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

I-INCE Classification: 4.3

METHODS OF EVALUATING THE INFLUENCE OF VIBRATIONS ON SOUND PRESSURE LEVELS IN BUILDINGS

M. Niemas, J. Sadowski

Acoustic Department of Building Research Institute, 21 Ksawerow St, 02-656, Warsaw, Poland

Tel.: +48 228430707 / Fax: +48 228432931 / Email: akustyka_itb@zigzag.pl

Keywords:
SIMULTANEOUSLY MEASUREMENTS OF VIBRATIONS AND NOISE, COHERENCE FUNCTION, HEAVY ROAD TRAFFIC, INFLUENCE OF VIBRATIONS ON SOUND PRESSURE

ABSTRACT
The paper presents measurement-calculation procedure, which may be use for estimation of increase of sound pressure level in dwellings radiated from vibrating partitions. The procedure is based on simultaneously twin channel measurements of vibration velocity on partitions and sound pressure level in dwellings. This method using properties of coherence function between has measuring signals. The calculations of the sound radiated from vibrating walls induced by vibro-acoustic sources (e.g. heavy traffic) which has been made by new measure-computational procedure directly from two channel measurements are presented as well.

1 - INTRODUCTION
The passing of vehicles, particularly heavy ones, is a source of both airborne as well as material sounds. The penetration of both types of sounds to premises in buildings located near transportation routes takes place:

- by air, i.e. by the weakest, from the acoustic point of view, element of the external wall, that is the window,
- by the material path, i.e. through the base to the building's structure and through the structure on to building partitions.

These issues are relatively well known [1], [2], [6], [8] (perhaps with the exception of low frequencies, which may appear during the passing of heavy vehicles).

2 - THE ANALYSIS OF THE PHENOMENON, ASSUMPTIONS FOR METHOD DEVELOPMENT
In order to accurately define and determine the range of the work leading to solving the problem set out earlier on, the following assumptions were adopted [5]:

- the source of simultaneous (occurring at the same time) noise and vibrations penetrating to premises was taken to be heavy road traffic in a city, including passing busses, truck and rail vehicles (trams),
- the studied premises are found in residential buildings,
- the reverberation time in premises with furniture is T=0.5−0.6s on average,
- noise (airborne sounds) penetrating into the premises mainly through the weakest, from the acoustic point of view, element of the external wall, that is the window,
- the term "acoustic conditions in the premises" means the average level over time and space of sound pressure subsequently evaluated with correctly selected single-figure evaluation indices (in the case of residential premises with furniture, due to their geometrical parameters, it is possible to omit the spatial distribution of the acoustic field),

- residential buildings subjected to the study have a massive structure, which is important when analyzing the emitted sound by the building partitions.

This phenomenon is a vibro-acoustic phenomenon, where noise and vibrations appear at the same time and are physically inseparable. At the same time, i.e. the time of occurrence is the same for both phenomena, despite the fact that their sources differ. When developing the measurement method, an analysis was carried out of the applied measurement methods which could be used for solving the given problem.

3 - THE MEASUREMENT-CALCULATION PROCEDURE

In order to carry out the measurements the following measurement equipment and additional devices were required:

- sound calibrator,
- free field microphone,
- microphone preamplifier,
- piezoelectric vibration converter,
- calibration exciter,
- laser head with laser vibration meter,
- two-channel portable frequency analyzer with programming for narrow band analysis by FFT technique,
- tripod for laser head,
- probe for attaching accelerometer in the ground,
- connecting cables to microphone.

Calculation procedures [5]

★ Calculating the value of the increase in sound pressure $\mathbf{\Delta L}_{\mathrm{p},1-200}$ (increase in the level of sound pressure for sound transmission by material path by the examined partitions) and the level of sound pressure for airborne sound transmission $\mathbf{L}_{\mathrm{air},1-200}$ (using the value of the coherence function)

$$\Delta L_{p_i} = \gamma_i^2 \cdot L_{p_i} \text{ where } \begin{cases} \Delta L_{p_i} = \Delta L_{p_i} & \text{for } L_{p_i} - \Delta L_{p_i} > L_{p,bgd_i} \\ \Delta L_{p_i} = L_{p_i} - L_{p,bgd_i} & \text{for } L_{p_i} - \Delta L_{p_i} < L_{p,bgd_i} \end{cases} \tag{1}$$

where:

- ΔL_{p_i} - the value of increase in the level of sound pressure (rise in the level of sound pressure for sound transmission by material path by the examined partitions) for i frequency band, dB, i= 1,2,...200
- γ_i^2 - the value of the coherence function for i frequency band,
- L_{p_i} - the real value of the level of sound pressure in the studied room for i frequency band, dB
- L_{p,bgd_i} - the value of the level of acoustic background in the studied room for i frequency band, dB

$$L_{air_i} = \left(1 - \gamma_i^2\right) \cdot L_{p_i} \text{ where } \begin{cases} L_{air_i} = L_{air_i} & \text{for } L_{air_i} > L_{p,bgd_i} \\ L_{air_i} = L_{p,bgd} & \text{for } L_{air_i} < L_{p,bgd_i} \end{cases} \tag{2}$$

where:

- L_{air_i} - the value of the level of sound pressure for airborne sound transmission for i frequency band, dB, i=1,2,...,200
- remaining markings as above.

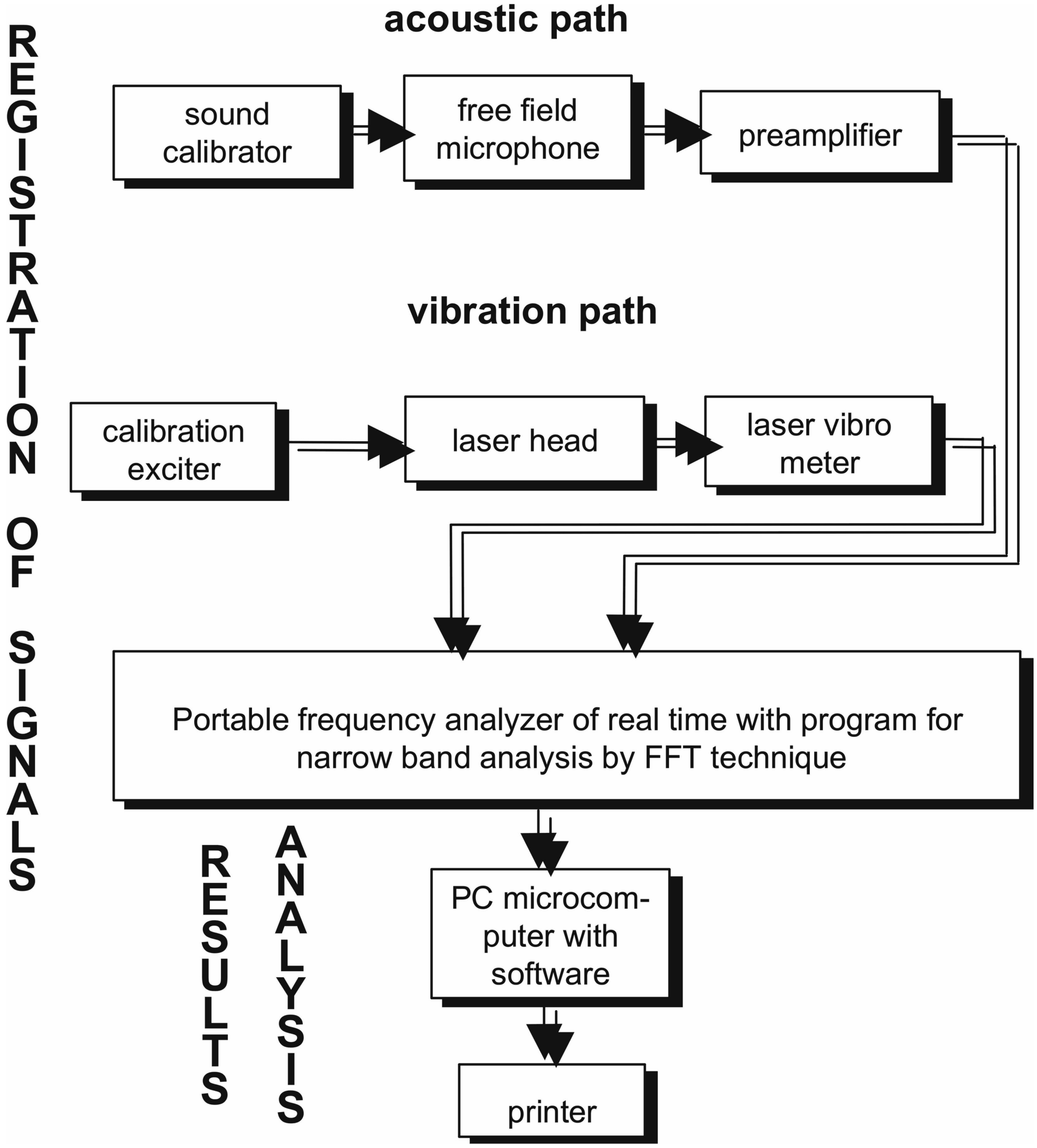

Figure 1: Diagram of the measurement set-up for registering vibro-acoustic signals in residential premises [5].

★ Calculating the values: the real level of sound pressure $\mathbf{L}_{\mathrm{p},1/3\mathrm{oct}}$, increase in the level of sound pressure $\Delta\mathbf{L}_{\mathrm{p},1/3\mathrm{oct}}$ (increase in the level of sound pressure for sound transmission by material path by the examined partitions) and the level of sound pressure for airborne sound transmission $\mathbf{L}_{\mathrm{air},1/3\ \mathrm{oct}}$,

$$L_{p_k,1/3oct} = 20\log\left[\sum_{f_{b_k}}^{f_{t_k}} (p_i \cdot \Delta f)/n_k \cdot p_0\right] \text{ where } p_i = 10^{0.05 L_{p_i}} \cdot p_0, dB,\ i = 1, 2, \ldots, 200 \qquad (3)$$

where:

- $L_{p_k,1/3oct}$ - the value of the real level of sound pressure for the next 1/3 octave band, dB
- L_{p_i} - value of the real level of sound pressure for i frequency band, dB
- f_{b_k}, f_{t_k} - bottom and top border frequency of k 1/3 octave band, Hz
- p_i - absolute value of sound pressure in the next constituent band of k 1/3 octave band, Pa
- n_k - the number of measurement bands in the range of the analyzed 1/3 octave band

- p_0 - reference value for sound pressure, Pa
- Δf - resolution of narrow band analysis (in our case Δf=1 Hz).
- i - next frequency band in k 1/3 octave band
- k - next 1/3 octave band

$$\Delta L_{p_k,1/3oct} = 20\log\left[\sum_{f_{b_k}}^{f_{t_k}} (p_i \cdot \Delta f)/n_k \cdot p_0\right] \text{ where } p_i = 10^{0.05\Delta L_{p_i}} \cdot p_0, dB,\ i = 1, 2, \ldots, 200 \tag{4}$$

where:

- $\Delta L_{p_k,1/3oct}$ - value of the increase in the level of sound pressure (increase in the level of sound pressure for sound transmission by material path by the examined partitions) for next 1/3 octave band, dB
- ΔL_{p_i} - the value of the increase in the level of sound pressure (increase in the level of sound pressure for sound transmission by material path by the examined partitions for i frequency band, dB
- remaining markings as above.

$$L_{air_{k,1/3oct}} = 20\log\left[\sum_{f_{b_k}}^{f_{t_k}} (p_i \cdot \Delta f)/n_k \cdot p_0\right] \text{ where } p_i = 10^{0.05L_{air_i}} \cdot p_0, dB,\ i = 1, 2 \ldots, 200 \tag{5}$$

where:

- $L_{air_{k,1/3oct}}$ - the value of the level of sound pressure for airborne sound transmission for next 1/3 oct. band, dB
- L_{air_i} - the value of the level of sound pressure for airborne sound transmission for i frequency band, dB
- remaining markings as above.

★ Calculating the total real level of sound pressure $\mathbf{L}_{\mathrm{p}(1-160)}$, total increase in the level of sound pressure $\mathbf{\Delta L}_{\mathrm{p}(1-160)}$ (total increase in the level of sound pressure for sound transmission by material path by the examined partitions) and the total level of sound pressure for airborne sound transmission $\mathbf{L}_{\mathrm{air}(1-160)}$ from the frequency range 1−160 Hz

$$L_{p(1-160)} = 10\log\left[\sum_{k=1}^{23} 10^{0.1 \cdot L_{p_{k,1/3oct}}}\right],\ dB \tag{6}$$

$$\Delta L_{p(1-160)} = 10\log\left[\sum_{k=1}^{23} 10^{0.1 \cdot L_{p_{k,1/3oct}}}\right] - 10\log\left[\sum_{k=1}^{23} 10^{0.1 \cdot L_{air_{k,1/3oct}}}\right],\ dB \tag{7}$$

$$L_{air(1-160)} = 10\log\left[\sum_{k=1}^{23} 10^{0.1 \cdot L_{air_{k,1/3oct}}}\right],\ dB \tag{8}$$

where:

- $L_{p(1-160)}$ - the value of the total real level of sound pressure from the frequency range 1−160 Hz, dB
- $\Delta L_{p(1-160)}$ - the value of the total increase in the level of sound pressure (total increase in the level of sound pressure for sound transmission by material path by the examined partitions) in the frequency range 1−160 Hz, dB
- $L_{air(1-160)}$ - the value of the total level of sound pressure for airborne sound transmission from frequency range 1−160 Hz, dB

- $L_{p_{k,1/3oct}}$ - the value of the real level of sound pressure in k 1/3 octave frequency band, dB
- $L_{air_{k,1/3oct}}$ - the value of the level of sound pressure for airborne sound transmission in k 1/3 octave frequency band, dB
- k- next 1/3 octave band in frequency range $1-160$ Hz.

4 - OBJECTIVE MEASUREMENTS IN RESIDENTIAL PREMISES

In order to better examine the problem of vibrations in flats on building partitions confining the residential premises, accompanying the passing of heavy vehicles and confirming the influence of the influence of vibrations on building partitions on the level of sound pressure in the studied room, measurements of vibrations velocities and the levels of sound pressures were carried out simultaneously in several residential buildings according to the developed measurement procedure. The residential premises in all cases were found on the ground floor on the side of the street (in order to minimize the influence of the building's structure on the transmission of vibrations).

Below are presented the graphic results of the calculations of the levels of sound pressure being the consequence of vibrations appearing on the partitions confining the studied residential premises using the coherence function and measured levels of the acoustic background found in the studied premises. The above calculations were conducted according to formulas found in the developed measurement procedure. The results of calculations of the levels of sound pressure resulting from the existence of vibrations on building partitions confining the studied premises were treated as the rise in the level of sound pressure caused by sound transmission by material path by the examined partitions with respect to the levels on only the airborne path.

Localization of building (source)	$L_{p(1-160)}$, dB	$\Delta L_{p(1-160)}$, dB
Solidarnosci Ave. (tram)	90,8	10.3
Mickiewicza St. (tram)	78.6	9.1
Nowowiejska St. (tram)	72	8.6
Wiktorska St. (bus)	70.1	6.8
Grochowska St. (tram)	84.3	3.3
Grochowska St. (bus)	82.6	1.7
Niepodlegsosci St. (truck)	70.3	4.8
Wiktorska St. (tram)	68.1	4.4
Wiktorska St. (truck)	68.5	4.2
Niepodleglosci Ave. (bus)	69.3	3.9
Grochowska St. (truck tractor with semi-trailer)	88.4	7.6

Table 1: The total values of the real level of sound pressure $L_{p(1-160)}$ and the total rise in the level of sound pressure $\Delta L_{p(1-160)}$ (for sound transmissions by material path) from range $1-160$ Hz [5].

5 - SUMMARY AND CONCLUSIONS

The aim of the work was to demonstrate the possibility of developing a method for evaluation of traffic noise and vibrations occurring simultaneously on the acoustic conditions in residential buildings located near communication routes.

A measurement-calculation method was developed for this purpose, which enables the numerical determination of the value of the emitted sound to the interior of the closed (residential) premises, by building partitions excited to vibrations by a passing heavy vehicle. It was confirmed by measurement that vibrations occurring on confining partitions do influence the value of the level of sound pressure in the studied premises

A measurement procedure was developed based on the statistical method of the coherence function, which made it possible to directly on the spot of the measurement determine the influence of occurring vibrations on the existing level of sound pressure in the premises.

Analyzing the results of measurements we can formulate the following specific conclusions, as these results may not be the basis for setting out general conclusions owing to their low number:

- the total real levels of sound pressure $L_{p(1-160)}$ from the range proposed for evaluation calculated from the results of measurements obtained from the narrow-band analysis $1-200$ Hz and calculated into 1/3 octave bands for real passage of heavy vehicles, depending on the analyzed vehicle and location of the flat, take on values from $68.1-90.8$ dB,

Trams

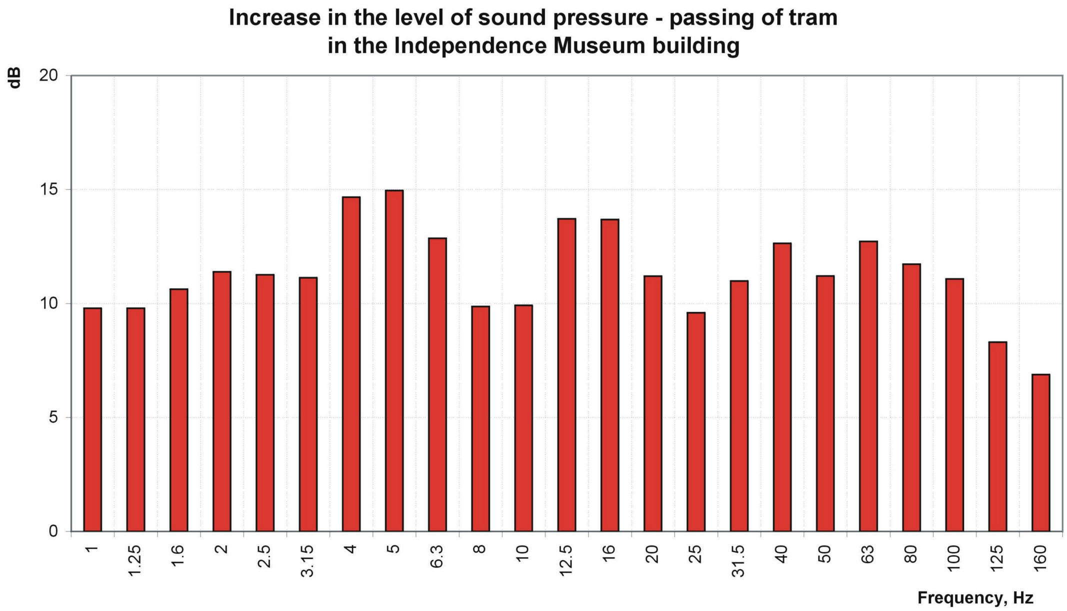

Figure 2: Increase in the value of the level of sound pressure (resulting from the coherence function) – room in the building of the Museum of Independence (passing of a tram) [3], [4], [5].

- the total increases in the level of sound pressure $\Delta L_{p(1-160)}$ (for sound transmission by material path) from the frequency range 1–160 Hz calculated using the coherence function taking into consideration the existing acoustic background, depending on the analyzed vehicle and location of the flat, adopt values from 1.7–10.3 dB.

ACKNOWLEDGEMENTS

The paper presents the tests and obtained results in the framework of the author's doctor's theses, which was promoted by Prof. Jerzy SADOWSKI, Head of Acoustics Department in ITB. Finishing the works and preparing the results was additionally financed by KBN in the framework of the promoter's grant no. 7 T07B 01311.

REFERENCES

1. **Ciesielski R., Kawecki J., Maciag E.**, *Ocena wplywu wibracji na budowle i ludzi w budynkach*, Wydawnictwo ITB, 1992 (in Polish)

2. **Ciesielski R., Maciag E.**, *Drgania drogowe i ich wplyw na budynki*, Wydawnictwo Komunikacji i Lacznosci, 1990 (in Polish)

3. **Niemas M., Sadowski J.**, Vibration and noise in building located near tramway lines and the influence of vibrations from heavy road traffic on the level of sound pressure, In *flats. CIB W51 Meeting, Paris, 1998*

4. **Niemas M., Sadowski J.**, Wplyw drgan od ciezkiego ruchu kolowego na poziom cisnienia akustycznego w mieszkaniach, In *Materialy konferencji Wplyw Wibracji na otoczenie, Janowice wrzesien, 1998 (in Polish)*

5. **Niemas M.**, Ocena wplywu jednoczesnego wystepowania halasu i drgan od ruchu komunikacyjnego na warunki akustyczne w budynkach mieszkalnych, *Rozprawa doktorska, Promotor prof. zw. dr hab. inz. Jerzy Sadowski, Warszawa 1999 (in Polish)*

6. **Sadowski J.**, Podstawy izolacyjnosci akustycznej ustrojow, *PWN Warszawa, 1973 (in Polish)*

7. **Szudrowicz B.**, Podstawy ksztaltowania izolacyjnosci akustycznej pomieszczen w budynkach mieszkalnych, *Wyd. ITB Warszawa, 1992 (in Polish)*

Busses

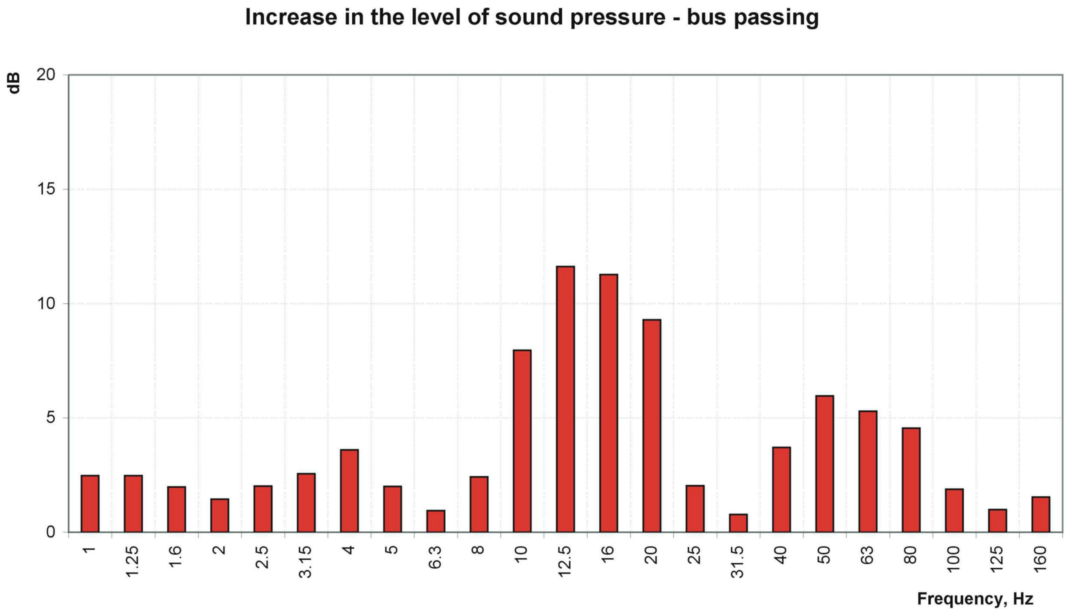

Figure 3: Increase in the value of the level of sound pressure (resulting from the coherence function) – residential building at Niepodleglosci Ave. in Warsaw (passing of MZK bus) [3], [4], [5].

Trucks

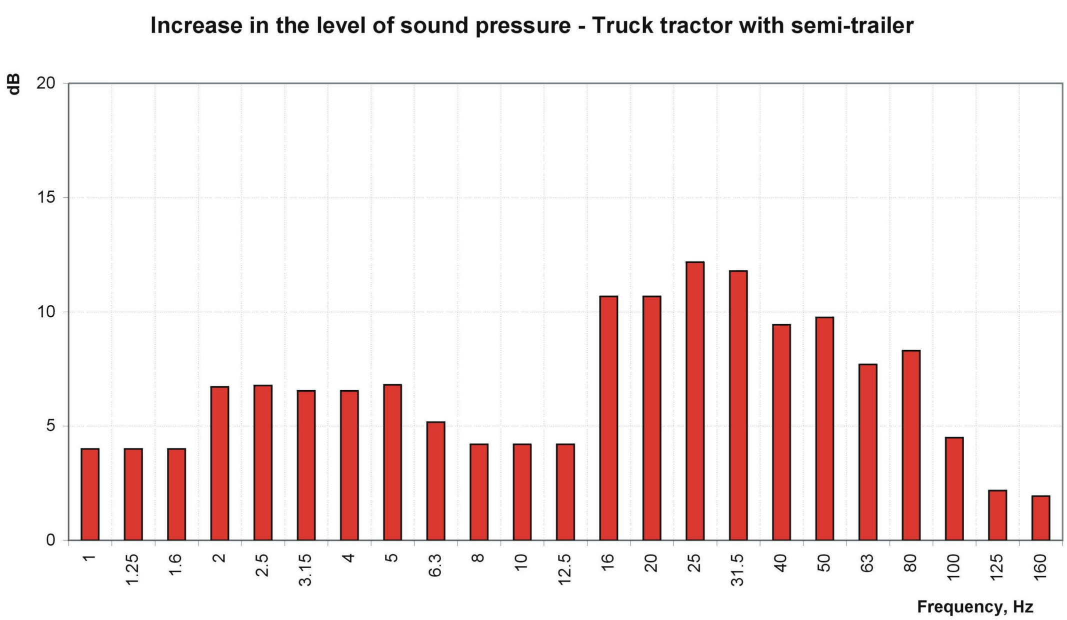

Figure 4: Increase in the value of the level of sound pressure (resulting from the coherence function) – residential building at Grochowska St. in Warsaw (passing of truck tractor with semi-trailer) [3], [4], [5].