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Uporaba zvočne jakosti in preizkusne načinovne analize za določitev hrupa dizelskega motorja

The Application of a Sound-Intensity Analysis and an Experimental Modal Analysis for Determining the Noise Emissions of a Diesel Engine

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Motor z notranjim zgorevanjem predstavlja večkratno vzbujan vir vibracij in hrupa, ki izvira iz sestavov, katerih delovna energija se spremeni v energijo zvočnega valovanja. Energija, ki jo absorbira sestav motorja, vzbuja lastna nihanja večjih motornih delov (blok motorja, zbiralnik olja, glava valja itn.), skozi katerih površine seva zvok.

Za določitev stopnje zvočne emisije v posameznih delih motorja pri različnih hitrostih delovanja so bile narejene podrobne analize v podjetju "Industrija motora Rakovica" iz Beograda, z uporabo preizkusne načinovne analize in zvočne jakosti. V tem pomenu je bila ugotovljena povezava med lastno frekvenco in emitiranim zvokom na posameznih zunanjih površinah motorja.

Del rezultatov, dobljenih med temi raziskavami, je predstavljen v tem prispevku.

(Ključne besede: dizelski motorji, emisija hrupa, zvočna jakost, načinovna analiza)

The internal combustion engine represents a multi-exciting source of vibration and noise that originates from its assemblies, and whose energy of operation is transformed into sound-wave energy. The energy absorbed in the engine's structure excites the natural modal oscillations of the larger engine parts (cylinder block, oil sump, cylinder head, etc.), through whose surfaces the sound is radiated.

To determine the level of emitted sound in individual areas of the engine at various running speeds, detailed research was carried out at Industrija motora Rakovica of Belgrade using experimental modal analyses and sound-intensity measurements. In this way a correlation was made between the natural modal frequencies and the emitted sound from particular external areas of the diesel engine.

Some of the results obtained in the course of these investigations are presented in this paper.

(Keywords: diesel engine, noise emissions, sound intensity, modal analysis)

0 UVOD

Raziskovalno delo pri pojavu nastajanja zvoka v motorjih z notranjim zgorevanjem poteka v več smereh. Prva obsega zgorevalni postopek, vključno s plinskim tokom skozi dovod in izpuh. Druga smer v razvoju se nanaša na moteče pojave, kakršni so udarci, drsenje, resonance gibljivih delov, npr. kolenasta gred, bati in podobno. Tretja skupina pokriva raziskave sestavne togosti in dušenja (blok, glava, zbiralnik itn.). Pogon odmične gredi, pomožni mehanizmi in agregati predstavljajo še eno skupino ali smer raziskovalnega dela na področju hrupa motorjev.

0 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 the impacts, the sliding, and the resonance of the moving parts, e.g., the crankshaft and the 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.

Področje raziskav v tem prispevku je pojav nastanka hrupa v sestavu motorja, ki ga povzročajo premični deli, na primer kolenasta gred z batnim mehanizmom.

Raziskave so bile narejene pri podjetju "Industrija motora Rakovica" na S54 visokem štirivaljnem dizelskem motorju. Namen teh raziskav je bila sprememba v konstrukcijskih rešitvah osnov razvitega mehanizma nastanka zvoka, da bi zmanjšali stopnjo hrupa.

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

The research was carried out at Industrija motora Rakovica of Belgrade on a S54 high 4-cylinder diesel engine. The aim of the research was to make modifications to the design solutions on the basis of the developed mechanism of noise generation in order to reduce the noise levels.

1 SPEKTER HRUPA, KI GA USTVARJA MOTORNI SESTAV

1 THE NOISE SPECTRUM GENERATED BY ENGINE ASSEMBLIES

1.1 Izvir zvoka

Slika 1a) prikazuje sestav motorja, ki je namenjen tem raziskavam. Sestoji iz bloka motorja, kolenaste gredi z vztrajnikom, štiribatnim mehanizmom in oljnim zbiralnikom z mazalno črpalko.

Sestav poganja električni motor s spremenljivo kotno hitrostjo. Vseeno je mogoče simulirati delovni pojav in nastanek hrupa v področju motorja. Udarne sile se povečujejo s povečevanjem kotne hitrosti in večanjem zračnosti. Med delovnim postopkom se sile povečajo zaradi tlaka zgorevalnega plina. Vendar je hkrati sunek med zračnostmi na splošno odvisen od vztrajnosti, ki postane bolj intenzivna zaradi vibracij kolenaste gredi. Zaradi lastnih vibracij se kolenasta gred elastično deformira s povečanjem moči teh sunkov.

Pojav nastanka zvočnih valov, povzročen s sunki v ležajih in podobnimi motnjami, je zapleten. Lahko ga razdelimo v naslednje faze:

1. Primarni zvočni val nastane pri točki sunka z neposrednim stikom bližnjih površin. Ta zvok se širi skozi okolišni prostor v motorju, še posebej v zbiralniku olja. Tu se ojači z resonanco in prodre skozi zbiralnik olja in blok motorja v okolico (sl. 1a).
2. Iz točke sunka se energija prenese na zunanje površine bloka in zbiralnika olja. Prenos poteka z elastičnimi deformacijami, ki se širijo kot valovi. Ko val doseže zunanje površine, se energija prenese na okolico kot zvočni valovi (sl. 1b).
3. Valovi elastičnih deformacij vzbujajo lastne (modalne) vibracije. Načinovne vibracije bloka motorja in oljnega zbiralnika so

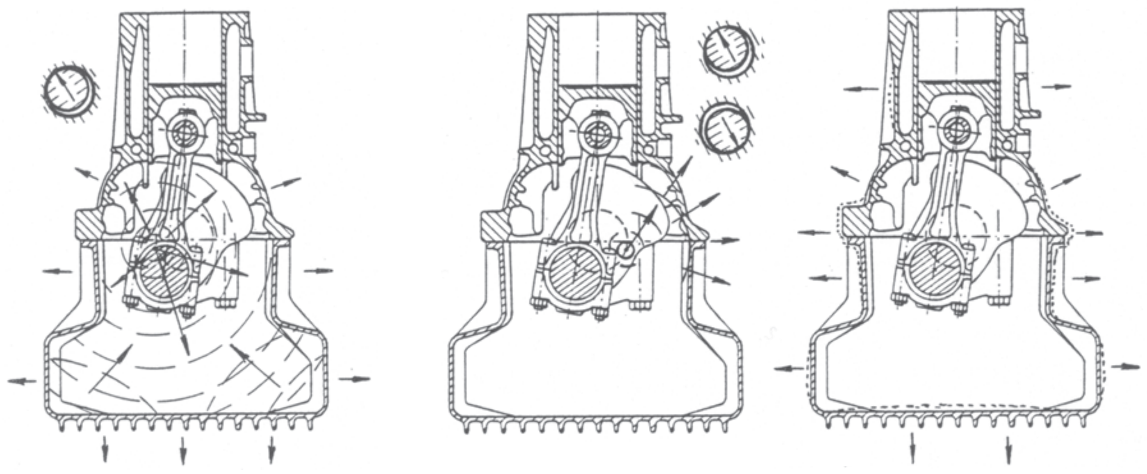
1.1 Noise excitation

Figure la shows the engine assembly that was the subject of these examinations. It consists of an engine block, a crankshaft with a flywheel, four piston mechanisms, and an oil sump with a lubrication pump.

The assembly is operated by an electric motor with a variable angular speed. Nevertheless, it is possible to simulate the operation process and the noise generation in this engine area. Impact forces increase with the angular speed and with the clearance magnitude. During the working process, because of the combustion gas pressure, the forces are increased, but the impact within the clearances generally depends on the inertia, which becomes more intensive due to crankshaft vibrations as well. Because of its own vibrations, the crankshaft elastically deforms with the increase in the intensity of these impacts.

The process of sound-wave generation, caused by the impacts in the bearings and by similar disturbances, is complex. It can be divided into the following stages:

1. Primary sound waves occur at the point of impact in the direct contact of contiguous surfaces. This sound spreads through the enclosed space in the engine, especially in the oil sump. Here, it is amplified by the resonance and penetrates through the engine sump and block walls into the environment (Fig. 1a).
2. From the impact point, energy is transmitted to the external surfaces of the block and the sump. The transmission is carried out by means of elastic deformations spreading as waves. When a wave reaches the external surfaces, the energy is transmitted to the surroundings as sound waves (Fig. 1b).
3. The waves of elastic deformation excite the engine parts' natural (modal) vibrations. The modal vibrations of the engine block and the oil sump are the most



Sl. 1. *Sestav testnega motorja in pojav nastanka hrupa: a) sunek v reži ročičnega ležaja in primarno nastajanje hrupa, b) sunek v reži kolenaste gredi in nastanek valov v elastični sestavi motorja, c) lastna nihanja motorja in drugotno nastajanje hrupa*

Fig. 1. *The tested engine assembly and the process of noise generation: a) impact in the clearance of the connecting-rod bearing and the primary noise generation, b) impact in the clearance of the crankshaft bearing and the wave generation in the elastic structure of the engine, c) natural vibrations of the engine structure and secondary noise generation*

najpomembnejše. Ta dva dela imata velike površine, ki oddajajo zvok in sta v neposrednem stiku z okolico. Tako se oddajajo zvočni valovi s frekvenco, ki je enaka njihovi lastni frekvenci sten teh delov. Slika 1c) prikazuje vibracije in zvok nastale na ta način.

1.2 Meritve hrupa ločenih motornih sestavov

Motorni sestavi s slike 1 so bili preizkušeni v brezodmevnem prostoru. Pogon je bil izveden iz sosednjega prostora z uporabo električnega motorja s spremenljivo kotno hitrostjo. V brezodmevnem prostoru je bil tlak merjen 1 m stran od testnega predmeta.

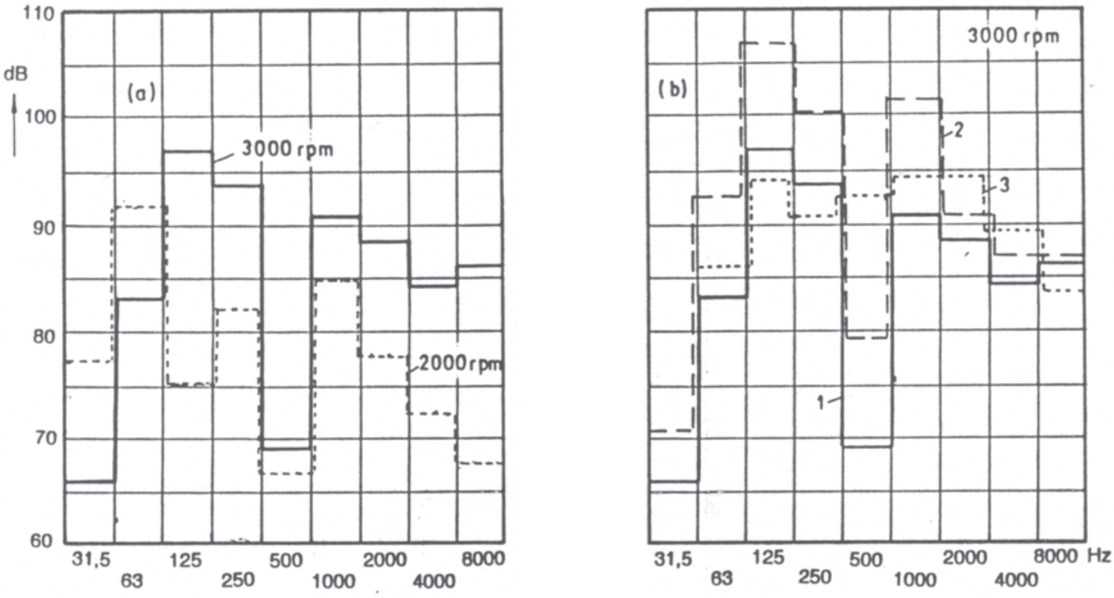
Slika 2 prikazuje spekter hrupa v različnih preizkusnih razmerah. Na sliki 2a) sta primerjana spektra hrupa oddana iz motornih sestavov (sl. 1) pri dveh hitrostih vrtenja. Slika 2b) vsebuje primerjavo spektrov hrupa, ki ga oddaja sestav motorja (črta 1), spekter hrupa, ki ga oddaja celoten od zunaj gnan motor (črta 2) in spekter hrupa avtomobilskega motorja z zgorevanjem pri polni obremenitvi (črta 3). Na podlagi primerjav zapisanih spektrov lahko naredimo naslednje sklepe.

important. These parts have large surfaces to emit the sound and are in direct contact with the surroundings. In this way, sound waves are emitted, the frequencies of which are equal to the individual frequencies of the walls of these parts. Figure 1c, designates the vibration and sound generated in this way.

1.2 Measurement of the noise of a separate engine assembly

The engine assembly shown in Figure 1 was tested in an anechoic chamber. The propulsion was effected from an adjacent room by means of an electric motor with variable angular speed. In the anechoic chamber, the acoustic pressure was measured at a distance of 1 m from the tested object.

Figure 2 illustrates the noise spectra for different experimental conditions. In Figure 2a is a comparison of the noise spectrums emitted by the engine assembly (Fig.1) for two rotation speeds. Figure 2b contains a comparison of the noise spectra emitted by the engine assembly (line 1), the noise spectra emitted by the complete externally operated engine without combustion (line 2), and the noise spectra of the automotive engine with combustion under full-load conditions (line 3). On the basis of the comparison of the spectra of registered noise, the following conclusions can be drawn.



a) b)

Sl. 2. *Spektri hrupa: a) motorni sestav, predstavljen na sliki 1, b) celoten od zunaj gnan motor v primerjavi s spektrom hrupa motornega sestava (1 s slike a) in avtomobilski motor z zgorevanjem pod polno obremenitvijo (3)*

Fig. 2. *The noise spectra of: a) the engine assembly presented in Fig. 1, b) the complete engine driven externally (2) in comparison with the noise spectrum of the engine assembly (1 - from Fig.a) and the noise spectrum of the automotive engine with combustion under full-load conditions (3)*

1. Spekter hrupa, ki ga oddajata kolenasta gred in batni mehanizem v bloku motorja, je razdeljen v dva ločena pasova. V nizkofrekvenčnem območju se frekvenca visokih stopenj hrupa ujema s frekvenco sunka v glavnem ležaju. V visoko frekvenčnem področju se frekvenca hrupa približno ujema z lastno frekvenco kosa. Nizkofrekvenčni pas predstavlja vsiljeni del spektra, visokofrekvenčni pa lastni del spektra.
2. S povečanjem kotne hitrosti (iz 1000 na 4200 vrt/min) se frekvenca sunka poveča, kar lahko vidimo na vsiljenem delu spektra: najvišja raven zvočnega tlaka je pri 2000 vrt/min v oktavi od 63Hz in v 125Hz pri 3000 vrt/min (sl. 2a). Oblika lastnega dela spektra ni spremenjena, ker lastna frekvenca delov motorja ni odvisna od frekvence vzbujanja.
3. Oblika spektra hrupa (črta - sl. 2b) dobljena z motornim sestavom, predstavljenim na sliki 1, je enaka kakor spekter hrupa v celoti zunanje gnanega motorja (črta 2 - sl. 2b). Kaže, da so vztrajnostne sile in sile zaradi sunka v reži v glavnem ležaju najpomembnejše motnje, ki

1. The spectrum of noise emitted by the assembly of the crankshaft and the piston mechanism in the engine block is divided into two separated bands. In the low-frequency range the frequency of the high noise levels is approximately the same as the frequencies of impact in the main bearings. In the high-frequency band, the noise frequency is approximately the same as with the parts' natural frequencies. The band of lower frequencies represents a forced part of the spectrum, and that of the higher frequencies represents a natural part.
2. With an increase in the angular speed (from 1000 to 4200 rpm.) the frequency of the impacts increases, which can be seen in the forced part of the spectrum: the highest level of sound pressure is at 2000 rpm in the octave of 63 Hz, and in the 125 Hz range at 3000 rpm (Fig. 2a). As a result, the shape of the natural part of the spectrum is not changed, because the frequency of the engine parts' natural vibrations does not depend upon the frequency of excitation.
3. The shape of the noise spectrum (line - Fig. 2b) generated by the engine assembly presented in Figure 1 is the same as the noise spectrum of the complete engine driven externally (line 2 - Fig. 2b). It shows that the inertial forces and the impact forces

povzročajo hrup. Oddajanje tega hrupa je odvisno od frekvence in dušilnih lastnosti bloka, zbiralnika in podobnih motornih delov. Stopnja hrupa celotnega motorja je odvečna energija, zapravljena z udarci v celotni strukturi in s utripanjem tlaka.

4. Stopnja hrupa celotnega zunanje gnanega motorja je nekoliko manjša od hrupa avtomobilskega motorja pod polno obremenitvijo (črta 3 - sl. 2b). Med zgorevanjem so sunki v režah dušeni. V primerjavi z od zunaj gnanim motorjem je absorbirana energija v sestavi motorja razsipana.

in the clearances in the main bearings are the most important disturbances causing the structural noise. The emission of this noise depends on the frequency and the damping characteristics of the block, the sump and similar engine parts. The noise level of the complete engine is higher because of the energy absorbed by impacts in the complete engine structure and by the pressure pulsation.

4. The noise level of the complete engine, driven externally, is somewhat higher than the noise level of the automotive engine under full-load conditions (line 3 - Fig. 2b). During the combustion, the clearance impacts and the parts' inertial forces are dumped. In comparison with the engine driven externally, the absorbed energy in the engine structure is distressed.

2 FREKVENČNA ANALIZA

2.1 Vzbujane frekvence

V frekvenčnem spektru posnetega hrupa (sl. 2), so zvočne tlačne stopnje povečane pri prvih treh oktavah (31,5; 63 in 125 Hz) z namenom, da se najvišja stopnja premakne na višjo oktavo (iz 63 na 125 Hz) s povečanjem vzbujane frekvence. Frekvenca najvišjih stopenj hrupa v vsiljenem delu spektra se ujema z vzbujano frekvenco.

V vseh spektrih je najnižja zvočna tlačna stopnja pri oktavi s srednjo frekvenco 500Hz. Ta oktava jasno ločuje vsiljeni del spektra od vzbujanega. Zato so ti spektri zelo značilni. V drugih mehanskih sistemih se delno prekrivajo ali so oddaljeni drug od drugega , kar jih naredi neprimerne za primerjavo.

2.2 Lastne frekvence

V frekvenčnih spektrih oddanega hrupa, prikazanih na sliki 2, se območje nad 1000 Hz ne spremeni ne po legi ne po obliki. Spreminja se samo velikost zvočnega tlaka. To dokazuje, da so zvočni valovi v tem delu spektra posledica lastnih nihanj delov motorja. Da bi to izboljšali, so bile narejene obširne raziskave, še posebno na bloku in zbiralniku. Modalno testiranje je bilo izvedeno s sunkovitim vzbujanjem in merjenjem vibracij kot odziva.

Primerjava je narejena med odzivom v obliki pospeška (a) in vzbujanja v obliki sile (F), dobljene z množenjem mase kladiva in njegovega pospeška ob udarcu. Slika 3 kaže frekvenčni spekter, dobljen na ta

2 FREQUENCY ANALYSIS

2.1 Exciting frequencies

In the frequency spectra of registered noise (Fig.2), the sound-pressure levels are increased for the first three octaves (31.5, 63 and 125Hz) with the tendency that the highest level moves to the higher octaves (from 63 to125Hz) with the increase of the impact frequency. The frequency of the highest noise level in the forced part of the spectra coincides with the impact frequency.

In all the spectra the lowest acoustic pressure level is in the octave with a mean frequency at 500Hz. This octave clearly separates the forced part of the spectrum from the natural. Therefore, these spectra are very characteristic. In other mechanical systems they partially coincide or are distant from one another, which makes them unsuitable for a comparison.

2.2 Natural frequencies

In the frequency spectra of the emitted noise shown in Figure 2, the area above 1000 Hz does not change its position or its shape during the change of operating conditions; only the magnitude of the acoustic pressure changes. This proves that the sound waves in this area of the spectrum occur due to the natural oscillation of the engine parts. In order to improve this, comprehensive examinations of the natural vibrations of the engine parts were made, especially of the block and the sump. The modal testing was carried out by excitation with the method of impact and by measuring the vibrations as a response.

A comparison was made between the response expressed in terms of acceleration (a) and the excitation in terms of force (F), obtained by multiplying the hammer način. Razmerje med odgovorom in vzbujanjem je na ordinati a/F izraženo z m/Ns^2 in s frekvenco na abscisi.

Blok motorja je bil vzbujen z načinovnim kladivom na podporah, kjer nalega kolenasta gred. To so mesta, kjer se pojavi vzbujanje v dejanskih obratovalnih okoliščinah. Odziv je bil merjen na bočni strani bloka. S premikanjem točke vzbujanja iz ležaja na ležaj in točke merjenja odziva, je bila največja intenzivnost odziva vedno na frekvenci 2800 Hz. Slika 3 prikazuje rezultat ene od teh meritev.

Zbiralnik olja je tankostenski z ojačitvenimi rebri. Vzbujanje je bilo izvedeno z udarci z načinovnim kladivom na prirobnico od povezave z blokom, hrup pa je bil merjen iz bočne strani. Dobljenih je bilo več frekvenc (sl. 3), pri katerih je bila stopnja odziva izredno velika. To so frekvence 2400, 3500 in 4600 Hz.

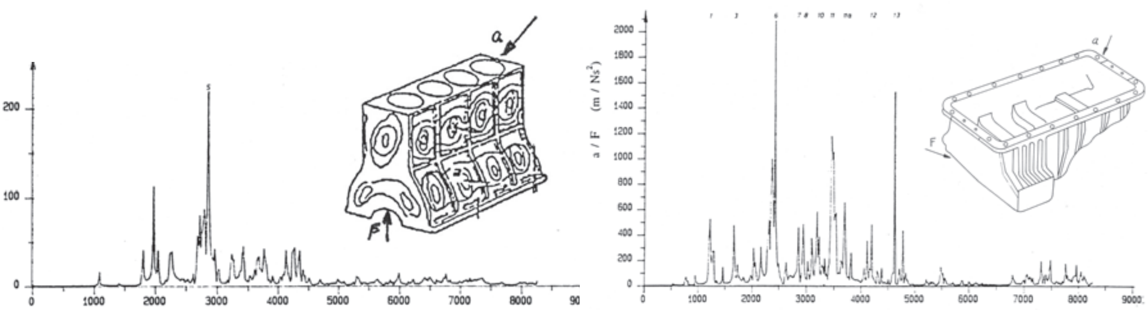
Vrhovi v visokofrekvenčnem področju spektra so sestavljeni iz lastnih frekvenc motornih delov. Poleg lastnih frekvenc bloka in zbiralnika so bile vsebovane še lastne frekvence kolenaste gredi, vztrajnika, ročic, oljne črpalke in drugih delov. Te frekvence so bile vključene tako, da se je po sunku iz cone sunka osnovni zvočni val razširil s frekvenco enako lastnim frekvencam delov, vpletenih v sunek neposredno. Vse te frekvence predstavljajo lastni del spektra enotskega zvočne tlačne stopnje od 1 do 8 kHz. Zato so potrebna dodatna testiranja, da bi podrobno preučili mehanizem izvira zvoka v strukturi tako zapletenega mehanskega sistema. To je analiza gibanja motilnih valov skozi dele motorja z uporabo metode končnih elementov, kar ni vsebovano v tem prispevku. Druga možnost je lociranje točk

mass and its acceleration at the impact. Figure 3 shows the frequency spectra obtained in this way. The response/excitation ratio is of the ordinate a/F, expressed in m/Ns^2 and the frequency on the abscissa.

The engine block was excited by modal hammer impacts on the supports where the crankshaft lies. These are the locations where the excitation is introduced during real operating conditions, too. The response was measured from the lateral sides of the block. By displacing the excitation point from bearing to bearing and the point response measurement, the highest intensity response was always for the 2800 Hz frequency. Figure 3 shows the result of one of these measurements.

The oil sump has thin rib-stiffened walls. The excitation was carried out by striking a modal hammer on the flange from a connection with the block, and the response was measured from the lateral sides. Several frequencies were obtained (Fig. 3b), for which the response level was extraordinarily high. These frequencies were 2400, 3500 and 4600 Hz.

The peaks in the high-frequency part of the spectrum in Figure 2 consist of the engine parts' natural frequencies. Besides the block's and the sump's natural frequencies the frequencies of the crankshaft, the flywheel, the connecting rods, the oil pumps and other parts were also recorded. These frequencies were included in such a way that, after the impact from the zone of the stroke, primary sound waves spread with frequencies equal to the natural frequencies of the parts directly involved in the impact. All of these frequencies together represent the natural part of the spectrum of the unified sound-pressure level from 1 to 8 kHz. Therefore, additional testing is necessary in order to study in detail the mechanism of the origin of the sound in the structure of such a complex mechanical system, i.e., the analysis of the motion of disturbance waves through engine parts by applying the final-element method, which is not included in this work. Another



a) b)

Sl. 3. *Izbrani rezultati načinovnih testov: a) za blok motorja, b) za zbiralnik olja*

Fig. 3. *Selected modal test results: a) for engine block, b) for engine sump*

v prostoru, od koder so zvočni valovi ustreznih frekvenc.

3 ANALIZA LOKACIJ ZVOČNIH VIROV V MOTORNEM SESTAVU

Za določitev prostorske razporeditve zvočnih valov ustreznih frekvenc, so bile izvedene meritve zvočne intenzivnosti celotnega motorja pri polnih obremenitvah. Meritve so bile narejene za vse oktave v frekvenčnem spektru in samo značilne so prikazane na sliki 4.

Slika 4 prikazuje porazdelitev zvočne jakosti za vsiljeni del spektra in točno za oktave s srednjo frekvenco območja pri 125 Hz in 250 Hz. Zvočna jakost je najvišja v oktavi s 125 Hz, največje vrednosti 110 dB (A) pa so sproščene v območju vrtenje kolenaste gredi.

Razpon najvišje zvočne jakosti se razprostira na desno stran. Ker je na tej strani vztrajnik, lahko predpostavimo, da so sunki v ležajih povečani zaradi večje mase. Jakost je večja v območju izpostavljenih delov oljnega zbiralnika. Lahko sklenemo, da so to zvočni valovi, ustvarjeni s sunkom, ki prodira skozi stene motornega zbiralnika.

4 SKLEP

Veliko različnih preizkusov in analiz v zvezi s strukturnim hrupom IMR S54 dizelskega motorja ponuja naslednje ugotovitve:

1. Stopnja mehanskega hrupa je blizu stopnji celotnega hrupa motorja pri polni obremenitvi.

possibility is to locate the points in space from where sound waves of corresponding frequencies come.

3 ANALYSIS OF THE LOCATION OF THE SOUND SOURCES IN THE ENGINE'S STRUCTURE

In order to determine the spatial layout of the sources of sound waves of corresponding frequencies, the measurements of the sound intensity of the complete engine under full-load conditions were made. The measurements were made for all octaves in the frequency spectrum, but only the typical ones are shown in Figure 4.

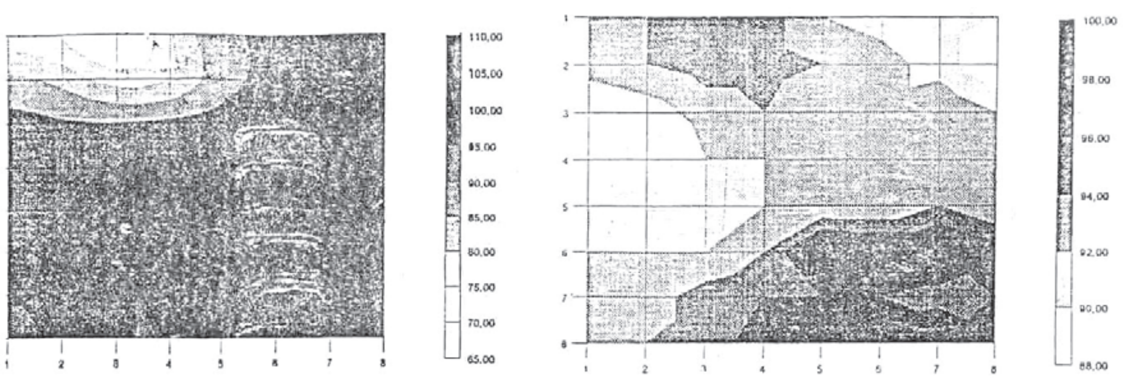
Figure 4 illustrates the sound-intensity maps for the forced part of the spectrum and precisely for octaves having the means of frequency range at 125 Hz and 250 Hz. The sound intensity is highest in the octave of 125 Hz, and the highest values of 110 dB(A) are found in the crankshaft's rotating area.

The range of the highest sound intensity spreads to the right-hand side. Since the flywheel is on that side, it may be supposed that the strokes in the bearings are amplified because of the increased mass. The intensity is higher in the area of the extended part of the sump. It can be concluded that these are the sound waves generated by the stroke, which penetrated through the engine sump's walls.

4 CONCLUSION

Our experiments and analyses concerning the structural noise of the IMR S54 diesel engine suggest the following:

1. The level of mechanical noise is close to the total noise level of the engine under full-load



Sl. 4. *Zvočni obrisi v vsiljenem delu spektra hrupa: a) oktava s srednjo frekvenco 125 Hz, b) oktava s srednjo frekvenco 250 Hz*

Fig. 4. *Sound maps in the forced part of noise spectrum: a) octave with the mean frequency of 125 Hz, b) octave with the mean frequency of 250 Hz*

Na razdalji 1 m, pri 4200 vrt/min je splošna stopnja mehanskega hrupa 104 dB(A), stopnja obremenjenega motorja med zgorevalnim postopkom pa je 105 dB(A). To kaže, da je delež mehanskega hrupa v celotnem hrupu pomemben. Če se poveča zračnost, se mehanska stopnja hrupa znatno poveča.

2. Spekter mehanskega hrupa je razdeljen v del z vsiljenimi frekvencami (sunki) in del z lastnimi frekvencami delov motorja. Najvišja stopnja vsiljenega dela spektra je na oktavi s srednjo vrednostjo 125 Hz. Frekvenca najvišje stopnje hrupa se približno ujema s frekvenco sunkov v zračnosti glavnega ležaja.
3. Za vse oktave v spektru je narejena porazdelitev zvoka po metodi zvočne jakosti. Te kažejo, da največja jakost hrupa prodira skozi območje kolenaste gredi. V tem območju se udarci dogajajo v zračnosti ležajev. V tem delu je togost stene najmanjša, zato se pojavijo ojačana lastna nihanja. Tam je zračni prostor v notranjem delu motorja. V tem prostoru se zračni hrup poveča in prehaja skozi sorazmerno tanke stene.

conditions. At a distance of 1 m, 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, the mechanical noise level can increase considerably.

2. The spectrum of the mechanical noise is divided into the part with forced frequencies (strokes) and the part with the engine parts' natural frequencies. The highest level is in the forced part of the spectra, for the octave with a medium frequency of 125Hz. The frequency of the highest noise level approximately coincides with the frequency of the strokes in the main-bearing clearances.
3. For all octaves in the spectrum, sound maps are made using the sound-intensity method. They show that the highest noise-intensity penetrates from the crankshaft area. In this area, the impacts occur in the bearing clearances. In this area the wall stiffness is the lowest, and amplified individual vibrations occur. There is an air gap in the internal area of the engine. In this space, the air noise increases and passes through relatively thin walls.

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