

Vpliv okrova na hrup batnega kompresorja

The Influence of the Housing on the Noise Emitted by a Reciprocating Compressor

Anže Jerič - Janez Gradišek - Igor Grabec - Edvard Govekar
(Fakulteta za strojništvo, Ljubljana)

V prispevku analiziramo vpliv okrova na hrup tipičnega batnega kompresorja za gospodinjske aparate. Analiza lastnosti hrupa kompresorja z okrovom in brez njega temelji na meritvah zvočnega tlaka in zvočne intenzivnosti. Eksperimentalno ugotovljene elastične lastnosti okrova kompresorja primerjamo s teoretičnim izračunom, ki temelji na metodi končnih elementov. Rezultati izkazujejo dobro ujemanje glavnih frekvenc hrupa z lastnimi frekvencami okrova. V prispevku pokažemo, kako lahko s preprosto ojačitvijo okrova zmanjšamo amplitudo in spremenimo frekvenčno vsebino hrupa, izmerjenega zunaj kompresorja.
© 2007 Strojniški vestnik. Vse pravice pridržane.

(Ključne besede: gospodinjski aparati, batni kompresorji, hrup, intenzivnost hrupa)

The influence of the housing on the noise emitted by a typical reciprocating compressor for domestic appliances is analyzed. Sound-pressure and sound-intensity measurements were conducted to analyze the properties of the noise emitted by the compressor with and without the housing. The experimentally determined elastic properties of the compressor housing were compared with calculations based on a finite-element model. The results show that the dominant noise frequencies correspond to the eigen frequencies of the housing. Simple stiffening of the housing is shown to reduce the amplitude and modify the frequency content of the noise recorded outside the compressor.
© 2007 Journal of Mechanical Engineering. All rights reserved.

(Keywords: domestic appliances, reciprocating compressors, noise, sound intensity)

0 UVOD

Pri izbiri kompresorjev za gospodinjske aparate na današnjem trgu je hrup eno najpomembnejših meril. Z namenom zmanjšanja hrupa kompresorja je treba raziskati tako vire hrupa kakor tudi poti prenosa hrupa ([3] in [2]). V splošnem so viri hrupa odvisni od načina stiskanja hladilnega medija, prenosne poti hrupa pa od konstrukcije kompresorja [2].

V pričujočem prispevku raziskujemo hrupnost enobatnega kompresorja, ki vsebuje v okrov vgrajeno kompresorsko enoto. Izkaže se, da so glavni viri hrupa v kompresorski enoti utripanje hladilnega medija vzdolž cevi in komor ter vibracije sesalnega in izpušnega ventila. Hrup oddan znotraj okrova, se prek okrova prenese v okolico, kjer ga sliši uporabnik gospodinjskega aparata z vgrajenim kompresorjem. Ker hrup v okolico oddaja okrov, pričakujemo, da njegove elastične lastnosti vplivajo na lastnosti hrupa zunaj kompresorja.

0 INTRODUCTION

Noise is one of the most important selection criteria in today's market for the compressors in domestic appliances. In order to reduce the noisiness of a compressor, one has to investigate both the noise sources and the noise transmission paths ([3] and [2]). In general, noise sources depend on the physical principle employed for compression, while the transmission paths depend on the design of the compressor [2].

In this article the noisiness of a single-piston reciprocating compressor is investigated. The compressor consists of a compressor unit mounted in a housing. The dominant noise sources within the compressor unit appear to include the cooling-media pulsations in the muffler and along the pipes and chambers, the inlet/outlet valve vibration, etc. The noise emitted within the housing is then transmitted through the housing to the outside, where it is heard by the owner of the domestic appliance in which the compressor is used. Since the housing acts as a noise transmitter, it is expected that its elastic properties affect the properties of the noise outside the compressor.

Cilj tega prispevka je preučiti vpliv okrova na hrup zunaj kompresorja. V ta namen smo izmerili in primerjali zvočni tlak in prostorsko porazdelitev zvočne intenzivnosti kompresorja z okrovom in brez njega. Prenosno funkcijo okrova smo ugotovili eksperimentalno in teoretično z modelom končnih elementov. Analiza je pokazala, da se glavne frekvence hrupa kompresorja z okrovom ujemajo z lastnimi frekvencami nihanja okrova. Preprosta ojačitev okrova kompresorja spremeni frekvenčno vsebino hrupa in zmanjša amplitudo glavnih frekvenc hrupa.

1 PREIZKUSI

Da bi ugotovili vpliv okrova na oddani hrup kompresorja, smo pri preizkusih uporabili dva kompresorja: enega z okrovom in enega brez okrova. Kompresor v okrovu je deloval v enakih razmerah kakor v gospodinjskem aparatu. Pri kompresorju brez okrova sta bili sesalna in izpušna cev odprti, kar je preprečevalo normalno delovanje. Prevzeli smo, da odprte cevi nepomembno spremenijo lastnosti hrupa, ki je oddan med delovanjem kompresorja. Preizkuse smo opravili v sobi za standardno merjenje ravni zvočne moči kompresorjev za gospodinjske aparate.

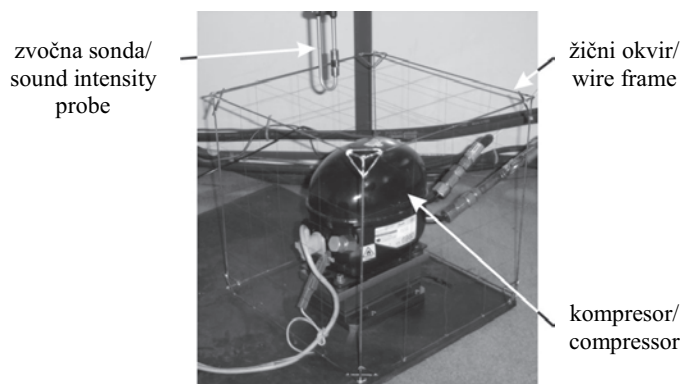
Z uporabo mikrofona in zvočne sonde smo pri obeh kompresorjih izmerili zvočni tlak in zvočno intenzivnost. Mikrofon je bil nameščen navpično nad kompresorjem, približno 25 cm nad pokrovom okrova kompresorja. Znotraj 2 min periode delovanja kompresorja smo izmerili po 10 signalov zvočnega tlaka pri frekvenci vzorčenja 16 kHz. Dolžina signalov

The aim of the article is to examine the influence of the housing on the noise outside the compressor. For this purpose, the sound pressure and the spatial distribution of the sound intensity are recorded and compared for a reciprocating compressor with and without a housing. The transfer function of the housing is determined experimentally and theoretically using a finite-element model. The analysis shows that the dominant frequencies of the noise from the compressor with the housing mainly correspond to the eigen frequencies of the housing, and that a simple reinforcement of the compressor housing modifies the frequency content of the noise and reduces the amplitudes of the dominant noise frequencies.

1 EXPERIMENTS

In order to determine the influence of the housing on the noise emitted by the compressor, experiments were conducted using two reciprocating compressors: one with a housing and one without. The compressor with a housing was operated under realistic conditions. In the compressor without a housing the suction and exhaust pipes had to be opened, which prevented normal operating conditions. However, it was assumed that the open pipes did not significantly change the properties of the noise emitted during the operation of the compressor. The experiments were conducted in a room designed for standard measurements of the sound-power level for the compressors of domestic appliances.

Sound pressure and sound intensity were recorded for both compressors using a microphone and a sound-intensity probe. The microphone was mounted directly above the compressor at a distance of approximately 25 cm from the compressor surface. During a 2-min period of compressor operation, 10 sound-pressure signals were recorded at a sampling



Sl. 1. Eksperimentalno mesto za meritve zvočne intenzivnosti
Fig. 1. Experimental setup for sound-intensity measurement

je bila 4 s. Signale smo shranili za poznejšo frekvenčno analizo.

Za merjenje zvočne intenzivnosti smo uporabili sondo z dvema mikrofonom, obrnjenima čelno drug proti drugemu. Med mikrofonom je bil nameščen 12 mm debel distančnik, ki omogoča kakovostne meritve signalov s frekvencami do 5 kHz. Pri meritvah prostorske porazdelitve zvočne intenzivnosti smo zvočno sondo postavljali na navidezno kocko, ki jo je predstavljal okvir iz tanke žice.

Vsaka od petih primerjalnih ravnin kocke je vsebovala 16 naključno razporejenih primerjalnih točk. Razdalja med primerjalnimi ravninami in površino kompresorja je bila približno 15 cm. Na vsaki primerjalni točki smo izmerili 6 parov 4 s dolgih signalov zvočnega tlaka pri frekvenci vzorčenja 20 kHz. Zvočno intenzivnost smo nato izračunali iz imaginarnega dela križnega spektra parov signalov zvočnega tlaka ([1] in [4]). Zvočna sonda je bila vedno usmerjena pravokotno na primerjalno ravnino. Tako izračunana in analizirana zvočna intenzivnost je bila komponenta vektorja zvočne intenzivnosti pravokotno na površino kompresorja.

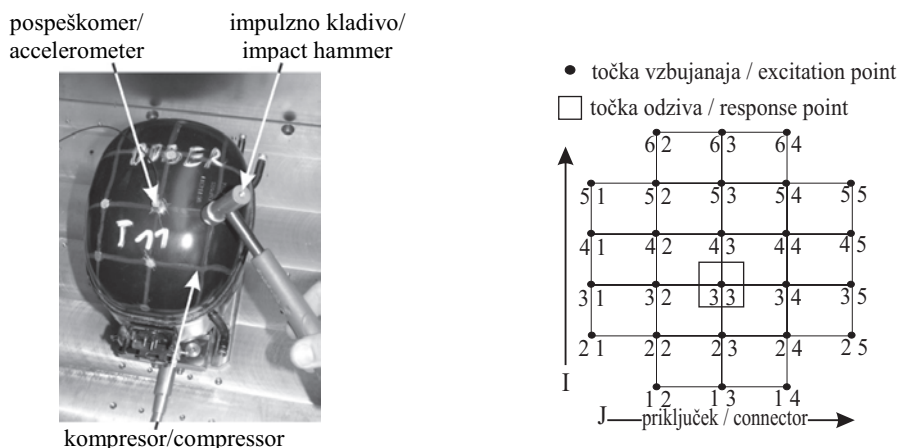
Modalne lastnosti okrova kompresorja smo ugotovili eksperimentalno in teoretično. Eksperimentalni način vključuje impulzno vzbujanje okrova z instrumentalnim kladivom na več naključno razporejenih točkah vzdolž pokrova okrova (sl. 2). Odziv okrova smo izmerili s pospeškometerom nameščenim na vrh pokrova. Na vsaki točki vzbujanja

frequency of 16 kHz, lasting 4 sec each. The signals were stored for subsequent frequency analysis.

For the sound-intensity measurement a probe with a face-to-face arrangement of the pressure microphones was employed. A 12-mm solid spacer was used between the microphones, allowing high-quality measurements of signals with frequencies up to 5 kHz. To determine the spatial distribution of the sound intensity the outer form of the compressor was modelled with a virtual square block represented by a thin wire frame.

Each of the five reference planes of the block contained 16 evenly distributed reference points. The distance between the reference planes and the compressor surface was approximately 15 cm. At each reference point, six pairs of sound pressure signals were recorded at a sampling frequency of 20 kHz, lasting 4 sec each. The sound intensity was then calculated from the imaginary part of the cross-spectrum of a pair of sound pressure signals ([1] and [4]). The sound-intensity probe was always oriented perpendicularly to the reference plane, and thus the sound-intensity calculated and analyzed in this article is in fact a component of the sound-intensity vector normal to the reference plane.

The modal properties of the compressor housing were determined experimentally and theoretically using a finite-element (FE) model. The experiments involved impact excitation of the housing using an instrumented hammer at several points evenly distributed along the housing cover (Fig. 2). The response of the housing was recorded by an accelerometer mounted on top of the cover. At each excitation point, 10 excita-



Sl. 2. Eksperimentalno mesto za merjenje prenosne funkcije (levo) in porazdelitev točk vzbujanja in točke odziva

Fig. 2. Experimental setup for transfer-function measurement (left), and the distribution of the excitation points and the response point

smo izmerili po 10 parov 1 s dolgih signalov vzbujanja in odziva pri frekvenci vzorčenja 25 kHz. Izmerjene signale smo nato uporabili za izračun prenosne funkcije pokrova okrova [5].

Lastne frekvence in lastne oblike okrova smo izračunali tudi prek modela končnih elementov z uporabo ustreznega tržnega programa.

2 REZULTATI

2.1 Zvočni tlak

Najprej obravnavajmo zvočni tlak hrupa, ki ga odda kompresor z okrovom in brez njega. Slika 3 prikazuje povprečna amplitudna spektra izmerjenih signalov v logaritemski skali za oba kompresorja. Povprečna amplituda hrupa kompresorja z okrovom je približno dva reda velikosti nižja od tiste pri kompresorju brez okrova. Opazimo lahko tudi razliko v frekvenčni vsebini hrupa obeh kompresorjev. V hrupu kompresorja z okrovom so glavni spektralni vrhovi pri frekvencah 4,2 kHz, 5,3 kHz in 5,7 kHz. V spektru hrupa kompresorja brez okrova pomembnih vrhov pri teh frekvencah ne opazimo, glavni vrhovi so na območju od 50 Hz do 2 kHz. V obeh primerih so

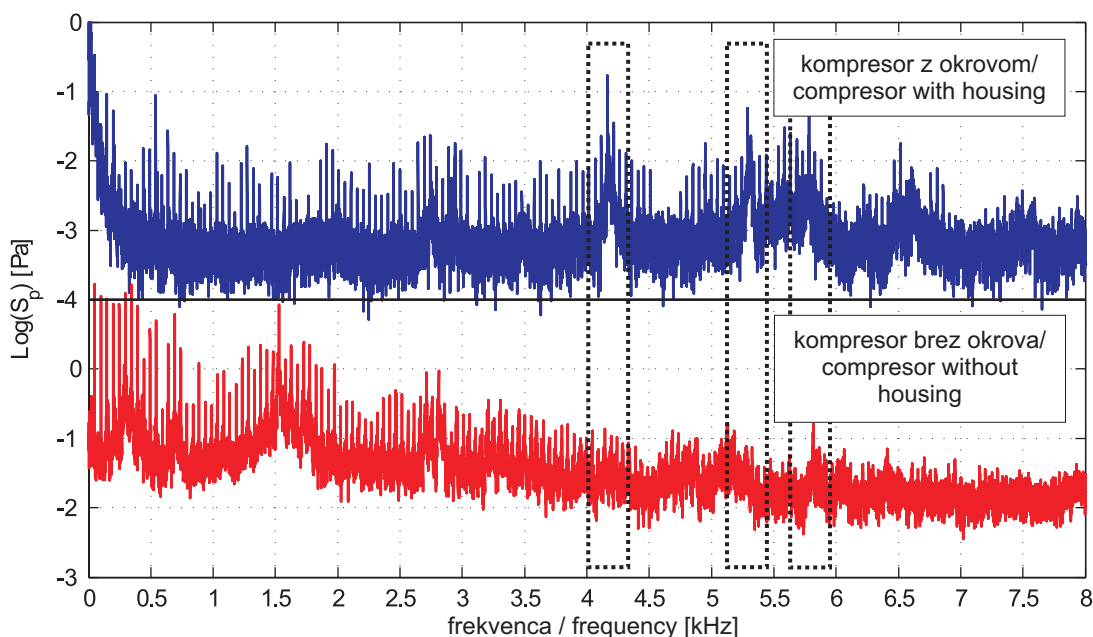
tion-response signal pairs were recorded at a sampling frequency of 25 kHz, lasting 1 sec each. The recorded signals were then used to calculate the transfer function of the housing cover [5].

The eigen frequencies and eigen modes of the housing were also calculated using an FE model with a commercial FE solver.

2 RESULTS

2.1 Sound Pressure

Let us first consider the sound pressure of the noise emitted by the compressor with and without the housing. The average amplitude spectra of the recorded sound-pressure signals for the two compressors are shown in Fig. 3. It is obvious that the average amplitude of the noise emitted by the compressor with the housing is much lower than without the housing. A difference in the frequency content of the two noises can also be observed. In the noise of the compressor with the housing, the dominant spectral peaks are found at frequencies of 4.2 kHz, 5.3 kHz and 5.7 kHz. In the noise of the compressor without the housing, these spectral peaks are not observed at all, although there are several dominant peaks in the range from 50 Hz to 2



Sl. 3. Povprečni amplitudni spekter zvočnega tlaka za kompresor z okrovom (zgoraj) in brez njega (spodaj)

Fig. 3. Average amplitude spectra of the sound pressure of the noise emitted by the compressor with (top) and without the housing (bottom)

spektralni vrhovi večinoma pri večkratnikih frekvence 50 Hz, ki se ujema z osnovno frekvenco delovanja kompresorja. Ti rezultati dokazujejo, da okrov ne samo zmanjša amplitudo hrupa oddanega znotraj okrova kompresorja, temveč tudi izrazito spremeni frekvenčno vsebino hrupa. Analiza prostorske porazdelitve zvočne intenzivnosti, ki jo bomo predstavili v naslednjem razdelku, pokaže nekatere dodatne vplive okrova na lastnosti hrupa.

2.2 Zvočna intenzivnost

Slika 4 prikazuje prostorsko porazdelitev zvočne intenzivnosti za kompresor z okrovom in brez njega. Vsak od petih polj s 16 kvadrati ustreza eni od petih referenčnih ravnin okrog kompresorja, tako kakor je prikazano v desnem zgornjem kotu slike. Na vsakem od 16 kvadratov posamezne ravnine je povprečna amplituda in usmerjenost zvočne intenzivnosti predstavljena v osenčeni skali. Negativna vrednost povprečne zvočne intenzivnosti tako predstavlja obratno smer širjenja zvoka. Ravni zvočne moči L_{wi} nad petimi polji pa pomenijo moč hrupa, oddanega skozi posamezno referenčno ravnino. Uokvirjena vrednost L_w pomeni celotno raven zvočne moči iz vseh primerjalnih ravnin.

Kompresor z okrovom odda največ hrupa skozi vrhnjo (5) in desno (2) primerjalno ravnino. Največje amplitude zvočne intenzivnosti smo opazili na vrhnji ravnini (5). Prostorska porazdelitev zvočne intenzivnosti za kompresor brez okrova je precej drugačna. Ta večino hrupa odda skozi spodnjo desno (2) in zadnjo (3) ravnino, kjer so dušilnik ter sesalna in izpušna cev. Celotna raven zvočne moči, ki jo odda kompresor z okrovom in brez okrova, je 34,1 dB in 79,3 dB. To označuje močan dušilni učinek okrova. Razlika med prostorsko porazdelitvijo zvočne intenzivnosti kompresorja z okrovom in brez okrova kaže, da poleg zmanjšanja amplitude hrupa in spremembe njegove frekvenčne vsebine okrov tudi prostorsko prerazporedi oddani hrup.

Rezultati analize zvočnega tlaka in zvočne intenzivnosti kažejo, da okrov močno popači hrup kompresorja zunaj okrova. Da bi vpliv okrova na hrup bolje razumeli, bomo v naslednjem razdelku predstavili analizo modalnih lastnosti okrova.

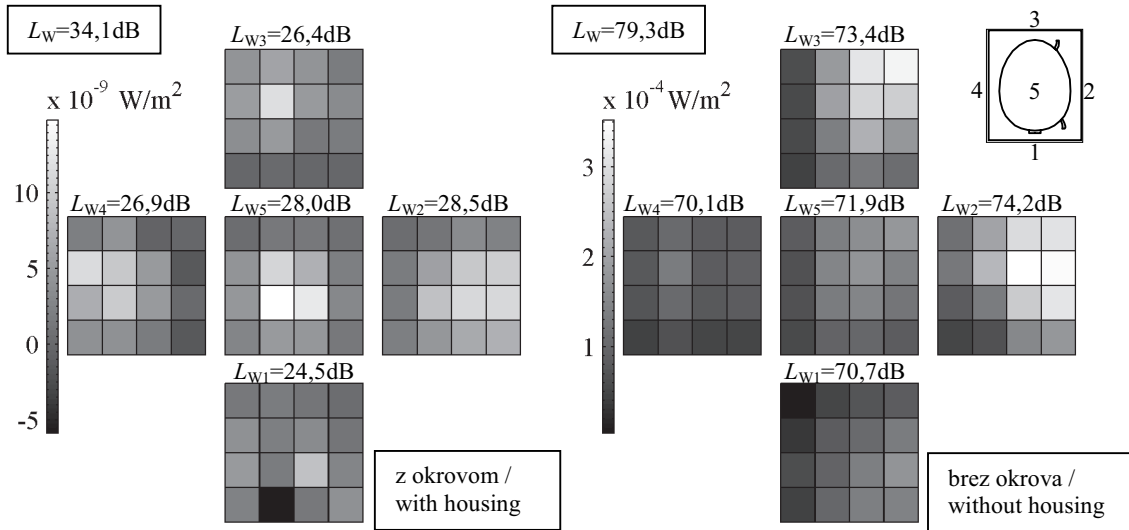
kHz. In both cases the spectral peaks are mostly located at multiples of 50 Hz, which corresponds to the fundamental operating frequency of the compressor. These results therefore indicate that the housing not only reduces the amplitude of the noise emitted by the compressor, but it also markedly changes the frequency content of the noise. The analysis of the spatial distribution of the sound intensity presented in the next section shows some additional influences of the housing on the properties of the noise.

2.2 Sound intensity

Fig. 4 shows the spatial distribution of the sound intensity for the compressor with and without the housing. The five fields with 16 squares each correspond to the five reference planes around the compressor, as illustrated in the top-right-hand corner of the figure. On every square of each reference plane the average sound-intensity amplitude and its orientation are represented on a colour scale. In this way a negative value of the average sound intensity denotes the opposite sound-propagation direction. The sound-power levels L_{wi} above the five fields denote the noise power emitted through the five reference planes. The boxed sound-power level L_w stands for the total sound-power level from all the reference planes.

The compressor with a housing emits most of the noise through the top (5) and right (2) reference planes. The highest sound-intensity amplitudes are found at the top plane (5). The spatial distribution of the sound intensity for the compressor without the housing is significantly different. Most of the noise is emitted from the bottom-right-hand (2) and back (3) planes, where the muffler and inlet and outlet pipes are located. The total sound-power levels emitted by the compressor with and without the housing are 34.1 dB and 79.3 dB, respectively, indicating the tremendous damping effect of the housing. However, the differences between the spatial distributions of the sound intensity of the compressors with and without the housing also show that, apart from decreasing the noise amplitude and modifying its frequency content, the housing also spatially rearranges the noise emitted by the compressor.

The results of the sound-pressure and sound-intensity analyses therefore indicate that the compressor noise recorded outside the housing is significantly affected by the housing. In order to better understand the influence of the housing on the noise it is necessary to determine the modal properties of the housing.



Sl. 4. Prostorska porazdelitev zvočne intenzivnosti v frekvenčnem območju od 200 Hz do 8 kHz za kompresor z okrovom (levo) in brez njega (desno); amplitudni skali se razlikujeta za več velikostnih redov.

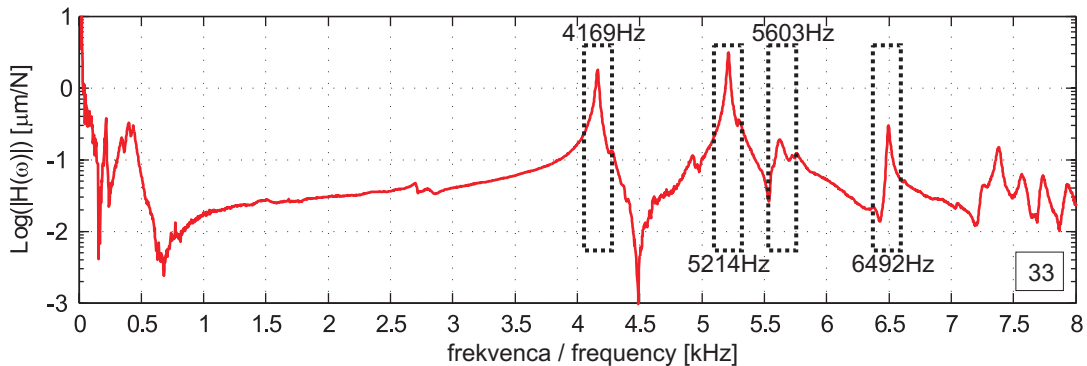
Fig. 4. Spatial distribution of the sound intensity in the frequency range from 200 Hz to 8 kHz emitted by the compressor with (left) and without housing (right). Note that the amplitude scales differ by several orders of magnitude.

2.3 Prenosna funkcija pokrova okrova

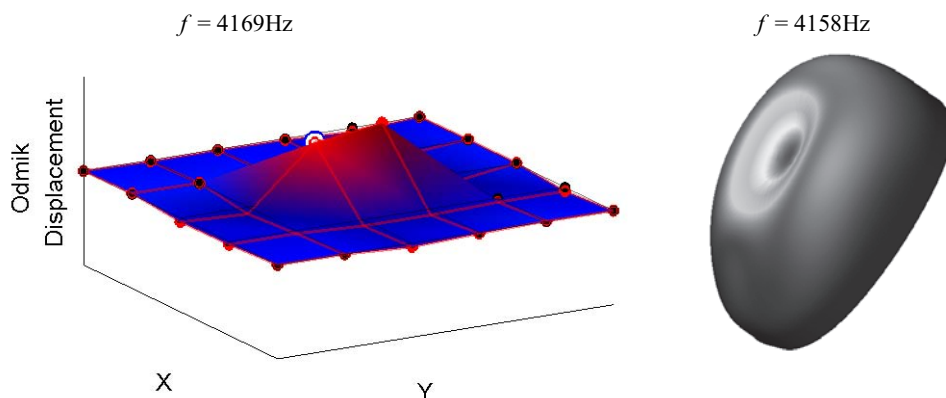
Prenosno funkcijo pokrova okrova smo ugotovili eksperimentalno z merilnikom pospeškov nameščenim na vrh pokrova kompresorja in teoretično z modelom končnih elementov. Slika 5 kaže amplitudo izmerjene prenosne funkcije na vrhu pokrova okrova (mesto označuje točka 33 na sl. 2). Najvišji spektralni vrhovi, ki predstavljajo lastne frekvence okrova, so pri frekvencah 4,2 kHz, 5,2 kHz, 5,6 kHz in 6,5 kHz. Omenjene frekvence so zelo blizu frekvencam glavnih spektralnih vrhov v spektru hrupa, ki ga odda kompresor z okrovom (sl. 3).

2.3 Transfer function of the housing cover

The transfer function of the housing cover was determined experimentally using the accelerometer mounted on the top of housing cover and theoretically by the finite-element (FE) method. Fig. 5 shows the amplitude of the recorded transfer function at the top of the housing cover (point 33 in Fig. 2). The highest spectral peaks appear at frequencies of 4.2 kHz, 5.2 kHz, 5.6 kHz and 6.5 kHz, which represent the eigen frequencies of the housing. Similar frequencies were obtained using the FE method. These frequencies closely match those of the dominant spectral peaks in the spectrum of the noise emitted by the compressor with the housing (Fig. 3).



Sl. 5. Amplituda prenosne funkcije pokrova okrova na vrhu pokrova
Fig. 5. Amplitude of the transfer-function amplitude of the housing cover at the cover top



Sl. 6. Rekonstruirana (levo) in z metodo končnih elementov izračunana (desno) glavna lastna oblika pri frekvenci 4169 Hz

Fig. 6. The reconstructed (left) and the FE-calculated (right) shapes of the dominant eigen mode at a frequency of 4169 Hz

Slika 6 kaže meritev rekonstruirane in z metodo končnih elementov izračunane oblike izrazitejših lastnih oblik pokrova okrova. Lastne oblike po obeh metodah se zelo dobro ujemajo. Iz lastnih oblik lahko razberemo, da se mesta največjih odmikov okrova ujemajo z mesti največjih amplitud zvočne intenzivnosti (sl. 6). Za zmanjšanje amplitude hrupa kompresorja, ki se prenese skozi okrov, se tako zdi najbolj logična rešitev ojačitev okrova [2].

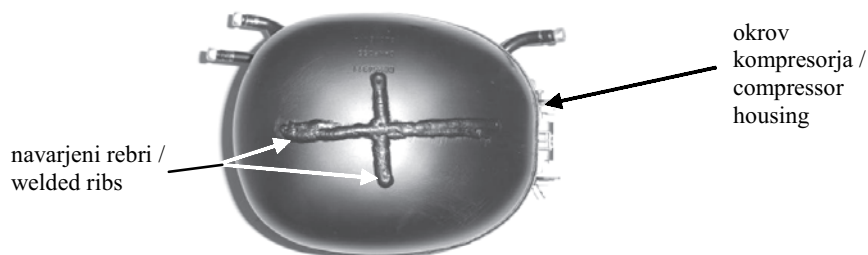
Fig. 6 shows the reconstructed and FE-calculated shapes of the dominant eigen mode of the housing cover. The two mode shapes agree very well. It is clear from the mode shapes that the location of the maximum housing displacement corresponds to the location of the highest sound-intensity amplitudes (Fig. 6). It therefore seems reasonable to stiffen the housing in order to decrease the amplitude of the noise emitted by the compressor through the housing [2].

3 PREPROSTA SPREMEMBA OKROVA

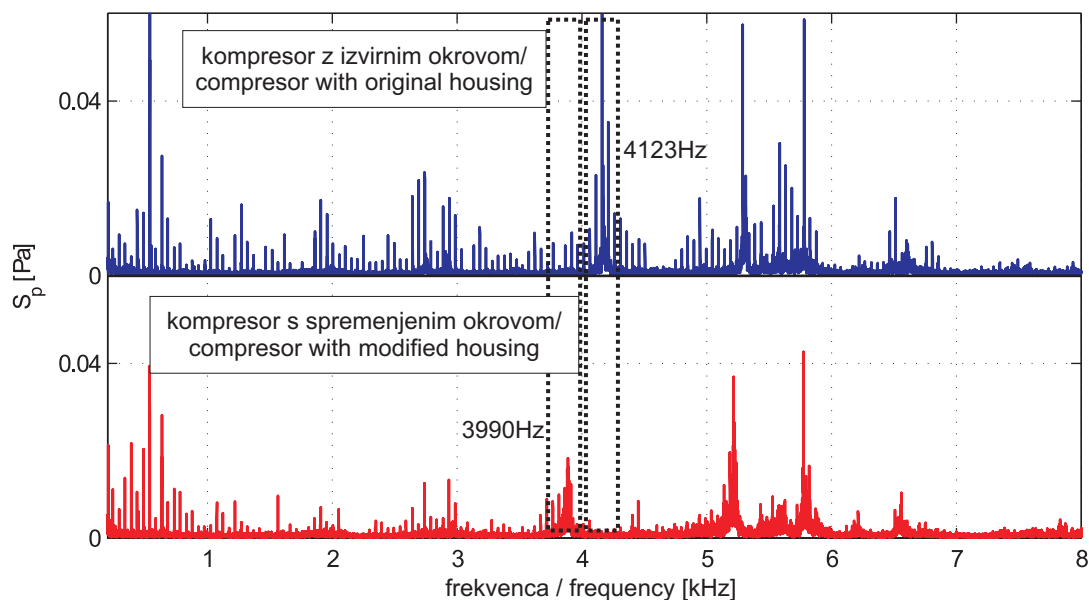
Obstaja več načinov ojačanja okrova. Na primer sprememba oblike okrova, povečanje njegove debeline ali pritrditev ojačitvenih reber. V naši raziskavi smo izbrali zadnji način in na vrh okrova navarili dve prekrizani rebri (sl. 7). Mesto reber smo določili na podlagi analize lastnih oblik in porazdelitve zvočne intenzivnosti, medtem ko smo za obliko reber izbrali kar najpreprostejši profil vara. Vpliv spremenjenega okrova smo vrednotili z analizo zvočnega tlaka in porazdelitve zvočne

3 SIMPLE MODIFICATION OF THE HOUSING

There are several ways to stiffen the housing, such as modifying its design, increasing its thickness or attaching stiffening ribs to it. For this investigation, the last of these methods was chosen, and two crossed ribs were welded to the top of the housing (Fig. 7). The location of the ribs was determined based on the analysis of the eigen-mode shapes and the spatial distribution of the sound intensity, while the shape of the ribs was chosen to be as simple as possible. The influence of such a modification was evaluated by an analysis of the sound pres-



Sl. 7. Kompresor s spremenjenim okrovom
Fig. 7. Compressor with modified housing



Sl. 8. Povprečni amplitudni spekter zvočnega tlaka za kompresor z izvornim (zgoraj) in spremenjenim okrovom (spodaj)

Fig. 8. Average amplitude spectra of the sound pressure of the noise emitted by the compressor with the original (top) and modified housings (bottom)

intenzivnosti hrupa kompresorja s spremenjenim okrovom.

Slika 8 primerja amplitudni spekter zvočnega tlaka hrupa kompresorja z izvornim in spremenjenim okrovom. Sprememba okrova zmanjša amplitudo in spremeni frekvenco glavnih spektralnih vrhov hrupa. Glavni spektralni vrh se s 4,1 kHz za izvorni okrov premakne na 3,9 kHz za spremenjeno okrov, medtem ko se njegova amplituda opazno zmanjša. Analiza prenosne funkcije spremenjenega okrova tudi potrdi, da frekvence glavnih spektralnih vrhov hrupa še vedno ležijo blizu lastnih frekvenc okrova.

Slika 9 primerja prostorsko porazdelitev zvočne intenzivnosti za kompresor z izvornim in spremenjenim okrovom. Sprememba okrova je zmanjšala ravni zvočne moči na desni (2), levi (4) in vrhnji (5) primerjalni ravnini, medtem ko celotna raven zvočne moči pade s 34,1 dB na 33,1 dB. Natančnejša analiza je pokazala, da raven moči najbolj pade na območju od 3,5 kHz do 4,3 kHz [6], ki vsebuje glavne spektralne vrhove hrupa.

4 SKLEP

V prispevku smo analizirali vpliv okrova na hrup batnega kompresorja. Analize

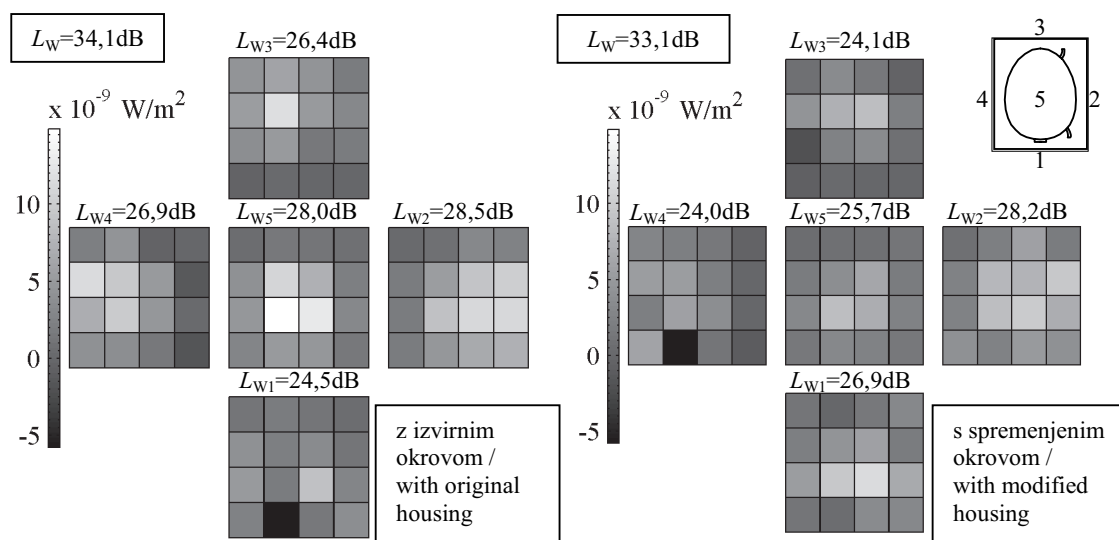
sure and the sound-intensity distribution of the noise emitted by the compressor with a modified housing.

Fig. 8 compares the amplitude spectra of the sound pressure for noise emitted by the compressors with the original and modified housings. The modification of the housing decreases the amplitudes and changes the frequency of the dominant spectral peaks of the noise. The dominant spectral peak is shifted from 4.1 kHz for the original housing to 3.9 kHz for the modified housing, while its amplitude is significantly decreased. An analysis of the transfer function of the modified housing also confirms that the frequencies of the dominant spectral peaks of noise still lie close to the eigen frequencies of the housing.

The spatial distributions of the sound intensity emitted by the compressors with original and modified housings are compared in Fig. 9. The housing modification decreased the sound-power levels at the right (2), left (4) and top (5) reference planes, while the total sound-power level decreased from 34.1 dB to 33.1 dB. A detailed analysis revealed that the largest decrease in the power level occurs in the frequency range from 3.5 kHz to 4.3 kHz [6], which contains the dominant spectral peak of the noise.

4 CONCLUSION

In this paper we analysed the influence of the housing on the noise emitted by a reciprocating



Sl. 9. Prostorska porazdelitev zvočne intenzivnosti v frekvenčnem območju od 200 Hz do 8 kHz za kompresor z izvirnim (levo) in s spremenjenim okrovom (desno)
 Fig. 9. Spatial distribution of the sound intensity in the frequency range from 200 Hz to 8 kHz emitted by the compressor with the original (left) and with the modified housing (right)

izmerjenega zvočnega tlaka in prostorske porazdelitve zvočne intenzivnosti za kompresor z okrovom in brez njega so pokazale, da je vpliv okrova na hrup oddan znotraj kompresorja ter prenesen skozi okrov zelo velik. Okrov ne samo zaduši amplitudo hrupa, temveč tudi spremeni njegovo frekvenčno vsebino in prostorsko porazdelitev okrog kompresorja.

Glavni spektralni vrhovi hrupa kompresorja z okrovom so blizu lastnih frekvenc okrova. Mesta največjih amplitud zvočne intenzivnosti se ujemajo z mesti največjih odmikov, ki smo jih ugotovili prek lastnih oblik okrova. Za ojačanje okrova kompresorja smo na vrh pokrova okrova navarili dve rebri. Ta sprememba je zmanjšala amplitudo hrupa in spremenila frekvence glavnih spektralnih vrhov hrupa, medtem ko je raven zvočne moči hrupa kompresorja se je znižala s 34,1 dB na 33,1 dB. Ti rezultati kažejo, da hrup kompresorja lahko zmanjšamo s spremembo okrova. Prepričani smo, da naprednejša a še vedno cenovno ugodna sprememba okrova lahko vodi do znatnega zmanjšanja hrupa batnega kompresorja za gospodinjske aparate.

compressor. An analysis of the recorded sound pressure and the spatial distribution of the sound intensity emitted by the compressor with and without the housing revealed that the housing significantly affects the noise emitted inside and transmitted through the housing. The housing not only dampens the noise amplitude, but it also modifies its frequency content and the spatial distribution around the compressor.

The dominant spectral peaks of the noise emitted by the compressor with the housing are located close to the eigen frequencies of the housing. The locations of the dominant sound-intensity amplitudes match the locations of the displacement maxima determined by the eigen modes of the housing. In order to stiffen the housing, two ribs were welded to the top of the housing cover. This modification decreased the noise amplitude and changed the frequencies of the dominant spectral peaks of the noise, while the sound-power level of the noise radiating from the compressor was decreased from 34.1 dB to 33.1 dB. These results show that a reduction of the compressor noise can be achieved by modifying the housing. We believe that more advanced, yet inexpensive, housing modifications could lead to considerable reductions in the noise emitted by a reciprocating compressor in domestic appliances.

5 LITERATURA
5 REFERENCES

- [1] M.J. Crocker, J.P. Arenas (2003) Fundamentals of the direct measurement of sound intensity and practical applications, *Acoustical Physics* 2(2003), pp.163–175.
- [2] S. Le Moyne, J.-L. Tebec, I. Tawfiq (2005) Acoustical influence of stiffeners on acoustic radiation of plates, *Mechanical Systems and Signal Processing* (2005), pp. 195–212.
- [3] M.P. Norton (2003) Fundamentals of noise and vibration analysis. *Cambridge University Press*.
- [4] F.J. Fahy (1995) Sound intensity, Second edition. *E & FN Spon*.
- [5] D. J. Ewins (2000) Modal testing: theory, practice and application. *Research Studies Press*, Philadelphia.
- [6] A. Jerič (2005) Acoustic emission analysis of a compressor for domestic appliances (in Slovene), Undergraduate thesis. *University of Ljubljana, Faculty of Mechanical Engineering*, Ljubljana.
- [7] “ISO 9614-1 – Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points”.

Naslov avtorjev: Anže Jerič
doc. dr. Janez Gradišek
prof. dr. Igor Grabec
prof. dr. Edvard Govekar
Univerza v Ljubljani
Fakulteta za strojništvo
Aškerčeva 6
1000 Ljubljana
anze.jeric@gmail.com
edvard.govekar@fs.uni-lj.si

Authors' Address: Anže Jerič
Doc. Dr. Janez Gradišek
Prof. Dr. Igor Grabec
Prof. Dr. Edvard Govekar
University of Ljubljana
Faculty of Mechanical Eng.
Aškerčeva 6
1000 Ljubljana, Slovenia
anze.jeric@gmail.com
edvard.govekar@fs.uni-lj.si

Prejeto: 12.2.2007
Received:

Sprejeto: 25.4.2007
Accepted:

Odprto za diskusijo: 1 leto
Open for discussion: 1 year