Applied Acoustics 111 (2016) 116–120

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical note

Estimation of the long term average sound level from hourly average sound levels

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ARTICLE INFO

Article history:
Received 23 June 2015
Received in revised form 13 April 2016
Accepted 19 April 2016
Available online 23 April 2016

Keyword:
Traffic noise

ABSTRACT

It is shown how to estimate the long-term average sound level, L_{AeqLT} (for free flowing road traffic) from measurements of the hourly A-weighted equivalent sound level, L_{Aeq1h}. To estimate the parameters of the model which describe noise emission and attenuation, concurrent measurements of L_{Aeq1h} at two distances from the considered road are needed. A semi-empirical formula is derived for L_{AeqLT} approximation. Also the uncertainty of this approximation is given as a function the distance from the road and receiver height.

1. Introduction

The exact value of the A-weighted long-term average sound level, such as L_{day}, $L_{evening}$, and L_{night} [1], can be calculated from

$$L_{AeqLT} = 10\lg\left\{\frac{1}{N_{LT}}\sum_{k=1}^{N_{LT}}10^{0.1(L_{Aeq1h})_k}\right\}, \tag{1}$$

where $(L_{Aeq1h})_k$ is the k-th hourly A-weighted equivalent sound level. L_{Aeq1h} is determined over all the day time periods (7:00–19:00) of a year with $N_{LT} = 365 \cdot 12$, evening periods (19:00–23:00) with $N_{LT} = 365 \cdot 4$, and night periods (23:00–7:00) with $N_{LT} = 365 \cdot 8$. For these three periods, the "long" time interval $LT = N_{LT} \cdot 3600$ s. In practice, however, the number of L_{Aeq1h} measurements is lower, $N < N_{LT}$, and the A-weighted long-term average sound level can be approximated by,

$$L_{AeqT} = 10\lg\left\{\frac{1}{N}\sum_{k=1}^{N}10^{0.1(L_{Aeq1h})_k}\right\}, \tag{2}$$

where the corresponding time interval, $T = N \cdot 3600$ s. Note that $T < LT$. We assume that the sample of $(L_{Aeq1h})_k$, with $k = 1, 2, \ldots N < N_{LT}$, is representative of the entire year and the error of approximation, $L_{AeqLT} \approx L_{AeqT}$, is,

$$\Delta L = L_{AeqT} - L_{AeqLT}. \tag{3}$$

For the i-th sample of L_{Aeq1h}, Eq. (2) yields the i-th approximation of the A-weighted long-term average sound level,

$$(L_{AeqT})_i = 10\lg\left\{\frac{1}{N}\sum_{k=1}^{N}10^{0.1(L_{Aeq1h})_{ik}}\right\}. \tag{4}$$

With a large number of measurements, q (all the day-, evening-, and night periods), the variance

$$\sigma^2 = \lim_{q\to\infty}\left\{\frac{1}{q}\sum_{i=1}^{q}\left[(L_{AeqT})_i - L_{AeqLT}\right]^2\right\}, \tag{5}$$

characterizes the approximation error and Eq. (3) can be rewritten in the form:

$$L_{AeqLT} \approx L_{AeqT} \pm \sigma. \tag{6}$$

The method of L_{AeqT} and σ predicting is based on $(L_{Aeq1h})_k$ measurements and concurrent counts of the hourly traffic flows n_k.

2. Error of the L_{AeqLT} approximation

For illustrative purposes we consider only one category of vehicle. Each vehicle is characterized by the relative A-weighted sound exposure,

$$e_j = \frac{1}{p_o^2 t_o}\int_{-\infty}^{+\infty} p_{Aj}^2(t)dt, \tag{7}$$

where $p_o = 20$ μPa, $t_o = 1$ s, and $p_{Aj}^2(t)$ (Fig. 1) is the time pattern of the A-weighted squared sound pressure. Making use of the results from Refs. [2,3] one gets

$$(L_{Aeq1h})_k = 10\lg\left\{\frac{t_o}{T_o}n_k e_k\right\}, \tag{8}$$

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http://dx.doi.org/10.1016/j.apacoust.2016.04.016

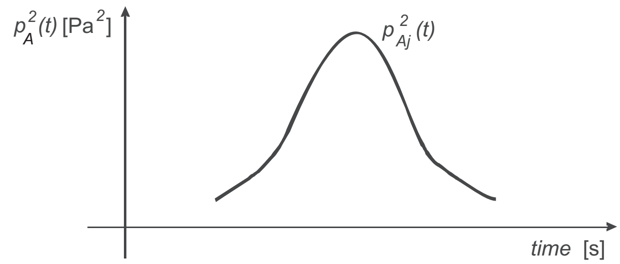

Fig. 1. The time pattern of the noise emitted by a single vehicle.

where $T_o = 3600$ s. The mean sound immission due to a single pass-by, during the k-th hour is

$$e_k = \frac{1}{n_k}\sum_{j=1}^{n_k} e_{kj}. \tag{9}$$

The hourly traffic flows n_k, with $k = 1, 2, \ldots N$, are characterized by the mean- and variance estimations,

$$\langle n\rangle \approx \frac{1}{N}\sum_{k=1}^{N} n_k, \quad \sigma_n^2 \approx \frac{1}{N-1}\sum_{k=1}^{N}[n_k - \langle n\rangle]^2, \tag{10}$$

where N denotes the number of hourly measurements. We assume that the sample; $n_1, n_2, \ldots, n_N$; portrays the traffic flow of the whole year. From Eqs. (4) and (8) it follows that

$$(L_{AeqT})_i = 10\lg\left\{\frac{t_o}{T_o}\Phi_i\right\}, \tag{11}$$

where the i-th sample sound exposure is,

$$\Phi_i = \frac{1}{N}\sum_{k=1}^{N} n_{ik}e_{ik}. \tag{12}$$

The mean relative A-weighted sound exposure, $\langle e\rangle$, similar to mean traffic flow $\langle n\rangle$ (Eq. (10)), one arrives at the mean sound exposure [4,5],

$$\langle\Phi\rangle = \lim_{q\to\infty}\left\{\frac{1}{q}\sum_{i=1}^{q}\Phi_i\right\} \approx \langle n\rangle\langle e\rangle. \tag{13}$$

Here q denotes a large number of measurements (all the day-, evening-, and night periods). Consequently, the A-weighted long-term average sound level can be defined by (Eqs. (1), (8), (13)),

$$L_{AeqLT} = 10\lg\left\{\frac{t_o}{T_o}\langle\Phi\rangle\right\}. \tag{14}$$

If the sample sound exposure variations are small (Eqs. (12) and (13)),

$$\left|\frac{\Phi_i - \langle\Phi\rangle}{\langle\Phi\rangle}\right| < 1, \tag{15}$$

then Eqs. (5), (11), (14) yield the variance of the A-weighted long-term average sound level [4,5],

$$\sigma^2 = \left(\frac{10}{\ln 10}\right)^2 \lim_{q\to\infty}\left\{\frac{1}{q}\sum_{i=1}^{q}\frac{[\Phi_i - \langle\Phi\rangle]^2}{\langle\Phi\rangle^2}\right\}. \tag{16}$$

It can be shown that,

$$\langle\Phi^2\rangle = \lim_{q\to\infty}\left\{\frac{1}{q}\sum_{i=1}^{q}\Phi_i^2\right\} \approx \langle n\rangle^2\langle e\rangle^2 + \frac{1}{N}\left[\langle n\rangle^2\sigma_e^2 + \langle e\rangle^2\sigma_n^2\right]. \tag{17}$$

Finally, Eqs. (13), (16), (17) give the standard deviation of the A-weighted long-term average sound level,

$$\sigma \approx \frac{10}{\ln(10)}\frac{1}{\sqrt{N}}\sqrt{\frac{\sigma_n^2}{\langle n\rangle^2} + \frac{\sigma_e^2}{\langle e\rangle^2}}, \tag{18}$$

where $\langle n\rangle$ and σ_n^2 are defined by Eq. (10). The mean and variance of the relative sound exposure, $\langle e\rangle$ and σ_e^2, will be discussed in the next section.

3. Sound emission and propagation

In the Harmonoise model [6] a road vehicle is considered as being composed of three incoherent sub-sources at different heights, $h_1 < h_2 < h_3$, with the total A-weighted sound power, $W_A = W_{A1} + W_{A2} + W_{A3}$. If the maximal height h_3 and the receiver height z are both significantly lower than the length of the propagation path (Fig. 2),

$$h_3 + z << r, \tag{19}$$

then 3 real and 3 imaginary sources can be replaced with the virtual source at the ground, $h = 0$, with the modified A-weighted sound power, βW_A. The road coefficient β depends on the surface type (e.g. dense-graded asphalt concrete, portland cement concrete, open-graded asphalt concrete) and surface condition (dry, wet, icy or snow-covered). Thus, the A-weighted squared sound pressure for a non-directional point source can be written as,

$$p_A^2 = \beta W_A \rho c \cdot \frac{F_A(r)}{4\pi r^2}. \tag{20}$$

Here ρc is the impedance of the air and F_A characterizes the wave phenomena in excess of geometrical divergence, i.e. the ground effect, air absorption, scattering by vegetation and atmospheric turbulence, and finally, refraction of sound rays due to the temperature- and wind speed gradient.

Suppose that the vehicle moves at a steady speed V at the perpendicular distance D from the receiver (Fig. 3). Introducing the polar coordinate system with $r = D/\cos\phi$ and $x = D \cdot tg\phi$, one gets the relative A-weighted sound exposure (Eq. (7)),

$$e = \frac{D}{p_o^2 V t_o}\int_{-\pi/2}^{+\pi/2}\frac{p_A^2(\phi)d\phi}{\cos^2\phi} \tag{21}$$

which can be transformed into (Eqs. (20) and (21)),

$$e = S \cdot \frac{D_o}{D}K, \quad D_o = 1\text{ m}. \tag{22}$$

The *emission parameter* S is proportional to the A-weighted sound power, βW_A (Eqs. (20)–(22)), and depends on the vehicle speed, the road surface type, and the surface conditions. The ratio D_o/D stems from geometrical divergence (a line with a moving point source equates to a line source), and the function of the horizontal distance, D,

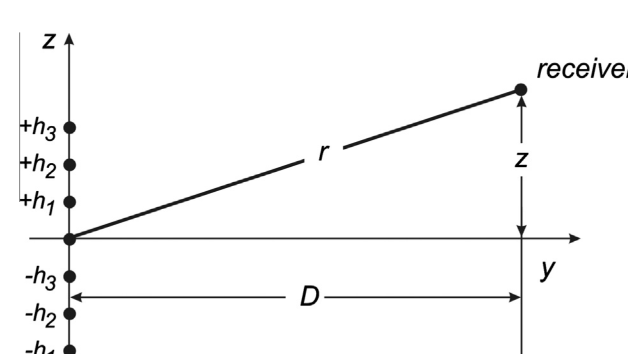

Fig. 2. Three sub-sources at different heights can be replaced with a virtual source at the ground level ($z = 0$).