An indicator based on modal intensity for testing the influence of the environment on the sound power of an acoustic source

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A new indicator very sensitive to the room resonances excited by an acoustic source is here introduced and used as an environmental parameter for certifying the sound field condition when measuring the acoustic power of the source by the intensity method. This quantity will be called *resonance indicator.* Thanks to its experimentally proved properties a definitive insight of the physical meaning of the "oscillating intensity" as introduced in previous papers is accomplished. The results of a set of measurements of the sound power of a reference source in different acoustical environments will be presented and discussed using the introduced indicator.

INTRODUCTION

The definition of the acoustic power of sources is based on the well-known acoustic energy corollary which is demonstrated to be consistent with the requirement of energy conservation in a fluid to second order [1]. Within this theoretical frame, the power Π of an acoustic source can be expressed in terms of the stationary time-averaged radiant (active) intensity $\mathbf{A}(\mathbf{x})$ as

$$\Pi \equiv \int\!\!\int_S \mathbf{A}(\mathbf{x}) \cdot \mathbf{n}\, d^2\mathbf{x} \tag{1}$$

where the integral is taken over a closed spatial surface S bounding the volume V which usually contains the source. Π is a real quantity measured in $\mathrm{W} = \mathrm{J\,s^{-1}}$whose sign can be positive for a radiating source, negative for a dissipative or absorbing source (a sink) and must be equal to zero when the integral of Eq. 1 is derived from the homogeneus continuity equation $w_t + \nabla \cdot \mathbf{j} = 0$, where $w(\mathbf{x}, t)$ and $\mathbf{j}(\mathbf{x}, t)$ stand respectively for the instantaneous sound energy density and intensity. In this paper only the case $\Pi \geq 0$ will be considered.

When a source is enveloped by S the continuity equation takes the inhomogeneous form $w_t + \nabla \cdot \mathbf{j} = \wp(\mathbf{x}, t)$ where $\wp$ is the *power density* depending in general *both* on the source and the environment. It is worth noting that w_t vanishes when a stationary time-average is performed on it so that also its integral over any volume (contained or not in S) is zero. This fact, often misunderstood, has an important physical meaning because tells us that when stationary energy conditions are reached the time rate of the energy emission from the source (i.e. the source power) must be equal to the time rate of the energy absorption by the boundaries. Due to the equality $\langle w_t \rangle \equiv 0$ the rate of energy absorption, in turn, must be equivalent to the integral of $\langle \wp(\mathbf{x}, t) \rangle$ over V (stationary energy balance). Unfortunately, neither mathematical nor experimental handling definition for $\wp(\mathbf{x}, t)$ has been formulated yet, so the only way for evaluating the acoustic power of a source must be based on sound intensity: Π can be experimentally evaluated determining the time average vector field $\mathbf{A}(\mathbf{x})$ at some discrete points $\mathbf{x} \in S$ and then approximating the integral (see [2]). In this paper a careful experimental investigation about the influence of field boundaries condition on the measured power of a reference acoustic source has been carried out and a new field indicator accounting for the sound energy "trapped-in-the-average" in the standing waves (normal modes of the environment) excited by the source itself has been usefully employed as an environmental parameter for acoustically certifying the source power measurement.

The resonance indicator

Following a reasoning similar to the one which led to the definition of the sound radiation indicator $\eta \overset{def}{=} A/c\,\langle w \rangle$ the resonance indicator will be here introduced as

$$\mu \overset{def}{=} \frac{M}{c\,\langle w \rangle} \tag{2}$$

where $M \overset{def}{=} \sqrt{\langle \mathbf{r}^2 \rangle}$ (apart from a numerical factor) is the Hilbert-Schmidt norm of the sound intensity polarization tensor [3]. In other words μ is defined as the effective value of the *modal intensity* M normalized to $c\,\langle w \rangle$ thus representing the fraction of the energy density which is locally associated in the average to the normal modes excited by the source. A preliminary analysis on a similar indicator can be found in Ref. [4]

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SESSIONS

MEASUREMENT AND RESULTS

Figure 1 shows the reference source and the intensity probe used for measuring the sound power in two different rooms. The first one is very "dead" due to the absorbing upholstery ($T_{60} < 10^{-1}\,\mathrm{s}$) while the second one is a normal room of the same volume and characterized by $T_{60} \simeq 1\,\mathrm{s}$. The input signal to the source (white noise) and the enveloping surface (a sphere centered at the top of the source having a radius of $1.5\ \mathrm{m}$) were the same for the two measurement sets.

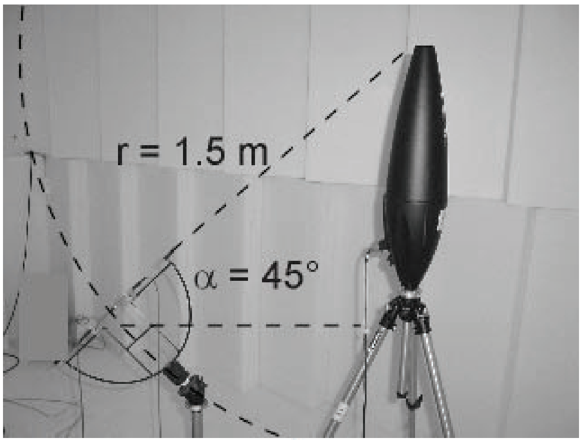

FIGURE 1: The source and a measurement point.

Once fixed the equatorial plane parallel to the floors, the radial component of sound intensity in two positions 45° North and 45° South belonging to 4 meridians 90° apart for a total of 8 points was measured. These data were then used for the power computation. We collect data for evaluating μ at only one measurement point in the equatorial plane at a distance of $2\ \mathrm{m}$ from the centre of the sphere.

Figure 2 reports the calculated power of the source in the two rooms for third-octave bands ranging from 100 to 5000 Hz. Figure 3 reports the comparison between the indicators η and μ, measured at one point in front of the source in the two rooms.

CONCLUSION

According to the precision of our measurements the power of the reference source results slightly greater (1 ÷ 2 dB) for all bands when the source is radiating in the absorbing room. This can be considered an experimental evidence of the fact that the power of an acoustic source depends inescapably from the boundaries conditions or, stated in other words, that when the acoustic field feeds back to the source, the source itself becomes a boundary condition for the acoustic field. For this reason, when accurate power measurements of acoustic sources are needed, the two indicators η and μ should be employed for certifying the influence of the environment on the measured field. This should be done optimally at every point where data for the power computation are collected.

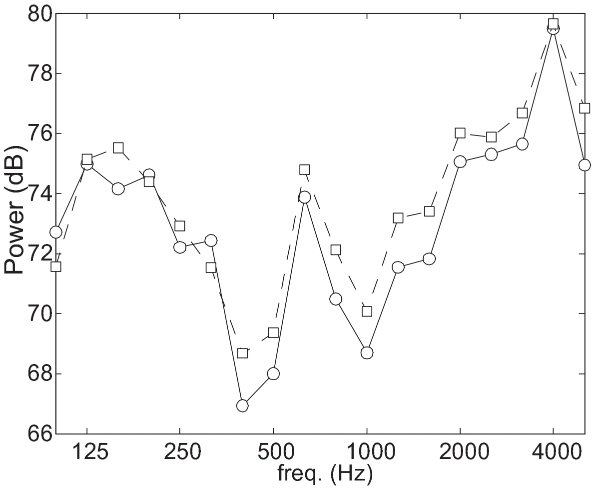

FIGURE 2: Values of sound power (squares: dead room, circles: normal room).

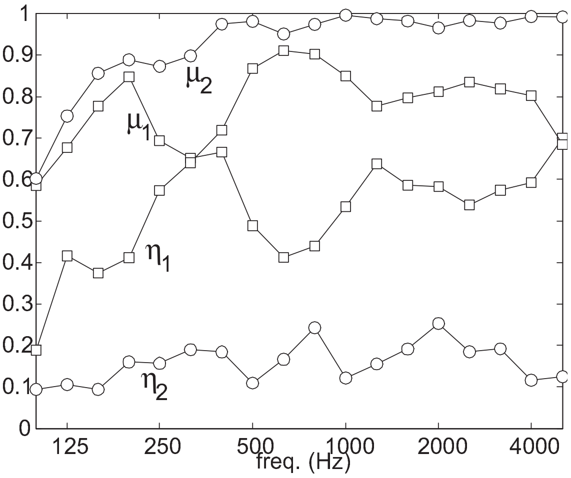

FIGURE 3: Values of μ and η (squares: dead room, circles: normal room).

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