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EVALUATION OF NOISE EMISSIONS OF CARS BASED ON LOUDNESS

U Widmann

Müller-BBM, Acoustic Consultants, Planegg near Munich, Germany

1. INTRODUCTION

This paper will investigate to what extent for traffic noise emissions of cars a psychoacoustic annoyance concept according to Zwicker [1] is influenced by loudness. The correspondence of different physical measuring units of noise with the subjective assessment will be described. It will be shown how the appropriate physical measures depend on the driving speed. An example of the application of the results for the evaluation of noise immissions is given.

2. MEASUREMENTS

In the actual street traffic, the majority of the vehicles are cars. In order to investigate the relationship between noise evaluation and objective measuring units, the noise measurements were carried out with passing cars at constant speed. The sounds were recorded unweighted with a portable tape recorder at two measurement situations (see Fig. 2).

In a listening test, the psychoacoustic annoyance caused by traffic noise emissions was determined by means of a magnitude estimation without anchor sound. For each pass-by sound the maximum loudness value was in the temporal middle of the presentation.

8 test persons aged between 25 and 35 took part in the experiment. The sounds were offered diotically via electrodynamical headphones with free-field equalizer [4]. As test material, 22 car sounds were used. Also untypical driving situations were taken into account intentionally in order to gain a variety of different components of psychoacoustic annoyance of cars. Each sound had a duration of 15 s and the sequence was separated

by breaks of 5 s in which the test persons had to evaluate the presented sound.

As physical descriptors of the sounds the temporally variable loudness (N) and the A-weighted sound pressure level (L) were evaluated with an analyzing system. From the measured sound levels (L), the quantity $10^{L/10}$ was calculated in order to gain a linear measure which is proportional to the radiated sound power.

3. RESULTS

The medians and interquartile ranges of the subjective assessment of the relative psychoacoustical annoyance (filled circles) and of the relative loudness (open circles) of the test sound are shown in Fig. 1. They were standardized to the results of sound 9, a constant passing at a speed of 110 km/h. The relative percentile values N_5 (triangle) or $10^{LAF5/10}$ (crosses) were also depicted.

The results show that the subjective assessment of loudness and psychoacoustic annoyance largely corresponds. The correlation factor amounts to 0.98.

Table 1 compares the average square variations of the subjective assessment with the quantities determined by measurements. The results show that the percentile loudness N_5 (triangles in Fig. 1) have the smallest variations from the subjective assessment of loudness.

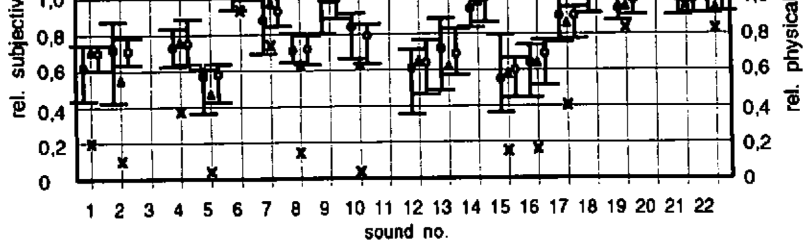

Fig. 1. Relative psychoacoustic annoyance (filled circles) and relative loudness (open circles) of car pass-by sounds. Medians and interquartile ranges for 8 subjects. Triangles: rel. percentile loudness N_5; crosses: rel. $10^{LAF5/10}$.

physical quantity	average square variation from subjective loudness evaluation in %	average square variation from subjective psycho-acoustic annoyance evaluation in %
N_{max}	1.4	2.0
N_5	0.4	0.7
N_{10}	1.8	1.3
L_{AFmax}	25.8	25.5
L_{AF5}	17.0	16.1
L_{AF10}	35.4	31.1

Tab. 1. Variations of physical quantities compared with subjective assessment.

A comparison of the subjective results and those calculated from the A-weighted levels show a quantitatively misinterpretation (crosses in Fig. 1). The average square variations are considerably higher. The results show that by measuring the percentile loudness N_5 the subjective assessment of loudness and psychoacoustic annoyance of traffic noise emissions can be well simulated.

As the noise emission of a passing cars depends mainly on the car's speed, in the following it is shown how the measured loudness N_5 changes with speed. In an intermediate step the maximum loudness N_{max} is closer examined.

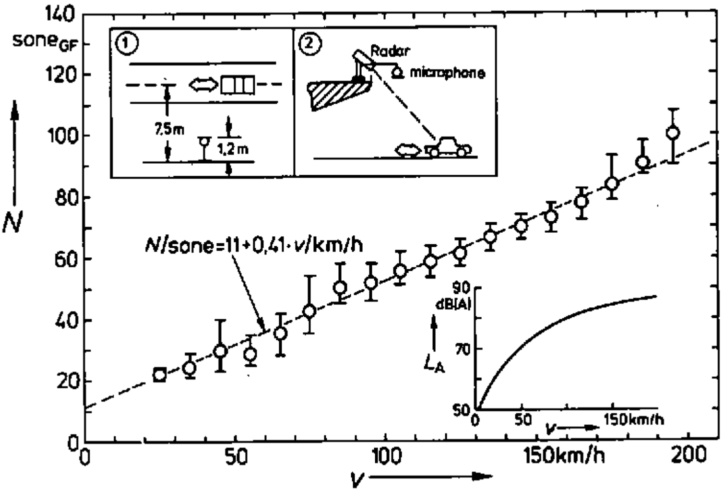

Fig. 2. Loudness N_{max} of cars versus the driving speed. Medians and interquartile ranges. Sketch: measurement assembly: 1) passing cars at a distance of 7.5 m, 2) measurements on a motorway bridge. Sketch: A-weighted sound pressure level as a function of speed.

Fig. 2 depicts the maximum values N_{max} of the measured loudness over the driving speed. In order to provide a better overall view, the data within the big speed range are united into classes of 10 km/h. The data come from an investigation of 1746 passing cars.

The medians of the maximum loudness N_{max} increase in the whole range. The approximation whose foot is orientated at the average idling noise measured at a distance of 7.5 m fits the data very well.

The A-weighted sound pressure levels L_{AFmax} which are entered in the partial figure below show a logarithmic behaviour which is in accordance with the data known from the respective literature [2]. In order to gain the percentile loudness N_5 of passing cars as function of the driving speed, the recordings of the individual passings were evaluated statistically. The analysis was based on a measurement time of 15 s and it was guaranteed that the maximum value of the loudness was located in the temporal middle of the analysis period. As there are only data of our own passing cars in the lower speed range of approx. 110 km/h and the statistical analysis was therefore restricted, the description of N_5 for the whole speed range is calculated from the different gradients in Fig. 3 and the approximate equation from Fig. 2.

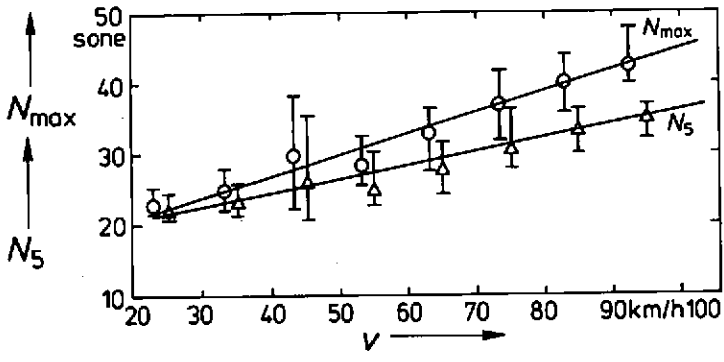

Fig. 3. Comparison of N_{max} (circles) and N_5 (triangles) as function of the driving speed. Medians and interquartile ranges for five test cars.

For the dependence of the percentile loudness N_5 from the driving speed (v) the following formula results:

$$N_5 \,/\, \text{sone} \approx 11 + 0.29 \cdot v \,/\, \text{km/h} \qquad (1)$$

For the moving traffic by this simple function the noise reduction gained by a speed limit can be assessed. If the driving speed is reduced from e. g.

150 km/h to 100 km/h, for the percentile loudness N_5 a reduction of approx. 27 % is achieved.

4. APPLICATION OF THE RESULTS FOR NOISE IMMISSIONS

Sounds of passing cars were recorded unweighted according to situation 1 (see Fig. 2) with the help of a portable DAT-recorder at constant speeds of 30 km/h, 50 km/h, 80 km/h, and 100 km/h and were reduced in the laboratory by fading in and out parts of 40 s duration.

The sounds were offered diotically via electrodynamical headphones with free-field equalizer to 9 subjects aged between 24 and 47 with normal hearing capabilities sitting in a sound absorbing booth [4].

For the immission assessment tapes with duration of 15 min were produced with different speeds and sound levels ($L_{eq,\,30\,km/h}$ = 45,2 dB(A), $L_{eq,\,50\,km/h}$ = 49,6 dB(A), $L_{eq,\,80\,km/h}$ = 55,1 dB(A), $L_{eq,\,100\,km/h}$ = 58,3 dB(A)). In order to simulate realistic traffic situations, the noise of 15 individual passings were masked with a low background noise.

The assessment of noise immissions was carried out after the 15-minute sound presentation. The test persons took down the perceived total loudness on the length of a line [3] and on the other hand by means of the method of the absolute magnitude estimation.

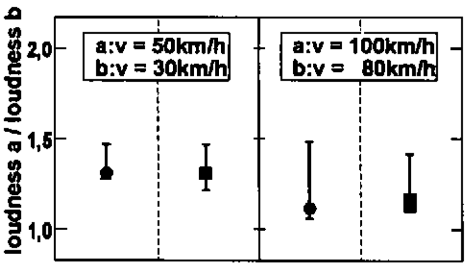

Fig. 4. Medians and interquartile ranges of the proportions of the subjective loudness evaluation of noise immissions. Left: comparison v = 50 km/h versus v = 30 km/h. Right: comparison v = 100 km/h versus v = 80 km/h. Circles: magnitude estimation, squares: line length.

The medians and interquartile ranges are calculated from the averaged ratio of the absolute magnitude estimation or line length of each subject.

Magnitude estimation and line length provided corresponding results.

The results show that the test persons experienced passing cars at a speed of 50 km/h by the factor 1.3 louder than cars at a speed of 30 km/h. According to Equation 1, the loudness proportion for N_5 is calculated with 1.29. At higher speeds the difference is not as conspicuous. The average test person experiences in the immission test with a passing speed of 100 km/h with a loudness factor of 1.14 (absolute magnitude estimation) or

1.15 (line length) louder as the immission test with 80 km/h. According to Equation 1, the loudness proportions for N_5 is calculated with 1.17.

These results show that by measuring the percentile loudness N_5 the subjective evaluation of traffic noise can be well described for short lasting as well as for long lasting sound influences.

Compared with another objective quantity, namely the A-weighed equivalent continuous level, one has to realize that this level overestimates the subjective immission assessment. The L_{eq}-values imply an improvement-factor of 2.8 for city traffic and of 2.1 for country roads.

6. SUMMARY

The loudness of the noise of passing cars provides the most essential contribution to psychoacoustic annoyance. The subjective assessment is governed by the loudest events and can therefore be simulated by the evaluation of the percentile loudness N_5. For free-flowing traffic, the given approximations allow a simple assessment of the possible noise reduction by speed reduction.

For car noises, the application of the results by a reduction of speed from 50 km/h to 30 km/h or from 100 km/h to 80 km/h was investigated with respect to noise immission. In city traffic, the thus gained noise reduction amounts to approx. 30 %, on country roads to approx. 15 %. For the subjective assessment, the measurement method of the absolute magnitude estimation as well as the line length method are well suitable. The alteration of the noise immission can be relatively well assessed by taking into account the emission data in terms of a percentile loudness N_5.

The equivalent A-weighted continuous level L_{eq}, which is used up to now, overestimates with a mid-parameter of $q = 3$ the perceived loudness differences considerably.

References

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