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Vpliv načina hlajenja valjev na oddajo hrupa

Influence of Cylinder Cooling on Engine Noise Emission

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Delovanje motorjev z notranjim zgorevanjem je močno povezano z oddajo nadležnega hrupa. Vzrokov in virov hrupa je mnogo. Del energije, ki se sprošča pri zgorevanju v valju motorja, se neposredno in posredno prenaša v okolico v obliki hrupa. Plašč hladila, ki obdaja zgorevalni prostor, lahko nekaj hrupa zadrži. V prispevku je prikazan vpliv oblike valja, izbranega hladila in pogojev za delovanje motorja na moč oddanega hrupa.

Ključne besede: motorji z notranjim zgorevanjem, hlajenje valjev, emisije hrupa, vplivi hlajenja

The operation of an internal combustion engine is normally accompanied by an unpleasant emission of noise. The noise has different origins; part of the energy that is released during the combustion process in an engine cylinder is emitted directly to the surroundings as noise. Part of this noise can be absorbed by the cooling jacket in the cylinder wall. The influence of the cylinder design, coolant applied and engine running conditions on the emitted noise level is described in the paper.

Keywords: internal combustion engine, cylinder cooling, noise emissions, influence of cooling

0 UVOD

Hrup, ki se sprošča pri delovanju motorjev z notranjim zgorevanjem, upravičeno prištevamo k onesnaževanju okolja. Zato je vsak poseg, ki vodi k zmanjševanju hrupa, dobrodošel. V tem prispevku so osvetljeni predvsem vplivi načina hlajenja valjev na velikost oddanega hrupa dizelskega motorja. Tekočinska pregrada, ki jo sestavlja hladivo v steni valja, lahko bolj ali manj zadrži, oziroma zaduši hrup, ki izhaja iz notranjosti motorja. Za lažje in natančnejše merjenje hrupa je pomembna že sama izbira motorja: njegova konstrukcijska izvedba, število valjev in razporeditev pomožnih agregatov, ki so nujno potrebni za nemoteno delovanje.

Eksperimentalne raziskave so bile opravljene na enovaljnem, štiritaktnem dizelskem motorju HATZ E79. Tako smo lahko izključili dodatne vplive, ki lahko popačijo meritve hrupa in razlago rezultatov. Enovaljni motor je omogočil dostop h glavnemu viru hrupa z vseh strani, poleg tega smo lahko z motorja začasno odstranili tudi tiste pomožne agregate in mehanske ovire, ki so preprečevali neposreden dostop do valja z vseh strani. Poleg osnovnega zračno hlajenega valja, sta bile motorju prigrajeni še dve različici ustreznega valja s tekočinskim hlajenjem (z vodo in oljem za mazanje motorja). Razmere za delovanje motorja so bili za vse tri izvedbe hlajenja popolnoma enake, kar je bil tudi osnovni pogoj za primerjalne analize.

0 INTRODUCTION

Noise emitted by operation of an internal combustion engine (ICE) is also a sort of environmental pollution, and any effort towards its decrease is warmly welcomed. The influence of the engine cylinder cooling art, application of different coolants on engine emitted noise is discussed in this paper. The liquid jacket around the cylinder liner can more or less absorb and restrain the emission of noise from the combustion chamber and the cylinder. Determination of the measured emitted noise generally depends on the engine design: its baseline design, number of cylinders, arrangement of necessary auxiliary systems, etc.

Experimental work was performed on a single-cylinder, 4-stroke and air-cooled Diesel engine HATZ E79. The single cylinder version made possible the omission of the major side-influences (noise sources) that could affect the results. This engine was also very convenient for the measurements around the periphery of the cylinder and along its longitudinal axis; consequently, some auxiliary aggregates (engine starter and some mechanical obstacles) could be temporarily removed during the measurement sequence. Measurements were performed at the same engine running conditions; the stabilised and equal running conditions made possible comparison of the results.

1 POTEK RAZISKAV IN POSTOPKI MERITEV

Za analizo učinka različnih vrst hlajenja in obratovalnih razmer na nastali hrup smo uporabili metodo merjenja zvočne intenzivnosti, ki omogoča določanje karakteristik (sliko sevanja in moč hrupa) vira hrupa v poljubnem zvočnem polju.

Izmerjeni spekter zvočnega tlaka je pokazal, da se pojavljajo vplivne ravni zvočnega tlaka v dB(A) na delu spektra med frekvencami 200 do 8000 Hz. Zato smo merili raven zvočne intenzivnosti v frekvenčnem območju od 10 Hz do 10 kHz.

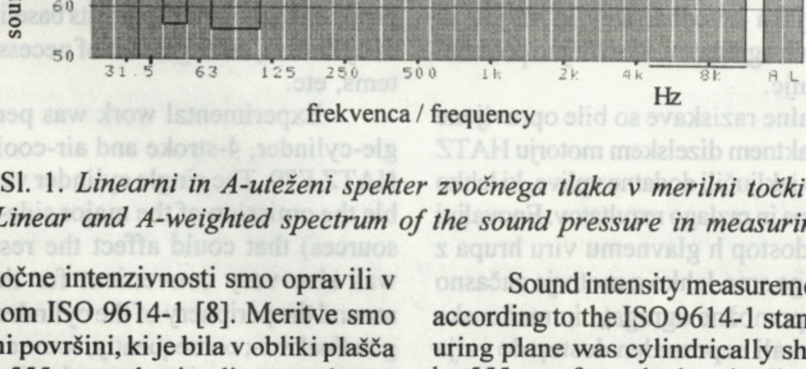
Iz primerjave med spektri z linearno skalo in spektrom z A-uteženjem, ki je na sliki 1 označen s poudarjeno ovojnico, lahko ugotovimo, da se pojavi ekstrem pri linearnem zvočnem spektru pri osnovni frekvenci procesa zgorevanja v motorju (pri imenski vrtilni frekvenci motorja je to pri 40 Hz). Ta vrh pomeni hrup zaradi sproščanja energije pri zgorevanju goriva in je celo za 5 dB višji kakor pri frekvencah 1600 in 2000 Hz, ki sta prevladujoči pri A-utežnem zvočnem spektru. Iz spektra z A-uteženjem, ki ga zaznava tudi človeško uho, lahko ugotovimo, da hrup zgorevanja pri 40 Hz lahko zanemarimo, saj je za 30 dB nižji od ravni hrupa pri prevladujočih frekvencah 1600 in 2000 Hz.

1 DESCRIPTION OF THE APPLIED EXPERIMENTAL METHODS

The method of sound intensity was applied to determine and to analyse the influence of different engine cooling systems, different coolants and engine running conditions on the emission of the generated noise. This method leads to the determination and characteristic (noise radiation pattern and noise power) of the noise source in a sound field.

The spectrum of the sound pressure level was measured to find out typical frequencies and influential sound pressure amplitudes. A frequency range between 200 Hz and 8 kHz was selected, and this made possible further measurements of the sound intensity level in the range between 10 Hz to 10 kHz.

Analysis of the results from figure 1 shows maximum amplitude at 40 Hz (linear scale), which corresponds to the basic frequency of the engine combustion process at its rated speed. This peak represents noise caused by release of the fuel energy during the combustion process. Its peak is higher by as much as 5 dB in comparison with the noise at 1600 and 2000 Hz. The noise spectrum must however follow the characteristic of the human ear: "A" weighting sound pressure level must therefore be applied (Bold black line in figure 1). We can therefore conclude from figure 1 that A weighted combustion noise at 40 Hz can be neglected because it is lower by 30 dB in comparison to the predominant amplitudes at 1600 and 2000 Hz.



Sl. 1. *Linearni in A-uteženi spekter zvočnega tlaka v merilni točki 1*

Fig. 1. *Linear and A-weighted spectrum of the sound pressure in measuring point 1*

Meritve zvočne intenzivnosti smo opravili v skladu s standardom ISO 9614-1 [8]. Meritve smo izvedli na nadzorni površini, ki je bila v obliki plašča valja s polmerom 555 mm od osi valja motorja. Po višini nadzorne površine so bile meritve opravljene v treh prečnih ravninah, ki so bile med seboj oddaljene 60 mm. Srednja ravnina je ustrezala srednji razdalji med nasedom valja na okrov motorja in stikom valja z glavo motorja.

Sound intensity measurements were performed according to the ISO 9614-1 standard [8]. The measuring plane was cylindrically shaped and displaced by 555 mm from the longitudinal axis of the engine cylinder. In addition, three transverse engine cylinder planes were selected to determine the longitudinal (within 60 mm) noise distribution. The middle plane correponds to the contact between the cylinder housing to the engine head.

Obod valja merilne površine smo razdelili na 12 enakih segmentov, v katere smo postavili merilne točke. Pri tem sta bili merilni mesti št. 1 in 7 v smeri sesalnega oz. izpušnega ventila, merilno mesto št. 4 je bilo v smeri vztrajnika. Merilno mesto št. 10 je bilo v neposredni bližini krmilnega mehanizma ventilov.

Meritve zvočne intenzivnosti smo opravili v različnih obratovalnih razmerah, in sicer v treh obremenitvah (polna, polovična in prosti tek) ter treh vrtilnih frekvencah (2500, 2000, 1500 min^{-1}).

Rezultate meritev ravni zvočne intenzivnosti pri delnih obremenitvah smo primerjali s tistimi pri imenski obremenitvi v točki 10. Točka 10 je izbrana zato, ker so v njej izmerjene najvišje ravni zvočne intenzivnosti, vseh obratovalnih razmerah motorja. Mehanizem za krmiljenje ventilov in zračnost mehanizma samega sta verjetno vzrok velikega odstopanja skupne ravni zvočne intenzivnosti v tej merilni točki, saj s 101,75 dB(A) kar za 3,5 do 4,8 dB presega skupno raven zvočne intenzivnosti v preostalih merilnih točkah. S takšno izbiro oziroma redukcijo merilnih mest smo izdatno zmanjšali obseg meritev, pri čemer kakovost rezultatov ni bila prizadeta.

Na podlagi primerjave totalnih ravni zvočne intenzivnosti v vsakokratni merilni točki po obodu valja smo lahko ugotovili njihovo relativno razmerje v primerjavi s celotno ravnjo zvočne intenzivnosti v merilni točki št. 10.

V nadaljnjih raziskavah smo ugotavljali, kakšni so vplivi obremenitve motorja, števila vrtljajev in načina hlajenja na skupno raven zvočne intenzivnosti.

2 PRIMERJAVA SKUPNIH RAVNI ZVOČNE MOČI ZA RAZLIČNE IZVEDBE HLAJENJA VALJA V ODVISNOSTI OD OBREMENITVE IN VRTILNE FREKVENCE MOTORJA

Skupna raven zvočne intenzivnosti v odvisnosti od vrtilne frekvence in za polno obremenitev motorja v merilni točki 10 je prikazana na sliki 2. Iz diagrama na sliki 2 vidimo, da se zmanjša pri polni obremenitvi raven zvočne intenzivnosti pri 2500 min^{-1} z vrednosti 101,75 dB(A) pri zračno hlajeni izvedbi na 97,5 dB(A) pri oljno hlajeni izvedbi, kar pomeni znižanje hrupa za več ko 4 dB. To pomeni, da se zvočna intenzivnost hrupa zmanjša za dva- in polkrat. Podobno je tudi pri drugih vrtilnih frekvencah motorja, saj je skupna raven zvočne intenzivnosti nižja za 3,5 oziroma 4,5 dB.

The circumference of the engine cylinder was divided into 12 equal segments, where the measurements were performed. Measuring points No.1 and 7 were located close to the intake and the exhaust valve respectively: No. 4 at the engine flywheel, and No. 10 at the vicinity of the valve-train.

The measurements were performed at different engine running conditions: three different loads (full - rated load, half load, no-load), and three different engine speeds: rated speed - 2500 rpm, peak torque speed - 1500 rpm, and intermediate speed - 2000 rpm.

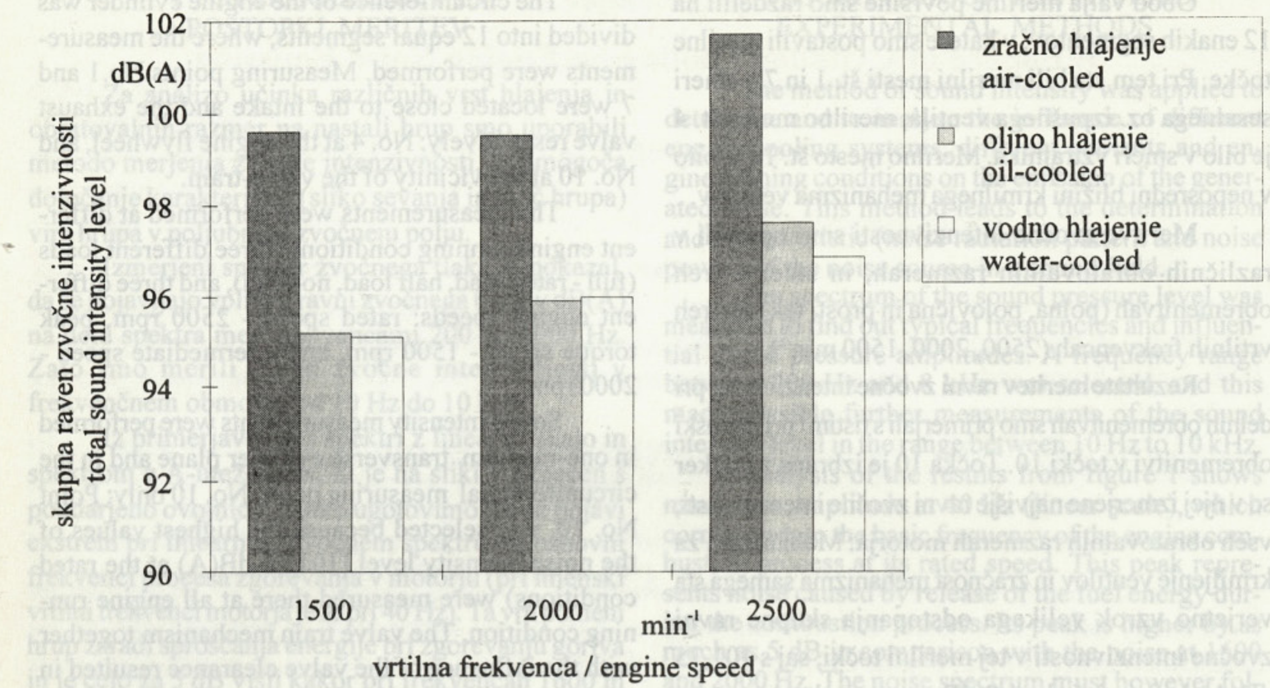
Sound intensity measurements were performed in one-medium transverse cylinder plane and in the circumferential measuring point, No. 10 only; Point No. 10, was selected because the highest values of the noise intensity level (101.75 dB(A) at the rated conditions) were measured there at all engine running condition. The valve train mechanism together with the influence of the valve clearance resulted in an allover deviation (increase) of the total noise intensity level which was more than 3.5 to 4.8 dB in comparison with the measured total noise intensity level at the other measuring locations. This selection greatly reduced the necessary experimental work and did not affect the quality of the results.

Comparison of the results of the total sound intensity level in the sound intensity spectrum at different locations around the cylinder periphery and at point No. 10 served for estimation of the reasons for such differences.

The research work was then concentrated on the influence of the cooling medium and engine running conditions on the total sound intensity level.

2 COMPARISON OF THE TOTAL SOUND INTENSITY LEVEL FOR DIFFERENT COOLING MEDIA AND DIFFERENT ENGINE RUNNING CONDITIONS

Figure 2 demonstrates the influence of the engine running speed at full load on the total level of the sound intensity at the measuring point No. 10. At the rated engine conditions there is a pronounced decrease of the sound intensity level by more than 4 dB (A) when air (101.75 dB(A)) is replaced by engine lubrication oil (97.5 dB(A)). This also means that the sound power is simultaneously decreased by 2 to 2.5 times. Similar results were also obtained with other engine speeds: the sound intensity level decrease amounted to 3.5 and 4.5 dB respectively.



Sl. 2. *Odvisnost skupne ravni zvočne intenzivnosti od vrtilne frekvence motorja in načina hlajenja valja pri polni obremenitvi*

Fig. 2. *Influence of the engine speed and cooling system on the total level of the sound intensity at full engine load*

3 SKUPNA RAVEN ZVOČNE INTENZIVNOSTI PO OBODU VALJA

Skupna raven zvočne intenzivnosti v merilnih točkah na nadzorni površini po obodu valja je prikazana na sliki 3. Na tej sliki so predstavljene vrednosti, ki ustrezajo delovanju motorja pri imenski moči (polna obremenitev in 2500 min^{-1}). Prikazane vrednosti skupne ravni zvočne intenzivnosti pri določeni vrtilni frekvenci pomenijo povprečje izmerjenih skupnih vrednosti zvočne intenzivnosti v treh prečnih merilnih ravninah po višini valja v vsaki točki oboda valja (od točke 1 do 12). Prikazane so ustrezne primerjave za zračno, oljno in vodno hlajen valj.

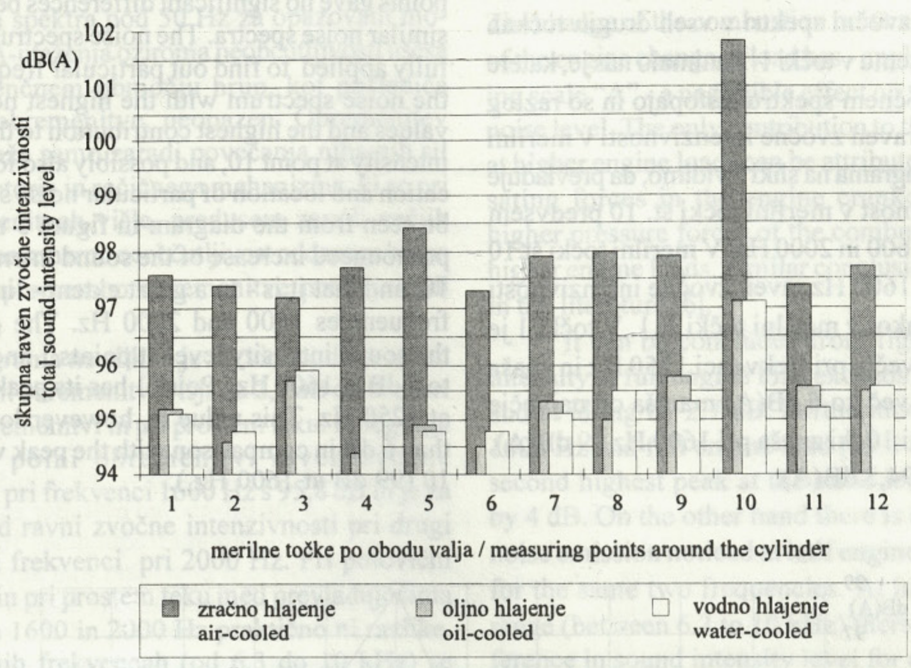
Na sliki 4 je prikazana raven skupne zvočne intenzivnosti za merilne točke 1 - 12 za razvit plašč valja - nadzorne površine in tri različne prečne merilne ravnine po višini valja. Vidimo, da je slika sevanja zvočne intenzivnosti v vseh merilnih prečnih ravninah zelo podobna. Hrup v točki 7 je v primerjavi z vrednostmi v točkah 1 in 4 višji za 0,5 dB. Razlog za to odstopanje je verjetno povezan s hrupom bata, ki se v bližini ZML bočno naslanja (udarja) ob steno valja

3 DISTRIBUTION OF THE TOTAL SOUND INTENSITY LEVEL AROUND THE CYLINDER PERIPHERY

The distribution of the total sound intensity at the different locations (Measurement points 1 to 12) around the cylinder periphery is presented in figure 3 for the engine rated conditions (2500 rpm and full load). Average values from three transverse cylinder planes for each measuring point in the cylinder circumference were taken into account for presentation in figure 3. The results and comparisons are presented for air, water, and engine lubrication oil cooling of the cylinder.

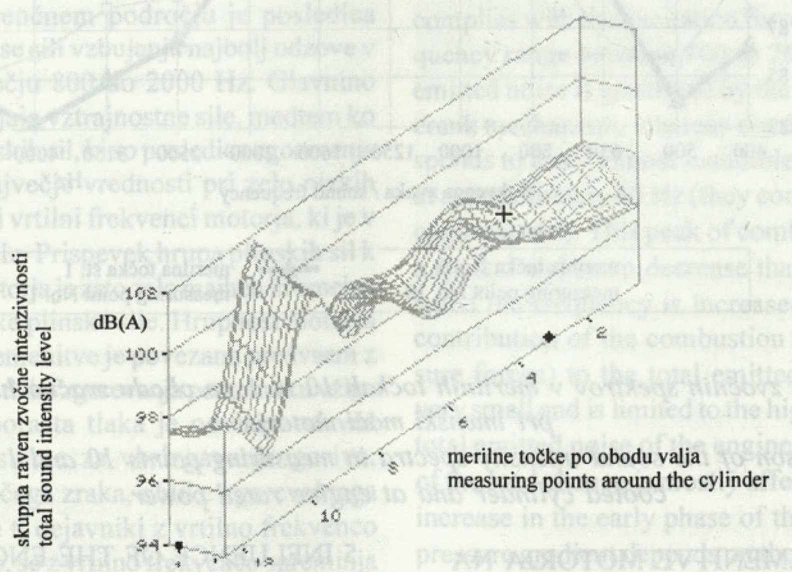
The total sound intensity level for the fully developed measurement plane, 12 different measuring locations, and three different transverse planes of the cylinder is presented in figure 4. Similar values of sound intensity were obtained in different transverse planes. The noise at point No. 7 is by approximately 0.5 dB higher in comparison to the noise at points 1 and 4. This increase is attributed to the noise of the piston in the TDC, caused by its transverse displacev bližini točke 7. Poleg tega pa je v bližini istega merilnega mesta nahaja tudi izpušni kanal, ki tudi prispeva k povečani ravni hrupa.

ment and striking the cylinder wall close to the measuring point No. 7. In addition the exhaust channel is also located very close to the point 7.



Sl. 3. *Primerjava celotnih ravni zvočne intenzivnosti po obodu valja za zračno, vodno in oljno hlajen valj in imensko moč motorja.*

Fig. 3. *Comparison of the total sound intensity level around the engine cylinder for air, water, and oil-cooled engine and rated conditions*



Sl. 4. *Potek skupne ravni zvočne intenzivnosti po nadzorni površini zračno hlajenega valja in imenski moči motorja*

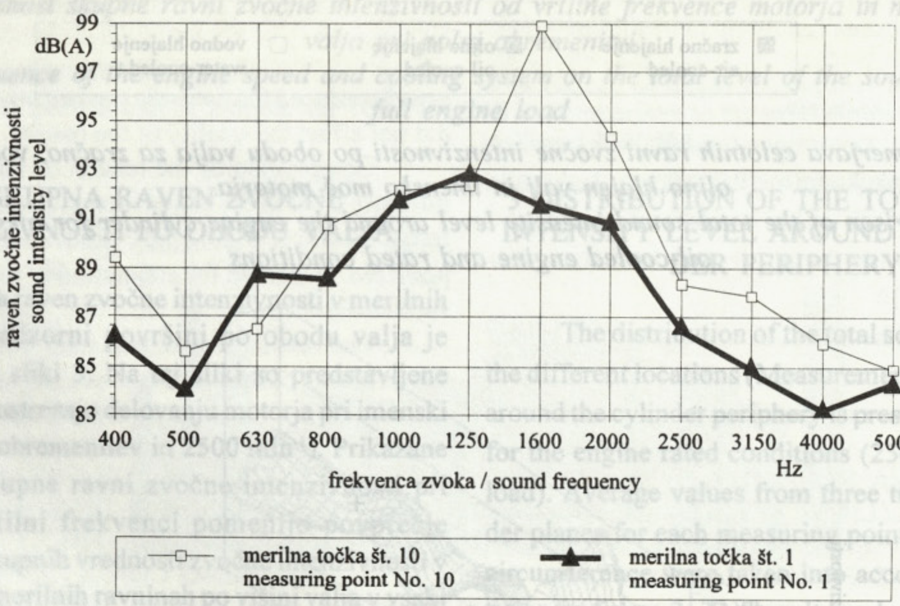
Fig. 4. *Total sound intensity level around the air-cooled cylinder surface at the engine rated power*

4 ANALIZA SPEKTROV ZVOČNE MOČI

V sklopu raziskav so bile opravljene tudi primerjave zvočnih spektrov v merilni točki št. 10 s tistimi v točki št. 1. Primerjava je narejena samo s točko 1, ker so zvočni spektri v vseh drugih točkah zelo podobni tistemu v točki 1. Zanimalo nas je, katere frekvence v zvočnem spektru izstopajo in so razlog za toliko večjo raven zvočne intenzivnosti v merilni točki št. 10. Iz diagrama na sliki 5 vidimo, da prevladuje zvočna intenzivnost v merilni točki št. 10 predvsem pri frekvencah 1600 in 2000 Hz. V merilni točki št.10 je pri frekvenci 1600 Hz raven zvočne intenzivnosti za 8 dB večja kakor v merilni točki št.1. V točki 1 je raven hrupa največja pri frekvenci 1250 Hz in znaša 93 dB. Ta je za več ko 6 dB(A) manjša od največje vrednosti v točki 10, ki znaša pri 1600 Hz 99 dB(A), pri 2000 Hz pa 94,5 dB(A).

4 ANALYSIS OF THE SOUND INTENSITY SPECTRA

Comparisons of the sound intensity spectra for points 10 and 1 were performed, and are also presented here. Comparisons between other measuring points gave no significant differences because of very similar noise spectra. The noise spectrum can be usefully applied to find out particular frequencies from the noise spectrum with the highest noise intensity values and the highest contribution to the total sound intensity at point 10, and possibly also for the identification and location of particular noise sources. It can be seen from the diagram in figure 5 that there is a pronounced increase of the sound intensity for point 10, and that it is - to a great extent - linked with the frequencies 1600 and 2000 Hz. The difference of the sound intensity level at points 1 and 10 amounts to 8 dB at 1600 Hz. Point 1 has its peak value 93 dB at 1250 Hz. This value is, however lower by more than 6 dB in comparison with the peak value of point 10 (99 dB at 1600 Hz).



Sl. 5. *Primerjava zvočnih spektrov v merilnih točkah 10 in 1 po obodu zračno hlajenega valja in pri imenski moči motorja*

Fig. 5. *Comparison of the sound intensity spectra in measuring points 10 and 1 around the air-cooled cylinder and at engine rated power*

5 VPLIV OBREMENITVE MOTORJA NA MOČ HRUPA

Obremenitev motorja ne vpliva bistveno na celono raven hrupa motorja, ki ga neposredno ali posredno povzroča proces zgorevanja goriva v valju. Proces zgorevanje goriva v valju motorja je podoben

5 INFLUENCE OF THE ENGINE LOAD ON EMITTED SOUND INTENSITY

The engine load had a negligible influence on the total emitted noise of the engine. The combustion process in the cylinder is similar for all engine load conditions; however, peak cylinder pressure strictly pri polni obremenitvi ter pri delni obremenitvi in pri prostem teku, vendar se tlaki zgorevanja bistveno razlikujejo. Pri večji obremenitvi motorja so tlaki zgorevanja višji in pričakovati je tudi večji hrup motorja, ki se širi prek sten valja in izpušnega sistema. Vendar, ker je tako oddani hrup motorja v spodnjem področju frekvenčnega spektra pod 50 Hz za opazovani motor, je zaradi A-uteženja oziroma neobčutljivosti ušesa v tem frekvenčnem območju hrup, kot posledica spremembe obremenitve, neopazen. Obremenitev motorja se kaže samo zaradi povečanja nihajnih sil na okrovu motorja in ročičnega mehanizma, ki so pri višjih obremenitvah višje, predvsem zaradi večjih plinskih sil. Sorazmerno neobčutljivost oddanega hrupa motorja na spremembo obremenitve potrjuje tudi literatura [6].

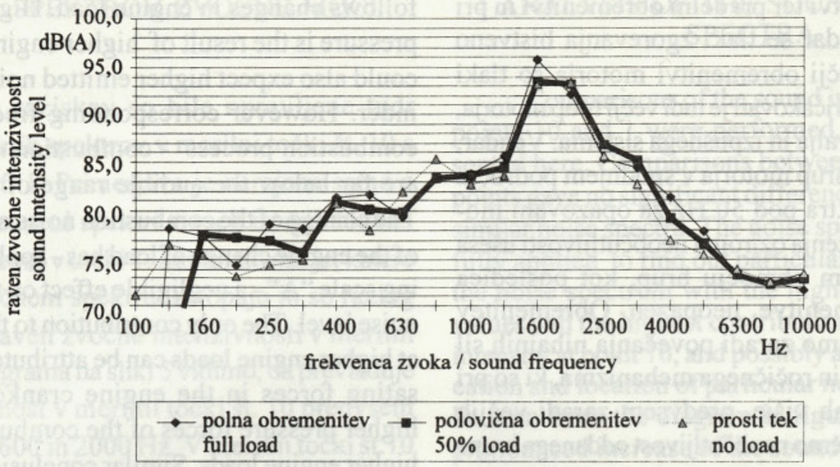
Iz diagrama na sliki 6 je razvidno, da je raven hrupa pri polni obremenitvi višja za 2,7 dB od tiste pri polovični obremenitvi in pri prostem teku. Poleg tega izstopa pri polni obremenitvi raven zvočne intenzivnosti pri frekvenci 1600 Hz s 95,8 dB in je za 4 dB višja od ravni zvočne intenzivnosti pri drugi najvplivnejši frekvenci pri 2000 Hz. Pri polovični obremenitvi in pri prostem teku med prevladujočima frekvencama 1600 in 2000 Hz praktično ni razlike. Tudi pri višjih frekvencah (od 6,3 do 10 kHz) se vrednosti ravni zvočne intenzivnosti zelo malo razlikujejo pri različnih obremenitvah motorja.

Literatura [6] in [7] tudi navaja, da motorji z notranjim zgorevanjem vzbujajo največ hrupa v frekvenčnem območju od 1000 do 2000 Hz. Raven hrupa v tem frekvenčnem področju je posledica zgradbe motorja, ki se sili vzbujanja najbolj odzove v frekvenčnem območju 800 do 2000 Hz. Glavnino hrupa motorja vzbujajo vztrajnostne sile, medtem ko ima hrup zaradi plinskih sil, ki so posledica zgorevanja v valju motorja, največje vrednosti pri zelo nizkih frekvencah, to je pri vrtilni frekvenci motorja, ki je v našem primeru 40 Hz. Prispevek hrupa plinskih sil k celotnemu hrupu motorja je zato zelo majhen in omejen le na višje harmonike plinske sile. Hrupnost motorja v odvisnosti od obremenitve je povezana predvsem z gradientom zvišanja tlaka zgorevanja po trenutku vžiga goriva. Gradient porasta tlaka je odvisen od več dejavnikov: od sistema za vbrizgavanje goriva, vrtinčenja vstopajočega zraka, oblike zgorevalnega prostora itn. Ker se ti dejavniki z vrtilno frekvenco motorja spreminjajo, se z vrtilno frekvenco spreminja tudi hrup zgorevanja. Rezultat teh različnih vplivov je, da so pri prostem teku in polovični obremenitvi nižje ravni hrupa pri nižjih vrtilnih frekvencah od imenskih, medtem ko so pri imenski vrtilni frekvenci 2500 min^{-1} višje ravni hrupa kakor pri polni obremenitvi (sl. 9).

follows changes in engine load. Higher combustion pressure is the result of higher engine loads, and we could also expect higher emitted noise from the cylinder. However corresponding frequencies of the combustion process - combustion noise at 50 Hz - are far below the audible range of the human ear. The change of the combustion noise as a consequence of the engine change of load has - applying the weighting scale "A" - a negligible effect on the total emitted noise level. The only contribution to the emitted noise at higher engine loads can be attributed to higher pulsating forces in the engine crankcase caused by higher pressure forces of the combustion process at higher engine loads. Similar conclusions may be seen in the literature [6].

It can be concluded from figure 6 that noise intensity at full engine load exceeds that at half load and at idling by 2.7 dB. Furthermore noise peak at 1600 Hz and full engine load (95.8 dB) exceeds the second highest peak at the same load and 2000 Hz by 4 dB. On the other hand there is no difference in noise emission noticed at half engine load and idling for the same two frequencies. At higher frequency range (between 6.3 to 10 kHz) there is again no difference in sound intensity level for different engine loads.

Authors [6] and [7] report that most of the emitted noise from the ICE corresponds to the frequency range between 1000 and 2000 Hz and is the consequence of the engine design. Engine structure complies with the excitation forces mostly in the frequency range between 800 to 2000 Hz. Most of the emitted noise is generated by the inertia forces of the crank mechanism, whereas combustion noise corresponds to low - almost inaudible - basic frequencies at approximately 40 Hz (they correspond to the basic engine speed). This peak of combustion noise shows a typical and steep decrease that amounts to 30 dB when the frequency is increased by a decade. The contribution of the combustion noise (engine pressure forces) to the total emitted noise is therefore very small and is limited to the higher harmonics. The total emitted noise of the engine as the consequence of the load change is mostly affected by the pressure increase in the early phase of the combustion. This pressure gradient depends on the engine combustion system, fuelling system, etc. Many influences differently affect the total noise of the engine; as a consequence the relatively lower noise level can be observed at lower speeds and lower engine loads, but higher noise is noted at lower loads and rated engine speed (Fig. 9).



Sl. 6. *Vpliv obremenitve motorja na spekter hrupa zračno hlajenega valja pri 2000 min^{-1}*
Fig. 6. *Influence of engine load on the noise intensity spectrum for the air-cooled cylinder and 2000 rpm*

Iz spektra na sliki 7 vidimo, da znaša tudi pri oljno hlajeni izvedbi valja razlika med zvočno intenzivnostjo, pri prevladujočih frekvencah 1600 in 2000 Hz 4 dB. Že prej smo ugotovili (sl. 6), da je pri teh dveh frekvencah raven zvočne intenzivnosti praktično enaka za polovično obremenitev in prosti tek. V frekvenčnem območju nad 4000 Hz se raven zvočne intenzivnosti z zmanjševanjem obremenitve hitro znižuje, vendar je njihov prispevek k skupnemu hrupu neznaten, saj so vrednosti ravni zvočne intenzivnosti pri teh frekvencah nižje za 20 dB in več od tistih pri frekvencah 1600 in 2000 Hz. Glede na osnovno zračno hlajeno izvedbo valja je oddani hrup pri oljno hlajenem valju v območju prevladujočih frekvenc (1600 in 2000 Hz) manjši za več ko 4 dB.

6 VPLIV OBLIKE VALJA IN IZBIRE HLADIVA NA SPEKTER ZVOČNE INTENZIVNOSTI

Pri osnovni izvedbi motorja smo imeli orebren, zračno hlajen valj. Pri oljnem in vodnem hlajenju motorja smo osnovni valj nadomestili s kompaktnim jeklenim valjem brez hladilnih reber. V plašč valja smo vdelali vodoraven kanal, po katerem se je pretakalo hladilno olje oziroma mešanica vode in tekočine proti zmrzovanju. Primerjalne meritve smo opravili za vse tri načine hlajenja valja in v različnih razmerah delovanja motorja. V diagramu na sliki 7 so prikazani rezultati meritev za zračno in oljno hlajen valj pri polni obremenitvi motorja in vrtilni frekvenci 2000 min^{-1}. Očitno je, da je zračno hlajena izvedba opazno glasnejša od oljno hlajene. Pri prevladujočih frekvencah (1600 in 2000 Hz) znaša razlika od 4 do 5 dB. Pri višjih frekvencah so razlike tudi opazne.

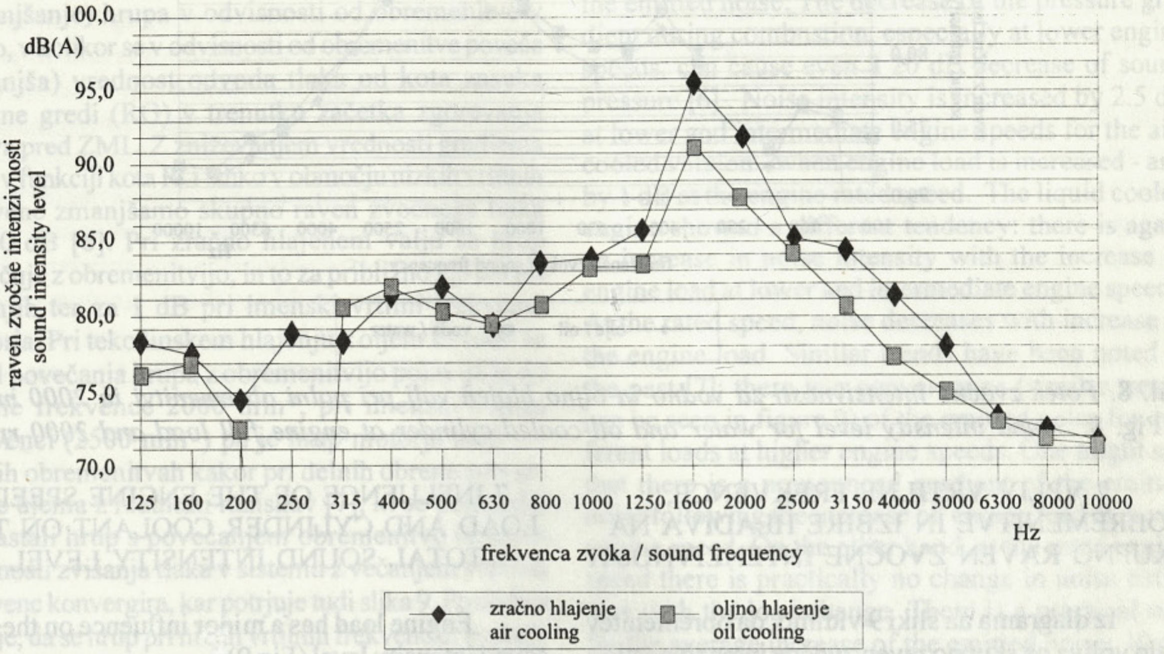
One can conclude from the sound intensity spectrum in figure 7 that there is a significant drop of 4 dB even for the oil-cooled cylinder and full engine load at the two dominant frequencies 1600 and 2000 Hz. From figure 6 it is evident that at partial engine loads this drop disappears. At higher frequencies (above 4000 Hz) the decrease of the emitted noise follows the decrease of the engine load. Owing to the substantially lower noise intensity level (a drop of 20 dB can be noticed when the frequency is increased from 1600 to 6000 Hz) at higher frequencies there is practically no change in the total emitted noise caused by the change of the engine load. We can also conclude from figure 7 that noise reduction of the oil-cooled engine compared to the baseline air-cooled engine (in the most important frequency range 1600 - 2000 Hz) exceeds 4 dB.

6 INFLUENCE OF THE CYLINDER DESIGN AND COOLANT ON THE EMITTED NOISE INTENSITY SPECTRUM

A finned air-cooled cylinder is typical of the baseline engine. Special compact water or oil jacket cylinders without additional cooling fins were applied in the case of the liquid-cooled engine. A horizontal channel was introduced in the upper part of the new cylinder, and water with antifreeze or lubrication oil fed by a special pump. Measurement conditions: temperatures and other engine running conditions were kept unchanged for three different cooling media and cylinders. Figure 7 shows the results of the air- and oil-cooled cylinder at full load and 2000 rpm. The air-cooled version is evidently noisier, especially at the predominant frequencies 1600 and 2000 Hz (by 4 to 5 dB), and also at higher frequencies.

S slike 8 vidimo, da se spektra zvočne intenzivnosti pri oljnem in vodnem hlajenju valja le malo razlikujeta. Pri vodno hlajeni izvedbi so ravni zvočne intenzivnosti večje za približno 1 dB, razen pri frekvenci 1600 Hz.

The sound intensity spectra for the oil and water-cooled cylinder, presented in figure 8, do not greatly differ. The "water jacket" is noisier by approximately 1 dB at lower frequencies, except at 1600 Hz.



Sl. 7. *Primerjava ravni zvočne intenzivnosti za zračno in oljno hlajen valj pri polni obremenitvi motorja in n = 2000 min*$^{-1}$

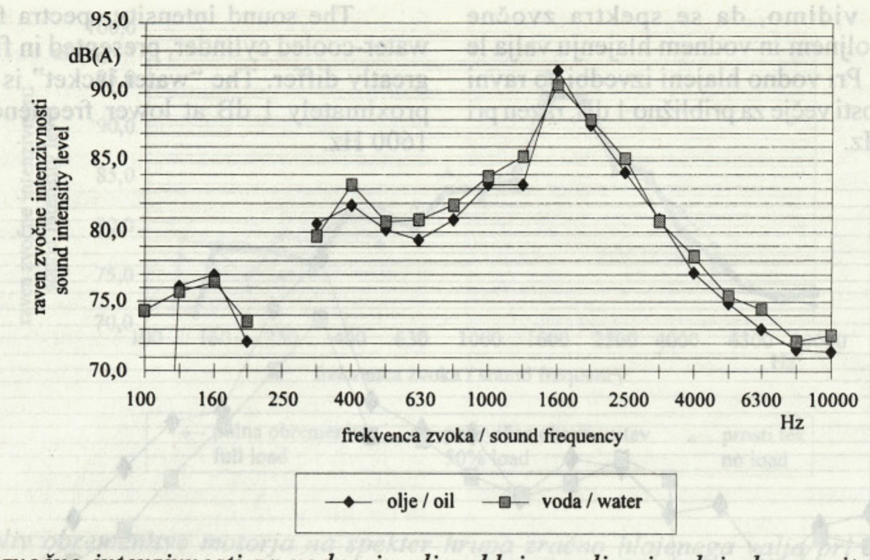
Fig. 7. *Comparison of the sound intensity level for the air and oil-cooled cylinder, rated engine load and n = 2000 rpm*

Raziskave, podane v literaturi [6], kažejo, da je povečanje hrupa z velikostjo motorja sorazmerno majhno in je povezano predvsem s površino, ki oddaja hrup. Površina, ki oddaja zvok, je pri večjih motorjih večja, s tem pa v okolico oddaja tudi več hrupa. Ker je bila delovna prostornina motorja pri vseh izvedbah hlajenja enaka, zunanja površina plašča valja pri zračno hlajeni izvedbi valja pa bistveno večja, je možen tudi sklep, da je višja raven oddanega hrupa pri zračno hlajenem valju posledica sevanja z večje hladilne površine in turbulence toka zraka na orebrenem valju. Poleg tega je tudi mogoče, da se je del zvočne energije absorbiral v plašču (kanalčku) hladilne tekočine v steni valja.

Pri prostem teku so ravni zvočne intenzivnosti pri posameznih frekvencah zvočnega spektra še manjše kakor pri polovični obremenitvi, te spet manjše kakor pri polni obremenitvi. Zmanjševanje ravni zvočne intenzivnosti je posledica manjšega mehansko povzročenega hrupa, ki je povezan s silami v ročičnem mehanizmu. Sile v ročičnem mehanizmu so (pri isti vrtilni frekvenci) manjše pri delnih obremenitvah zaradi manjših plinskih sil, kot posledice manjše količine zgorelega goriva.

The results of the research report [6] show that there is no typical increase of the emitted noise in relation to the increase of the engine size. It is the surface that emits the noise; larger size engines have a larger surface noise emission. We can therefore conclude that three-cylinder versions give the same power output, even though, the outer surface of the finned air-cooled cylinder exceeded the surface of the two compact liquid-cooled cylinders. A higher emitted noise can be expected when the air-cooled cylinder is considered to be the consequence of the larger external surface of this engine and of local turbulence of the cooling air-flow within the cooling passages. A certain portion of the emitted noise can be also absorbed by the cooling jacket around the cylinder.

The sound intensity level at idling condition is lower in comparison with that at higher engine loads for most of the frequency range. Reduction of noise intensity is the consequence of lower mechanically indicated noise caused by the forces in the crank mechanism. These forces are smaller at lower engine loads for the same engine speed owing to reduced gas forces i.e.less fuel is burned.



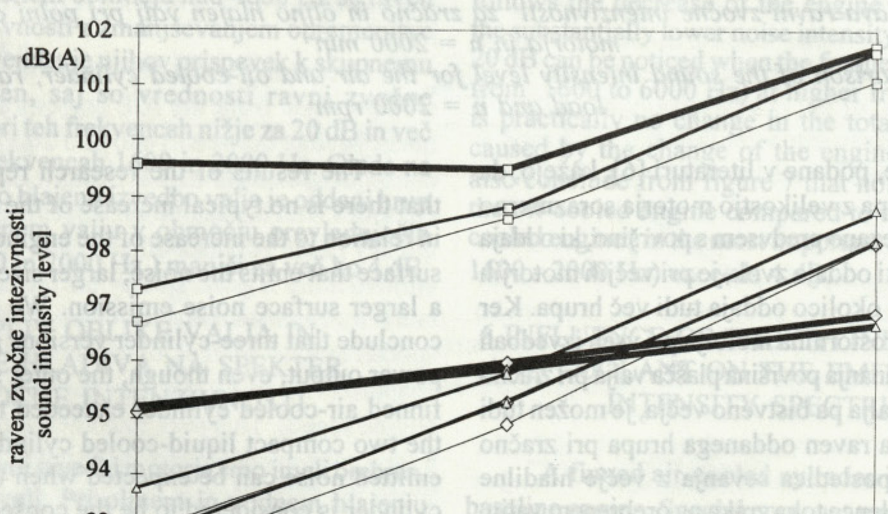
Sl. 8. *Potek zvočne intenzivnosti za vodno in oljno hlajen valj pri polni obremenitvi in 2000 min^{-1}*
Fig. 8. *Sound intensity level for water and oil-cooled cylinder at engine full load and 2000 rpm*

7 VPLIV VRTILNE FREKVENCE, OBREMENITVE IN IZBIRE HLADIVA NA SKUPNO RAVEN ZVOČNE INTENZIVNOSTI

Iz diagrama na sliki 9 vidimo, da obremenitev malo vpliva na skupno raven zvočne intenzivnosti.

7 INFLUENCE OF THE ENGINE SPEED, LOAD AND CYLINDER COOLANT ON THE TOTAL SOUND INTENSITY LEVEL

Engine load has a minor influence on the total sound intensity level (Fig.9).



Sl. 9. *Odvisnost skupne ravni zvočne intenzivnosti od vrtilne frekvence, načina hlajenja in obremenitve motorja*
Fig. 9. *Influence of engine cooling, speed and load on total emitted sound intensity*

Povečana obremenitev pomeni sicer več goriva za zgorevanje, večjo plinsko silo v valju in zaradi tega tudi večjo deformacijo konstrukcije. Vpliv obremenitve se kaže s spremembo plinskih sil v motorju. Plinske sile povzročajo povečanje (zmanjšanje) hrupa v odvisnosti od obremenitve v toliko, v kolikor se v odvisnosti od obremenitve poveča (zmanjša) vrednost odvoda tlaka od kota zasuka ročične gredi (RG) v trenutku začetka zgorevanja goriva pred ZML. Z zniževanjem vrednosti gradienta tlaka v funkciji kota RG lahko v območju nizkih vrtilnih frekvenc zmanjšamo skupno raven zvočnega tlaka do 20 dB [6]. Pri zračno hlajenem valju se hrup povečuje z obremenitvijo, in to za približno 2,5 dB pri srednjih ter za 1 dB pri imenski vrtilni frekvenci motorja. Pri tekočinskem hlajenju z oljem in vodo se trend povečanja hrupa z obremenitvijo pojavlja le do vrtilne frekvence 2000 min^{-1}, pri imenski vrtilni frekvenci (2500 min^{-1}) pa je hrup motorja nižji pri polnih obremenitvah kakor pri delnih obremenitvah. To se ujema z rezultati raziskav [7], ki so pokazale, da nastali hrup s povečanjem obremenitve in s tem vrednosti zvišanja tlaka v sistemu z večanjem vrtilnih frekvenc konvergira, kar potrjuje tudi slika 9. Posledica tega je, da se hrup pri nižjih vrtilnih frekvencah zvečuje hitreje kakor pri višjih vrtilnih frekvencah. Sicer pa pri dizelskih motorjih velja pravilo, da se zvečuje raven hrupa približno 30 dB za desetkratno povečanje vrtilne frekvence [6]. Raziskave [7] so še pokazale, da ustreza največje zvišanje tlaka v procesu zgorevanja polovični obremenitvi motorja. S slike 9 vidimo, da se pri vseh obremenitvah in vrtilnih frekvencah hrup zmanjša pri tekočinskem hlajenju. V povprečju se z zamenjavo zračnega hlajenja s tekočinskim zmanjša hrup za 3 do 5 dB.

8 SKLEP

Hrup, ki nastaja pri delovanju motorja z notranjim zgorevanjem ima različne vire. Pomembno vlogo imajo tudi način hlajenja, konstrukcijska izvedba in vrsta hladiva. V tem delu smo proučevali vplive vrste hladiva (vode, zraka in olja za mazanje motorja) na oddani hrup motorja. Pri tem je bila uporabljena metoda merjenja zvočne intenzivnosti. Preizkusi so bili opravljeni na enovaljnem, 4-taktnem dizelskem motorju HATZ E79 v različnih razmerah delovanja: različnih obremenitvah (imenski, polovični) in pri razbremenjenem motorju ter različnih vrtilnih frekvencah (imenski, srednji in frekvenci pri največjem momentu motorja). Raven zvočne intenzivnosti je bila izmerjena v 36 različnih točkah po zunanji površini valja. Analiza rezultatov je pokazala, da je oddani hrup po obodu valja zelo usmerjen z izrazito vršno vrednostjo v bližini izpušnega kanala (točka 10) in da so ravni zvočne intenzivnosti izrazite v območju najbolj slišnih frekvenc

A higher load means more burned fuel and results in bigger gas forces and in turn causes larger deformations of the engine structure. The pressure gradient in the early phase of the combustion process is more important for the generation and size of the emitted noise. The decrease of the pressure gradient during combustion, especially at lower engine speeds, can cause even a 20 dB decrease of sound pressure [6] . Noise intensity is increased by 2.5 dB at lower and intermediate engine speeds for the air-cooled version - when engine load is increased - and by 1 dB at the engine rated speed. The liquid cooled engine showed a different tendency: there is again an increase in noise intensity with the increase of engine load at lower and intermediate engine speeds. At the rated speed, noise decreases with increase of the engine load. Similar trends have been noted in the past [7]: there is a convergence (similar trends can be seen in figure 9) of the emitted noise for different loads at higher engine speeds. One might say that there is a pronounced gradient of the emitted noise following the increase of engine load at lower engine speed. On the other hand, at the rated engine speed there is practically no change in noise emission with the load change. There is a practical rule for the average increase of the emitted noise: 30 dB increase can be expected when the engine speed increases by 10 times [6] . There is one more feature concerning pressure gradients during the combustion process: the highest pressure gradients can be expected at the intermediate engine loads [7]. It can also be seen from figure 9 that the noise of a liquid cooled engine increases continuously with increasing engine speed and load. Overall reduction of the emitted noise when cooling air is replaced by a liquid coolant amounts to 3 to 5 dB.

8 CONCLUSION

Noise emitted by an internal combustion engine has different origins. It is generally affected by the engine design, cylinder cooling system, coolant applied, etc. The influence of three different coolants: air, water, and engine lubrication oil on the level of the engine-emitted noise is discussed in this work. The sound-intensity measurement method was ued for this purpose. Experiments were performed on a 4-stroke, single cylinder Diesel engine HATZ E79 at different engine running conditions: full, partial, and zero load, as well as at 2500 (rated), 2000, and 1500 (peak torque) rpm. Sound intensity measurements were performed at 12 measuring points located circumferentially around the cylinder liner and three different transverse planes along the cylinder axis. Analysis of the results showed pronounced noise peaks in the vicinity of the exhaust channel (measuring point No. 10). In addition the predominant values (med 1600 in 2000 Hz). Prav tako je bilo ugotovljeno, da je oddani hrup zračno hlajenega motorja v primerjavi z oljno oziroma vodno hlajenim motorjem za 3,5 do 4,5 dB(A) večji, da ni posebnih razlik med obema različicama tekočinsko hlajenih motorjev in da veljajo omenjene ugotovitve za vse vrtilne frekvence motorja. Potrjena je tudi splošno znana ugotovitev, da se hrup motorja zvečuje s četrto potenco povečanja vrtilne frekvence, da je vpliv obremenitve motorja na zvečanje hrupa izrazit le pri nižjih vrtilnih frekvencah, medtem ko pri višjih vrtilnih frekvencah hrup drugih virov zabriše vpliv spremembe obremenitve na celotni oddani hrup.

Nazadnje lahko ugotovimo, da lahko z zamenjavo hladilnega sistema zračno hlajenega valja s tekočinskim hlajenjem znižamo raven hrupa kar za 4,5 dB(A).

of the noise intensity level correspond to the audible frequency range between 1600 and 2000 Hz. The emitted noise of the air-cooled cylinder was 3.5 to 4.5 dB(A) higher in comparison to the liquid cooled (water and engine lubrication oil) cylinder at all engine speeds, whereas there is a negligible difference in the emitted noise level of the water and oil-cooled cylinder. It was again confirmed that noise increases with the fourth power of the increase of engine speed. The influence of the engine load on the emitted engine noise is more pronounced at lower engine speeds, whereas at higher engine speeds practically no differences in the emitted noise were noticed.

Finally we could say that if air were replaced in the cylinder coat by a liquid coolant, total noise reduction of an engine by 4.5 dB (A) could be expected.

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