

# Dominant noise sources identification as cost-effective way in total sound power reduction

Slobodan Jankovic<sup>1</sup>, Miodrag Ivkovic<sup>2</sup>

<sup>1</sup> Tech. Faculty "Mihailo Pupin", Zrenjanin, S&MN, post code 23000 Dj. Djakovica 1, phone: +381 63 85 11 718, fax: + 381 23 510 520; e-mail: [sjankovi@Eunet.yu](mailto:sjankovi@Eunet.yu)

<sup>2</sup> Tech. Faculty "Mihailo Pupin", Zrenjanin, S&MN, post code 23000 Dj. Djakovica 1, phone: +381 64 61 21 737, fax: + 381 23 510 520; e-mail: [miodragivko@telekom.yu](mailto:miodragivko@telekom.yu)

**Abstract** – The paper deals with sound intensity measurement technique and its application in dominant sound sources identification as well as the reduction of total radiated sound power from a complex technical system.

Based on more restrictive regulation and other demands, mainly related to the environment protection, noise attenuation of technical systems has become common task for. Often the only solution is only system redesign. To enable cost effective approach to this demand the paper exposes a rational methodologie. The SI mapping is used as framework for sound power integration across the independent subsystems, ranking their contribution to the total system noise level and finally, optimizing redesigning process based on expenses and expected noise attenuation. Paper presents results achieved through the diesel engine noise attenuation.

## I. Introduction

Nowadays, all technical systems are exposed to serious demands for low emission to the environment including noise emission. For significant number of products the quite restrictive regulations related to the allowed sound level have been applied since 60's. European noise regulations are especially advanced. It is obvious that we have higher and higher standards for noise measurement and regulations which controls approach to the EU market for large range of the products. Consequently, industry is faced with the problem of sustaining their products as competitive in the market even through enabling quiet products. Measurement role is to provide techniques for reliable noise problem researching and practical solutions for their solving.

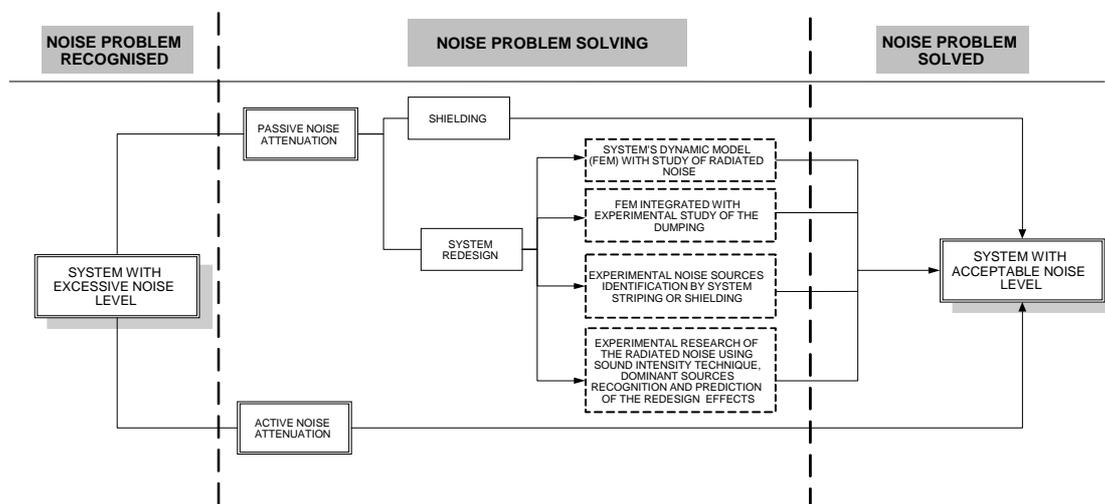


Figure 1. Different approaches in technical system's noise attenuation

The problem referred in the paper is frequently immanent within the industry. The developed product or one already in production has excessive noise level. If the shielding or other passive noise attenuation techniques are not possible, it has to be redesigned. The redesigning process must be cost-effective i.e. they shouldn't make significant impact to the product cost.

There are a few methodologies which can be used for the stated problems' solving (see Fig. 1). The first one is finite element modelling (FEM) and dynamic behaviour study based on it. This approach is improper when object which has to be redesigned already exist i.e. once when physical model is available. Actually, FE modelling process is always connected with difficulties of inaccurate

structure's dumping prediction. Although superior in the design stage, this approach is not recommended in post prototype product life.

The next possibility is to integrate FEM approach with experimental defining of system dumping. This approach is better but, still, it deals with simulation and based on that it is less accurate than pure experimental defining of noise level as it is exposed in the paper.

Experimental solution is measurement of particular system's parts, to determine its total noise level. Conventional approach in that direction was objects' "stripping" and parts shielding which were limited in possibilities to provide measurement data for only one part of the system. Also, that approach was inaccurate.

## II. Experimental approach using SI

The paper exposes methodologies of sound power flux measurement. Since flux is integral of elementary sound power vector across the defined surface, it is possible to establish following approach (see,  $S_{ij}$  on the Fig. 2). All elementary surfaces used for measurement have to form (all together) closed area around the object. Consequently, total sum of sound power fluxes through all the elementary surfaces will be the total sound power of object under investigation. Once the total sound power is defined in said way, it would not be necessary to make any further measurement and all succeeding actions will be based on already measured data. The further activities in noise attenuation are as follows. Firstly, the measured data have to be recalculated. Actually, instead of summing across all the elementary surfaces one has to define subsystems which can be redesigned and elementary surfaces which correspond to appropriate subsystems. In that way, it is possible to find accurate contribution of each particular subsystem to the total system noise level. As a consequence, analyses where one subsystem (or a few of them) makes dominant impact to total noise level, are possible.

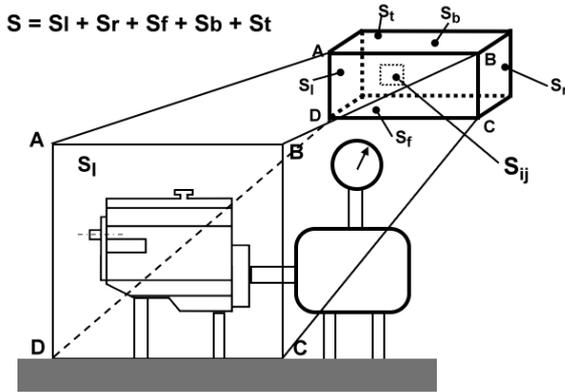


Figure 2. Sound power measurement based on particular values of sound intensity measured around the object

The next step is to integrate design and production experts to estimate the cost of particular subsystem redesigning. Based on that it is possible to find cost-effective solution for noise attenuation. It means that the part of the system which is the chipset one for redesign and which makes a dominant contribution to the noise level will be the first one changed (redesigned).

### A. Theoretical background

Work performed in the stationary fluid in the elementary time "dt" through the surface, represents the scalar product of the force "F" which dominates among the fluid particles on both left and right side of the imaginary surface and particles velocity "u" which "flow" through  $\delta S$ , i.e. it is:

$$\frac{dW}{dt} = \vec{F} * \vec{u} = p \delta \vec{S} * \vec{u} = p \delta \vec{S} \vec{u} * \vec{n} \quad (1)$$

If the observed flux is reduced to unit area surface, then the vector  $p \vec{u}$  is called the sound intensity (SI), marked as I.

$$\vec{I} = p \vec{u} \quad (2)$$

Consequently, the sound intensity represents the energy flux through the unit area surface. It appears that for determining the source's sound power it is enough to determine the sum intensity on the surface that encloses the volume in which the source is placed.

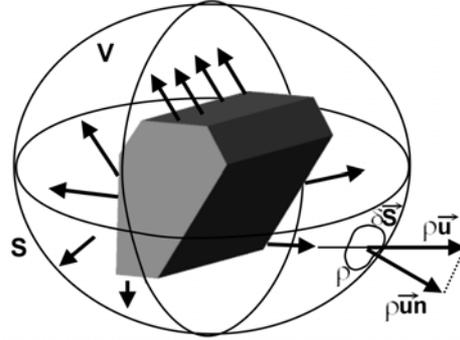


Figure 3. Sound flux

According to Gauss's Theorem, the volume integral of intensity divergence is equal to the integral of normal intensity component on the surface that forms the volume i.e. it is:

$$W_s = \int_V \Delta \vec{I} dV = \int_S \vec{I} \cdot \vec{n} dS \quad (3)$$

$$W_s = \int_S \vec{I}_n dS \quad (4)$$

There are the two important consequences of exposed theoretical approach. The first one is the possibility of direct total sound power determination of particular technical system by sound intensity measurement.

It has to be noted that total sound power is the only value which determines the quality of a system in accordance to noise. Previously, the total sound power was measured only indirectly i.e. based on sound pressure level (SPL). As SPL is the result of the object's sound power level (SWL) but, also impacted by acoustical properties of the ambient in which SPL was measured, there were some limitation and disadvantage of that approach. Introducing SI technique one is in position to measure SWL without ambient impact as well as in a presence of other sound sources. This implication is essential since it is easier, direct and SWL determination of the object even in service conditions.

The second implication is related to possibilities of dominant sound sources allocation through SWL measurement. As this implication is of special interest for the scope of the paper it will be explained with more details.

### III. Sound intensity mapping for dominant noise sources recognition

The technique exposed above will be illustrated with the example of a high speed diesel engine. The producer of the "S54" engine (2.5 l, 4 cylinders in line, water cooled, high speed diesel engine for vehicle application) was interested in noise attenuation. To implement the SI technique in problem solving the following approach was applied.

The side surface of the engine (please, see bottom right side of the Fig. 4,) was taken as the referent one which has to enable sufficient information on radiated noise for further analyses. The referent plan surface of 0.64 m<sup>2</sup> was placed 470 mm away from the engine left side. It was divided into 8 equal horizontal segments denoted from Y1 to Y8 from the top to bottom so that the level Y1 was at the height of the head lid and the level Y8 somewhat below the lower edge of the oil sump. Also, the whole referent surface is divided vertically. Consequently, 8x8 grid was provided at the engine side view. It has to be noted that proper grid has to enable sufficient number of fields which would enable proper analyses. Based on that, in each particular case one has to make preliminary study of number of field at the referent surface which would enable him to make proper conclusions in post measurement process and, also, to define proper distance of the referent surface from the object.

For the first approach to the problem study, the sound intensity was measured at the referent surface by using "A" filter. To enable one to get the complete picture of dominant noise sources, in detail sound intensity map was made (see Fig 4).

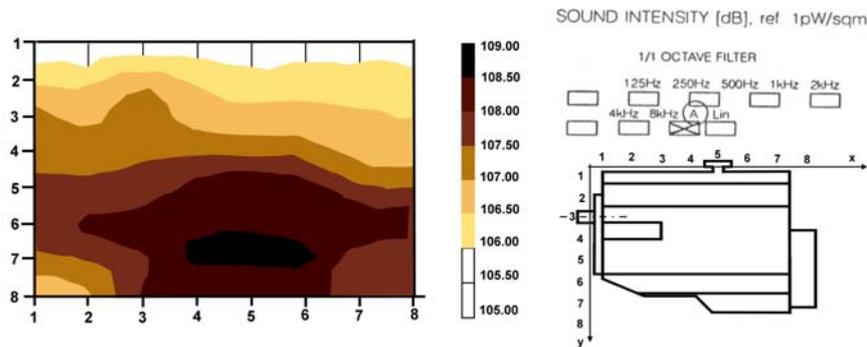


Figure 4. Engine's sound intensity – frequency range from 63 Hz to 16 kHz, “A” weighting

Based on the proper geometrical grid which enabled good reference to the particular engine subsystems it was possible to calculate the total sound power radiated by the three dominant engine's subsystems: cylinder head, crankcase and oil sump. It has to be underlined that engine producer is always interested in noise problem solving by redesigning minimum number of subsystems. Consequently, it is logical to enable analyses of total sound power radiated by particular subsystems. “SI Map/Power” software was developed to enable fast and accurate analyses to the test engineers and other staff. Actually, the main idea was to enable one to see the map of the SI immediately after the measurement and to enable recalculation of total sound power from different parts of the object .

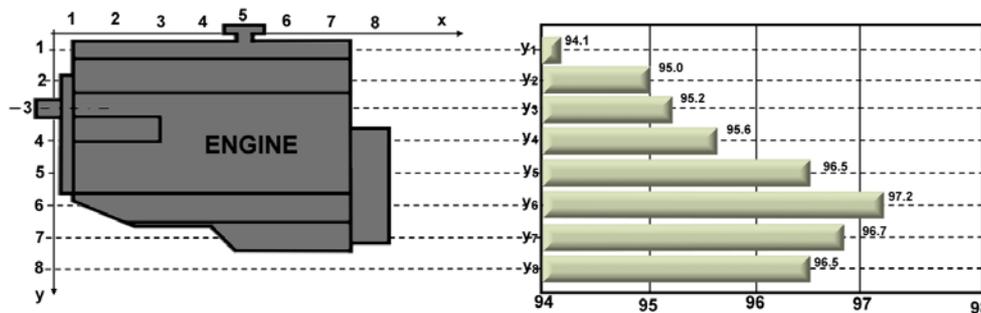


Figure 5. Vertical distribution of the sound intensity radiated from the engine. Values given in dB(A)

Using the software it was found that vertical distribution of the radiated noise was as in Fig 5. It was obvious that oil sump and the lower part of the crankcase were the parts of the engine with dominant influence to the total sound power. More precisely, by taking total sound power radiated at levels Y1, Y2 (which correspond to the engine head), Y3 to Y5 (engine's crankcase) and Y6 to Y8 (opposite to the sump) it was clear that:

- There was no purpose in making any noise reduction on the engine's crankcase and especially head before significant noise attenuation on the oil sump.
- The reduction of SI from the oil sump to the level of 96.5dB(A) or less, will eliminate the sump as the dominant noise source and enable significant reduction of the total engine's sound power.
- As the redesign of the oil sump is the less expensive (compared with price for head or crankcase redesign) and since it can enable significant and sufficient reduction of the total sound power it was necessary to make experimental analyses of the frequency domain of radiated noise, especially from the oil sump. The figures 6 to 10 expose the SI maps at different frequencies. Actually, the frequency analyses was made by 1/1 octave filets from  $c_f = 128$  Hz to  $c_f = 8$  KHz, ( $c_f$  – central frequency), while the most important frequency range (500 Hz to 4 kHz) is given in the fig. 6 to 9, for further discussion.

Based on the 1/1 octave analyse of the Ii it is obvious that 1 to 4 KHz is the dominate frequency range in which the oil sump radiates the noise. Consequently, the redesign of the sump has to be done in a way which would make significant dumping of the sump structure at said frequencies. Based on SI maps from figure 6 to figure 9 it is obvious as follows:

- The flywheel housing was the engine subsystem which has significant contribution to the total engine's sound power at the frequency range ~ 500 Hz. Based on the “A” curve attenuation at 500 Hz it is not of interest to make redesign of that engine part at the initial stage.

- At the frequency range of 1/1 octave filter with central frequency of 1 kHz there were the two dominant sources: the injection pump and the left part of the oil sump. Based on the fact that the injection pump is extremely complicated and expensive for reconstruction it is rational to reduce the total emission of the oil sump only at this frequency range.
- The SI analyses at the frequencies covered by octave filters with central frequencies of 2 and 4 KHz show that, again, the oil sump is the main source of noise.

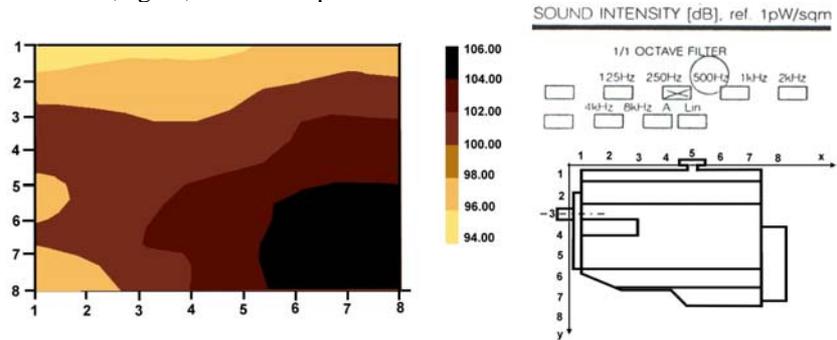


Figure 6. Engine's sound intensity – 1/1 octave filter,  $c_f = 500$  Hz

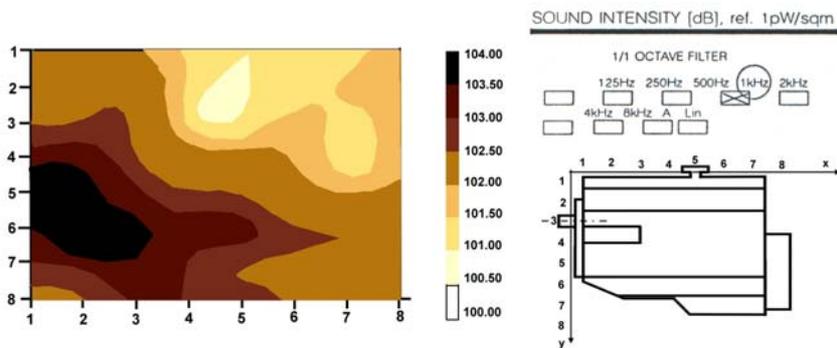


Figure 7. Engine's sound intensity – 1/1 octave filter,  $c_f = 1$  kHz

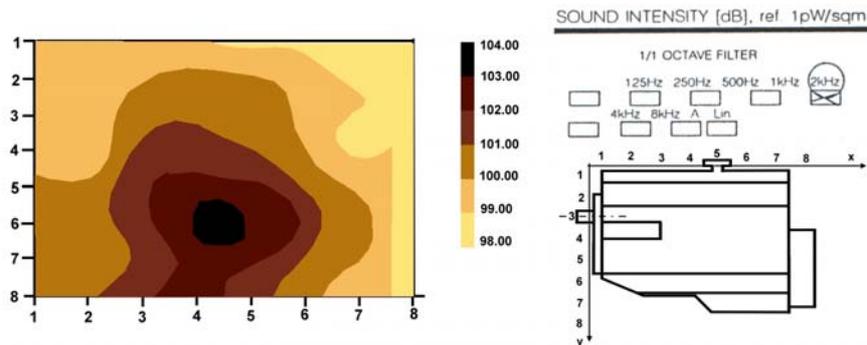


Figure 8. Engine's sound intensity – 1/1 octave filter,  $c_f = 2$  kHz

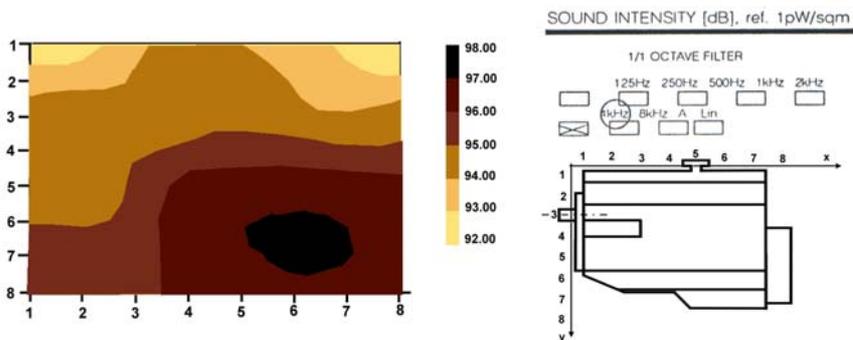


Figure 9. Engine's sound intensity – 1/1 octave filter,  $c_f = 4$  kHz

#### IV. Rational approach to noise reduction

The rational approach to noise reduction has to be based on proper redesign of the oil sump as it was already shown. Also, the connection between oil sump and the crank case has to be improved.

Further noise reduction can be done with passive protection i.e. shielding. The shielding material needs to have the greatest attenuation in frequency range where the greatest sound power is emitted. For particular engine these are the frequencies 500 Hz and 1 KHz (see fig. 6, and 7). There is also, a significant emission in the lower frequency range (< 500 Hz) but it is not of great influence to reduce noise in that band based on the "A" curve character. Finally, as the oil sump is the dominant source especially at the frequencies above 1 KHz and having in mind that it has to be redesigned it is not necessary to use shielding for the oil sump.

The new designee was done based on given analyses and FE study of the oil sump. The applied concept was based on "deep skirt crankcase" with dramatically redesign of the oil sump. Actually, to prevent total redesign of the crankcase (with a purpose to make it's bottom part more rigid and prevent vibrations transfer to the oil sump) the whole oil sump was divided in a two parts. The first part became the extension of the crankcase and it's purpose was to reduce vibration propagation to the oil sump. The second part was the new designed oil sump with reduced radiation surface, high duping and improved rigidity.

The results of said rational approach to the noise attenuation are given in the Fig. 10. It has to be noted that following results were achieved:

- The total sound power radiated from the engine was reduced from 102.9 dB (A) to 100.8 dB(A).
- The price and weight of the new designed engine was increased for less than 0.3% in comparison to the old design.
- Usage of SI enabled recognition of dominant sources, easy defining of appropriate way for noise reduction and significant reduction of the testing time.

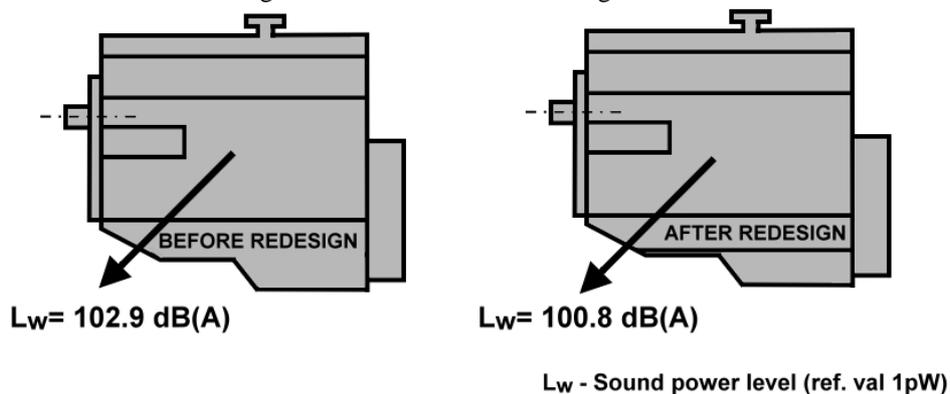


Figure 10. Comparison of the old (left) and redesigned engine

The most important achievement through out this noise reduction is that it was done only by one item i.e. subsystem redesign i.e. the one which was the chipset for redesign and which enables the total engine noise reduction at the sufficient level.

#### V. Conclusions

SI measurement approach to noise problem study enables a deep scope to the total sound power of the system and simultaneously i.e. based on the same measurement results, enables overview of different system's items contribution to the total noise level. This approach is accurate one and enables precise defining of effective route to system redesigning so as to achieve it's noise attenuation.

Results presented in the paper are related to noise attenuation on the diesel engine. It was shown that SI measurement and appropriate data evaluation enables easily allocation of the dominant sources. Also, it shows prediction of effect of particular part redesign i.e. preliminary calculation of redesigned object noise.

#### References

- [1] F.J. Fahy, "Sound Intensity", Elsevier Applied Science, London, 1989.
- [2] ISO 9614-1:1993, "Acoustics - Determination of Sound Power Levels of Noise Sources Using Sound Intensity- Part 1: Measurement at Discrete Points."