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Measurement of the Sound Power of a Self Propelled Nut Harvester

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Abstract

This document is based on the determination of the sound power of a self-propelled machine used for harvesting nuts. To calculate the level of sound power given out by the machine, the method defined by the UNI EN ISO 3744:2010 standard has been adopted.

This standard provides that the machine to be examined must be placed on a reflecting surface and the microphones must be placed all around the machine in predetermined locations on a fictitious measurement surface.

During the realization phase of this survey it merged the existence of a lack in the methodology between the UNI EN ISO 3744:2010 and the UNI EN ISO 4254-1:2013 “Agricultural machinery - Safety - Part 1: General requirements”.

The UNI EN ISO 3744:2010 specifies that the measurement surface to be used for the location of the microphones is the hemisphere. For big machines, this measurement surface is not always applicable because the upper central microphone is located at heights unreachable with conventional poles (25-30 m). Instead, the UNI EN ISO 3744 standard allows the utilization of a different measurement surface (parallelepiped surface) to locate the microphones, but this surface is not mentioned in the UNI EN ISO 4254-1:2013 standard.

Results show that the UNI EN ISO 4254-1:2013 standard could be revised adopting the criteria of UNI EN ISO 3744 for the measurement of sound power for agricultural machinery.

Keywords: Noise, sound power, nut harvesters

1. Introduction

In order to commercialize agriculture machines in the European market, constructors must carry out strict safety controls to satisfy communitarian standard and thus introducing in the market safer machines.

One of the several controls that can be carried out on machines, to guarantee the health of the worker, is the analysis of sound power level (Carletti, 2013; Monarca *et al*, 2009; Riccioni *et al*, 2015).

According to Shanks (2014) unexpected conflicts, confusion and inconsistencies have been observed for the declared sound pressure levels and sound power levels for machinery supplied in Europe.

When a specific determination of the sound power is requested, the standard to follow is severe and complicated, therefore during the measurement phase a tool that guarantees the reliability of the data is needed (Barnard, 2014). Environmental conditions, the number of microphones, the source position and the method to calculate the mean value are all parameters accurately established and imposed. In order to obtain precise results, the levels of sound pressure must be measured in a dozen of points for each position in which the machine must be placed. This document is based on the determination of the sound power of a self-propelled machine used for harvesting nuts. To calculate the level of sound power given out by the machine, more specifically the Facma Cimina 300 S, the method defined by the UNI EN ISO 3744:2010 standard has been adopted. This standard provides that the machine must be placed on a reflecting surface and the microphones must be placed all around the machine in predetermined points located on a fictitious measurement surface defined as the lateral surface of a parallelepiped with an area equal to *S*, which includes the source, its sides are parallel to the sides of the referring parallelepiped and are located at a distance equal to *"d"* (distance of measurement)
from the referring parallelepiped that includes the examined machine.
All tools and instruments utilized for this work have been provide by the INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, Roma, Italy) research centre of Monte Porzio Catone (RM). The tests have taken place at the Research Center for Agricultural Engineering of CREA-ING (Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria - Unità di ricerca per l'Ingegneria Agraria) in Monterotondo (Roma) on a grassy surface and not on a reflecting one. To remedy to this lack and to guarantee reliable data, the measurement has been repeated using a reference sound source, thus it was possible to characterize and verify the effect of the grass in the determination of the sound power of the examined machine. When measuring the sound emissions of a machine of big dimensions there are many problems to face, mainly related to the placement of microphones in pre-defined locations at a relevant ground elevation (up to 3 meters); a further difficulty is represented by the environmental conditions that can easily compromise the sound data: for instance, the wind or the noise coming from the surrounding areas can inevitably compromise the test.

2. Materials and methods

The test has been carried out in several successive days. The first day, at the Laboratory of Physical Agents of INAIL research centre in Monte Porzio Catone, the whole instrumentation has been tested.

2.1 Instrumentation

The instrumentation used for data acquisition during the measurement phase is: Bruel & Kjaer "2290" model microphones, equipped with pre-amplifiers and connecting cables; Bruel & Kjaer "7507" model sound power meter (figure 1); Bruel & Kjaer "2711" model multiplexer with 8 channels (figure 2).

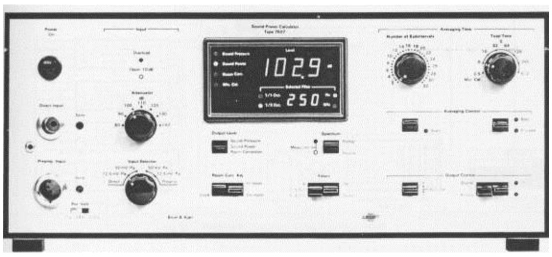

Fig. 1 - Bruel & Kjaer "7507" model sound power meter.

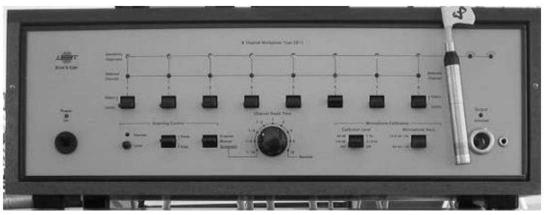

Fig. 2 - Bruel & Kjaer "2711" model multiplexer with 8 channels

2.2 Sources description

2.2.1 Facma Cimina 300 S

The self-propelled harvester made by Facma (Vitorchiano, Italy), model "Cimina 300 S" (figure 3), is a one operator agricultural machine that taking advantage of the lift effect produced by the airflow is able to harvest the nuts directly from the ground into sacks or trailers (Monarca *et al*, 2009, 2012). The harvester's characteristics are reported in table 1.

Fig. 3 - Facma Cimina 300 S during hazelnut harvest

Technical data	Values
Length	5,760 mm
Width	1,700 mm
Operating width	2,500 – 3,000 – 3,500 mm
Height	1,700 mm
Mass	2,330 kg
Engine model	Diesel 4T VM D704 TE2
Power	61 kW

TABLE 1 - Facma Cimina 300 S: technical data

2.2.2 Source Bruel & Kjaer type "4204"

The reference sound source utilized to characterize the testing environment is the Bruel & Kjaer type "4204" (figure 4). This machine guarantees a constant standardize noise in the whole surrounding area.

Fig.4 - Reference sound source Bruel & Kjaer "4204".

2.3 Test description

Before carrying out the field test, a trial source has been installed in the reverberation room of the INAIL laboratory.

The measurement parallelepiped necessary to calculate the sound power has been formed around this source. This last value has been determined to characterize the standard source verifying the data given by the manufacturer.

Then, the instruments needed for the test, placed in appropriate containers, have been transferred to the measurement location (CREA-ING research centre in Monterotondo).

Afterwards, in the area arranged for the sound test, the base of the measurement parallelepiped has been delimited by iron poles inserted into the ground and linked by a white thread, as it is provided by the UNI EN ISO 3744 standard.

To facilitate the measurement operation and, as well, for safety reasons, all the poles have been orange coloured.

At last, the distance required by the standard between the tested machine and the obstacles has been verified. The minimum distance of 13 meters between the fixed obstacles and the measurement parallelepiped has been respected.

Facma, the manufacturer industry of the Cimina 300 S, provided for the transportation, by truck, of the brand new harvester to be tested at the CREA - ING research centre.

A specialized worker placed the machine in the centre of the basis of the measurement parallelepiped; in order to respect the minimum distance "*d*" of one meter between the measurement parallelepiped and the set one (figure 5 and 6).

Fig. 5 - Facma Cimina 300 S machine placed in the centre of the measurement parallelepiped

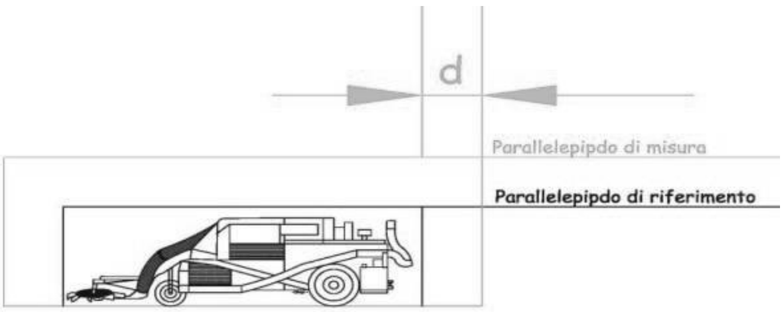

Fig. 6 - Scheme of the "d" distance between the measurement and the set parallelepiped

The measurement instrumentation has been sited on a table near the machine and all the microphones have been placed at a variable height on apposite poles, according to a pre-determined scheme, delimited by the measurement parallelepiped defined by the UNI EN ISO 3744 standard (figure 7 and 8).

The five sides of the measurement parallelepiped have been considered separately; they have been divided in order to obtain the smaller number of partial rectangular areas with a maximum side of 3*d*.

Microphones were placed in the centre and in every corner of each partial area, with the exception of those corners that cross the reflecting surface where the machine was placed.

All microphones, before the placement, have been checked using a “4231” Bruel & Kjaer calibrator that generates a pure tone at 1 kHz and with a 94 dB level.

To regulate the instrumentation the calibrator has been introduced in each transmitter unit, then the potentiometer of the multiplexer Bruel & Kjaer type “2711”, relative to the input of the microphone to calibrate, has been moved until the display of the sound power calculator Bruel & Kjaer type “7507” showed a sound power of 94 dB.

In order to verify if the levels obtained were reliable, this procedure has been repeated for each microphone displacement.

To avoid the influence of temporary noises, the measurement has taken place immediately after the placement of all microphones in the correct positions of the surface of the side to be measured.

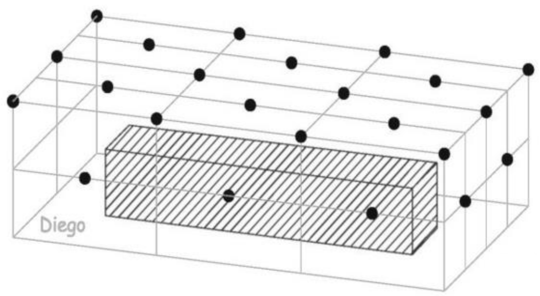

Fig. 7 - Scheme of the microphone locations: the internal parallelepiped contains the machine, while on the external one the microphone positions are highlighted

Fig. 8 - The tested machine with 8 microphones at a 3 meter height

Such problem comes out because in the area is frequent the transit of trains and low-route airplanes.

Before starting the test, the engine of Facma Cimina 300 S has been properly heated and stabilized to the normal functioning temperature, at an engine speed of 1250 min^{-1}.

The data were captured by the Bruel & Kjaer type “7507” sound power calculator in the “automatic” mode. This setting has permitted, after defining the total time and the number of subintervals relative to the side of the measurement parallelepiped to be tested, the determination of the number of scans.

The measurement time chosen for each side has been 64 seconds and on the basis of the number of microphones placed on each side the Bruel & Kjaer type “2711” multiplexer has automatically established the mean time and therefore the number of scans of each microphone location. The instrument has been sampling continuously for 64 seconds on all microphones: the sampling time *T* related to each microphone is given by the following equation:

$$T = Tm/N \qquad (1)$$

where: *Tm* is the total time of measurement (in this case is 64 s)

N is the number of microphones (in this case from minimum of 5 to a maximum of 8 for each side).

After the 64 seconds scanning the instrument has given the following values:

1. global equivalent noise level (*Leq*), expressed in dB and weighted A, of sound pressure related to the single side of the measurement parallelepiped;
2. global equivalent noise level (*Leq*), expressed in dB not weighted (Lin), related to each third octave frequency from 100 Hz to 10,000 Hz.

The measurement of the sound power of the point source has been carried out similarly, but the instrument utilized is a Bruel & Kjaer type “2260 Investigator” integrating sound level meter with the microphone placed on apposite poles (figure 9 and 10).

The measurement of the sound power of the point source is necessary to quantify the influence of the turf when measuring the sound power of the Facma Cimina 300 S machine and also to verify if the correction factor reported in the INAIL manual of good practices was correct.

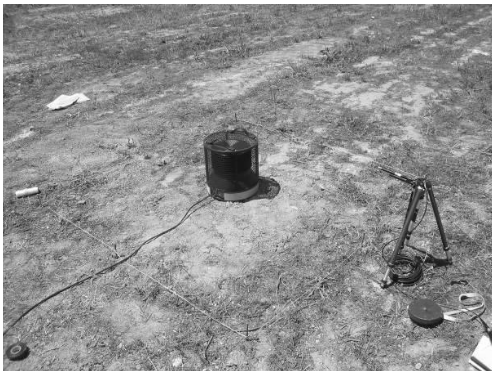

Fig. 9 - Tested point source and microphone placed on apposite pole

The measurement parallelepiped located around the Bruel & Kjaer source has been chosen according to the distances provided in the UNI EN ISO 3744 standard.

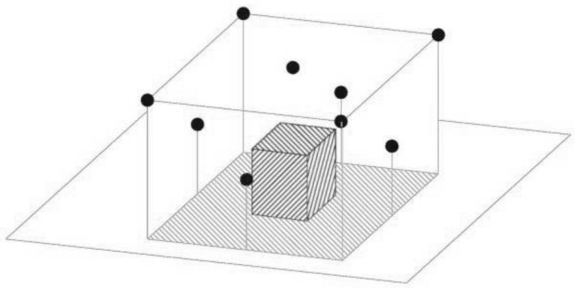

Fig. 10 - Scheme of the Bruel & Kjaer "4204" source (in the middle) and the microphone locations around it

2.4 Testing environment

2.4.1 Testing square

The measurement has taken place on a square made of pressed ground located at the CREA - ING research centre in Monterotondo (RM).

This square, from an obstacle distance point of view respects the characteristics of a free sound field, but differently from what it is stated in the UNI EN ISO 3744 standard, it lacks of a reflecting surface since it is covered by grass.

To compensate this lack of conformity, a specific correction factor taking into account the sound absorption due to the grass and reported in the INAIL manual of good practices has been introduced.

This value must be added to the sound pressure level obtain on each surface of the measurement parallelepiped (with the exception of the upper surface).

To verify the influence of the grass surface in the measurement, an environmental characterization has been carried out through the sound power detection emitted by the *Bruel & Kjaer type "4204"* point source, which has the peculiarity of giving a constant value of sound emission (white noise or pink noise); measuring the level of sound pressure in correspondence with the microphones on the testing square and comparing the sound power calculated with these data with the one previously measured in the INAIL reverberant room it has been possible to quantify the influence of the grass. At the same time, the analytic correction factor suggested by INAIL literature has been verified.

2.4.2 Environmental values

The monitoring station located near by the testing square has collected the following climate data (mean values related to the testing days):

- Mean temperature: 22°C
- Atmospheric pressure: 1017 mbar

- Solar radiation: 768 W/m^2
- Mean wind speed: 1.27 m/s

3. Results

3.1 Background noise evaluation

The background noise has been measured with a CELL type “593” integrating sound level meter responding to the IEC 61672-1-2 (ex IEC 651) and CEI EN 61672-1-2 (ex 804 group I) standard for precision integrating sound meter.

The instrument has been previously calibrated using a CEL type 284/2 sound calibrator responding to the IEC 942 class 1 standard. The measuring time has always been greater than 3 minutes. Measurement operations have been repeated 3 times.

The level of sound pressure of the background noise, coming out from the average of the 3 measurements, is equal to 49.2 $\pm$ 0.7 dB(A).

3.2 Average time sound pressure level ($L_{peq,T}$)

The average time sound pressure levels are defined by the UNI EN ISO 3744 standard as the level of sound pressure of a steady and constant sound that, during the measurement time interval *T*, gives the same mean square value of sound pressure of the variable sound in the considered time:

$$L_{peq,T} = 10\log\left[\frac{1}{T}\int_0^T 10^{0,1L_p(t)}\,dt\right] = 10\log\left[\frac{1}{T}\int_0^T \frac{p^2(t)}{p_0^2}\,dt\right] \quad \text{dB} \qquad (2)$$

3.3 Sound pressure level on the entire measurement surface (L_{pfA})

It is the energetic mean of the average time sound pressure levels in correspondence of all the microphones locations on the measurement surface, with the appropriate corrections for the background noise (K_{1A}) and the environmental conditions of reflection (K_{2A}):

$$L_{pfA} = L'_{pA} - K_{1A} - K_{2A} \qquad (3)$$

where: L'_{pA} = sound pressure level
K_{1A} = background noise correction factor
K_{2A} = reflection correction factor

During the test the Facma Cimina 300 S recorded a L_{pfA} value equal to 84.4 dB(A).

Table 2 shows the L_{pfA} values, weighted *A*, related to the measurement parallelepiped sides for the Facma Cimina 300 S machine.

Facma Cimina 300 S	Active source		
	Measured L_{Aeq} dB(A)	Attenuation due to the grass	Corrected L_{Aeq} dB(A)
Side 1	84.5	0.7	85.2
Side 2	83.3	1.7	85.0
Side 3	81.9	0.7	82.6
Side 4	75.8	1.7	77.5
Side 5	85.3	No attenuation	85.3
L'_{pA}	83.8 ± 2.2	= = =	84.4 ± 1.9

TABLE 2 - Values recorded for Facma Cimina 300 S

3.4 Measurement surface (S) Facma Cimina 300 S

It is the fictitious surface with an area *S* that includes the source and where the measurement locations are placed.

The measurement surface, as the standard provides, is delimited by a reflective plane.

In the case study the measurement surface equals to 104 m^2.

3.5 Background noise correction factor (K_{1A})

It is the correction factor that takes into account the influence of the background noise on the level of superficial sound power; it depends on frequency and it is measured in decibel. For weighted levels A, the correction factors is indicated as K_{1A}. In this case *the value is negligible* because the difference between the equivalent levels L'_{pA} measured on the single sides of the measurement parallelepiped and the equivalent level L''_{pA} of the background noise in the location of Facma Cimina 300 S is greater than 15 dB.

3.6 Reflection correction factor (K_{2A})

It is the correction factor that takes into account the influence of the sounds reflected or absorbed by the superficial level of sound power; K_{2A} depends on frequency and it is measured in decibel weighted A.

In this case *the value is negligible* because there are no reflecting objects in the surrounding area.

3.7 Facma Cimina 300: sound power level (L_W)

Generally, it is indicate as L_{WA} and it is defined by the following equation:

$$L_{WA} = L_{pfA} + 10\log(S/S_0) \quad \text{dB(A)} \tag{4}$$

where: S = measurement surface (m^2);
S_o = reference surface (1 m^2).

In this case it equals to 104.6 dB(A).

3.8 Bruel & Kjaer "4204": sound power level (Lw)

The value of sound power calculated on the basis of the measurements carried out during the field test (table 3) for the *Bruel & Kjaer type "4204"* source is 93.4 ± 1.7 dB(A) (table 4).

Bruel & Kjaer "4204"	Active source Measured L_{Aeq} dB(A)
Side1	84.5
Side 2	83.3
Side 3	81.9
Side 4	75.8
Side 5	85.3
L'_{pA}	83.8 ± 2.2
S	17 m^2

TABLE 3 - Measured values related to Bruel & Kjaer type "4204"

$K_{1A} = -10 \log (1-10^{-0,1\, \Delta L})$	Neglegible, because for each side and frequency $\Delta L = L'_{pA} - L''_{pA} \geq$ 15 dB
K_{2A}	Neglegible, because < 0,5 dB
$L_{pfA} = L'_{pA} - K_{1A} - K_{2A}$	81.1 ± 1.7 dB(A)
$L_{WA} = L_{pfA} + 10 \log (S/S_0)$	81.1 + 12.3 = 93.4 ± 1.7 dB(A)

TABLE 4 - Sound power calculation for the source Bruel & Kjaer type "4204"on the testing square

Comparing the values certified by the manufacturer (Bruel & Kjaer), those recorded in the reverberant room and the ones obtained during the field test, it is clear that the grass has an irrelevant influence on the test results. Indeed, the attenuation values introduced to correct the equivalent levels, taken from the available data in literature, can be considered suitable for the purposes of this experimentation.

4. Conclusions

During the realization phase of this survey it merged the existence of a lack in the methodology between the UNI EN ISO 3744:2010 standard “Acoustics. Determination of sound power levels of noise sources using sound pressure. Engineering method in an essentially free field over a reflecting plane.” and the UNI EN ISO 4254-1:2013 standard “Agricultural machinery - Safety - Part 1: General requirements”.

To determine the sound power of agricultural machines the standard to be followed is the UNI EN ISO 4254-1:2013, which refers to the UNI EN ISO 3744:2010 specifying that the measurement surface to be used for the location of the microphones is the hemisphere. For big machines, this measurement surface is not always applicable because the upper central microphone is located at heights unreachable with conventional poles (25-30 m). Instead, the UNI EN ISO 3744 standard allows the utilization of a different measurement surface (parallelepiped surface) to locate the microphones, but this surface is not mentioned in the UNI EN ISO 4254-1:2013 standard. Due to this severe lack, technicians operating with big machines are often forced to apply the parallelepiped surface not mentioned by the UNI EN ISO 4254-1:2013 standard.

It is important to notice that the UNI EN ISO 4251-1 standard, implemented for the first time in Italy on the 22nd of June 2006, replaced the UNI EN 1553:2001 standard, withdrawn in the same date. The new standard, for all it concerns the sound power of agricultural machines, is just alike the previous one: perhaps, during the ISO 4254-1 standard implementation stage at the CEN level it would have been more proper, as it regards the determination of sound power, to integrally refer to the EN ISO 3744 standard. Indeed, it is not clear for which reason the measurement parallelepiped surface must be excluded for agricultural machines, while it is accepted for other kind of machines. Because of this standard incongruity technicians are frequently put in the conditions of operating in a not-conforming way, due to the objective difficulty on placing microphones at 10 or more meters above the ground.

As it concern the sound power emission, the results obtained in the experimental trial show that, at the moment, both Facma Cimina 300 S operators and manufacturer are enforced to follow the rules imposed by the existing standard about safety and health at work (Machine Directive, Directive 89/391/EEC and other Directives concerning safety and health of workers at work). In fact, workers must wear apposite individual protection devices (ear muffs, earplugs), but at the same time they must be informed and trained as provided by Directives concerning safety and health of workers.

The manufacturer, given that the examined machine is characterized by a sound pressure value greater than 85 dB(A) (value recorded in real working conditions), must report on the “utilization and maintenance” manual, as clearly required in the “Machinery Directive”, the value of sound power obtained according to the methodology shown in this paper.

Furthermore, the manufacturer should hypothesize and implement various interventions that may reduce the value of sound emissions of the machine. Thus, deep surveys to individuate all sources of sound emission on the machine are needed and an enhancement program must be implemented.

It is possible to work on:

1. *noise sources;*
2. *noise propagation.*

As it regards these last interventions, it is important to be aware that the noise emitted by any source can be directly spread by air or by solid (for instance, through the machine frame).

4.1 Interventions on sources

They are always to be favoured because they remove the noise (risk) directly at the source.

It is necessary to look for the application of noiseless functioning systems on the machine and try to decrease the high noise of some sources.

In order to do so a deepen study on all the components of the machine is needed (for instance trough the measure of intensity), thus the possible intervention points can be highlighted. If the noise of the sources is caused by lacks in the designing phase, these must be immediately removed or corrected. Then, the noise origin must be determined:

- if the noise has a *mechanic* origin (rotating elements, transmission elements like gears and bushes, metallic collisions), speed and load must be reduced, while vibrations transmitted to the surfaces must be eliminated;
- if the noise has an aerodynamic origin, beside the utilization of sound dampers, it is necessary to correct the loops and the fan functioning; rotation noises and fluid vorticity must be eliminated.

In this specific case, since the machine functioning is based on suction (flow of depressed air), the possibility to realize a more corrected aerodynamic flow that permits noise reduction should be analysed.

4.2 Interventions on propagation

Interventions on propagation can be realized trough different strategies of interventions:

- *damping pads:* are necessary in case of vibrations transmitted to the frame from the engine or the fans used for air suction. In the case of the machine under examination this kind of intervention has been partly realized by the manufacturer, but it should be improved in some points. The same kind of intervention can be used to eliminate the continuity of extended metal structures.

- *Integral shrouding:* is an intervention to be done when it is no longer technically possible to reduce the noise of the source. It is required when a big noise reduction is needed (at least 15-20 dB).

  It is a very effective kind of intervention, but the costs are often high and it is not always technically feasible.
- *Partial shrouding:* it can be useful when it is not possible to close all the machine, when the decrease needed is not greater than 15 dB, when the frequencies to be lowered are medium high. Interventions of partial shrouding can determine reduction of sound power for the operator ear between 3-5 dB and 12-15 dB.
- *Worker isolation:* in same cases it can be useful to isolate in a sound-insulating cabin the operator (such intervention can be also useful against other risks, like dust). It is a feasible and advisable kind of intervention for many noisy machines for which a reduction of noise at the source or integral shrouding are not reasonably practicable. For the machine under examination (self-propelled nut harvester) the driving cab is not easily realizable because the machine must operate in tree plantations.

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