An investigation of infrasonic in traffic flow noise

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Abstract

The society is aware of traffic noise and participates with local municipalities and cities in solving the noise problems. Positive economic indicators can be achieved when health is good. One of the important factors is restful sleep, which can be interrupted by traffic noise. The increased use of wind energy by windmills and various modes of transportation could increase the low frequency sound that could have a negative effect on the population. When humans are exposed to low frequency sound, only the high sound can be heard. The low intensity infrasonic sound could affect human health and induce various psychological disorders. The infrasonic sound could travel long distances and penetrate the openings in a welling occupied by humans and interrupt rest and sleep.

The infrasonic measurements were performed using the Brüel & Kjaer instrumentation. Components of infrasonic energy frequencies were obtained by calculating the difference between the averaged sound pressure level and the A-weighted sound pressure level. Aerodynamic turbulent noise propagations over ground are affected by diffraction from jaggedness and stress viscosity from secondary sound sources. The noise barriers are effective in the diffraction process by reducing noise to the living environment. Measurements were performed using acoustic barriers for traffic noise reduction in the suburbs. At 15 m from the highway, a 2 m high barrier was constructed and the measurements were taken at 15 m and 45 m from the barrier. More intensive sound diffraction was observed at the measurement distance of 45 m. These observations indicate the importance of infrasonic diffraction and of the design of acoustic barriers for the reduction of low frequency noise.

Keywords: traffic noise, infrasonic, noise barriers, diffraction.
1 Introduction

More people are exposed to noise from traffic than from any other noise sources. The degree of noise perception by humans is influenced by various psychological factors and of the surrounding physical environment [1, 2]. There are numerous health risks due to elevated and prolonged exposure to noise such as irritation, hearing degradation, ability to perceive and process information, sleep deprivation, etc. Lack of sleep has a negative effect on performance, attentiveness and alertness.

The transport systems in Lithuania are dominated by relatively old vehicles that are prone to generate high levels of traffic noise. Due to a lack of economic means, the process of upgrading transportation vehicles to more modern and less noisy models in Lithuania is much slower than in other European Union countries. From the studies presented in [3], it is estimated that traffic noise will need to be reduced further by at least 3-4 dBA by the year 2010 [4, 5].

![Figure 1: The number of transport through 20 years.](image)

According to various psycho acoustic studies, the audible noise levels not exceeding 35 dBA have no influence on sleep quality. Also, when noise levels in bedrooms do not exceed 45 dBA, considered to be the limiting level, the effect on sleep rest is negligible and the long term effects from various negative factors such as exposure to noise during the day hours on night sleep are not significant. The frequency composition of environmental noise plays an important role in assessing the effects of noise on humans [2, 6]. The low and very low frequencies contributions need to be included in assessing the qualitative effects of noise [2, 3, 6, 7].

The infrasonic is defined as sound composed of waves in the frequency range of 0.1-20 Hz. These frequencies are below the typically considered low frequency sound. That is often defined in the range of 20-200 Hz. Infrasonic pressure levels generated by natural sources such as wind, air turbulence, thunder, waterfalls and ocean waves are often very low, and their dominating frequencies are in the low frequency range.
The human ear is not equally sensitive to all frequencies in the defined audible range of 20-16000Hz. The ear seems to be most sensitive to sounds generated in the frequency range of 2000-5000 Hz and less sensitive to frequencies outside this range [8, 9].

The basic effect of infrasonic on humans occurs at sound levels that are below the threshold of human perception. However, the threshold of hearing a specific sound level rises rapidly as the frequency decreases, i.e. from 85dB at 32 Hz to 95 dB at 20 Hz. When a family of equal loudness contours added to the contours at the lower frequency, curves are obtained for the 20 Hz frequency. For example, a tone at 20 Hz needs to be higher by 35 dB than a tone at 1000 Hz for a pressure level of 60dB in order to give the same subjective loudness.

The hearing threshold that is often exceeded can be found in various industrial complexes, transportation systems, ships, rail transport, etc. Infrasonic in these cases causes special problems due to the capacity to propagate long distances. The various noise control devices installed for noise reduction are not very effective at these frequencies [3, 6, 9]. The hearing threshold is seldom exceeded by infrasonic in home or office environment.

Most ecological problems related to noise effects have been directed to cities, metropolitan regions and large towns. However, environmental noise from highway traffic, limited up to 55 dBA levels [5], can propagate significant distances affecting farms, resorts and small towns. In addition, the noise propagation into the interior increases by 10-15 dBA due to open vents, windows, doors, etc. For example, an opening in the door of 1-3 cm wide reduces the effectiveness of sound reduction by 6-10 dBA, [9,10].

The management and solution of the environmental noise related problems in our country due to transportation issues is mandated by all the European Union countries agreement Directive 2002/49/EC that needs to be satisfied as prescribed by the European Parliament. To satisfy these requirements and present reasonable solutions, additional information and studies on the various aspects of environmental noise, including the generation, propagation and effects of the low frequency sound is needed. This paper presents a study of the estimation and the variability of quantitative and qualitative factors from traffic induced infrasonic on the living environment.

2 Methods

The acoustic noise emission from highway traffic is estimated according to ISO 1996 standard [11]: specified by $L_{A, eg T}$ (equivalent continuous A-weighted sound pressure level over duration T) and $L_{AN}$ (percentile level), which are estimated from the time duration percentile of the required duration of measurement and taken as the radiated noise parameters $L_5$ or $L_{10}$, $L_{50}$, $L_{90}$ or $L_{99}$, $L_N$ that $L_{A, eg}$ are the levels that exceed accordingly 5%, 10%, 50%, 90% or N% from time duration of measurement analysis. To define noise pollution, the fluxion values of TNI (Traffic Noise Index) and $L_{NP}$ (Noise Pollution Level) were used [3, 12]. The estimation of the qualitative environmental noise is obtained with the comparable analysis to the parameters $L_{AN}$, $L_{NP}$, TNI.
An important aspect of infrasonic is the possibility of damage to hearing. The effects of audiometric frequencies above 125 Hz have been observed due to the exposure to infrasonic at 140 dB [5]. The infrasonic threshold for aural pain is approximately 140 dB at 20 Hz and 160 dB at 3 Hz. Choking, coughing and gagging sensations may develop at sound levels in the range of 130-150 dB.

A fundamental and important property of infrasonic is the ability to propagate over long distances due to the fact that energy attenuation at low frequencies with distance is relatively small. To reduce infrasonic levels, the screens need to be very large in order to have a shadowing effect. Since the sensibility of hearing depends on frequency, the audible sound is grouped into three frequency bands: low, middle and high frequency and denoted as LF, MF and HF, respectively. The sound in these bands that is being perceived is identified as “rumble”, “roar” and “hiss”. The interference phenomenon of vibro-acoustical signals for the living environment in the low frequency range is considered up to about 125 Hz. In many cases, light construction of various components in buildings such as window planes, thin screens and cladding could have noticeable vibrations due intense low frequency sound pressure. This phenomenon is often observed in rooms that contain rotating industrial equipment that emits strong vibro-acoustic signals.

When measuring and estimating the sound pressure levels (SPL) according to the family of equal loudness contours, the corrections to SPL were carried out with impact coefficients in the total schema of the available measurement instruments. The A-weighted measurement scale is the most appropriate procedure to account for the human hearing sensitivity at different frequencies. Using this approach, approximate loudness contours are developed and used for practical applications.

The G frequency response is obtained from a combination of poles and zeros in the complex frequency plane, as given in table 1. The relative frequency response corresponding to this pole-zero configuration is shown graphically in fig. 2.

G-weighted sound pressure level: Sound pressure level given by the formula:

\[
L_{pG} = 10 \log \frac{p^2}{p_0^2},
\]

where \(p^2\) is the mean-square value of the G-weighted sound pressure; \(p_0^2\) is the reference sound pressure (20 μPa) and \(L_{pG}\) is abridged by \(L_G\).

Recently, an international standard for the measurement of infrasonic introduced a weighting curve (G-weighting) based on perception data. Thus, G-weighted levels will reflect the direct perception of infrasonic (fig. 2) curve G. The weighted sound pressure levels below 90 dB will not be important to human sound susceptibility, although the influence can be felt physiologically or by other systems [2, 3, 6].

The normal threshold of perception is considerably higher than for audible frequencies, while tolerance for high levels is not increased correspondingly.
Compared to higher frequencies, the loudness curves are much closer in the infrasonic region. That is, the dynamic range and the rate of growth are much steeper. Infrasonic that is just perceptible to an average listener, will yield a (G-weighted) level close to 100 dBG. A very loud infrasonic will yield a level of 120 dBG, only 160 dB above. G-weighted levels that fall below 90 dBG will normally not be significant to human perception.

Figure 2: Weighting network curves A, B, C, D, G for sound level meters; [9].

For the estimation of quantitative and qualitative factors of environmental noise according to the amplitude frequency characteristics the energy-average spectral deviation factors and the quality assessment index, are used following the estimation procedure given in [9].

Step 1 is to determine the N or other noise criteria rating using the $L_{10}$, 1000µ or $L_{MF}$ as previously discussed. For convenience, this curve should be plotted together with the spectrum or listed in a table as discussed below.

Step 2 is to calculate the energy-average spectral deviations in each of the three previously mentioned frequency regions. These are as follows:

$$\Delta L_F = 10 \log \left( \sum_{i=1}^{n} \frac{10^{0.1 \Delta L_f}}{3} \right)$$

where $i = 1\ldots n$, is the number of octave frequency band, $\Delta L_F$ are the $\Delta L_f$ values which are the differences between the spectrum value and the NC or SC or other curve value at that frequency.

Step 3 is to determine the quality assessment index (QAI). The QAI is the difference between the highest and lowest energy-average spectral deviations. The RC curves are used for noise estimation in the living environment, [9], following the QAI factor. If the QAI is less than or equal to 5 dB, the spectrum is presumed to be neutral, i.e., exhibiting proper balance between low, mid, and high frequency ranges. If the QAI is greater than 5 dB, then the qualitative descriptor would be determined by the maximum energy-average spectral
deviation and $\Delta L_f$ is estimated according to eqn (2). If the spectrum exceeds the moderate or clearly noticeable criteria, the qualitative descriptors ($L_{VA}$) or ($L_{VB}$) would also be used.

These basic procedures attitudes of noise estimation are used to determine the quantitative and qualitative environmental noise, when we have $L_{pi}$, $L_A$, $L_C$, $L_M$ available (the measured data). Using $L_A$ and $L_C$ values, $L_{pi}$ are obtained by the integration using A or C – weighting amplitude frequency characteristics. By $\Delta L_f$ factor and of $L_{lin}$ parameter analogy in eqn (2), the following equation is obtained:

$$10 \log \left( 10^{0.1L_C} - 10^{0.1L_A} \right) = 10 \log \left( 10^{0.1L_{lin}} - 10^{0.1L_A} \right) = 10 \log (10^{0.1\sum 10^{0.1L_{ii}}})$$

Following this analogy, we obtain, that $10 \log (10^{qL} - 10^{q1}) = L_{lin} - L_C$, where the corrective coefficients in calculating $L_A$ and $L_C$ equation values are used according in fig. 2 given A and G amplitudes.

In this case, when $i=1$, according to (2) or (3) eqn is obtain that $(L_{lin} - L_A) = \Delta L_{p(A)}$ or $(L_{lin} - L_C) = \Delta L_{p(C)}$. In the investigative low frequency range, using A or C curves, it can be stated, that the maximum value will be in the frequency range of 50–100 Hz, and the minimum value in the range of 31,5–50Hz. The estimation of the quantitative low frequency sound is very important for the environmental noise when $(L_{lin} - L) > 20$dB and $(L_A - L_C) \geq 15$ dB, and $(\Delta L_f)$ parameters are important.

In table 3, the acoustic emission from mobile agriculture machines is given at a distance of measured SPL frequency spectrum, the A, B, C – weighting, the total ($L_{lin}$) levels, the QAI (quality assessment index) in the frequency range of LF and the evaluation of $(L_{lin} - L_A)$ factors. Here we obtain QAI > 5 dB and the qualitative acoustic emission is defined as “rumble” implying the importance to noise contents.

3 Results and discussions

The method of the quantitative and qualitative factors (LF, QAI, $(L_{lin} - L_A)$) is used to estimate environmental noise. This method has been applied to determine noise generated from traffic. A noise assessment study was performed according to the recommendations of Directive 2002/A9/EC in Lithuanian transport regions (in the territory of Kaunas–Klaipeda, VIA Baltica Kaunas–Marijampole, in the suburbs of Kaunas metropolitan region where the noise barriers are located). The requirements of Standard LST ISO 1996:1993 LST ISO 7196 and recommendations HN33: 2003 were satisfied [10]. Furthermore, the estimation of the traffic-radiated noise to the living environment was obtained using $L_{AN}$ (percentile level) parameters in determining the acoustic environment (Traffic load Noise). The conditions of acoustic measurements are indicated in LST ISO
1996-1:1993 were augmented to account for the variation of measured sound at an increasing distance from the source. The measurements were taken at the distance of 300 m and the direction was perpendicular to the road line. The microphone was placed in the positions of 1.5 m above the ground. The measurements were carried out using instrumentation and technique of the firm “Brüel & Kjær”, Denmark. The technique of acquiring and processing data required to obtain LF, QAI, \((L_{\text{lim}} - L_A)\), \((L_{\text{lim}} - L_C)\), \(L_C\) values was applied for the selected geographic region. The measured results are shown in table 1 and the calculated results in table 2.

When aerodynamic turbulent noise propagates over ground surface, diffraction is observed. At distant points \((r>100\text{m})\), the interference of acoustic waves is more important. Thus of sound attenuation noise reduction is less in this type of environment.

Table 1: The measured data of the traffic radiated noise.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Calculated values at the distance from sound source (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L_{p,31.5\text{Hz}}) (dB)</td>
<td>74</td>
</tr>
<tr>
<td>(L-A) (dBA)</td>
<td>82.0</td>
</tr>
<tr>
<td>(L_{\text{lin}}/L_{\text{lim}}) (dB)</td>
<td>91.0</td>
</tr>
<tr>
<td>(L_{p,L\text{ oct}}) (dB)</td>
<td>4Hz</td>
</tr>
<tr>
<td></td>
<td>8Hz</td>
</tr>
<tr>
<td></td>
<td>16Hz</td>
</tr>
<tr>
<td></td>
<td>31.5Hz</td>
</tr>
<tr>
<td></td>
<td>63Hz</td>
</tr>
<tr>
<td></td>
<td>125Hz</td>
</tr>
<tr>
<td></td>
<td>250Hz</td>
</tr>
<tr>
<td></td>
<td>500Hz</td>
</tr>
<tr>
<td></td>
<td>1000Hz</td>
</tr>
</tbody>
</table>

Note.\(*\)-sound pressure levels were measured in the zone of acoustic barriers.

When the total sound pressure levels \((L_{\text{lim}}, \text{dB})\) are estimated at the distance \((r, m)\) from noise source, the efficient of acoustic masking is by 10 dB less than the value using the A–weighted sound pressure level. Further than \(r>100-150\text{m}\) with the sense of “rumble” sound and the noise components with low and very low frequencies \((L_F-L_{\text{lim}})\) are estimated including the possibility of influence, because \((L_{\text{lim}}-L_{A})\geq20\text{ dB}\), as seen in table 2. According to this factor, the perception gradient of low and very low frequency sound is more pronounced in the vicinity where the noise barriers are located.
50 60 70 80 90 100

4 8 16 31,5 63 125 250 500 1000

foct, Hz

Figure 3: Values of sound pressure levels using the acoustic barrier, Noise Criteria (NC-50) and SC-50 of human levels of equal assessment index (QH) for calculation and estimation: series 1–r=25 m; series 2–r=50 m; series 3–r=150 m; series 4–NC-50 m; series 5–SC-50.

Table 2: Data of the quantitative and qualitative factors.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Calculated values at the distance from sound source (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7,5</td>
</tr>
<tr>
<td>$(L_{lin} - L_A)/(L_{lin} - L_P)^*$ (dB)</td>
<td>11,0</td>
</tr>
<tr>
<td>$\Delta L F/\Delta M F$</td>
<td>4,87/2</td>
</tr>
<tr>
<td>$Q AI^*$ (dB)</td>
<td>4,87/2</td>
</tr>
<tr>
<td>$L_{Gi}$ (dBG)</td>
<td>85</td>
</tr>
</tbody>
</table>

1 note: “*” in the zone of acoustic barriers.
2 note: QAI values are calculated using the measured data (L_p in fig.3) and NC-50 values.

This condition is important for the reduction of environmental noise using acoustic barriers. The data of the quantitative and qualitative factors of traffic noise when 2 m high barrier was constructed are given in table 2. The completeness of the quantitative $L_{proect}=f(foct)$ function was estimated using $(L_{lin}-L_A)$ and $(L_{lin}-L_c)$ factors to demonstrate the influence of low and very low frequency components noise. When the location is near the acoustic barrier, $(L_{lin}-L_A)\approx 6$ dB. However, when $r>40$ m it is more than $15–18$ dB and the reduction in $(L_{proect})$ is observed from the components of frequency range. At the
distant points from noise source, “infra” and “rumble” type sounds are more important to the noise environment, especially, when $(L_{\text{lin}}-L_A) \geq 20 \text{dB}$.

Table 3: Data of acoustic emission from mobile agriculture machines.

<table>
<thead>
<tr>
<th>$L_{Ai}$ (dB)</th>
<th>85</th>
<th>77</th>
<th>53</th>
<th>58</th>
<th>57</th>
<th>62</th>
<th>56</th>
<th>53</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{p1000}$ (dB)</td>
<td>57</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC-55</td>
<td>75</td>
<td>69</td>
<td>64</td>
<td>59</td>
<td>57</td>
<td>55</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>LF</td>
<td>MF</td>
<td>HF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta L_f$ (dB)</td>
<td>10</td>
<td>8</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>2</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>$\Delta LF$, $\Delta MF$, $\Delta HF$ (dB)</td>
<td>6.98</td>
<td>-1.1</td>
<td>5.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QAI</td>
<td>8.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta L_{p,\text{A}}$ (dB)</td>
<td>-35</td>
<td>-27</td>
<td>-23</td>
<td>-9</td>
<td>-3</td>
<td>0</td>
<td>2</td>
<td>-0.8</td>
</tr>
<tr>
<td>$L_{p+\Delta L_p}$ (A)</td>
<td>52</td>
<td>50</td>
<td>30</td>
<td>49</td>
<td>54</td>
<td>57</td>
<td>64</td>
<td>57</td>
</tr>
<tr>
<td>$L_A$, (dBA)</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_{\text{Lin}}$ (dB)</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QAI_{LF} (dB)</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Highlight of the proposed method for the investigation of traffic noise is to provide a reasonable approach using qualitative and quantitative factors and the influence at low and very low frequency noise. This is achieved when the weighting and combining of the 31.5, 63 and 125 Hz frequency octave band levels is used to determine a lower frequency band closely and $(L_{\text{lin}}-L_A)$ or $(L_{\text{lin}}-L_c)$ weighting levels matching the critical band and level to human hearing in the low and infrasonic sound frequency.

4 Conclusions

To characterize the reaction and influence of noise pollution on humans, the parameters of acoustic emission and their amplitude dispersion characteristics with frequency ($L_{f\text{oct}}$, $L_{\text{Lin}}$, $L_A$, $L_{CG}$), the derivatives QAI (equal assessment index), $L_{\text{Lin}}-L_A$ (low frequency infrasonic index) were used to determine the conditions of “rumble, roar, hiss” type sound.

Using the quantitative and qualitative environmental noise assessment parameters, studies were performed to analyse traffic noise effects on the living environment. According to the energy-average and QAI parameters, noise pollution is most influenced by “roar” (Q>$5\text{dB}$), while in the far field (QAI=$5\text{dB}$) the low frequency infrasonic ($L_{\text{Lin}}-L_A$)$\geq 20\text{dB}$) is most dominant.

When the acoustic barriers were used for traffic noise attenuation, low and very low frequency noise was mostly observed.

The presented method for estimating traffic noise was able to carry out a comprehensive investigation of an ecological problem and satisfy the rules of Directive 200/49/ECC requirements of the environmental factors for our traffic noise assessment.
References