

## Notranji hrup v sodobnih traktorskih kabinah

### Interior Noise Level of Contemporary Tractor Cabs

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*Zahteve za določitev notranjega hrupa traktorskih kabin so urejene po pravilnikih EEC za kolesne in gozdne traktorje. Novi prototip traktorske kabine je bil narejen za novi tip traktorja, na katerem so bile opravljene meritve notranjega hrupa glede na različne izolacijske materiale. Meritve so bile opravljene v primeru, ko so bile vse odprtine na traktorju zaprte in odprte. Hitrost traktorja in vrtilna frekvenca motorja so bili v predvidenih mejah. Nižja raven notranjega hrupa je bila dosežena z uporabo absorpcijskih in izolacijskih materialov za različne frekvence. Nižja raven notranjega hrupa je bila dosežena z uporabo elastičnega obesa kabine na šasijo traktorja. Glede na potrebo po zmanjšanju notranjega hrupa so bile izvedene meritve za izboljšavo traktorske šasije in kabine..*

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**(Ključne besede: traktorji, kabine vozil, hrup notranji, ukrepi protihrupni)**

*The requirements regarding the interior noise level of a cab for wheeled agricultural or forestry tractors are controlled by EEC regulations. A new prototype of tractor cab has been designed for new types of tractors, in which interior noise levels were measured using different types of isolation materials. Measurements were carried out while all openings of the tractor were closed, and also while all openings were left open. The speed of the tractor and the r.p.m. of the engine's governor were held under defined limits. The interior noise level of the cab was moderated by using adequate absorbing and isolating materials for a defined frequency range. Lower interior noise levels were achieved by using elastic suspension between the tractor's chassis and cab. To reduce interior noise levels some measures of modernization of the tractor's chassis and cab were analyzed.*

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**(Keywords: tractors, cab, interior noise, antinoise measures)**

#### 0 UVOD

Notranji hrup traktorjev je urejen s Pravilnikom EEC 77/311 [1], ki predpisuje pogoje, metode in postopke meritev ter rezultate in kriterije veljavnosti rezultatov. Sodobne kabine traktorjev so izdelane kot zasebni delovni prostor voznika, ki je popolnoma ločen od šasije traktorja z elastičnim obešanjem. Traktorji prilagojeni takšni izvedbi kabine imajo raven pod in vse krmilje nameščeno v kabini, kar je zelo ugodno za reševanje protihrupne izolacije. To je pglavitni pogoj za upravičeno in smotrno poseganje v prostor kabine zaradi ustreznih rešitev dušenja vibracij in hrupa. Elastično obešanje kabine preprečuje prenos vibracij od šasije na kabino, kar skupaj z ustrežno izolacijo posebej izpostavljenih hrupnih površin kabine zagotavlja možnost za doseganje predpisane ravni hrupa v notranjosti kabine.

Hrup se preverja med vožnjo pri popolnoma zaprtih odprtinah traktorja in pri popolnoma odprtih

#### 0 INTRODUCTION

The interior noise of wheeled agricultural or forestry tractors is controlled by regulation 77/311 of the EEC [1] which prescribes conditions, methods, and procedures of measurements, as well as data processing and results validation. Contemporary tractor cabs are designed to be a special driver's space, which is fully separated from the tractor chassis by elastic suspension. New series of tractor cabs have a flat floor, and all of the command pedals in the cab are separated from the chassis. It is a good solution regarding the problem of interior noise reduction. On the other hand, an effective and rational approach regarding the absorption or isolation of interior noise requires some modification or new design of cab interior space. The elastic suspensions prevent transmission of vibrations from chassis to cab; together with adequate materials for noise isolation and absorption, especially for elements that are near to the noise source, it is possible to achieve permitted cab interior noise.

In this study noise levels were measured in a moving tractor. Measurements were made while all openings of the tractor were closed, and also when all



odprtinah kabine traktorja pri hitrosti okrog 7,5 km/h, ki jo zagotavlja določena prestava v menjalniku traktorja pri največji vrtilni frekvenci motorja.

## 1 POGOJI ZA MERITEV

Pogoji za meritev notranjega hrupa [1] morajo biti izpolnjeni glede traktorja, testne površine in stanja okolice.

### 1.1 Traktor

- mora biti neobremenjen, in brez pripadajočega orodja,
- traktorski sistemi morajo biti napolnjeni z oljem, tekočino, gorivom, mazivom, nameščeno mora biti osnovno orodje in v njem voznik,
- predpisane morajo biti pnevmatike in tlak zraka v njih,
- motor, prenos in preme morajo biti ogreti na delovno temperaturo,
- žaluzije pred hladilnikom morajo biti odprte,
- med meritvami ne smejo delovati: brisalci, gretje - ventilatorji, odvzem moči,
- delovati morajo sistemi: ventilator za hlajenje motorja, črpalke za dovod goriva in maziva.

### 1.2 Preizkusna površina

- je na odprti in mirni lokaciji, brez ovir v krogu s premerom 50 m,
- osrednja preizkusna površina je v krogu s premerom 20 m trda in ravna ter suha in čista,
- površina mora biti brez dodatnega vzbujanja hrupa.

### 1.3 Okolica

- vreme mora biti lepo, brez vetra ali s šibkim vetrom,
- hrup okolice mora biti za 10 dB(A) manjši od najnižjega hrupa traktorja.

### 1.4 Merjenje ravni hrupa

Mikrofon je treba postaviti znotraj kabine, 250 mm od središča sedeža levo ali desno glede na največjo raven hrupa in ga usmeriti v smeri vožnje na višini 790 mm ter 150 mm naprej od referenčne točke sedeža.

Raven hrupa se meri med vožnjo traktorja na merilni poti, trikrat pri vseh zaprtih nato pa odprtih odprtinah na traktorski kabini v prestavi, ki pri največji vrtilni frekvenci motorja daje približno hitrost 7,5 km/h. Traktor je v tem primeru neobremenjen (Anex II EEC).

openings were left open. The velocity of the tractor had to be about 7.5 km/h, to provide the maximum r.p.m. of the tractor's engine.

## 1 CONDITIONS FOR MEASUREMENT

Measurements of cab interior noise level [1] must be carried out under the following conditions.

### 1.1 Tractor

- must be unloaded and without tractor's tools,
- all systems must be filled up with oil, liquids, fuel, lubricant, and the base tools and driver fixed in place,
- pneumatic shape must be defined and corresponding air pressure considered,
- engine, transmission and axles must be warmed to the work temperature,
- cooling louvers in front of the radiator must be opened,
- windscreen wipers, heating - ventilation and power transfer are turned off,
- engine fan, fuel pumps and lubricant circulation are operational.

### 1.2 Test area

- open and sufficiently silent location, open space of 50 m radius,
- central part of tested area must be at least 20 m which is practically level, solid and flat, clean and dry,
- surface of the track must be such so as not to cause excessive tire noise.

### 1.3 Environment

- the weather must be fine and dry, calm or with little wind,
- ambient noise level must be at least 10 dB(A) below the noise level of the tractor.

### 1.4 Noise level measurements

The microphone must be located 250 mm to the side of the center plane of the seat, on the side where the highest noise level is encountered. The microphone diaphragm must face forward and the center of the microphone must be 790 mm above and 150 mm in front of the seat reference point (SRP).

Measurements of interior noise level are carried out on a traveling tractor, three times when first all openings of the tractor are closed, and again when all openings are left open. The speed of the tractor must be given by the gear ratio of the gearbox, which gives a velocity close to 7.5 km/h with maximum engine r.p.m. According to Annex II of EEC regulation, measurements of interior noise levels must be carried out on unloaded tractor.

## 2 IZHODIŠČA

Študija in reševanje problemov protihrupne zaščite sodobnih traktorskih kabin se začne, ko so:

- potrjena varnostna konstrukcija traktorske kabine kot izhodišče za vgradnjo protihrupne zaščite,
- določen elastični sistem obesa kabine na šasijo,
- določena in sprejeta poglobljena zamisel notranje opreme kabine glede ergonomskih in oblikovnih parametrov,
- izbrani ustrezni protihrupni materiali za zvočno izolacijo notranjosti kabine,
- druga izhodišča glede učinkovite protihrupne zaščite.

## 2.1 Varnostna konstrukcija kabine

Način reševanja protihrupne zaščite kabine je zelo odvisen od končne izvedbe različice varnostne konstrukcije kabine. Ustreznost varnostne konstrukcije kabine oziroma trdnost njenega ogrodja je preverjena na prevračanje po Pravilniku EEC 88/413 [2].

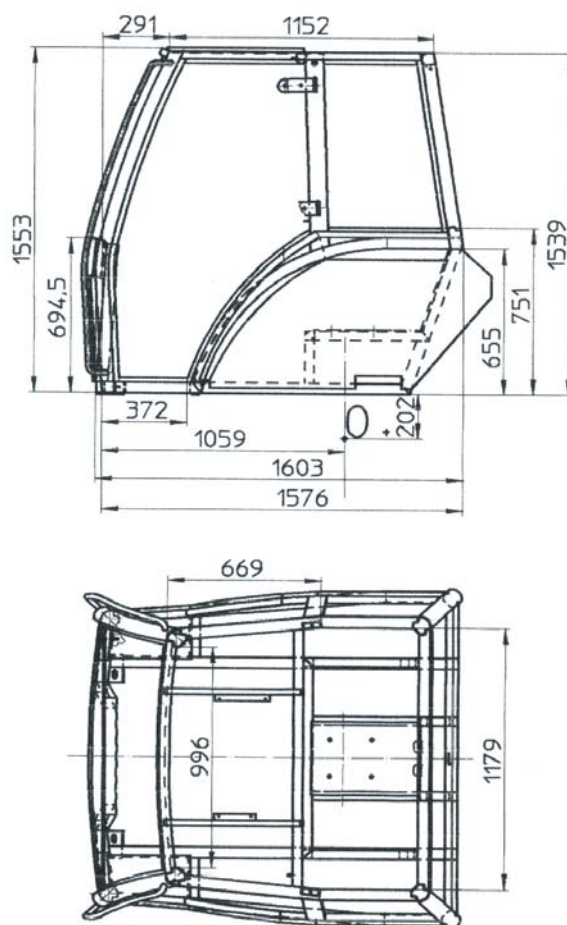
## 2 STARTING POINTS

Studying and solving problems of noise protection in modern tractor cabs starts when there is/are:

- a confirmed safety structure of the tractor cab as a starting-point for building noise protection,
- a defined elastic system of suspension between the tractor's chassis and cab,
- a defined and accepted base concept of the interior equipment of the cab, such as for ergonomics and shape parameters,
- selected suitable anti-noise materials for noise isolation in the interior of the cab,
- other points of departure for efficient noise protection.

## 2.1 Safety structure of a cab

The way of solving noise problems of a cab is mostly dependent upon the safety structure of the cab. The suitability of a safety structure of a cab or the strength of a skeleton is checked by roll-over according to the regulation EEC 88/413 [2].



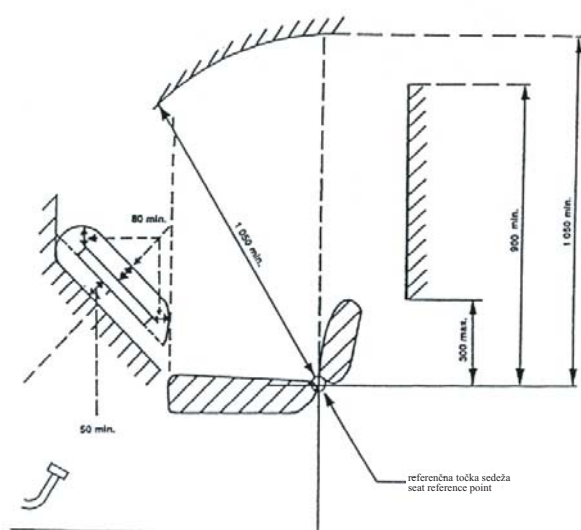
Sl. 1. Varnostno ogrodje kabine  
Fig. 1. Safety skeleton of cab



Z ogrodjem kabine so določene vse makro in mikro površine, ki jih je treba izolirati oziroma dodatno dušiti, da bi bila dosežena predpisana raven hrupa v notranjosti kabine (sl. 1).

## 2.2 Razmerje v notranjosti kabine

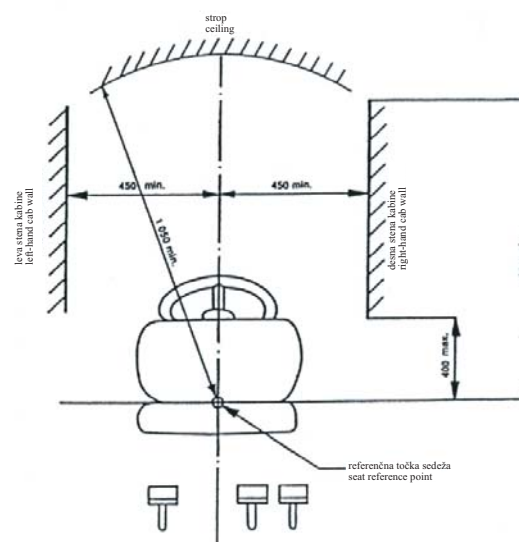
Notranje minimalne izmere kabine so določene glede na prevračanje oziroma najmanjši nedotaknjeni prostor v kabini, ki štiti voznika pred poškodbami pri obračanju traktorja v katerikoli delovni ali prometni nesreči (sl. 2). Izhodišče za določanje zaščitenega prostora je referenčna točka sedeža.



Within the skeleton of a cab, all macro- and micro-surfaces are defined, which should be isolated or extra muffled, so as to achieve the de desired level of noise in the cab interior (Fig.1).

## 2.2 Proportion of cab interior

The interior minimum dimensions of the cab depend on roll-over or the minimum untouched place in the cab, in order to protect the driver in all cases of injuries due to the tractor turning over while working or due to a traffic accident (Fig.2). The starting point for defining the untouched area is the reference point of the seat.



Sl. 2. Varnostni prostor v notranjosti kabine  
Fig. 2. Safety place interior of cab

## 2.3 Obes kabine

Sodobni obes kabine je izveden s posebnimi gumijastimi ležaji ali hidro elastičnimi ležaji, zmožnimi, da prevzamejo in dušijo večino frekvenčnih spektrov vzbujajočih sil motorja, transmisije ali koles. Takšni specialni ležaji (sl. 3), ki so konično montirani, prevzamejo vzbujajoče sile iz vseh treh smeri. Prav takšni ležaji so namenjeni za uporabo v avtomobilski industriji, posebej pa za vgradnjo kabine na šasijo.

## 2.4 Protihrupni izolacijski/absorpcijski materiali

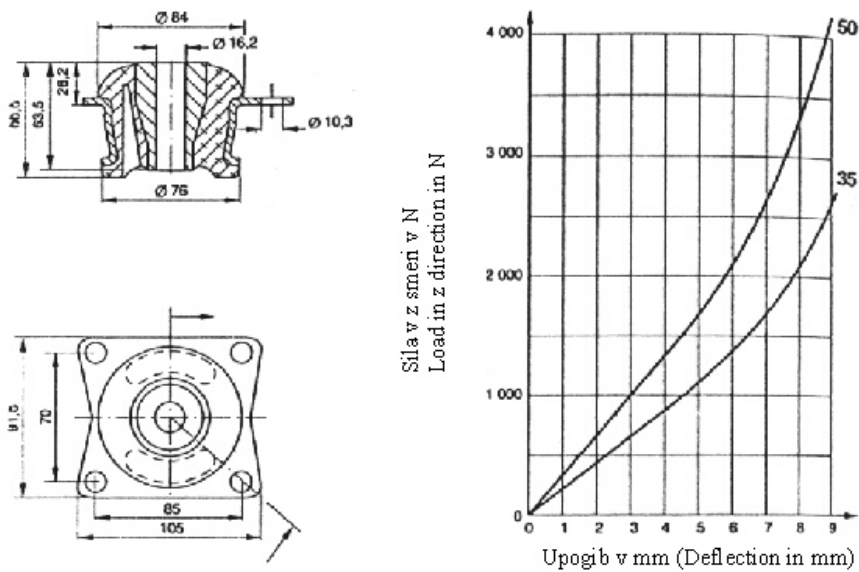
Za protihrupno izolacijo so uporabljeni danes že standardni absorpcijski materiali FAIST M1792 (sl.4) debeline 20 ali 40 mm, pa tudi izolacijski material FAIST M1735 (sl.5) debeline od 3 do 12 mm in težka folija debeline 3 mm. Glede zapiranja odprtín na traktorju: vrata, vetrobransko steklo, druga stekla in streha so izbrani materiali npr.: pločevine, poliester

## 2.3 Suspension between tractor's chassis and cab

The modern suspension between a tractor's chassis and cab is formed with the help of special rubber bearings or hydro-elastic bearings, capable of dampening most frequency spectrums of vibrational forces from the motor, transmission and wheels. These special bearings (Fig.3), which are conic mounted, take vibrational forces from all three directions. These kinds of bearings are designed for use in the car industry especially for building a cab on a chassis.

## 2.4 Anti-noise isolation/absorption materials

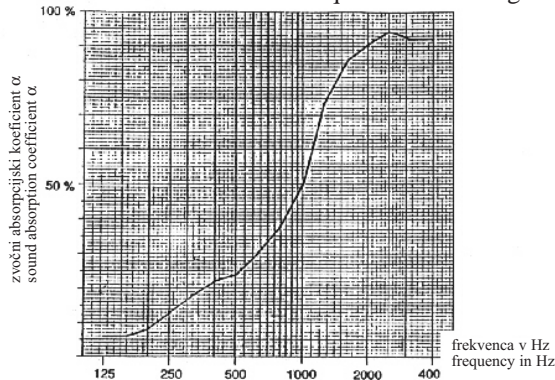
The standard absorption material for anti-noise isolation FAIST M1792 (thickness 20 or 40 mm) is used like the isolation material FAIST M1735 (thickness from 3 to 12 mm) and heavy foil (thickness 3 mm) (see Fig. 4 and 5). As for closings opening like the doors, and windscreen, other glasses and roof materials are chosen such as sheet metal, polyester



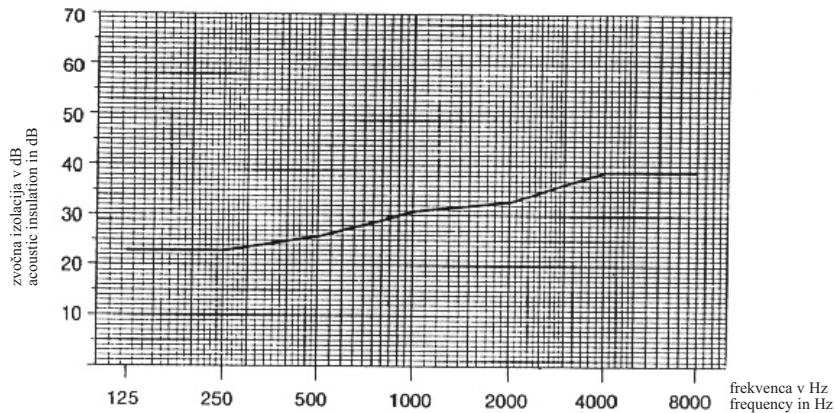
Sl. 3. Gumijasti konični ležaj obesa kabine na šasijo traktorja  
 Fig. 3. Rubber-conic bearing of suspension between tractor's cab on chassis

in stekla ustrezne debeline - pločevine od 1,5 do 2,0 mm, stekla pa debeline 5,0 mm. Tesnjenje vrat in oken, ki se odpirajo, je izvedeno s posebnim tesnilnim profilom. Tlačna sila med ogrodjem kabine in tesnilno gumo je precej močna, s čimer smo odpravili vibracije in tresenje delov, kar je bil pogosto vzrok za previsoko raven hrupa.

and glasses suitable thickness (sheet metal from 1.5 to 2.0 mm, glass thickness of 5.0 mm). Sealing of doors and windows is achieved through a special profile. The pressure force between the skeleton of the cab and the rubber on the profile is sufficiently strong to prevent vibrations, which was previously a frequent cause of high noise levels.



Sl. 4. Karakteristika protihrupne obloge FAIST M1792/20  
 Fig. 4. Characteristic of anti-noise material FAIST M1792/20



Sl. 5. Karakteristika protihrupne obloge FAIST M1735/3  
 Fig. 5. Characteristic of anti-noise material FAIST M1735/3



### 3 MERITEV NOTRANJEGA HRUPA

#### 3.1 Hrup brez posebne priprave kabine

Razvita je kabina za vgradnjo na traktorje od 34 do 52 kW. Narejena je po vseh zahtevah, ki so določene pri načrtu, pa tudi pri konstrukcijski in tehnološki izdelavi. V prvi fazi razvoja prototipne kabine niso dokončno usklajena vsa razmerja med deli kabine, ki se odpirajo, in ogrođjem, zato je pričakovano, da bo emisija hrupa višja glede na mejno raven. Posebej kritično mesto je povezava sprednjega dela kabine oziroma okrova armaturne plošče v kabini in motorja na šasiji traktorja. Očitno je, kar so pokazale tudi meritve, da je ta lokacija predvsem izpostavljena hrupu motorja, kar pomeni tudi posebne ukrepe za protihrupno izolacijo.

#### 3.2 Protihrupni ukrepi

Zmanjšanje hrupa v notranjosti traktorske kabine je izvedeno z uporabo posebnih absorpcijskih in izolacijskih materialov na notranjih blatnikih in podu kabine, težko folijo v sprednji steni armaturne plošče kabine, notranje strehe in dodatnim tesnjenjem vseh oken in vrat.

**Postavitev mikrofona:** Mikrofon je postavljen po navodilih točke 1.4. Uporabljen je merilnik zvoka CSL - 328/3 [3].

**Merilne razmere:**

- temperatura okolice 19 °C,
- vlažnost 85 %,
- hitrost vetra 1,3 m/s,
- hrup okolice 53,4 dB(A).

#### 3.3 Hrup mirujočega traktorja

Hrup mirujočega traktorja je prikazan v razpredelnici 1 in diagramu 1. Med meritvijo deluje samo motor traktorja in ventilator za hlajenje motorja.

#### 3.4 Hrup traktorja med vožnjo

Hrup traktorja med vožnjo je prikazan v razpredelnici 2 in diagramu 2. Meritev je narejena pri hitrosti traktorja 7,2 do 7,8 km/h in vrtilni frekvenci motorja 2490 do 2520 min<sup>-1</sup>.

Dopustna največja (mejna) vrednost hrupa traktorja je 86,0 dB(A) v primeru vožnje v prestavi menjalnika, ki zagotavlja hitrost približno 7,5 km/h in največjo vrtilno frekvenco motorja.

### 3 MEASUREMENT OF INTERIOR NOISE LEVEL

#### 3.1 Interior noise level without noise protection

The cab was developed as a prototype for installation on tractor's chassis of 34 to 52 kW. It was constructed by taking into consideration all of the requirements which were defined by the cab's design. In the first phase of development, the relationships between the opening cab parts and the skeleton of the cab did not finally harmonize. The reason was that we expected a high level of interior noise relative to the required limits of noise level. An especially critical place on tractors is the connection between the front panel of the cab, housing the instrument and the tractor's engine and transmission. It was very clear that the measured noise level in that part of the cab had the maximum level with regard to engine noise. It means we must have especially effective means for noise protection in this part of the cab.

#### 3.2 Anti-noise measures

Reduction of the interior noise level in the tractor's cab was achieved with the use of special sound-absorbing and isolation material on the interior mudguards and floor of the cab, with the addition of heavy foil on the instrument panel housing on the roof, and additional isolation of doors and windows.

**Position of microphone:** The microphone was located as described in section 1.4. The microphone used was CSL - 328/3 [3].

**Measurement condition:**

- environmental temperature 19 °C,
- humidity 85 %,
- wind speed 1.3 m/s,
- environmental noise level 53.4 dB(A).

#### 3.3 Noise level for tractor in stationary condition

The noise level for the tractor in its stationary condition is shown in Table 1 and Diagram 1. During measuring only the engine and engine fan were running.

#### 3.4 Noise of traveling tractor

Noise of traveling tractor is shown in Table 2 and Diagram 2. The measurements were made for speeds 7.2 to 7.8 km/h and 2490 to 2520 r.p.m.

The limit of interior noise level is 86.0 dB(A) in the case when the tractor travels in the gear ratio which provides speed nearest 7.5 km/h by maximum engine r.p.m.

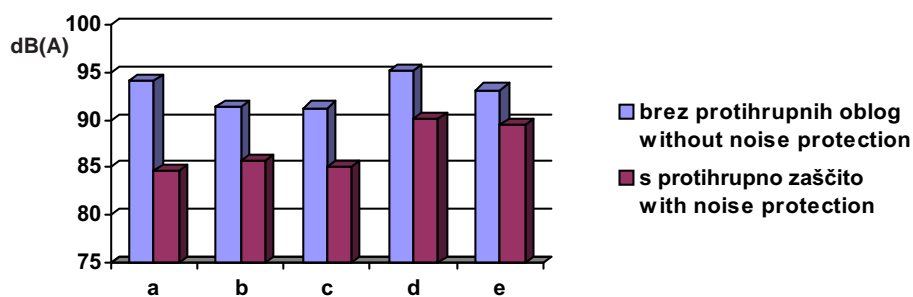
Razpredelnica 1. Hrup mirujočega traktorja v dB(A)

Table 1. Noise level for tractor in stationary condition dB(A)

vrsta odprtine type of opening	brez protihrupnih oblog without noise protection	s protihrupno zaščito with noise protection
a) vse odprtine zaprte all openings closed	94,1	84,7
b) vse odprtine odprte all openings opened	91,4	85,7
c) odprto le zadnje steklo rear window opened only	91,3	85,1
d) odprta oboja vrata both doors opened	95,1	90,2
e) odprta le leva vrata the left door opened only	93,2	89,5

Diagram 1. Hrup mirujočega traktorja

Diagram 1. Noise level for tractor in stationary condition



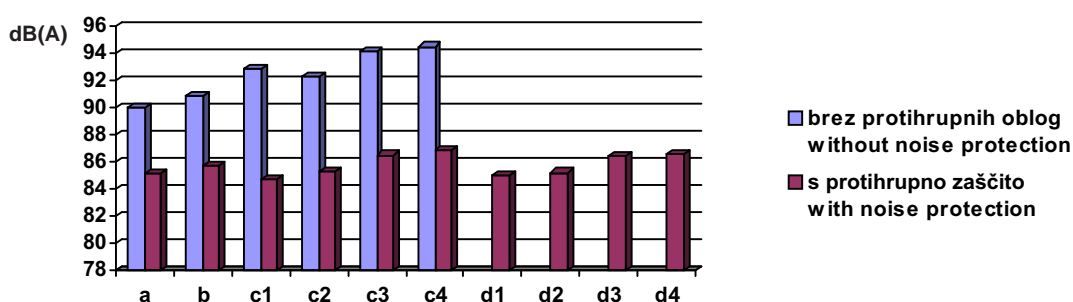
Razpredelnica 2. Hrup traktorja med vožnjo v dB(A)

Table 2. Noise level of traveling tractor dB(A)

vrsta odprtine type of opening	brez protihrupnih oblog without noise protection	s protihrupno zaščito with noise protection
a) vse odprtine zaprte all openings closed	90,0	85,1
b) vse odprtine odprte (vrata ne) all openings opened (doors not)	90,9	85,7
c) največja hitrost: vse zaprto / maximum speed: all closed		
1. prestava 1 <sup>st</sup> gear ratio	92,9	84,7
2. prestava 2 <sup>nd</sup> gear ratio	92,3	85,3
3. prestava 3 <sup>rd</sup> gear ratio	94,1	86,5
4. prestava 4 <sup>th</sup> gear ratio	94,5	86,9
d) največja hitrost: vse odprto / maximum speed: all opened		
1. prestava 1 <sup>st</sup> gear ratio	–	85,0
2. prestava 2 <sup>nd</sup> gear ratio	–	85,2
3. prestava 3 <sup>rd</sup> gear ratio	–	86,4
4. prestava 4 <sup>th</sup> gear ratio	–	86,6



Diagram 2. Hrup traktorja med vožnjo  
Diagram 2. Noise level of traveling tractor



### 3.5 Meritve notranjega hrupa pri obremenjenem traktorju

Test vleke ali obremenitve traktorja, pri katerem traktor oddaja hrup, ki je za 1 dB(A) nad tistim izmerjenim pri hitrosti okrog 7,5 km/h, je preverjen v naslednjih razmerah (razpredelnica 3):

### 3.5 Measurement of interior noise level of a loaded tractor

Interior noise levels were measured at the load corresponding to the maximum noise level in any gear other than in the case of the noise level at 7.5 km/h in which the noise level recorded is at 1 dB(A) above that recorded before (7.5 km/h). The results of the measurements are showed in Table 3:

Razpredelnica 3. Meritve hrupa  
Table 3. Measurement of noise

prestava gear ratio	silna na kljuki force on hook kN	hitrost speed km/h	vrt. frek. r.p.m. min <sup>-1</sup>	št. pog. osi drive axles	raven dB(A) vse odprto dB(A) all opened	raven dB(A) vse zaprto dB(A) all closed
1 I	17,3	0,84	2528	2	86,0	88,0
1 I	24,2	0,83	2526	4	86,0	87,5
2 I	24,0	1,25	2520	4	86,0	88,0
3 I	24,3	1,83	2513	4	86,0	87,5
4 I	24,3	2,34	2507	4	85,5	87,5
1 II	24,1	2,56	2506	4	85,5	87,5
2 II	24,2	3,79	2496	4	86,0	89,0
3 II	16,7	5,69	2495	2	86,0	89,0
<b>4 II</b>	<b>14,0</b>	<b>4,47</b>	<b>2401</b>	<b>2</b>	<b>85,0</b>	<b>89,5</b>
<b>4 II</b>	<b>13,3</b>	<b>7,83</b>	<b>2403</b>	<b>4</b>	<b>84,5</b>	<b>88,0</b>
1 III	11,1	9,56	2398	4	85,0	89,5
2 III	6,7	15,27	2395	4	85,0	89,5
3 III	3,8	23,1	2435	4	85,5	90,0

Rezultati meritev očitno potrjujejo uspešno rešitev protihrupne zaščite notranjosti kabine, ker so v primeru obveznega testa vsi rezultati v predpisanih mejah. Prvi sklop meritev iz točke 3.4 na neobremenjenem traktorju je dal rezultate meritev v mejah, ki so predpisani po Anex II EEC, in sicer 86,0 dB(A). V primeru meritev notranjega hrupa pri obremenjenem traktorju je dovoljena najvišja raven hrupa 90,0 dB(A).

The results of our measurements confirm that an effective solution for cab interior noise protection has been found because all measured data were within allowed limits. Interior noise measurements of the unloaded tractor were made by [1] Annex II. The limit of noise level in the case of a loaded tractor is 90 dB(A).



#### 4 SKLEPI

Notranji hrup kabine je predvsem odvisen od izvedbe prednje stene kabine v območju okrova armaturne plošče, ki je v neposredni povezavi s šasijo traktorja. Največ hrupa se prenaša v kabino prek okrova armaturne plošče, kar zahteva posebno previdnost pri izvedbi protihrupne zaščite. Vgradnja pločevine debeline 1,25 mm, težke folije debeline 3 mm, material M1792/20 - 40 mm in umetno usnje debeline 1,2 mm so bili dovolj za dosego zahtevane ravni hrupa.

Protihrupne absorpcijske obloge blatnikov (M1792/20 - 40 mm) in izolacijska obloga poda (M1735/3 - 12 mm) so skupaj z drugimi ukrepi v kabini pripomogli k zmanjšanju notranjega hrupa.

Tudi elastična povezava kabine in traktorske šasije prek koničnih gumijastih ležajev je pozitivno vplivala na zmanjšanje ravni notranjega hrupa kabine.

Glede traktorske šasije je treba pričakovati določene spremembe na motorju in okrog njega, menjalnika, reduktorjev in prem za znižanje ravni hrupa nasploh, pa tudi notranjega hrupa. Rešitve so vgradnja tihih prenosnikov v sklope traktorja, ustrezni materiali in togost okrova, dušilniki torzijskih vibracij itn.

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#### ZAHVALA

Avtorja se zahvaljujeta Ministrstvu za znanost in tehnologijo Republike Slovenije, ki je sofinanciralo projekt Razvoj traktorskih kabin.

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Prejeto: 15.2.1999  
Received:

#### ACKNOWLEDGEMENT

The authors would like to express our thanks to the Ministry of Science and Technology of the Republic of Slovenia for co-sponsoring the project Development of a Tractor's Cab.

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Sprejeto: 16.4.1999  
Accepted: