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PROPAGATION OF NOISE GENERATED BY A TRAM MOVING WITH UNIFORM MOTION

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The registration of level changes of sound generated by a single source (e.g. a rail-vehicle – tram) allows the determination of the resultant level of noise emitted by sets of mobile sources (e.g. rail-vehicle lines). Research was aimed at the determination of the relationship between parameters a and L_{AX}, which characterize the noise of a single source, and the distance from the observation point, d. Investigations were conducted in a not built-over, flat and covered by grass area, for various types of trams and several speeds.

1. Introduction

A tram is one of the main sources of traffic noise. The noise it generates determines the acoustic climate of the human environment. Among others, the acoustic climate depends on the acoustic field generated by single sources, e.g. a rail-vehicle. If certain parameters of such a field are known, then the values of the evaluation indicators of noise emitted by sets of these sources (e.g. rail-vehicle lines) can be predicted. The equivalent sound level for averaging time T, L_{eqT}, was accepted as the best noise evaluation criterion for the external environment. It is used in international regulations concerning the acoustic climate. The high suitability of the equivalent level, L_{eqT}, in acoustic comfort classification is due to a high degree of correlation between its value and the subjective evaluation of noise oppressiveness (correlation coefficient 0.96–0.98 [4]).

In order to predict the numerical value of the equivalent level, L_{eqT}, the value of parameter a_i and the traffic volume N_i/T has to be known; where N_i is the number of vehicles of the i-type, which pass the observation point in time T (e.g. at night measurements were conducted from 10 P.M. to 6 A. M. – 8 hours). Parameter a_i is the measure of noise reaching the observation point from a single vehicle of the i-type, e.g. tram 102 N. (In road traffic two types of vehicles are distinguished light: motorcars and delivery vans, $i = 1$, and heavy: trucks and buses, $i = 2$.)

The relation between a_i and the noise exposure level, L_{AXi}, is as follows [1]:

$$L_{AXi} = 10 \log(a_i/t_0) \tag{1}$$

where $t_0 = 1$ s.

Let us accept that there is a track-way at a distance d from the observation point O and that during the time T it is passed by N_1 trams of the 1-st type, N_2 trams of the 2-nd type, etc. Then, the equivalent level for time T is:

$$L_{eqT} = 10 \log\left\{\sum_i (N_i/T)\, a_i + 10^{0.1\bar{L}_{eq}}\right\} \tag{2}$$

where $\bar{L}_{eq}$ is the equivalent sound level at the observation point when the tram traffic is held up; it is the so called acoustic background.

Values of parameter a_i can be determined from expression

$$a_i = \int_{-\infty}^{+\infty} 10^{0.1L_i(t)} dt \tag{3}$$

when the changes of frequency weighted sound level, according to the correlation curve A, $L_i(t)$, are known [2].

2. The method of determining parameter a

The value of a can be determined from the direct measurement of L_{AX} (Eq. (1)). If we do not have an adequate measuring device, then in order to determine the value of parameter a_i and the equivalent level, L_{eqT}, according to equation (2), the actual values of the sound level for the noise generated by a single source $L_i(t)$ (equation (3)) has to be known. $L_i(t)$ can not be measured at daytime, because of strong signals from other sources, which reach the observation point. These signals are weaker at night. Nevertheless the acoustic background $L^{(0)}(t)$ occurs in every case. Therefore, changes of the sound level registered for a single source are described by the following function:

$$L^{(i)}(t) = 10 \log\{10^{0.1L_i(t)} + 10^{0.1L^{(0)}(t)}\}. \tag{4}$$

If we accept that the acoustic background $L^{(0)}(t)$ is constant in time, $L^{(0)}(t) \cong L^{(0)}$, then for a measurement done during η seconds, we have (equations (3) and (4)):

$$\alpha_i = \Delta t \sum_{k=0}^{N} 10^{0.1L^{(i)}(t_k)} - \eta\ 10^{0.1L^{(0)}} \tag{5}$$

where $L^{(i)}(t_k)$ are actual values of the sound level at the observation point O, while $t_0 = 0$, $t_N = \eta$ (Fig. 1). 1 second is the unit of parameter α.

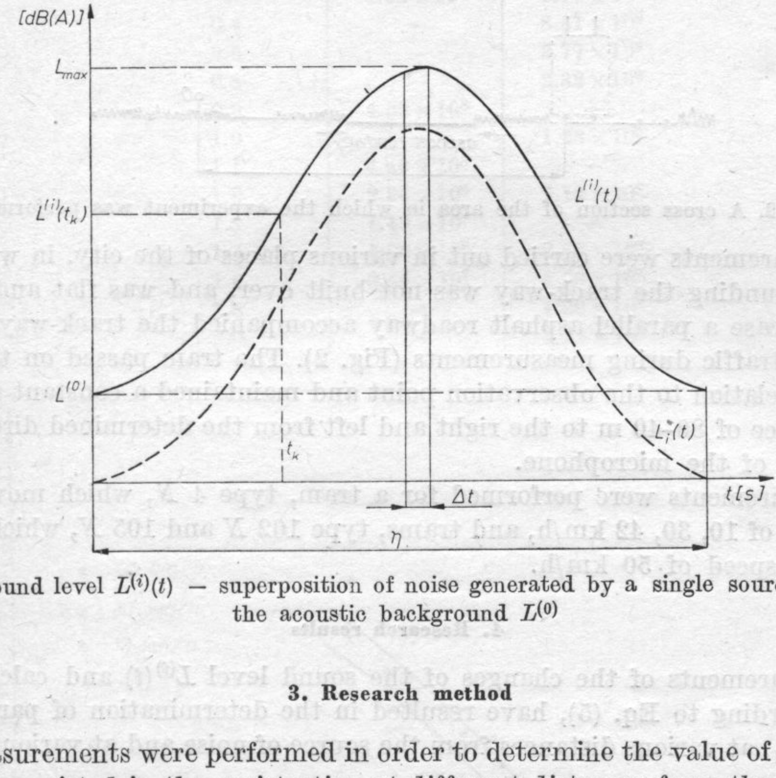

Fig. 1. Sound level $L^{(i)}(t)$ – superposition of noise generated by a single source $L_i(t)$ and the acoustic background $L^{(0)}$

3. Research method

Measurements were performed in order to determine the value of parameter α. They consisted in the registration at different distances from the track-way of changes of the sound level of trams passing with various speeds.

Measurements were carried out at night (12 P.M. – 3 A.M.), when the acoustic background was at the level of 30–45 dB(A). The value of the acoustic background was registered and included in calculations of parameter α. The weather was rainless and windless. The air temperature fluctuated from 10 to 15°C.

The apparatus produced by Bruel-Kjaer was used in the course of investigations. It consisted of: a 1′ microphone (type 4145), sound level meter (type 2209) and sound level recorder (type 2306). The apparatus was calibrated with a pistonphone (type 4220) before every measurement.

The microphone was placed 1.2 m above the ground level at various distances from the track-way, beginging at 1 m. The distance was measured from the outer rail head.

The following three types of trams have been investigated [3]:
- type 4 N – consists of 2 wagons, maximal speed – 42 km/h,
- type 102 N – jointed, developing higher speeds; has wheel shields (especially for middle wheels), resulting from the construction of the body,
- type 105 Na – has the greatest maximal speed, reaching 70 km/h (only one wagon was used in the course of measurements).

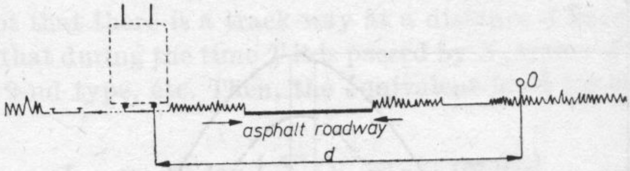

Fig. 2. A cross section of the area in which the experiment was performed

Measurements were carried out in various places of the city, in which the area surrounding the track-way was not built over, and was flat and grassy. In every case a parallel asphalt roadway accompanied the track-way. It was closed to traffic during measurements (Fig. 2). The tram passed on the track closer in relation to the observation point and maintained a constant speed on the distance of 80–40 m to the right and left from the determined direction of location of the microphone.

Measurements were performed for a tram, type 4 N, which moved with the speed of 10, 30, 42 km/h, and trams, type 102 N and 105 N, which moved with the speed of 50 km/h.

4. Research results

Measurements of the changes of the sound level $L^{(i)}(t)$ and calculations, done according to Eq. (5), have resulted in the determination of parameters, α and L_{AX}, at various distances from the source of noise and at various speeds.

Table 1. Mean values of parameter α [s] at various distances of the observation point from the tram (type 4 N moving with constant speed V)

d[m]	V[m/s]		
	2.(7)	8.(3)	11.(6)
1.0	1.68×10^8	2.34×10^9	5.56×10^9
8.0	1.25×10^7	4.38×10^8	9.04×10^8
10.0	–	2.44×10^8	2.87×10^8
12.6	3.91×10^6	–	–
15.8	1.66×10^7	7.77×10^7	1.33×10^8
20.0	1.36×10^6	3.64×10^7	8.92×10^7
25.0	5.22×10^6	3.29×10^7	6.94×10^7
40.0	2.66×10^6	1.24×10^7	1.30×10^7
63.0	8.33×10^5	5.70×10^6	7.65×10^6

Table 2. Mean values of parameter a [s] at various distances of the observation point from the trams (type 102 N and 105 Na) moving with a constant speed of 50 km/h (13.(8) m/s)

log$d$	Type of tram	
	102 N	105 Na
0	1.03×10^{9}	1.14×10^{10}
0.4	—	8.51×10^{9}
0.6	—	3.77×10^{9}
0.8	—	2.32×10^{9}
0.9	4.59×10^{8}	—
1.0	—	1.28×10^{9}
1.1	4.46×10^{8}	—
1.2	2.94×10^{8}	7.12×10^{8}
1.3	1.49×10^{8}	—
1.4	1.36×10^{8}	2.56×10^{8}
1.6	3.44×10^{7}	4.56×10^{7}
1.8	—	1.28×10^{7}
2.0	—	3.22×10^{6}

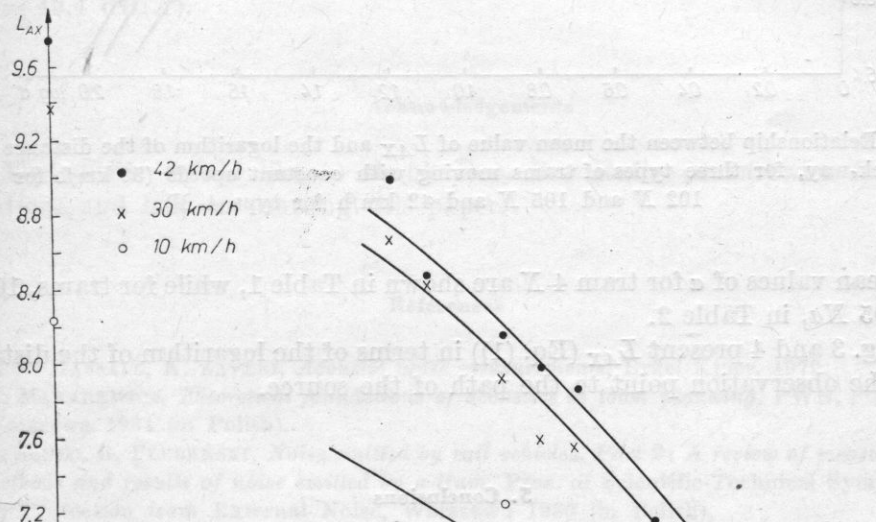

Fig. 3. Relationship between the mean value of L_{AX} and the logarithm of the distance from the track-way, for tram 4 N moving with uniform motion with the speed of 10, 30, 42 km/h

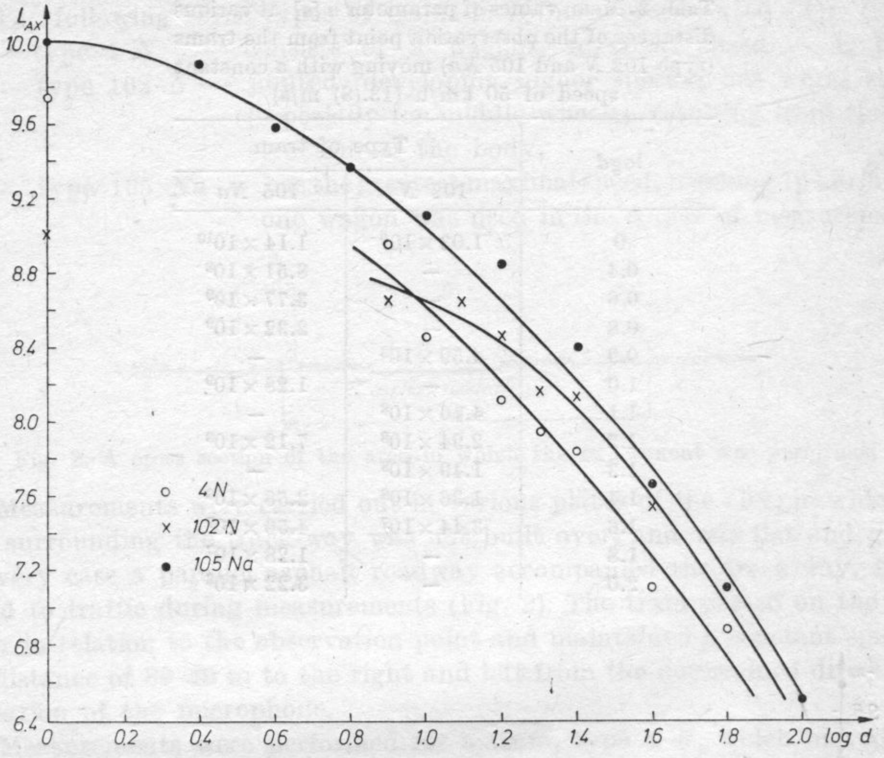

Fig. 4. Relationship between the mean value of L_{AX} and the logarithm of the distance from the track-way, for three types of trams moving with constant speeds (50 km/h for types 102 *N* and 105 *N* and 42 km/h for type 4 *N*).

Mean values of a for tram 4 *N* are shown in Table 1, while for trams, 102 *N* and 105 *Na*, in Table 2.

Fig. 3 and 4 present L_{AX} (Eq. (1)) in terms of the logarithm of the distance from the observation point to the path of the source.

5. Conclusions

This paper presents a method of determining parameters, a and L_{AX}, which characterize the noise generated by a single source. These parameters have been calculated for rail vehicles moving with uniform motion, with regard to the speed and type of the vehicle and distance of the observation point from the path of the source.

Parameter L_{AX} achieved the highest values for tram 105 *Na*; the lowest for tram 4 *N* (Fig. 4). Moreover (Fig. 3), values of L_{AX} increase with the increase of speed (type 4 *N*).

Hence, it results that trams 105 *Na* are the loudest. Trams 102 *N* are slightly less loud and trams 4 *N* are the least disturbing to the environment. Similar results have been obtained in paper [3].

The relationship between parameter L_{AX} and the logarithm of the distance (Fig. 4) for tram 102 *N* differs from such relationships for other types of trams. This is due to the construction of the body of the tram-shields placed especially on the middle wheels, cause that part of the energy does not reach the observation point, i.e. the microphone placed at a distance of about 10 m and 1.2 m above ground level.

Derived values of parameter a can be applied in calculations of the equivalent level L_{eqT} in town planning, but only at distances not exceeding 90 m. For example, at a distance of $d = 25$ m ($\log 25 = 1.4$) we have from Table 2 for tram 105 *Na* that $a = 2.49\ 10^8$. If during $T = 8$ hours $= 28800$ s (at night) $N = 10$ trams pass, then from Eq. (2) we have:

$$L_{eqT} = 10\ \log\left\{\frac{N}{28800}\, a + 10^{0.1\bar{L}_{eq}}\right\}.$$

If we accept the background sound level at $\bar{L}_{eq} = 30$ dB(A), then the equivalent sound level during 8 hours of the night, from 10 P.M. to 6 A.M., will be $L_{eqT} = 49.4$ dB(A).

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