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Sound Quantity and Quality of Sampo 3065 Combine Harvester

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ABSTRACT- Noise is considered as one of the most debilitating conditions in farming operations. In this study, a number of factors affecting the noise generated by Sampo 3065 combine harvesters were evaluated. Factors were engine speed and gear ratio for combines with and without original cabins. A factorial experiment arranged as a completely randomized design with four replicates was used. Results indicated that loudness level correlated strongly with A-weighted sound pressure level (R^2=0.99) but had a weak relationship with linear sound pressure level (R^2 = 0.60). Other results showed that original cabins decreased 30.5, 22.8 and 5.4 percent of the loudness level, A-weighted and linear sound pressure levels, respectively. Mean value averages for loudness level, A-weighted and linear sound pressure levels for high engine speed were 6.9, 9.1 and 11.1 percent higher than those at low engine speed.

Keywords: Combine Harvester, Loudness Level and Sound Pressure Level, Noise

INTRODUCTION

Sustainable development of agricultural mechanization has caused new concerns. Most problems are occupational health and safety issues for people who are engaged in various agricultural activities. Noise, which is one of these problems, is generally defined as unwanted or bothersome sound which can affect people in several physical, psychological and social dimensions by causing auditory lesions, stress, annoyance, distraction, tiredness or simply by impairing social communication (5, 6, 19). Also, it can induce temporary or permanent hearing losses (13).

There are many factors that affect the severity of hearing loss and the most important ones are range of frequency, intensity and duration of noise exposure. The frequency span for auditory sound processing in normal listeners is between 20 and 20,000 Hz. Lower frequency sounds lead to low pitch and higher frequency sounds lead to high pitch sensations. The frequency of a sound is relevant to environmental noise

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assessments. Higher pitch sounds are considered more annoying and more disruptive than lower pitch sounds.

As a physical phenomenon, sound can be described by acoustics quantities such as sound pressure level, fundamental frequency or frequency spectrum. Sound pressure level is the term most often used in measuring the magnitude of sound. It is a relative quantity where there is a ratio between the actual sound pressure and a fixed reference pressure. This reference pressure is usually the hearing threshold which has been internationally agreed upon as having the value 20 µPa at 1 kHz.

Sound pressure level, measured in decibels (dB), is a logarithmic measure of effective sound pressure above a standard reference level. The frequency response of the human ear must be considered while studying the effect of noise on people. Human hearing does not have a flat spectral sensitivity relative to frequency. Human being does not perceive low and high frequency sounds as well as they perceive sounds near 2–4 kHz. Sound measuring instruments are often designed to weigh sounds based on the way people hear. The frequency weighting most often used to evaluate environmental noise is called A-weighting and measurements from instruments using this system are reported in dBA. Unweighted sound pressure level is also known as linear sound pressure level and is often measured in dB.

One issue in vehicle acoustics is acoustic comfort as opposed to hearing damage. When evaluating the acoustic comfort of a sound, fundamental quantities such as sound pressure level are not adequate at all, because they do not represent actual hearing sensations. The science of psychoacoustics involves quantitative evaluations of these subjective sensations using sound quality metrics. The application of these metrics allows for the visualization of the complicated relationship between physical and perceptual acoustic quantities. To evaluate vehicle induction noise, several sound quality metrics including loudness, sharpness, roughness, fluctuation strength and articulation index were used (28).

Loudness is a standardized metric and an important psychoacoustical index. It describes the human perception of how loud a source is as opposed to a reported sound pressure level. In fact, loudness is a subjective measurement, often confused with objective measures of sound strength such as sound pressure level. Even though filters such as A-weighting attempt to adjust sound measurements to its corresponding loudness as perceived by the typical human ear, loudness perception is a much more complex process than A-weighting.

The unit of loudness, also known as a sone, is defined as loudness corresponding to a 1000 Hz tone 40 dB above the listener's threshold. The level of the 1000 Hz tone in dB is called the loudness level of the sound, which is expressed in phon.

People working in various agricultural sectors are exposed to a lot of noise sources. Nevertheless, the potential risks of such noise have not been fully specified yet (15). Due to the existence of various noise generators in the field including tractors, combines, choppers, chain saws, dryers, etc., agricultural workers have higher rates of hearing loss compared to workers in other occupations (3).

Grandjean (7) showed that for the first 10 years of exposure to noise with a 1000 Hz frequency and a 100 dB sound level, hearing loss is 7 dB, while during a 40 year exposure, this amount can increase to 12 dB. It is also reported that if exposure to a 4000 Hz frequency noise continues for 10 years, hearing damage can increase up to 30 dB. Sabanci et al. (23) studied characteristics of sounds emitted from tractors and their effects on users' auditory functions. They found that maximum hearing loss occurred at a frequency of 4000 Hz with an average hearing loss of 12.6 dB. They reported the level of sound emitted from the tested tractors from 78.25 to 87.63 dB.

Hassan Beygi and Ghobadian (8) found that the maximum overall noise at a driver ear's position at different gear ratios in asphalt, dirt rural roads and grassland was about 92 dBA for 2200 rpm engine speed which is higher than the allowable noise exposure prescribed by the National Institute for Occupational Safety and Health.

Solecki (25) showed that 56% of the tractor drivers had more than 20 dB hearing loss in the frequency range of 3 to 6 kHz. He maintained that the highest hearing risk was caused by low and medium power tractors with sound levels of 84-101 dB, and that powerful tractors created lower sound levels. Sumer et al. (26) reviewed sound levels in 37 combine harvester models. Their results showed that while frequency increases, sound level tends to decrease in combines. They also showed that sound pressure levels for combines without cabins and those with installed or original cabins were 85-90 dB, 81-83 dB and 76-81 dB, respectively. Aybek et al. (2) showed that the frequency band center increased during various operations with tractors while sound pressure level decreased. This research showed that tractors equipped with original cabins had better noise reduction compared to those without cabins or with installed cabins. Saral and Avcioglu (24) indicated that regardless of their sound insulation and the material used in their production, tractor cabins had no significant impact on noise absorption, and did not help reduce the sound level for the driver.

Behroozi Lar et al. (4) showed that the sound pressure level at the driver's ear for tractors without cabins was higher than that approved by the National Institute for Occupational Safety and Health in all gears (91 dBA to 93 dBA). Other results showed that sound pressure level of tractors with open cabin windows was between 86 to 88 dBA, which was again, higher than the standard but lower than tractors without cabins. In all cases, sound pressure level for closed cabins stayed below 82 dBA.

Several studies have also been conducted on the effects of subjective sound levels on machine operators' performances (14, 17, 19, 27).

In Iran, the grain harvesting season continues for over 6 months. Along this period, combines which have been modified to harvest crops such as rice, corn and canola, are used intensively despite being old and the numerous ergonomic problems they cause. Unfortunately, most have no cabin and expose their operators to high noise levels. This noise is one of the most important detrimental factors affecting the operator's health and working capacity.

The most effective way to reduce noise exposure is isolating the operator from the noise source using acoustically designed noise insulation cabins. The Environmental and Occupational Health Center has specified 85 dBA as the maximum permissible exposure to continuous noise for an 8 hour work shift (1).

The first objective of the present study was to determine and compare noise levels for operators of combines with and without original cabins. Another aim was to find the relationship between sound pressure level and loudness level. To this end, sound pressure level (as sound quantity) and loudness level (as sound quality) of a model 3065 Sampo combine harvester were measured and evaluated.

MATERIALS AND METHODS

To determine and compare the noise of combines with and without cabins, sound pressure levels (dB and dBA) and loudness levels (Phon) were measured at the ear level of the operators of a Sampo 3065 combine harvester.

Instrumentation

In order to measure the noise level of the combine at the operators' ear level, a microphone was placed at a distance of 100 mm away from the operator's ear (Fig. 1).

Fig. 1. Instrumentation used and microphone position

Test location characteristics were considered based on ISO standards (12). To this end, a free field at the Iran Combine Manufacturer Company site was selected. Measurements were carried out on the pavement route. During the test, wind speed was measured by a Lutron digital anemometer model AM-4205A. Wind speed was less than 5 m/s and the ambient temperature was above 5°C as compare to the standard (12).

The difference between the measured sound pressure levels and the environmental or background sound pressure level in the field must be at least 6 dB and preferably more than 10 dB. In order to validate sound pressure level measurements, environmental sound pressure level was measured first. Since measurement differences in this test conformed to the mentioned standard, there was no need to apply sound corrections. A track length of 30 meters was considered for the combine movement, during which the emitted signals were recorded.

The measuring equipments of the study were an MIC model MA231, MP201 model amplifier and data acquisition system model MC3022, all made by BSWA. The microphone was a type 1 based on the IEC 60651 standard with a sensitivity of 50mV/Pa and a dynamic range of 146 dB (3% distortion limit). The received signal was saved on a laptop computer, using Scope V1.32 software. Before the measurement, microphones were calibrated by a model CA111 calibrator, which creates 94 dB constant sound levels in a pure frequency of 1 kHz. Based on the IEC 60942 standard, since the selected microphone was type 1, the calibrator should also be type 1. For each treatment combination, at least 6 seconds of the sound signal was recorded. Figs. 1 and 2 show instrumentation features and a typical set of sound pressure signals in the time domain.

Sound Pressure Level

ISO 1999 (11) provides a definition for equivalent linear sound pressure level in decibels, identified as L_{eq}. This function gives the value of the unweighted sound pressure level of a continuous, steady sound within a specified time interval T, which has the same mean square sound pressure as the sound under consideration whose level varies with time. It is expressed by the following equation:

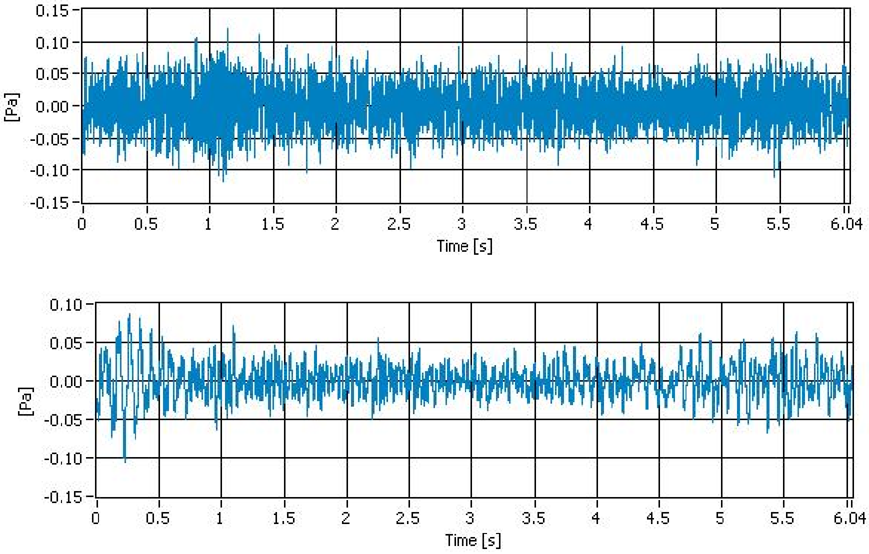

Fig. 2. Sound pressure signal in time domain for combine harvester without cabin (top) and with original cabin (bottom) at low engine speed and third gear ratio

$$L_{eq} = 10\,log\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{p^2(t)}{p_0^2}dt\right], \qquad (1)$$

where L_{eq}, is the equivalent continuous sound pressure level (in dB) determined over a time interval T (starting at t_1 and ending at t_2), P_0 is the reference sound pressure (20 mPa) and P(t) is the instantaneous linear sound pressure of the sound signal.

The A-weighted equivalent continuous noise level is calculated by replacing the unweighted sound pressure level in equation (1) with the A-weighted sound pressure level and is defined as:

$$L_{Aeq} = 10\,log\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{p_A^2(t)}{p_0^2}dt\right], \qquad (2)$$

where L_{Aeq}, is the equivalent continuous A-weighted sound pressure level (in dBA) determined over a time interval T (starting at t_1 and ending at t_2), P_0 is the reference sound pressure (20 mPa) and $P_A(t)$ is the instantaneous A-weighted sound pressure of the sound signal.

Figs. 3 and 4 show typical sets of linear and A-weighted frequency domain signals.

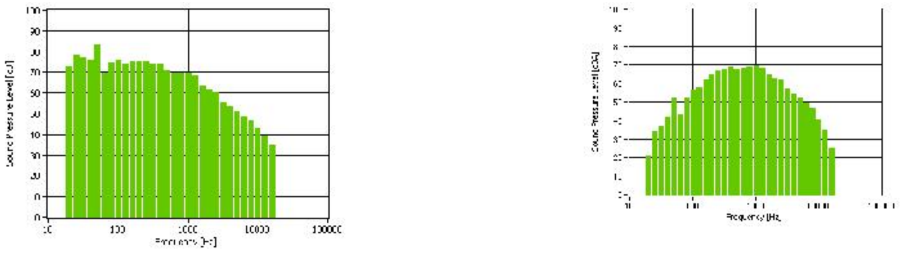

Fig. 3. Linear frequency domain signal (left) and A-weighted frequency domain signal (right) for combine harvester without cabin, at low engine speed and third gear ratio

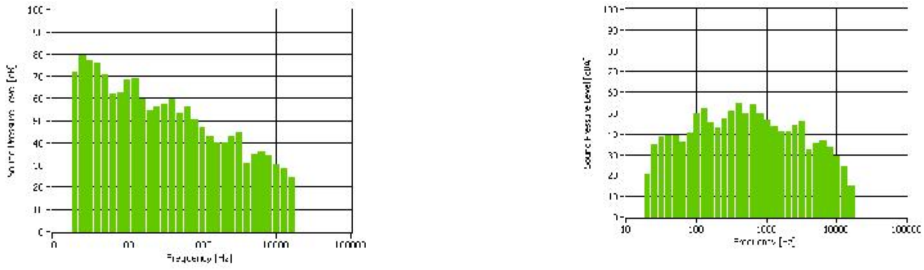

Fig. 4. Linear frequency domain signal (left) and A-weighted frequency domain signal (right) for combine harvester with original cabin, at low engine speed and third gear ratio

Loudness Level

Usually there are two procedures considered for physical loudness measurements:
a) Stevens' procedure, which is originally based on the octave-band analysis of sounds (9) and b) Zwicker's procedure, which is based on 1/3 octave-band analysis and predictive of all noise types (10).

The most important feature of Zwicker's loudness model is that the area under the specific loudness curve is always directly proportional to the perceived loudness. Due to its robustness, this loudness assessment procedure has been standardized in several sound level meters and computer programs. According to the ISO 532B standard (10), the specific loudness of a sound is defined as:

$$N' = 0.08\left(\frac{E_{TQ}}{E_0}\right)^{0.23}\left[\left(0.5 + 0.5\frac{E}{E_{TQ}}\right)^{0.23} - 1\right], \tag{3}$$

where N' is the specific loudness, E is the excitation of the sound, E_{TQ} is the excitation in the quiet ambient and E_0 is the excitation under a reference sound with an intensity of $I_0=10^{-12}\text{W/m}^2$.

Total loudness can be calculated by:

$$N = \int_0^{24\,Bark} N'\,dz\,, \tag{4}$$

where N is total loudness (in sone) and z is critical band rate (in Bark).

Total loudness value (in sone) is related to loudness level in the following way:

$$N = 2^{(P-40)/10}, \tag{5}$$

where P is loudness level (in phon).
Figure 5 shows a typical set of specific loudness.

Statistical Analysis

A factorial experiment arranged as a completely randomized design with four replications was considered. Engine speed at two low and high levels and different gear ratios in four levels (neutral, one, two and three) were considered for evaluation. The noise signal was recorded at the operator's ear position in combine harvesters with and without cabins. The data were retrieved by MATLAB software and analyzed using SPSS software. Since two data sets were missing from the study, the analyses were carried out on the remaining data.

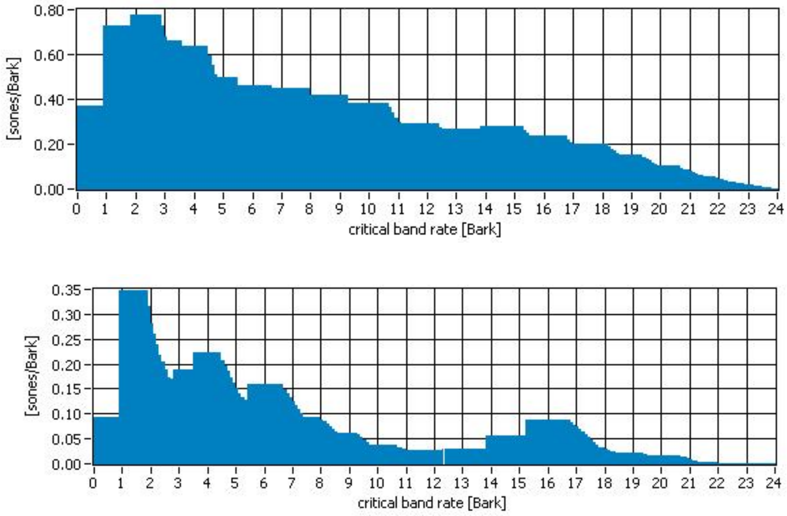

Fig. 5. Specific loudness for combine harvester without cabin (top) and combine with original cabin (bottom), at low engine speed and third gear ratio

RESULTS AND DISCUSSION

Table 1 shows the effects of engine speed and gear ratio on sound pressure level and loudness levels as obtained through an analysis of variance for combines without cabins and those with original cabins. According to the analysis of variance of linear and A-weighted sound pressure level and loudness level, effects of engine speed and cabin were found to be significant ($P<0.01$). This analysis showed that gear ratio had significant effects ($P<0.01$) on linear sound pressure level. However, no significant relationship was observed between gear ratio and A-weighted sound pressure level and loudness level.

Table 1- Analysis of variance of data on L_{eq} (dB), L_{Aeq} (dBA) and loudness level (phon)

Source	Degree of Freedom	F-Value		
		Sound Pressure Level (L_{eq})	Sound Pressure Level (L_{Aeq})	Loudness Level (P)
Engine speed	**1**	**464.623****	**733.838****	**444.499****
Gear ratio	**3**	**55.822****	**0.610 ^{ns}**	**0.644 ^{ns}**
Cabin	**1**	**289.878****	**4068.260****	**2821.550****
Engine × Gear	**3**	**0.978 ^{ns}**	**0.423 ^{ns}**	**0.339 ^{ns}**
Engine × Cabin	**1**	**5.965***	**0.890 ^{ns}**	**1.857 ^{ns}**
Gear × Cabin	**3**	**0.542 ^{ns}**	**0.728 ^{ns}**	**0.293 ^{ns}**
Engine × Gear × Cabin	**3**	**4.975****	**0.114 ^{ns}**	**0.128 ^{ns}**
Error	**46**			
Total	**61**			

- **^{ns} Non significant, ** Significant at p<0.01, * Significant at p<0.05**

As seen in the table 1, no significant relationship was found between linear and A-weighted sound pressure level and loudness level and the interactions between sources, except for that between linear sound pressure level and engine speed and cabin (P<0.05) and engine speed, gear ratio and cabin (P<0.01).
Also, the following results were found:

- In terms of engine speed, gear ratio and cabin interaction, the highest mean of linear sound pressure level occurred using the combine harvester without a cabin at high engine speed and third gear (110.4 dB), while the lowest mean of linear sound pressure level occurred using the combine harvester with the original cabin at low engine speed and neutral gear (92.3 dB).
- According to engine speed, gear ratio and cabin interaction, the combine harvester without a cabin caused the highest mean of A-weighted sound pressure level (98.3 dBA) at high engine speed and third gear while the combine harvester with the original cabin caused the lowest mean of A-weighted sound pressure level (72.5 dBA) at low engine speed and neutral gear.
- In terms of engine speed, gear ratio and cabin interaction, the highest mean of loudness level occurred in the case of the combine harvester without a cabin at high engine speed and neutral gear (91.6 phon). The lowest mean of loudness level occurred in the case of the combine harvester with the original cabin at low engine speed and neutral gear (62.1 phon).

Figure 6 depicts L_{eq} with respect to gear ratio. Both left and right graphs show similar data trending. The L_{eq} values rise slightly with increasing gear ratio from neutral to low second gear with no significant difference. But L_{eq} values increase significantly from low second to high third gear. It should be noted that higher gear selection results in fast combine harvester forward speed. The speed of the combine harvester also affects the noise level, due to the increase in tire and route interaction. As a tire rolls over the route, air is forced out of voids or pockets in the route. This rapid exit of air can lead to sound generation. As the tire rolls out of contact, air is rapidly sucked back into the route voids, creating again a rapid displacement of air which can generate sound. Air pumping also occurs when the air is pressed out of the voids in the tire tread pattern. Another related effect is the horn effect. This is an enhancement of the radiation of sound due to the geometry of the circular tire and the flat ground forming a horn that can amplify the sound generated by all kinds of suspected tire noise mechanisms.

Because there is no movement at neutral position and low speed at first and second gears, L_{eq} values increased slightly. In contrast, at the third gear ratio, the speed of the combine harvester was considerably higher compared to other gears. The effect of the higher speed of the combine harvester on L_{eq} values can be seen in Fig. 6.

It can also be clearly observed in figure 6 (left) that increasing engine speed leads to an upward trend in the value of the L_{eq} for all gear ratios. As expected, sound generation increases when engine speed increases, due to the increasing movement of the reciprocating and rotational parts of the engine. Similar results are reported by other studies (8, 16). Moreover, it can be concluded that the L_{eq} value of low engine speed for the high third gear almost equals the L_{eq} value of high engine speed for low gear ratios.

The mean values of L_{eq} for low and high engine speed equal 96.7 and 103.5 dB, respectively. As a result, the mean value of L_{eq} for high engine speed is on average 6.9% higher than that for low engine speed.

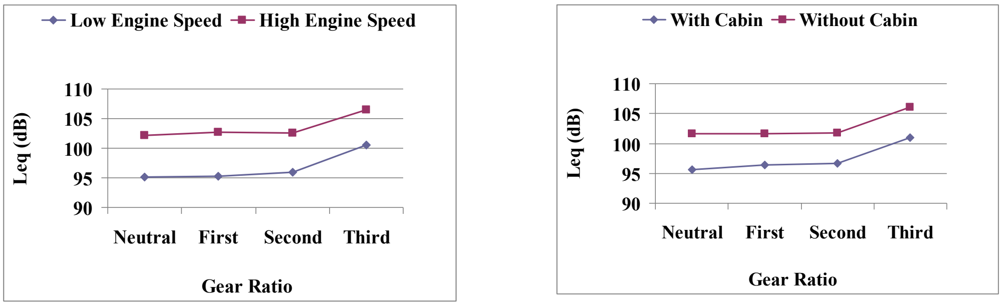

Fig. 6. L_{eq} values for all gear ratio at different engine speed(left) and in combine without cabin and with original cabin (right)

Fig. 6 (right) shows the effect of cabin on linear equivalent sound pressure level. Generally, the cabin absorbs some sound waves and reflects others. The emitted noises and the way these noises propagate into the cabin depend on numerous factors including cabin dimensions and shape, design of doors and windows and the materials used for noise and vibration insulation. Hence, cabins and their design are effective noise insulators. Such results have been previously reported by other researchers as well (2, 23, 26).

According to the results, the mean value of L_{eq} for the combine without a cabin was 102.7 dB as compared to that with the original cabin (97.4 dB). On average, the mean value of L_{eq} was 5.4% lower for the combine with the original cabin compared to the one without a cabin.

Figure 7 shows L_{Aeq} versus gear ratio. It is apparent that L_{Aeq} was not influenced by gear ratios. Since very low and high frequencies have less effect on the human perception of sound, these frequencies have little influence on the A-weighted equivalent sound pressure level. Therefore, a comparison between figs. 6 and 7 shows that at very low and high frequencies, the amplitude of the emitted sound is considerable as the gear shifts from second to third. Accordingly, during gear shift from second to third, L_{eq} values increase significantly, whereas L_{Aeq} values increased slightly due to the filtering of sound pressure level at very low and high frequencies.

A close look at these two parameters shows a higher sound pressure level in the third gear compared to other gear ratios. However, this amplitude has no harmful effect on the operator's ear. According to the results of this study, the mean values of L_{Aeq} for low and high engine speed equal 81.7 and 89.1 dBA, respectively. Moreover, the mean value of L_{Aeq} for the combine without a cabin was 94.2 dBA and for the one with the cabin was 76.7 dBA. Accordingly, the mean L_{Aeq} value for high engine speed was 9.1% higher than low engine speed and 22.8% lower for the combine with the cabin than the one without a cabin.

Fig. 8 shows the results for loudness level. It could be seen that similar to $L_{Aeq,}$ loudness level is not influenced by various gear ratios. In addition, the figures show that loudness level strongly depends on engine speed rather than combine harvester speed. At low speeds, engine noise is most apparent and most disturbing in terms of interior sound quality (18). At higher speeds, loudness level is influenced by aerodynamic and road noises. In fact, engine speed plays an important role in loudness (22).

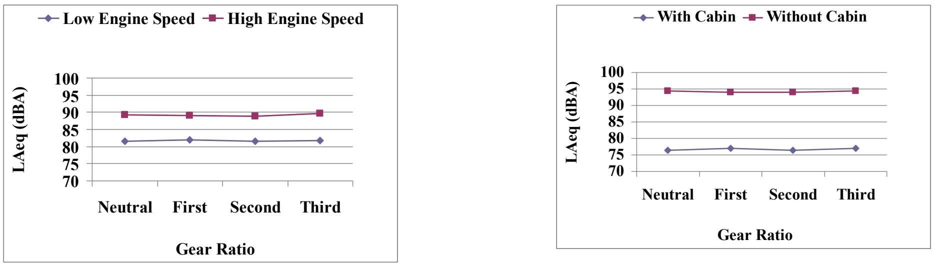

Fig. 7. L_{Aeq} values for all gear ratios at different engine speeds (left) and in combine without cabin and with original cabin (right)

These two parameters are expected to show similar trending data since they are both designed to compensate for the human perception of sound amplitude at various frequencies. Given these similarities, it can be deduced that loudness level is just as useful, if not better, a tool for induction noise analysis.

The mean values of loudness level for low and high engine speed were 73.1 and 81.2 phon, respectively. Therefore, the mean value of loudness level for high engine speed is on average 11.1% higher than the low engine speed. The mean value of loudness level for the combine without a cabin was 87.3 phon, while it was 66.9 phon for the original cabin. On average, the mean value of loudness level was found to be 30.5% lower for the combine with the original cabin compared to that without the cabin.

The relationship between linear equivalent sound pressure level and loudness level is shown in Fig. 9. The sound pressure level regressed on the loudness level had a better linear relationship, with a coefficient of determination of R^2=0.60.

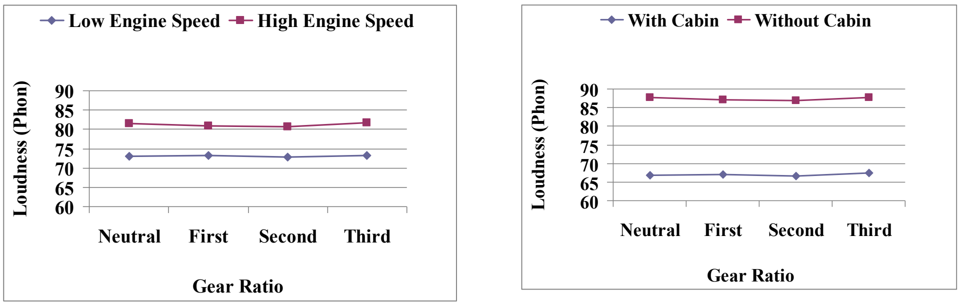

Fig. 8. Loudness level values for all gear ratio (left) at different engine speed and (right) in combine without cabin and with original cabin

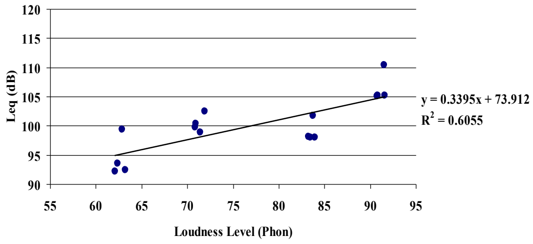

Fig. 9. Linear regressions of L_{eq} values and corresponding loudness levels for all gear ratio

The relationship between A-weighted sound pressure level and loudness level is shown in Figure 10. In general, increasing loudness level will increase A-weighted sound pressure level. As a result of the regression analysis, a regression function was obtained (Fig. 10), and a strong correlation was found between A-weighted sound pressure level and loudness level (R^2=0.99). The A-weighted sound pressure level obtained in this research can be a good indicator of the loudness level. This is consistent with the findings of Novak et al. (18).

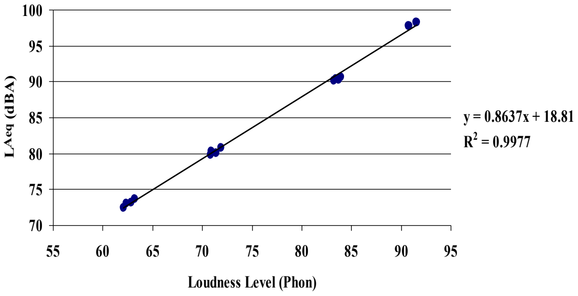

Fig. 10. Linear regressions of L_{Aeq} values and the corresponding loudness levels for all gear ratio

CONCLUSIONS

The findings of this study showed that loudness level was correlated well with A-weighted sound pressure level analysis (R^2=0.99), whereas, loudness level had no meaningful relationship with linear sound pressure level. Other results show that loudness level, A-weighted and linear sound pressure levels depend strongly on engine speed rather than combine harvester speed. Finally, it was found that using a cabin had a stronger effect on loudness level as a sound quality metric than sound quantity parameters. On average, the original cabin decreased 30.5, 22.8 and 5.4 percent of the loudness level, A-weighted and linear sound pressure levels, respectively.

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کمیت و کیفیت صدای کمباین سمپو ۳۰۶۵

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چکیده- سروصدا به عنوان یکی از مهمترین معضلات محیط‌های کشاورزی محسوب می‌شود که انجام تحقیقات جامع در این رابطه به منظور کاهش اثرات زیان‌بار آن را ضروری می‌سازد. در این تحقیق تعدادی از عوامل موثر بر سروصدای تولید شده توسط کمباین سمپو ۳۰۶۵ مورد ارزیابی قرار گرفتند. فاکتورهای مورد مطالعه شامل دور موتور و نسبت‌های مختلف دنده برای کمباین کابین‌دار و فاقد کابین بودند. بر این اساس، آزمایشاتی به صورت فاکتوریل و در قالب طرح کاملاً تصادفی و در چهار تکرار انجام شدند. نتایج حاصل از این بررسی نشان داد که رابطه خطی خوبی بین تراز بلندی صدا و تراز فشار صدا در شبکه A وجود دارد (R^2=۰/۹۹) و رابطه رگرسیونی معنی‌داری بین تراز بلندی صدا و تراز فشار صدای خطی وجود ندارد (R^2=۰/۶۰). همچنین نتایج نشان داد که استفاده از کابین، تراز بلندی صدا، تراز فشار صدا در شبکه A و تراز فشار صدای خطی را به ترتیب ۳۰/۵، ۲۲/۸ و ۵/۴ درصد کاهش می‌دهد. همچنین میانگین مقادیر تراز بلندی صدا، تراز فشار صدا در شبکه A و تراز فشار صدای خطی برای دور موتور بالا به ترتیب ۶/۹، ۹/۱ و ۱۱/۱ درصد بیشتر از دور موتور پایین بدست آمد.

واژه های کلیدی: تراز بلندی صدا، تراز فشار صدا، سروصدا و کمباین

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