by proper resonators. Because of the amplitude fluctuations the sound pressure level has been integrated during a long period of time (32 s). The applied real time analyzer has made it possible to measure the power of all components of the complex sound event simultaneously [5].

Sound power of string and brass instruments has been measured in co-operation with the Laboratory of Musical Acoustics of the PTB by the guidance of Prof.Dr. J. Meyer in Braunschweig 6 . The results show that the sound power level spectrum measured in a certain reverberation room is an individual characteristic of an instrument and it is independent of loudness. The spectra of two violins measured fortissimo and also pianissimo are shown in the Figure. This phenomenon could be utilized for rating and comparing musical instruments, but the effect of different rooms and of different musicians is still to be investigated.

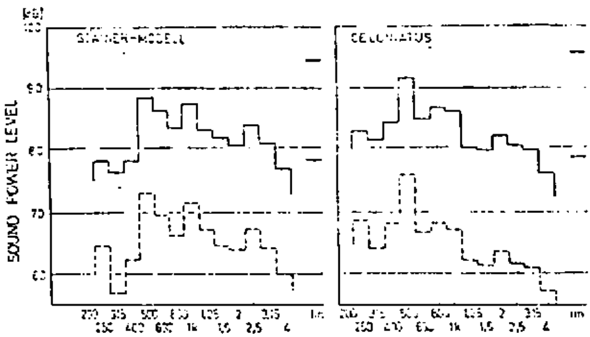

Figure 1. The sound power level spectra of two violins
——— fortissimo ---- pianissimo
a/ violin "Stainer-model"
b/ violin "Celoniatus"

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