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SOUND POWER DETERMINATION: A REVIEW OF ACTUAL PROBLEMS

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Introduction

Since a couple of years the sound power level is more and more accepted as the main quantity describing the noise radiated by machinery and equipment. The introduction of sound power for the "noise emission" was accelerated by 3 developments:

Recent Developments

(1) The increasing interest of the society in noise reduction caused several authorities to establish specific laws and regulations in which a clear distinction is made between polluter's source and the environmental conditions responsible for the noise propagation. Furthermore the check of limits prescribed for noise exposing one man's ear ("noise immission" limits) requires data from the relevant noise sources which enable us to summarize several sources, and to calculate the source influence on certain positions different located from the source. The past years brought the understanding that these tasks and some similar problems can be solved better using sound power information of the source than using its sound pressure data only. Thereby sound power is favoured by its independence from environmental and space influences. Of course for the solution of some of the problems sound power data are necessary but not sufficient and additional information are required, e.g. describing the source directivity.

(2) Investigations of the early 70th years brought a break-through for the determination of the sound power for a great lot of noise sources to be measured under environmental conditions of p r a c t i c e. Thereby the problems was - and some cases still remain - to determine sound power by sound pressure measurements n e a r the source with sufficient a c c u r a c y. Measurements in the vicinity of sound sources often are necessary in order to reduce the influence of undesired sound reflections caused by room boundaries and/or reflecting objects situated near the source under test. Such reflections are to be taken into consideration both for the so called "in situ" measurements and in acoustical measurement rooms like semi-anechoic rooms too which of course has limits in size and absorption.

In practice the sound power of machines and equipment mostly are determined under more or less free field conditions using the "method of enveloping measurement surface". For an estimation of the error correlated with this measurement method the usefulness of an systematic analysis was proved by splitting up the total error Δ_{tot} into 4 partial errors /1/:

$$\Delta_{tot} \hat{=} \Delta_1 \cdot \Delta_2 \cdot \Delta_3 \cdot \Delta_4 \qquad (1)$$

whereby
the "near field error":

$$\Delta_1 = \oint\!\!\!\oint_S \overline{p(v,dS)}^{\,t} \Big/ \frac{1}{\varrho_0 c}\oint\!\!\!\oint_S \overline{p^2}^{\,t} dS \tag{1.1}$$

which is composed by the "angle error" and the "impedance error",
the "finity error":

$$\Delta_2 = \frac{1}{\varrho_0 c}\oint\!\!\!\oint_S \overline{p^2}^{\,t} dS \Big/ \frac{1}{\varrho_0 c}\left(\frac{1}{S}\sum_{i=1}^{N}\overline{p_i^2}^{\,t} S_i\right) S \tag{1.2}$$

Δ_2 includes the influence due to the limited number of sound pressure values,

the "actual measurement error":

$$\Delta_3 = \frac{1}{\varrho_0 c}\left(\sum_{i=1}^{N}\overline{p_i^2}^{\,t} S_i\right)_{true} \Big/ \frac{1}{\varrho_0 c}\left(\sum_{i=1}^{N}\overline{p_i^2}^{\,t} S_i\right)_{\substack{measured\\ under\, FFC}} \tag{1.3}$$

Δ_3 includes the fluctuations, which are caused by instruments, observers, meteorological condition, etc.

the "environmental error":

$$\Delta_4 = \frac{1}{\varrho_0 c}\left(\sum_{i=1}^{N}\overline{p_i^2}^{\,t} S_i\right)_{\substack{meas.\\ FFC}} \Big/ \frac{1}{\varrho_0 c}\left(\sum_{i=1}^{N}\overline{p_i^2}^{\,t} S_i\right)_{corrected\, FFC} \tag{1.4}$$

Thereby the indices "FFC" indicate measurement under ideal free field condition and "corrected FFC" means measurements under approximative free field conditions the sound pressure values obtained are corrected by the "environmental correction factor K" according equation (2):

$$\boxed{L_W = (\overline{L_p} - K) + 10\,lg\frac{S}{1m^2} + B} \tag{2}$$

where L_W is the sound power level of the sound source under test,
$\overline{L_p}$ is the level of the mean-square sound pressure averaged over the enveloping surface,
S is the area of the enveloping surface in m^2,
K is the environmental correction which includes all undesired sound reflections and absorptions. For ideal free field conditions: K = 0,
B is the meteorological correction including mainly deviations of ϱc relative to 410 $Ns\cdot m^{-3}$. Such deviations influence L_W both in L_p and in ϱc itself.

The main step to make the method of enveloping surface "presentable in society" as mentioned before was obtained from theoretical and experimental investigations dealing with the near field error Δ_1 in function of relevant parameters varied in a very wide range /1/. Thereby it was shown that in many cases good conditions exist for the sound power determination by sound pressure measurements also within the vicinity of the source which generally is designated as the"near field".

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The main reason for this phenomenon is that for the validity of the well known condition: $\overline{pv}^{\,t} = \frac{1}{\rho c}\,\overline{p^2}^{\,t}$ (3)

is not necessary to fulfill each equation

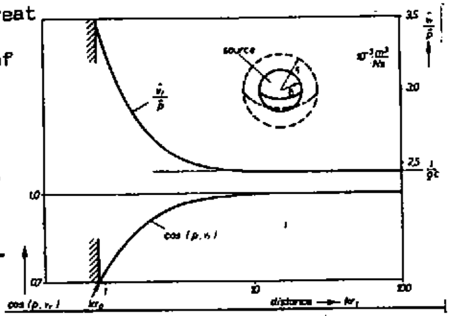
$$v = p/\rho c \quad \underline{\text{and}} \quad \cos(p,v) = 1 \tag{4}$$

for itself but only for the p r o d u c t

$$v \cdot \cos(p,v) = p/\rho c \tag{5}$$

Thereby existing deviations from the two equations (4) are totally or partially compensated within Equ.(5) (examples, see /2/ and figure 1.) Furthermore "near field measurements" are supported by the fact that a great lot of technical sound sources (machines, equipment) are sources of low radiation order, this means having a radiation efficiency σ which e.g. can approximately described by spherical sources of 0^{th} up to 1^{st} order (see /1/,page 971).

Last but not least the sound power determination was lightened by the normal character of noise of machines and equipment which is overwhelming random in its correlation over time and along the radiating outer surface.



Acoustic quantities in the "near"-field of a spherical source 0^{th} order

Figure 1.

The determination of the sound power of sources inside a <u>reverberant field</u> was developed forwards in the past years too. A summary of these researches is given in the paper /3/. Main problems are (1) to find a good approximation of $\langle p^2 \rangle$ for sources with predominate tones spending reasonable effort ("rotating vanes"), (2) to explain the so-called "Waterhouse effect" (referred to the sound field near the room boundaries), and (3) the comparison of sound power output of the same source measured both according free field and reverberant method /4/.

(3) In the past years International Standardization Bodies, ISO and IEC, and National Standardization groups have been prepared noise measurement codes for the determination of sound power which covers a large sector of the 3 dimensional "parameter space" of Figure 2 which is spread by the variation of the environmental conditions, variation of the accuracy of results obtained and for different types and families of specific machineries (including influences of specific source sizes, operating conditions, noise characters ..)

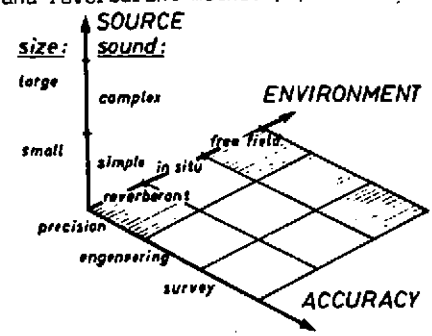


Figure 2. Parameter space

Thereby ISO/TC43/SC1 "Noise" have been prepared a set of 9 frame measurement codes: ISO 3740 .. 3748. All these standards are entitled: "Acoustics-Determination of Sound Power Levels of Noise Sources, Part XXX ...". They form the basis respectively they are the "bundled trunk" for the subordinated, "ramified" Standards dealing with specific kinds of machine families e.g. such as for rotating electrical machinery (ISO R1680, Part 1, 1979) or household appliances (IEC Draft TC59/N41).

Research in presence and future

Blanks within the parameter space of figure 2. indicate not only a lack of relevant measurement codes but mostly open scientific problems too. One group of these problems can be reduced to the question: "What degree of accuracy in determining sound power by sound pressure measurements can be ecpected under certain measuring conditions?" Thereby the measuring conditions not yet investigated finally are worst cases, such as:

(1) large machines radiating the noise unequally along its outersurface, means having one or more small "acoustical centers", and operating in environments not allowing large measurement distances,

(2) large machines radiating the noise in more than one room or as well in one room as into the outdoors (e.g. relevant for power stations),

(3) large and very large industrial plants.

Methods discussing in this field of tasks are the reference sound source method, especially for not movable machines using the "juxta-position" procedure /5/, the introduction of a partial sound power of a sound source regarding only a certain spatial sector of an ommidirectional radiating source (e.g. "window method"), new or better methods for the determination of the environmental correction K for different sound field structures /6/ and research dealing with the influence of gas quality (ρc) on sound power of a source especially for aerodynamic sound sources /7/. Furthermore the suitable numbers and distribution of microphone locations along the enveloping measurement surface was and is a further object of interest /4/. This concerns the partial error Δ_2.

Another group of problems is to find a certain definition of operating conditions for a specific kind of machinery representing its normal use. This is important for codes to reach unequivocal acoustical results, e.g. for tool machines etc. /8/.

Last but not least the sound power determination of machines operating under full load being disturbed by the background noise of the loading machine initiated a development of methods for the determination of the airborne sound power of a sound source by measurement of structure borne noise along the vibrating outersurface of the source. Thereby experimental data of radiation efficiencies σ typical for certain families of machines are collected.

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