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Research on Expansion of Elastic Deformation Through the Structure of a Diesel Engine Using an Experimental Model Analysis and Sound Intensity Method

Predrag PETROVIĆ

Institut "Kirilo Savić",
Vojvode Stepe 51,
11000 Beograd,
Republic of Serbia

mpm@eunet.rs

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Preliminary note

A part research results concerning the proces of the diesel engine structural noise generation is presented in the article. The very proces of the internal combustion engine functioning initiates the energy creation in its parts which then excitate own modal oscillations of particular components and through their surfaces the sound is emited into the envinomment.
The researches were done by the authors own method for the application of sound intensity and experimental modal analysis. The results relating to the engine head, block and the single-part engine oil sump are presented.

Istraživanje rasprostiranja elastičnih deformacija kroz strukturu dizel motora korišćenjem eksperimentalne modalne analize i metode zvučnog intenziteta

Prethodno priopćenje

U ovom radu prikazan je dio eksperimentalnih istraživanja procesa generiranja strukturne buke dizel-motora. Sam proces rada motora s unutrašnjim izgaranjem inicira stvaranje energije u svojim sklopovima, koja pobuđuje vlastite modalne oscilacije pojedinih komponenata preko čijih površina se emitira zvuk u okolinu.
Istraživanja su, provedena uz vlastiti razvoj softvera, za primjenu metode intenziteta zvuka i eksperimentalne modalne analize, a rezultati su prikazani za glavu, blok i jednodijelno korito dizel-motora.

1. Introduction

Research work on the way noise is generated by internal combustion engines can be conducted in several directions. The first involves the combustion processes, including the gas flow during inlet and exhaust. The second direction of research relates to disturbance processes, such as moving parts, e.g., the crankshaft and pistons. The third group covers research on structure stiffness and damping (block, head, sump, etc.). The timing gear, auxiliary mechanisms and aggregates represent another group or course of research work in the field of engine noise.

The scope of the research in this work is the noise generation process in the engine structure, caused by moving parts, i.e., the crankshaft with the piston mechanism.

The research was carried out at Industrija motora Rakovica of Belgrade on a 4-cylinder diesel engine. The aim of the research was to make modifications to desing solutions on the basis of the developed mechanism of noise generation in order to reduce the noise levels.

In this work a correlation of results is shown by applying an experimental modal analysis and a sound intensity on block method, single-sump and head of diesel engine.

2. Noise spectrum generated by engine assemblies

All noise excitations in diesel engines can be classified into three groups. The first group imcludes, dynamic forces caused by engine running (change in pressure during the combustion process, unbalanced inertial forces, variable torques, forces arising form non-uniformity of the working process, etc.)

The second group involves impact within design clearances (piston assembly, piston mechanism, valve timing, etc.):

The third group covers the excitations that may be caused by the operation of individual subassemblies and components (high-pressure pump, timing gear, water and oil pumps, fan intake and exhaust system alternator, flywheel, etc.):

The energy of disturbance is absorbed in the engine parts by impact, sliding, rolling, swirling, ets. A part of this energy is immediately transformed into sound waves (primary), and the other part excites modal vibrations of the parts amplifying the secondary sound waves radiated in the environment. Individual vibrations are amplified by the waves as well spreading through the engine structure and together they bring about vibrations of external surfaces (block, sump, head, etc.) (Figure 1a) [1].

A stick for example excited by a strice – will simultaneously oscillate in such a way that almost all mentioned types of waves will be present. Besides the direct waves, there are refleced waves too. These are the waves that arrive from the point of introduction of the disturbance to the external surface (at the end of the stick), where they are reflected and return. Between the direct and reflected waves and those of various nature, there is an interference, weakening or intensification. These effects are different with distinct frequencies and in various zones of the stick.

Figure 1b shows secondary sound waves radiated in the environment due to expansion in combustion chamber diesel engine.

They are reflected from external surfaces and collide on to another. At due points of impact of waves of the same frequency, "division-walls", i.e. "standing waves" form. These partitions divide the oscillating zone into smaller sections. Figure 1c shows an approximate presentation of this division. In each of the zones (1 and 2), wave energy intensifies with resonance. The degree of intensification depends on the magnitude and shape of the comprised zone and on the characteristics of the material. From test results, it was established that intensifications in zone 1 are larger.

3. Experimental determination of modal responses of diesel engine parts

A modal response can be obtained experimentally by measuring the response of an excited machine part and by carrying out a frequency analysis. The engine parts were excited by a modal hammer with an accelerometer and on the basis of measured deceleration of the striking mass, the force of striking is obtained. On engine parts surface the response is measured by means of an accelerometer. Both accelerations, of excitation mass and response, are introduced into A/D converter and then in a computer, where a frequency analyses is carried out. The relationship of acceleration of response and excitation force, i.e. a / F, is calculated for each of the frequencies and is expressed in m/(N·s^2), [1].

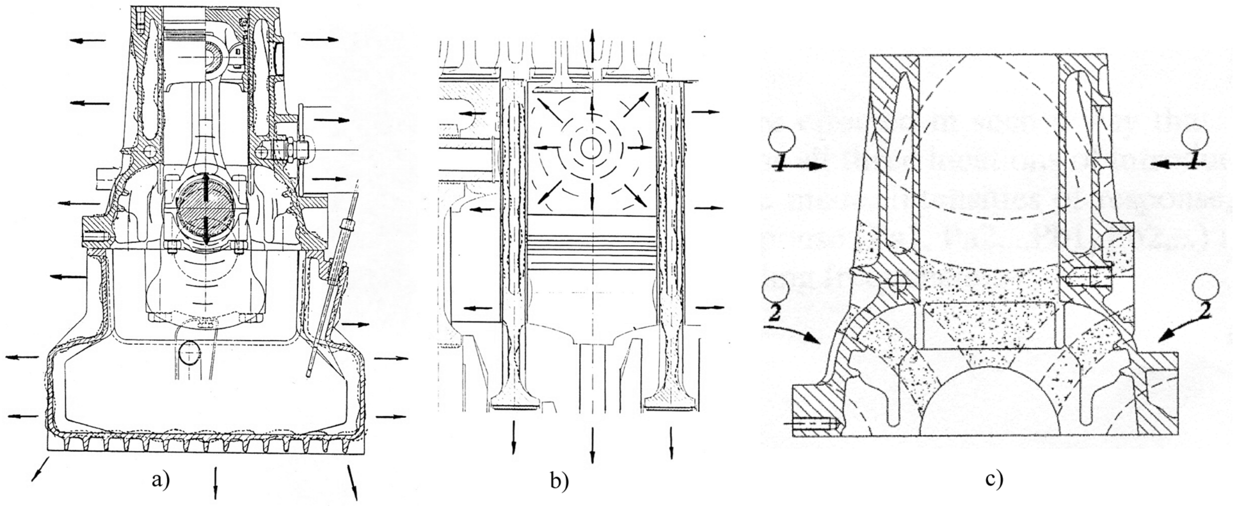

Figure 1. Expansion of elastic deformations: a) individual vibrations and secondary waves of engine block, b) due to expansion in combustion chamber c) division of machine part volume into oscillating zones at a given frequency

Slika 1. Širenje elastičnih deformacija: a) od konstrukcijskih zazora i sekundarnih valova, b) od ekspanzije u prostoru za izgaranje, c) oscilatorne obujamne zone strojnog dijela - blok dizel motora

3.1. Experimental determination of modal responses of diesel engine block

Figure 2 illustrates the layout of the spots on the engine block where excitation strokes were achieved and the spots where the response was measured. The strike was achieved on the supporting points of the crankshaft. At these locations, the strikes occur under real engine operating conditions as well. The locations of production of strikes were marked with letters a, b and c. The locations of response measurements were marked with nuumbers 1, 2, 3, 4 and 5.

The measurements were effected in such a way that the responses on the locations 1, 2, 3, 4 and 5 were measured for all three locations of introduction of the strikes (a, b, and c), i.e. fifteen measurements were made. Intensities of response *a/F* for these combinations of locations of excitation and response (Pa1, Pa2, ... Pb1, Pb2,....), [2].

The values of a / F are given for corresponding frequencies. Figure 3 shows the results chosen of the test.

The results of the test suggest that a natural frequency with the highest intensity of response does not depend on the location of introduction of excitation or on the location of measurement of response. The assumption presented in Figures 2 and 3, that at 2826 Hz frequency at least two zones of oscillation of engine block mass form. Can be accepted response intensity is higher in zone 1 (Figure 1c), (a / F = 2155 m/(N·s^2)), and lower in zone 2 (a / F = 1733 m/(N·s^2)).

Response intensity depends not only on the magnitude and shape of the oscillating zone but also on the position of the point where the excitation is introduced and where the response is measured. If the distance between these points is wider, it could be expected that the damping (attenuation) is higher. It did not happen because the measured response is not a disturbance wave that has lost its intensity on its path. The measured response is the total reaction of elastic environment to the excitation including also multiple reflection and resonance of the waves, [4]

3.2. Experimental determination of modal responses of an engine sump

For experimental determination of modal responses of the sump diesel engine, the method of impact by means of a modal hammer was used. Figure 4 illustrates the measuring points of excitation and response for sump, and Figure 5 illustrates the spectrum of modal responses of diesel engine sump.

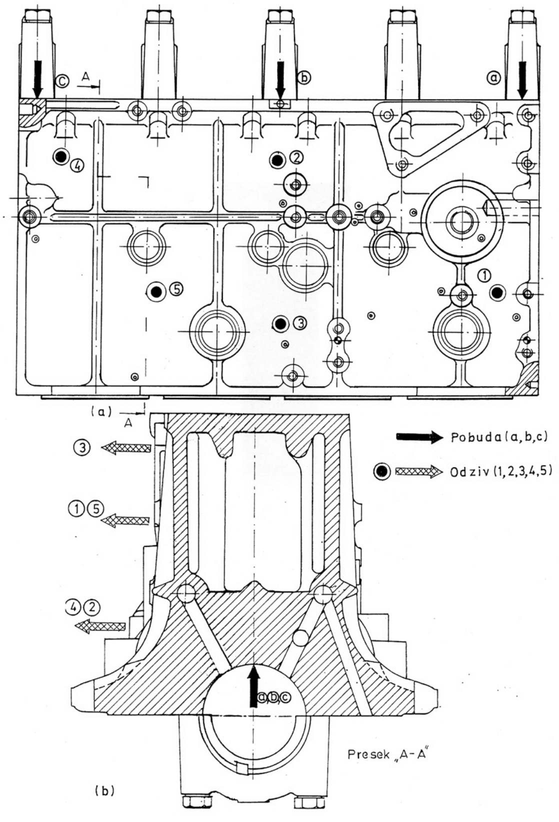

Figure 2. Measuring locations on diesel engine block
Slika 2. Mjerna mjesta na bloku dizel-motora

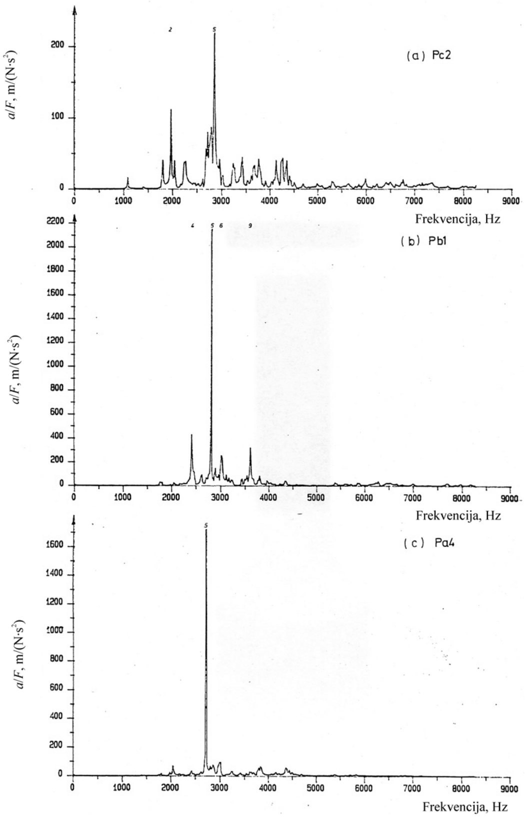

Figure 3. Diesel engine block modal response
Slika 3. Modalni odzivi bloka dizel-motora

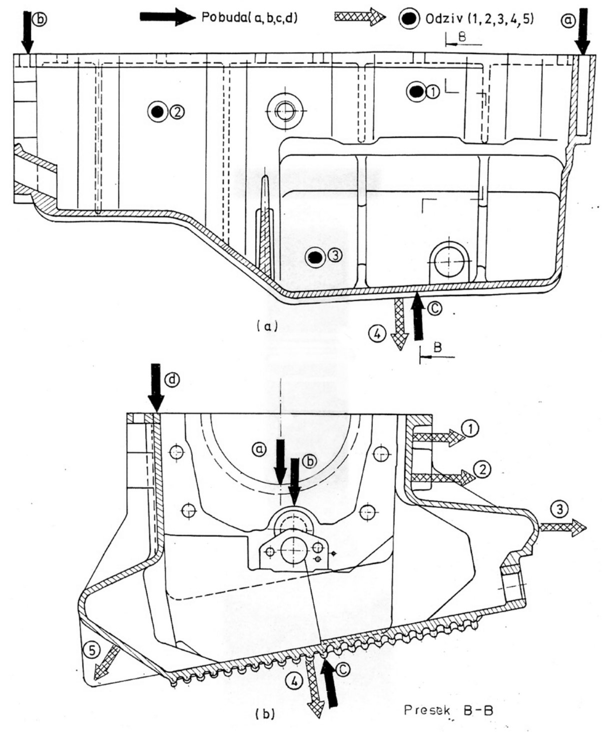

Figure 4. Measuring points of excitation for sump

Slika 4. Mjerna mjesta na jednodijelnom koritu za ulje dizel-motora

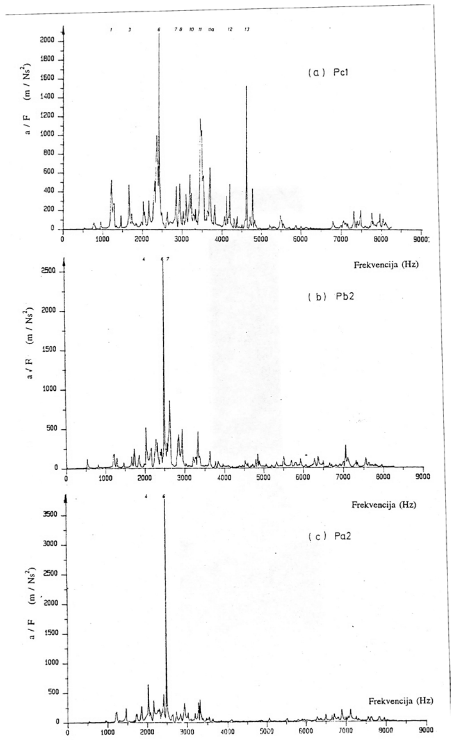

Figure 5. Spectrum of modal responses of sump of diesel engine

Slika 5. Modalni odzivi jednodijelnog korita za ulje dizel-motora

Oil sump has thin rib-stiffened walls. Excitation was carried out by strokes of a modal hammer on the flange form connection with the sump, and the response was measured from lateral sides. Several frequencies were obtained for which the response level was standingly out high. These are the frequencies 2400, 3500 and 4600 Hz.

These frequencies were included in a way that, after the impact from the very stroke zone, primary sound waves having a frequency equal to individual frequency of the parts directly involved in the impact spread. All of these frequencies represent together a natural part of the spectrum of a unified sound pressure level of 1-8 kHz. Therefore, other additional testings are necessary in order to study in detail the mechanism of the ring sound in the structure of such a complex mechanical system. That is the analysis of motion of disturbance waves through engine parts by applying the final element method which is not included in this work. Another possibility is to locate the points in space from where sound waves of corresponding frequencies come.

3.3. Experimental determination of modal responses of head engine

For experimental determination of modal responses of the head diesel engine, the method of impact by means of a modal hammer was used. Figure 6 illustrates the measuring points of excitation and response for head, and Figure 7 illustrates the spectrum of modal responses of head of diesel engine.The measurements were effected in such a way that the responses on the locations 1, 2, 3 and 4 were measured for all three locations of introduction of the strikes (a, b and c). The values of a / F are given for corresponding frequencies.

The results of the test suggest that a natural frequency with the highest intensity of response does not depend on the location of introduction of excitation or on the location of measurement of response.

The assumption presented in Figure 8 that at 2826 Hz frequency at two zones of oscillation of engine block can be accepted, [6].

Response intensity is higher in the zone 1 (a / F = 2155 m/(N·s^2)), and lower in zone 2 (a / F = 1733 (m/N·s^2)).

In the zone single sump the response is higher a/F=4556 m/(N·s^2)), at 2174 Hz. and (a / F = 3765 m/(N·s^2)), at 2522 Hz. In the zone head diesel engine the response is higher (a / F = 462,5 m/(N·s^2)), at 1381 Hz, [9].

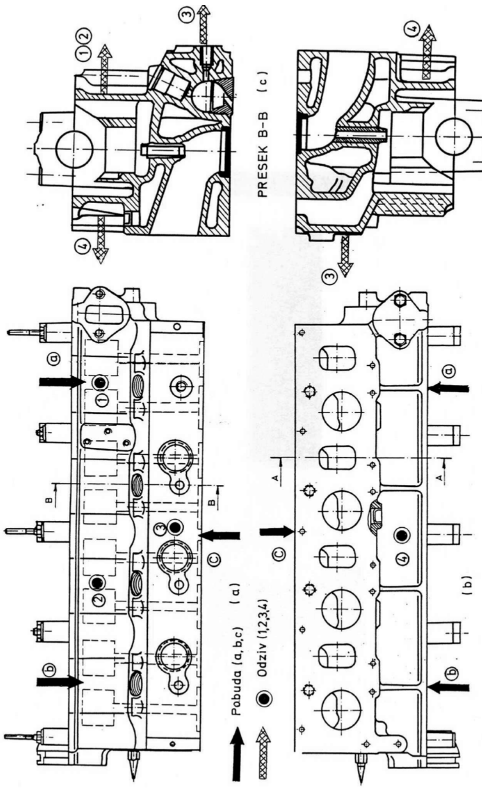

Figure 6. Measuring points of excitation for head of diesel engine

Slika 6. Mjerna mjesta na glavi dizel-motora

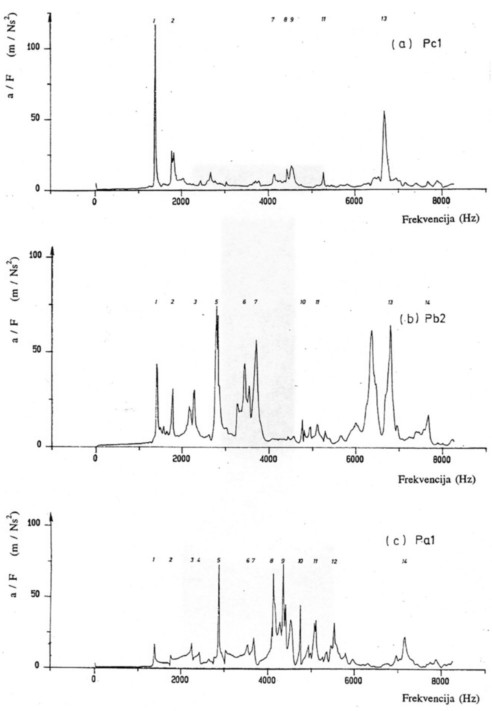

Figure 7. Spectrum of modal responses of head of diesel engine

Slika 7. Modalni odzivi glave dizel-motora

4. Applying sound intensity method in area of dominant noise of diesel noise

The method of sound intensity is of recent data and its application is multiple from the aspect of research of sound objects and of determination of the contribution of single areas of sources in the total emission of acoustic energy. With previous definition of the sound object, operating conditions measuring network, load distance of the micropfone from the measuring surface, etc, the measurements were carried out for each central frequency of the octave filter, as well as on “A” and on “Lin”, scale.

By analysing the obtained results, an experimental modal analysis and sound intensity in the area of parts diesel engine (cylinder block, head and sump), it is possible to establish the correlation of modal responses and sound emission in the environment, [2].

Figure 9a shows the sound map at 250 Hz, Figure 9b shows the sound map at 1 kHz and Figure 9c shows the sound map on “A” scale.

The character of layout of values for the general level of sound intensity is similar to the character at the frequency of 250 Hz with the dominant area in the lower

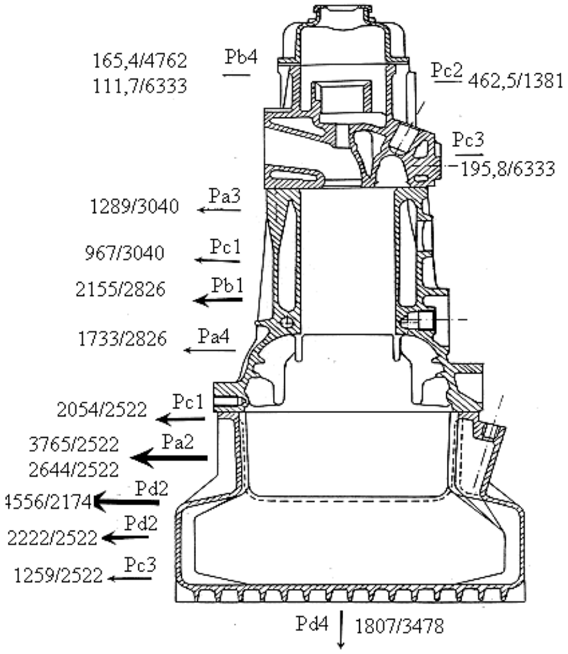

Figure 8. Maximalni modal responses of diesel engine structure (m/(N·s^2), Hz)

Slika 8. Maksimalni modalni odzivi strukture dizel-motora, (m/(N·s^2), Hz) central part the engine in zones (Y5-Y7) and (X4-X8) of the oil sump and along the connection of oil sump and block, (96-100 dB).

The character at the frequency of 1 kHz with the dominant area in the lower part of the engine (Y4-Y7) and (X1-X4) of the oil sump and along the connection of oil sump and block, (101-102,5 dB).

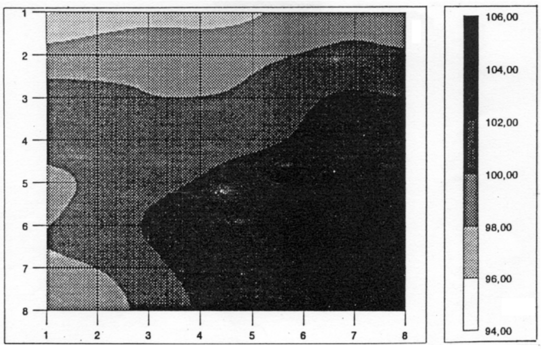

Figure 9a. Sound intensity level of diesel engine with single piece oil sump at 250 Hz

Slika 9a. Nivo zvučnog intenziteta dizel-motora s jednodijelnim koritom pri 250 Hz

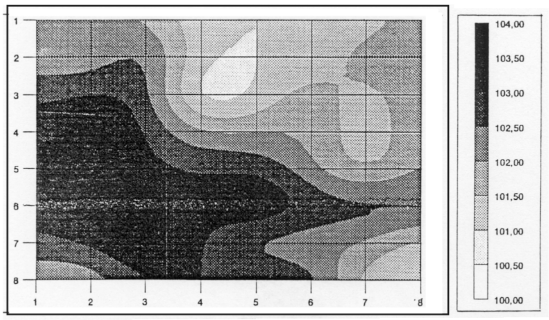

Figure 9b. Sound intensity level of diesel engine with single piece oil sump from at 1 kHz

Slika 9b. Nivo zvučnog intenziteta dizel-motora s jednodijelnim koritom pri 1 kHz

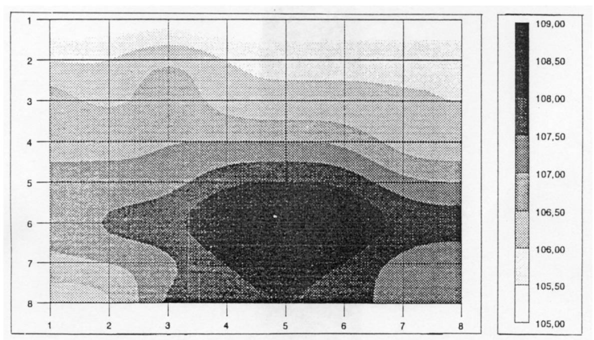

Figure 9c. Sound intensity level of diesel engine with single piece oil sump at as per "A" scale

Slika 9c. Nivo zvučnog intenziteta dizel motora s jednodijelnim koritom po ljestvici "A"

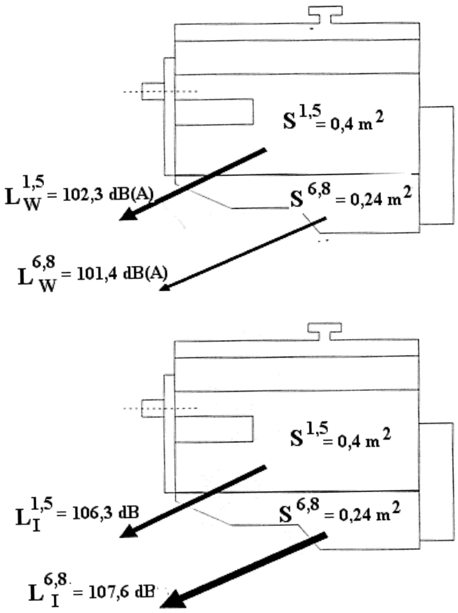

Figure 10. Sound intensity and sound power of block and single-piece oil sump areas of diesel engine at full output n = 4200 min^{-1}, $S_{1,5}$ = 0,4 m^2 and $S_{6,8}$ = 0,24 m^2

Slika 10. Zvučni intenzitet i zvučna snaga motora u zoni bloka i korita pri punoj snazi n = 4200 min^{-1}, $S_{1,5}$ = 0,4 m^2 and $S_{6,8}$ = 0,24 m^2

At a distance of 1 m at 4200 rpm. the general level of emission noise is 105,5-106,5 dB(A), in zones (Y5-Y7) and (X4-X6).

The input of spectra in Figures 1 and 2 with higher frequencies is combined from the engine parts natural frequencies. Besides block and sump' natural frequencies the frequencies of crankshafts flywheels connecting rods, oil pumps and other parts were comprised. These frequencies were included in such a way that, after the impact from the very stroke zone, primary sound waves having the frequency equal to individual frequency of the parts directly involved in the impact spread.

In Figure 10 it can be seen that the sound intensity in the area of connection of sump and block and sump of the engine is higher compared to the upper part of engine block and head. A similar conclusion applies to the sound power of the same area. Thus, it suggests that the areas of sump and the areas of connection of sump and block of the engine have a significant influence on the total emission of diesel engine noise. This can be attributed to the amplified excitation in this area, individual activity of sump and block and insufficient isolation, [6].

5. Conclusion

Elastic disturbers achieved on the surfaces of machine parts spread through their mass as waves of different nature. These waves excite natural oscillation of the mass, which occur in particular inter-separated zones. This division is different at each natural frequency. By modal test a natural frequency can be obtained. The values of natural frequencies do not depend on the spot of introduction of disturbance and measurement of response. Response intensity depends on the position of these spots, direction and intensity of excitation.

The response is of higher intensity, if the zone comprised by the oscillation is larger, if the measuring point is near the center of this zone (further away from the standing waves) and if it is more from the spot of introduction of excitation.

Abundant and various experiments and analyses concerning the structural noise of an IMR diesel engine suggest as follows:

1. The level of mechanical noise is close to the total noise level of the engine under full-load conditions. At a distance of 1m, at 4200 rpm. the general level of mechanical noise is 104 dB(A) and that of the loaded engine during the combustion process is 105 dB(A). This suggests that the share of mechanical noise in the total noise is significant. When the clearances are increased, mechanical noise level can be considerably increased.
2. The spectrum of mechanical noise is divided into the part with forced frequencies (strokes) and into the part with engine parts natural frequencies. The highest level is in forced part of the spectra, for the octave whose medium frequency is 125 Hz. The frequency of the highest noise level approximately coincides with frequency of strokes in the main bearing clearances.
3. For all octaves in the spectrum, sound maps are made by the intensity sound method. They show that the highest intensity noise penetrates from the crankshaft area. In this area, impacts occur in bearing clearances. In this area, wall stiffness is the lowest and amplified individual vibrations occur. There is an air space in this internal area of the engine. In this space, air noise increases and passes through relatively thin walls.

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