inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 2.1

ACCURACY CONSIDERATIONS ON THE METEOROLOGICAL CORRECTION FOR A NORMALIZED SOUND POWER LEVEL

G. Hübner

ITSM, Stuttgart University, Pfaffenwaldring 6, D-70550, Stuttgart, Germany

Tel.: + 711 685 3556 / Fax: + 711 685 3280 / Email: wittstock@itsm.uni-stuttgart.de

Keywords:
SOUND POWER, METEOROLOGICAL CORRECTION, STANDARDISATION

ABSTRACT
The ISO-formula describing a meteorological sound power correction developed for a mixture of different sound generation mechanisms can be used with high precision under laboratory measurement conditions even if one specific mechanism is relevant only. For meteorological conditions outside the range usual for laboratory measurements and especially for aerodynamic sound sources the use of noise generation mechanism specific correction formulas as given here are recommended.

1 - INTRODUCTION
Following relevant issues (listed in paper [1]) certain international standards dealing with sound power determination and being under revision offer terms by which the sound power measured under given meteorological conditions − static pressure B, temperature Θ, humidity H − should be corrected to normalized conditions: (B_N, Θ_N, H_N). Normalized sound powers are wanted for comparing noise emission values and for acoustical planning.
As known [1] different noise generation mechanisms such as describing aerodynamic noise or noise radiated from vibrating structures require different meteorological corrections on principle. On the other hand the ISO proposals use one common formula for all these different mechanisms only. Therefore an investigation was necessary to determine the span of the relevant correction errors. These errors may be used to define the ISO-correction's field of application.

2 - THE METEOROLOGICAL CORRECTION TERM OF ISO
The revised version of the sound power measurement standards ISO 3741, 3745 and 9614-3 assume a "mean" behaviour, by which the ratio of the sound powers P_1 and P_2 determined under different meteorological conditions can be described by the 1.5 $^{\text{th}}$ power of the ratio of the belonging to characteristic impedances (ρc):

$$\frac{P_1}{P_2} = \left[\frac{(\rho c)_1}{(\rho c)_2}\right]^{1.5} \tag{1}$$

Consequently the sound power level under normalized meteorological conditions $L_{W,N}$ is determined by the sound power level $L_{W,act}$ measured under actual conditions (B, Θ, H) using

$$L_{W,N} = L_{W,act} + K_{0,ISO} \tag{2}$$

with a correction

$$K_{0,ISO} = -15\lg\left[\frac{(\rho c)_{act}}{(\rho c)_N}\right]\ dB \tag{3}$$

According to an earlier state of discussion [1] the value for ($\rho c)_N$ was chosen as 400 Ns/m^3 which corresponds to $B_N = 101.325$ kPa and $\Theta_N = 41.3$°C. Now this relative high Θ_N - value caused a change to

$$(\rho c)_N = 411 \frac{\mathrm{Ns}}{\mathrm{m}^3} \tag{4}$$

with a reference temperature $\Theta_N = 23°\mathrm{C}$ and a remaining $B_N -$ value of 101.325 kPa. Using the well known gas equations

$$\rho = \frac{B}{R_L T},\ c = \sqrt{\kappa R_L T},\ \rho c = B\sqrt{\frac{\kappa}{R_L T}} \tag{5}$$

with R_L= 287.1 kJ/kg/K, $T/\mathrm{K} = 273.1 + \Theta/°\mathrm{C}$ and κ= 1.402 it follows

$$K_{0,ISO} = -15\lg\left[\frac{B}{B_0}\right] dB + 7.5\lg\left[\frac{T}{T_0}\right] dB \text{ with } T/K = 273.1 + \Theta/°C \tag{6}$$

For a larger range of temperatures and static pressures figure 1 shows the span of the relevant $K_{0,ISO}$ − values.

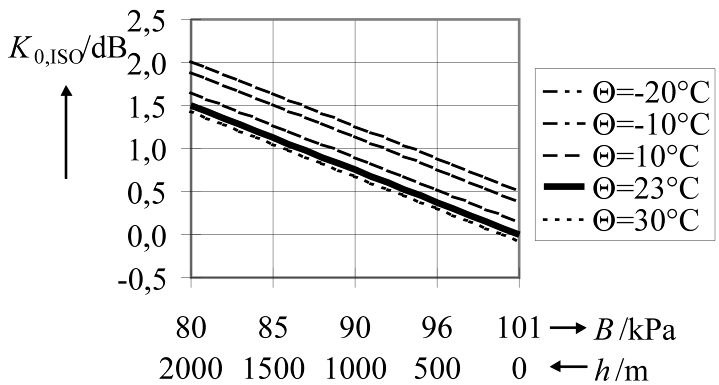

Figure 1: $K_{0,ISO}$ in function of static pressure B respectively altitude h.

The effect of humidity lies between zero and −0.06 dB [3] and can be neglected in all cases.

3 - CORRECTION TERMS FOR SPECIFIC NOISE GENERATION MECHANISMS

As well known the **sound radiated by vibrating structures** can be described by

$$P = \rho c \left\langle\left\langle v_n^2 \right\rangle\right\rangle S\sigma \tag{7}$$

Assuming a structure borne velocity v_n and area S independent of meteorological conditions on a first view a relationship

$$P \sim (\rho c)^1 \tag{8}$$

would be expected if a constant σ is assumed too. This is indeed correct for the frequency range with airborne wave length λ smaller than the typical dimension L_0 of the source means within the range I of figure 2. But for lower frequencies, $\lambda \gg L_0$ the source radiates the sound with a monopole character.

$$P \sim \left(\frac{\rho}{c}\right)^1 \tag{9}$$

(see range II of figure 2) because under these conditions the sound radiation efficiency σ depends on the meteorological conditions too.
For these two frequency ranges the following correction terms are relevant

$$\text{range I}: K_{0,1}/dB = -10\lg\left[\frac{(\rho c)_{act}}{(\rho c)_N}\right] = -10\lg\left[\frac{B}{B_N}\right] + 5\lg\left[\frac{T}{T_N}\right] \tag{10}$$

$$\text{range II}: K_{0,2}/dB = -10\lg\left[\left(\frac{\rho}{c}\right)_{act}\left(\frac{c}{\rho}\right)_N\right] = -10\lg\left[\frac{B}{B_N}\right] + 15\lg\left[\frac{T}{T_N}\right] \tag{11}$$

Depending on its different radiation characteristics for **aerodynamically generated noise** the following relationships are to be considered:

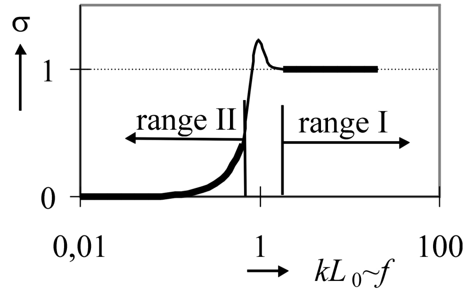

Figure 2: Sound radiation by vibrating surfaces.

- Monopole characteristic:

$$P \sim \left(\frac{\rho}{c}\right) \tag{12}$$

- Dipole characteristic

$$P \sim \left(\frac{\rho}{c^3}\right) \tag{13}$$

- Quadrupole characteristic

$$P \sim \left(\frac{\rho}{c^5}\right) \tag{14}$$

Whilst the " ρ/c-radiation" is already described by K_{02} according eq. (11) the other characteristics require meteorological corrections by
Dipole

$$K_{0,3}/dB = -10\lg\left[\left(\frac{\rho}{\rho_N}\right)\left(\frac{c_N}{c}\right)^3\right] = -10\lg\left[\frac{B}{B_N}\right] + 25\ \lg\left[\frac{T}{T_N}\right] \tag{15}$$

Quadrupole

$$K_{0,4}/dB = -10\lg\left[\left(\frac{\rho}{\rho_N}\right)\left(\frac{c_N}{c}\right)^5\right] = -10\lg\left[\frac{B}{B_N}\right] + 35\ \lg\left[\frac{T}{T_N}\right] \tag{16}$$

Investigations [2] dealing with the sound power of aerodynamic sound source, which were carried out in the very large range of static pressures B between 100 kPa and 1 kPa but for constant temperature ($\Theta \approx$20 °C) show a dependence $P \sim \rho^\alpha$ with α between 1.0 and 2.0 which covers the ISO-value of 1.5:

$$K_{0,5}/dB = -15\lg\left[\frac{B}{B_N}\right] + C\,(T) \tag{17}$$

4 - DEVIATIONS BETWEEN ISO AND SOURCE SPECIFIC CORRECTION TERMS

Although several technical sound sources radiate the noise by a mixture of different characteristics we now regard cases where the sound is generated by only one of the mechanisms discussed above in order to calculate the maximum of errors appearing when using the ISO-correction in all cases. From equations (6), (10), (11), (15), (16) and (17) follows directly

$$\Delta K_{0,1} = K_{0,1} - K_{0,ISO} = 5\lg\left[\frac{B}{B_N}\right] dB - 2.5\lg\left[\frac{T}{T_N}\right] dB \tag{18}$$

$$\Delta K_{0,2} = K_{0,2} - K_{0,ISO} = 5\lg\left[\frac{B}{B_N}\right] dB + 7.5\lg\left[\frac{T}{T_N}\right] dB \tag{19}$$

$$\Delta K_{0,3} = K_{0,3} - K_{0,ISO} = 5\lg\left[\frac{B}{B_N}\right] dB + 17.5\lg\left[\frac{T}{T_N}\right] dB \tag{20}$$

$$\Delta K_{0,4} = K_{0,4} - K_{0,ISO} = 5\lg\left[\frac{B}{B_N}\right] dB + 27.5\lg\left[\frac{T}{T_N}\right] dB \tag{21}$$

$$\Delta K_{0,5} = K_{0,5} - K_{0,ISO} = 0 + C\,(T) - 7.5\lg\left[\frac{T}{T_N}\right] dB \tag{22}$$

For calculating these deviations realistic ranges for static pressures B and temperature T/K respectively Θ/°C should be chosen which may be given by

- indoor measurement e.g. in laboratories — $90\text{ kPa} \leq B \leq 101\text{kPa}$, $10^o\text{C} \leq \Theta \leq 25^o\text{C}$ (altitudes between zero and 1000 m) (23)
- outdoot measurement — $80kPa \leq B \leq 101\text{kPa}$, $-20^o\text{C} \leq \Theta \leq 30^o\text{C}$ (altitudes between zero and 2000 m) (24)

Based on eq. (18) to (21) the figures 3 and 4 show the temperature errors appearing when using the "mean" ISO-correction under conditions where one specific noise generation mechanism is actual only. Under laboratory conditions (eq. 23) these errors caused by temperatures different from 23°C are

$$\Delta K^{\Theta}_{0,1}, \Delta K^{\Theta}_{0,2} = +0.05 \ldots - 0.15dB \tag{25}$$

$$\text{Maximum }: \Delta K^{\Theta}_{0,3}, \Delta K^{\Theta}_{0,4} = -0.34 \ldots - 0.54dB \tag{26}$$

Additional errors caused by static pressures B within altitudes between 0 and 1000 m are:

$$\Delta K^{B}_{0,1,2,3,4} = 5\lg\left[\frac{B}{B_N}\right] \text{ dB}, \ \Delta K^{B}_{0,5} = 0 \text{ dB} \ \Delta K^{B}_{0,1,2,3,4} = 0 \ldots - 0.25 \text{ dB} \tag{27}$$

For sound powers measured under meteorological conditions outside the laboratory range given by eq. (23) but being inside the span of eq. (24) significant larger errors may appear. Then the maximum for the amount of $\Delta K^{\Theta}_{0,1}, \Delta K^{\Theta}_{0,2}$ can reach 0.5 dB and for aerodynamic sound sources 1.2 dB excluding quadrupole mechanisms. Furthermore the graphs show that the ΔK^{Θ}_{0}-errors have negative signs mainly. Because the ISO-correction itself is positive in general (see figure 1) means that the ISO-corrected sound power values are predominantly on the safe side especially for the greater deviations.

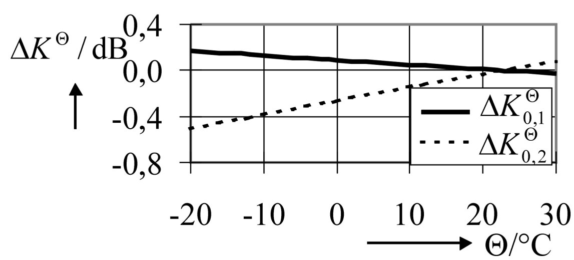

Figure 3: $\Delta K^{\Theta}_{0,1/2}$ in function of temperature.

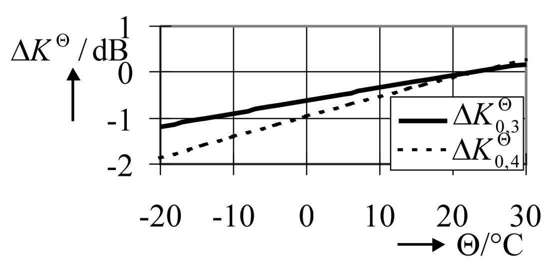

Figure 4: $\Delta K^{\Theta}_{0,3/4}$ in function of temperature.

REFERENCES

1. **G. Hübner**, Sound power related to normalized meteorological conditions, In *Inter Noise 99*, pp. 1529-1534, 1999

2. **G. Hübner, V. Wittstock**, Investigation of the sound power generation of solid cylinders moving in gases under different static pressures, In *Euro Noise 98*, pp. 865-871, 1998

3. **G.S.K. Wong**, Characteristic impedance of humid air, *JASA*, Vol. 80(4), pp. 1203-1204, 1986