DETERMINATION OF TOTAL NOISE LEVEL IN THE MOTOR VEHICLE

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INTRODUCTION

Engine functioning and vehicle motion on the road bring about the emergence of noise and vibration. The noise and vibrations produced by a motor vehicle are a result of a simultaneous influence from many sources, and, thus, the efficient reduction of them is possible only in the case of inspecting each source separately, and then doing an overall analysis of the problem [1, 2].

Engine and its supporting parts are a complex system of noise production. The engine noise appears as a result of the action of force originating from a mechanical source and action of gases onto the piston during the functioning process of the internal combustion engine. The passenger in the vehicle is exposed to a noise level which is a result of a general acoustic pressure appearing as a sum of various “primary” and “secondary” sources of noise [3, 4].

Primary noise sources originate mainly from:

- The noise and vibrations of the engine,
- The noise which is a consequence of the vehicle moving along various types of surface,
- The noise of an aerodynamic origin and
- The noise which is produced during the functioning of different vehicle parts and aggregates.

Primary noise is transferred partly directly through the supporting element of a vehicle, partly through various channels, ports, slots, etc., and partly by vibrating of smaller and bigger areas of the vehicle body which are on the way of sound waves.

The impulse which causes secondary noise, the body vibrations, originates from the effects of engine, rubber and metal elements, wheel motion over an uneven surface, exhaust system vibrations, streaming of the air over the vehicle during the motion. Secondary noise could appear as more intensive when the impulse has the components of frequency which respond to the resonance of the vehicle body parts or the enclosed space.

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Vehicle noise is directly dependent on the movement speed, gear, vehicle load, type of road surface, driving style, coefficient of streamlining, condition of the windows (open, partially open or close), heating and ventilation system functioning, vehicle production quality, characteristics of tires, etc.

All noise which is produced during drive aggregate functioning stands in a direct correlation with revolutions-per-minute of the crankshaft. The increase of revolutions-per-minute of the crankshaft causes the higher level noise.

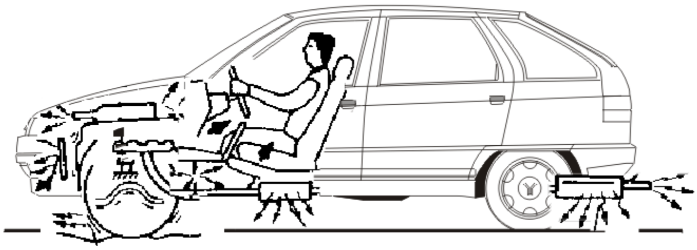

Figure 1: *Major noise and vibration sources*

Depending on the frequency characteristics of the produced noise and vibrations, the noise sources could be characterized as coherent and noncoherent.

Coherent sources of the sound waves are qualified by the same frequency and the same or different phase. An illustrative example could be a result of drive aggregate vibrations which act at the places of its location and the noise from the process of combustion. The parts of sound waves which pass through various environments but originate from one source could be considered coherent. E.g. the noise coming from the engine which passes through the air environment or through the engine prop to the body also belongs to the group of coherent acoustic waves.

Noncoherent sources are those sources which have the level of the sound whose frequencies are not identical. E.g. two noncoherent sources could be engine noise and aerodynamic noise.

NONCOHERENT SOURCES

Regarding complex sound waves which involve many noncoherent sources, it is necessary to determine an effective value of the sound pressure which contains many different acoustic pressures, waves which take part in the complex sound. The current value of the complex sound pressure is obtained as a square root of the sum of the squares of the current values of the pressure of the waves which take part in that complex sound:

$$p_u = \sqrt{p_1^2 + p_2^2 + \cdots + p_n^2} \qquad (1)$$

so that:

p_u - current value of the complex sound pressure, $p_1, p_2, \ldots p_n$ - acoustic pressures of the complex sound components.

Level of sound pressure is calculated by applying the formula (2):

$$L = 20\log\frac{p_u}{p_0}\text{, dB} \qquad (2)$$

for p_u - current value of acoustic pressure,

$p_0 = 2 \cdot 10^{-5}\ \text{N/m}^2$ – reference value of acoustic pressure.

As for two sound sources, the global level of the sound could be calculated by applying the formulae (1) and (2). According to these formulae, it is possible to make a graph of increase of the overall level of the complex sound depending on the value of subtraction of the sound level of every single component. That graph is very commonly applied in practice because it offers a solution in a quick and simple way (Figure 3). If two sources are placed at the points A and B, figure 2, with the point A sound level L_A expressed in dB, and the point B sound level L_B expressed in dB, then the point 0 sound level L_T expressed in dB is obtained according to the formula (3) by using the graph in Figure 2.

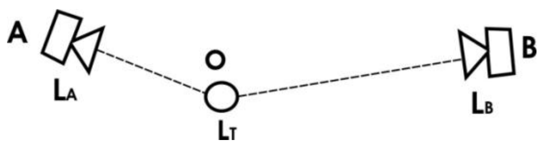

Figure 2: *Case with two noncoherent sources*

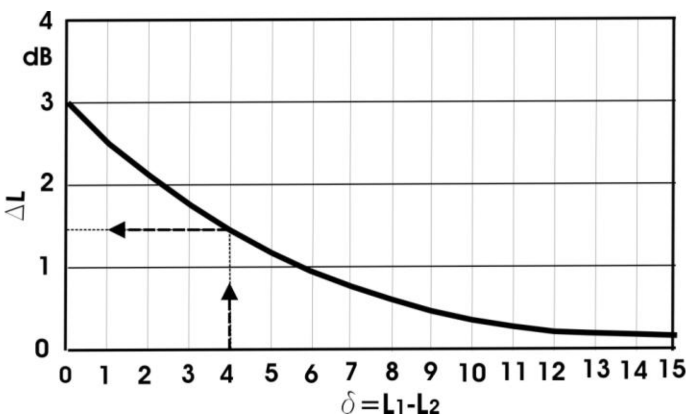

Figure 3: *Graph of logarithmic addition*

$$L_T = L_A + \Delta L\text{, dB} \qquad (3)$$

Supposing that $L_A > L_B$, one can calculate $\delta = L_A - L_B$, so that ΔL can be simply calculated from the diagram in the Figure 3.

Regarding two sources of the same level, the global level is obtained by adding 3 dB to the level of one of the sources, which can be easily concluded from the Figure 3. In practice, if the difference between the levels of two sources is bigger than 10 dB, then δ <0,5 dB, and the influence of the lower level source can be neglected.

Summation of several noncoherent sources is of great importance in practice, especially for global noise level reduction by sound insulation.

The examples of three or four noise sources can illustrate the influence of sound insulation applying.

As for three noncoherent sources with different levels, it is very important to know the noise levels of individual sources. Figure 4 shows an example of summation of sound coming from three sources.

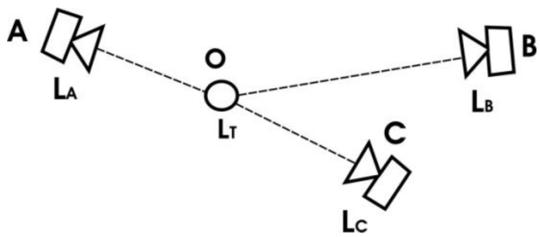

Figure 4: *Case with three noncoherent sources*

Table 1 shows noise levels from three sources and overall noise level L_T, before applying sound insulation and their levels after insulation of individual sources and all the sources.

Table 1: *Results of logarithmic addition for three sources*

	L_A	L_B	L_C	L_T	ΔL
Level, dB	85	80	75	86,5	-
Insulation L_A	65	80	75	81,3	5,2
Insulation L_B	85	60	75	85,4	1,1
Insulation L_C	85	80	55	86,2	0,3
Ins. L_A, L_B, L_C	65	60	55	66,5	20

Primary isolation is the isolation of the source of the highest level, just like it is shown in the Table 1, where the reduction of noise level of 10 dB gave a global noise level reduction of 5,2 dB. Isolation of the source of a lower level often can be wasteful because the results are negligible, so that the reduction of noise level of 20 dB at the noise source with the lowest level would achieve the reduction of 0,3 dB. The best solution is to insulate all the sources, if possible.

Also, an example with four sources with the same level, which is shown in the Figure 5, is illustrative. The results of the analysis are given in the Table 2.

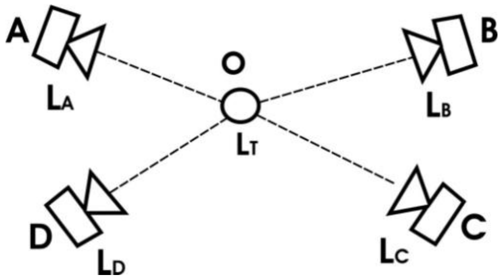

Figure 5: *Case with four noncoherent sources*

As a result of the effect of four sources with the same level, the global level will be higher for 6 dB in comparison with the effect of only one source. If we apply sound insulation to reduce one source level for 20 dB, the global level will be reduced for 1,2 dB. However, if the levels of three sources are reduced for 20 dB, the global level will be lower for 5,9 dB. The best results appear in the case of simultaneous insulation of all the noise sources.

Table 2: *Results of logarithmic addition for four sources*

	L_A	L_B	L_C	L_D	L_T	ΔL
Level, dB	80	80	80	80	86,0	-
Insulation L_A	60	80	80	80	84,8	1,2
Insulation L_A ,L_B	60	60	80	80	83,1	2,9
Ins. L_A ,L_B, L_C	60	60	60	80	80,1	5,9
Ins. L_A,L_B,L_C,L_D	60	60	60	60	66,0	20,0

COHERENT SOURCES

As for coherent sources, the sources of the same frequencies but variable phase, the rule of the sum of the squares of sound pressure effective pressures is not applied like it was the case with noncoherent signals. Considering coherent waves, the summation is done with regard to the interference of two or more waves, and their final sum does not depend on oscillation amplitude only, but on their phase difference, too. In the case of coherent sources, phasor addition is done, where the phasor module is proportional to the sound pressure, and phasor angle (argument) is determined by the phase. The Figure 6 presents the way of summing two coherent signals of the same acoustic pressure, but of different phases in a time domain. If two sources are of the same phases and levels then the resulting noise is two times higher, while the phase remains unchanged.

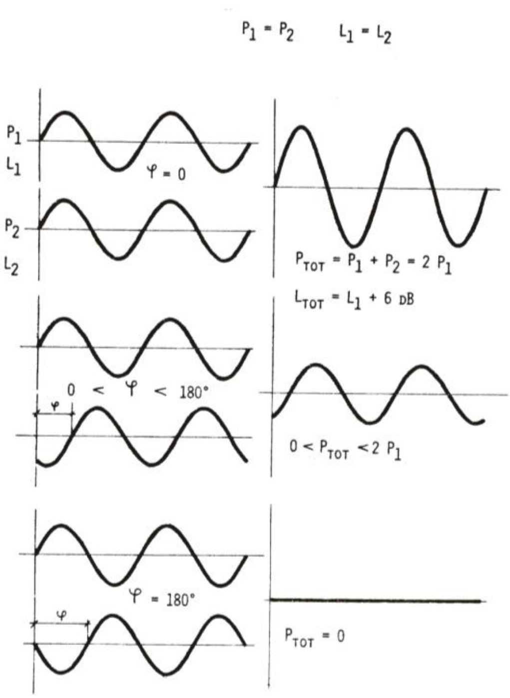

Figure 6: *Illustrative examples of summing of two coherent waves*

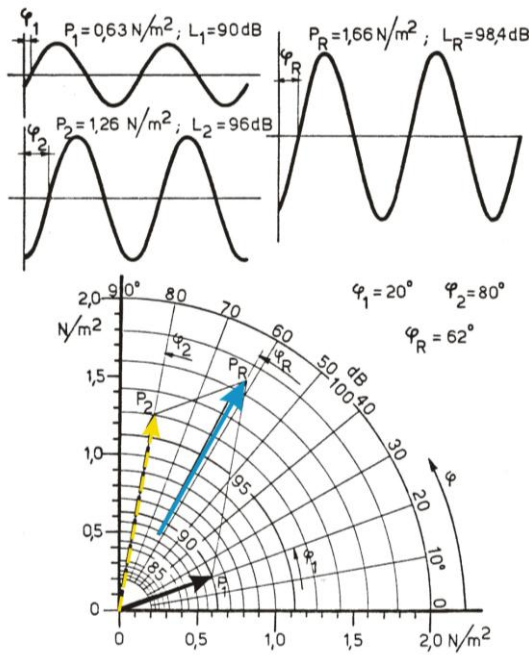

Figure 7: *Phasor diagram of summing two coherent sources*

In the case of a constant amplitude, but phase difference changing from 0 to 180^0, the resulting amplitude changes from 0 to 2. When the phase difference between two sources is 180^0, in terms of theory, the level, that is to say, amplitude is equal to zero point. This conclusion is applied in active noise reduction [5].

Figure 7 shows the way of phasor summation of two sources with different amplitude and phase.

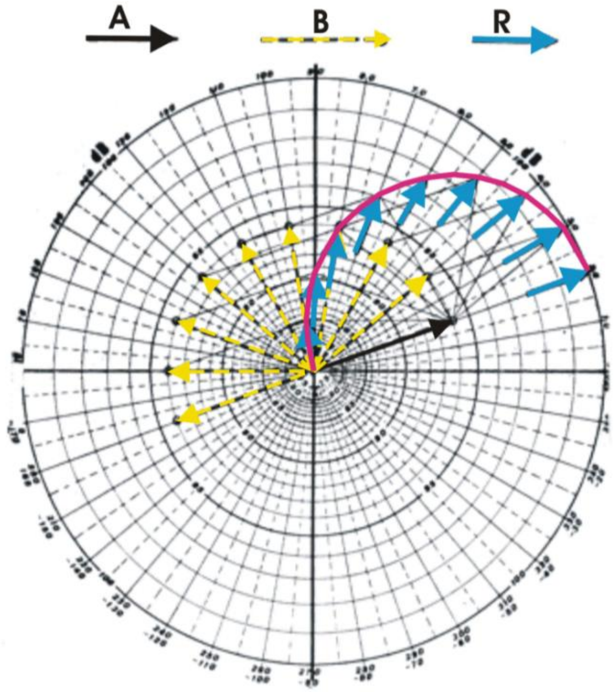

Figure 8: *Summing two coherent sources of variable phases*

The first coherent source level is $L_1 = 90$ dB, the second coherent source level is L_2 =96 dB, and acoustic pressures are given as formulae, (4 and 5):

$$p_1 = 0{,}63\sin\left(\omega t - 20^0\right),\ \text{N/m}^2 \tag{4}$$

$$p_2 = 1{,}26\sin\left(\omega t - 80^0\right),\ \text{N/m}^2 \tag{5}$$

The resulting level will be $L_R = 98{,}4$ dB, and its current value is given as formula (6):

$$p_R = 1{,}66\sin\left(\omega t - 62^0\right),\ \text{N/m}^2 \tag{6}$$

By using a phasor diagram in the Figure 7, it is easy to sum two or more coherent signals.

An illustrative example of summing two identical noise levels of coherent signals is shown in the Figure 8, where the mutual phase is changed from 0 to 180^0. The resulting amplitude is found in the range from the double amplitude value to zero.

A typical example of summing three coherent sources is given in the Figure 9 as following $\vec{A} = 98$ dB, $\vec{B} = 92$ dB and $\vec{C} = 86$ dB. Figure 9 shows graphic summing of phasors by application of circle diagram.

$$\vec{R}_0 = \vec{A} + \vec{B} + \vec{C} \tag{7}$$

Total sum $\vec{R}_0 = 93$ dB.

If one of the coherent sources, e.g. *A*, were modified so that its amplitude and phase were changed, and its level were $\vec{A} = 94$ dB , then the total sum would be $\vec{R}_0 = 84$ dB, that is to say, reduced for 9 dB.

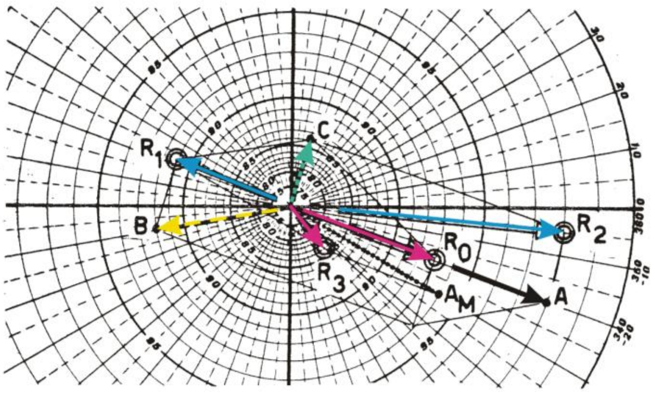

Figure 9: *Example of summing three coherent sources*

The arranged overview of the results of the previous analysis is given in the Table 3.

Table 3: *Results of summation of three coherent sources*

	A	*B*	*C*	R_0	ΔL
Level, dB	98	92	86	93	-
Insulation L_A	94	92	86	84	9

By using coherent controlled noise source one can do an active control and reduction of sound source. The source being controlled has an integrated device measuring the amplitude and phase of the coherent, undesirable source. Based on the measurements, the controlled source produces the sound of the same amplitude, but the opposite phase, and in that way it reduces the total level of noise.

CONCLUSIONS

In the case of summing several noncoherent sources, it is extremely important to analyse their level before applying insulation. If they are of the same or nearly the same level, the reduction, the insulation of each source is fully technically justified. If there are several sources of various levels, the insulation of the highest level source gives individually the most remarkable effects. The highest reduction is achieved by insulating all the sources.

As for coherent sources, besides the source level, the phase is of extreme relevance. By changing the phase between two or more signals, considerable results could be obtained, even without reduction of the source levels. This is commonly used with the active noise reduction.

ACKNOWLEDGMENTS

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