Effect of engine rotation speed and gear ratio on the acoustic emission of John Deere 1055I combine harvester

Ahmad Jahanbakhshi[1], Bahram Ghamari[1], Kobra Heidarbeigi[1*]

(1 Department of Mechanical Engineering of Biosystems, Ilam University, Ilam, Iran.)

Abstract: One of the problems of agricultural mechanization is noises caused by the use of machines. The noises should be evaluated due to the negative effects on health and safety level of humans working in this field. However, the purpose of this study is to investigate the effect of gear ratio and engine rotation speed on acoustic noise of John Deere 1055I combine harvester. The experiments were done based on sound international standards ISO 5131, ISO 7216 and the World Health Organization considering different levels of engine rotation speed (1800 and 2500 r/min), gear ratio (1, 2 and 3 H) and distance from the driver ear (10 cm, 7.5 m and 20 m). Three replications were considered for each treatment. The obtained data was analyzed by factorial test based on completely randomized block design. Analysis of variance showed that the interactions of engine rotation speed and gear ratio had significant effects on emitted sound level from the harvester. It was also observed that with increasing of distance from the driver's ear, the sound level was reduced due to the effects of ambient on noise damping. In position of the driver's ear, the sound levels were higher than the standard level of 85 dB(A) in all gears ratios and engine rotation speed. Therefore, the machine operator must use ear protection and the machine manufacturers should reduce the intensity of sound which emitted to the driver cabin.

Keywords: combine harvester, engine rotation speed, ergonomics, gear ratio, FFT Analysis, sound level.

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1 Introduction

Using of agricultural machinery in farms has caused a lot of problems in relation with safety and healthiness of the operators as well as employees working in the field. One of these problems is the acoustic noise from the machines and equipment (Brown, 1988; Solecki, 1998). The most important adverse effects of noise on humans are temporary and permanent hearing loss, negative effect on the body’s balance system, causing neurological and psychiatric disorders, reducing efficiency and increasing the risk of accidents, physiological effects on the body such as increasing heart rate, blood pressure and the number of inhalation and exhalation (Durgut and Celen, 2004). Bacher, 1980 conducted a study on the identification of the main sources of tractor noise. He resulted that the main sources of noise are the engine and gearbox, especially at high speeds and powers. Behroozi Lar et al, (2011) investigated the sound level of two tractors, Massey Ferguson 399 and Valtra T 170, in different levels of gear ratio and engine rotation speed. They reported that the average of sound level in the driver ear situation without cabin was higher than allowed level (85 dB) and the maximum sound level for Massey Ferguson 399 and Valtra 170 was 94.5 and 92.7 dB (A), respectively. In other study, Sumer et al. (2006) determined the sound level of 37 different types of combines. They reported that the sound pressure level for frequencies of 31.5-500 Hz was equal to 75-102 dB (A) and for frequencies of 500-8000 Hz was 46-89 dB (A). Their results showed that the sound level was decreased by increasing of frequency. In frequency of 4000 Hz, the sound level for combines with cabin and combines with main cabin was reported as 6-17 dB (A) and 9-25 dB (A)

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***Corresponding author: Kobra Heidarbeigi,** Assistant Prof., Department of Mechanical Engineering of Biosystems, Ilam University, Ilam, Iran. Email: kobra.heidarbeigi@gmail.com, Tel: +98-8432227015, Fax: +98-8432227015

respectively that showed lower sound levels compared to combines without cabin. Hassan-Beigi Bidgoli (2004) studied the sound of two-wheel tractor in transportation and in different conditions in the field. The results showed that by increasing the engine rotation speed from 1300 to 2200 rpm, the sound pressure level increased 12 dB (A) in the frequency range from 20 to 10000 Hz. Also he reported that the sound pressure reaches 92 dB (A) when engine rotation speed was 2200 r/min that was much more than standard level (85 dB (A)). In 2011, totally 12467 grain combine harvesters have been used in Iran including John Deere, Class, New Holland, Ferguson, Belarus and etc. (Statistics of Agriculture, 2011).

Based on these statistics, each year at least 12467 combine operators are exposed to sound caused of combine harvesters. Thus, the comfort and healthiness level of the operators reveals the necessity of a study to investigate the sound level of John Deere 1055 combine harvester that has not been reported any evaluation in this regard. Also, hazardous and non-hazardous time work for the operators and the farmers around those in different gear ratios and engine rotation speed was studied in the present research.

2 Materials and methods

In this study, a JD combine harvester (model: 1055I) was considered to evaluate experiments. The specifications of the harvester were presented in Table 1. The investigated factors in this study were: engine rotation speed (1800 and 2500 r/min), gear ratio (1, 2 and 3, heavy) and the position of the microphone (10 cm, 7.5 and 20 m far from the driver's ear). The levels of engine rotation speed and gear ratio factors in this research were based on common operation states of the harvester. Three replications were considered for each treatment. The tests were conducted using factorial experiment based on randomized complete block design. The experiments were done in a farm with flat regular topography after harvesting (corn) in Mehran Township (southwest of Ilam Province, Iran). The combine harvester and the instruments which were used in operation illustrated in Figure 1.

Table 1 Technical specifications of JD 1055I combine harvester.

Type of engine	Cylinders	Cutting width, m	Grain tank capacity, m^3	Power, hp
Diesel	6	3.05	2710-3500	119

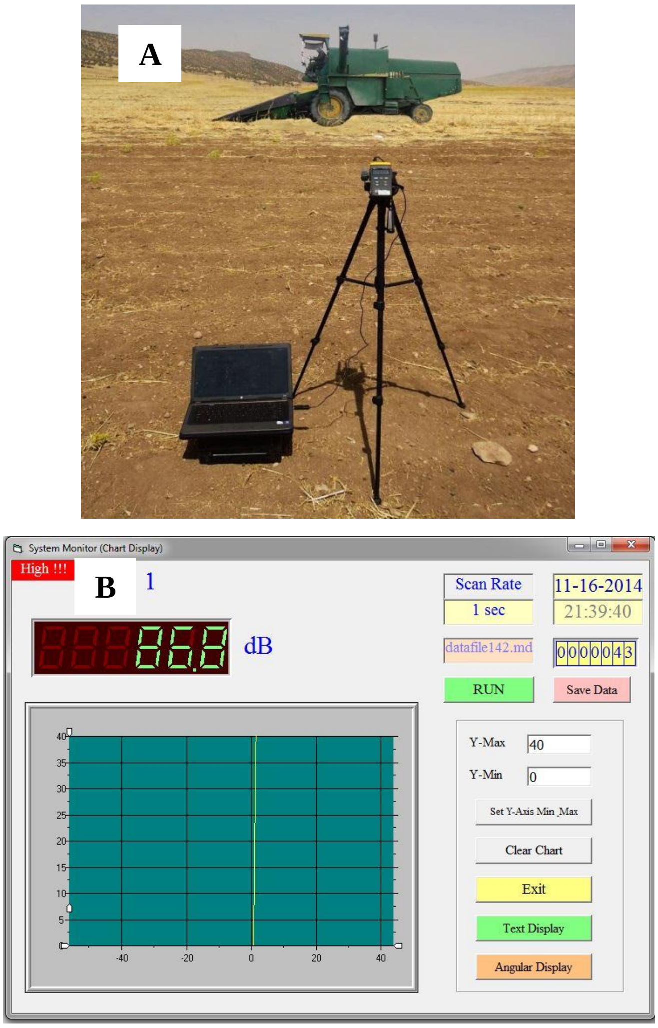

Figure 1 The used combine harvester (A) and measuring instruments software (B).

The effect of uncontrollable variables such as measuring equipment accuracy and test conditions should be removed as much as possible and also to ensure the accuracy of the experiments, the tests must be reproducible. For this purpose, the test location features were selected based on standards of International Organization of Standardization No. 5131 and 7216

(Anonymous, 1996; Anonymous, 1992), so that the location should be open, without dust or snow and at least 25 m far from reflective surfaces such as buildings and other cars, billboards and trees (Figure 1). The abbreviation R denotes the distance of obstacles in this area (buildings, trees, etc.) which is at least 25 m and L and W are the sound measurement area with size of 50×15 m^2, respectively.

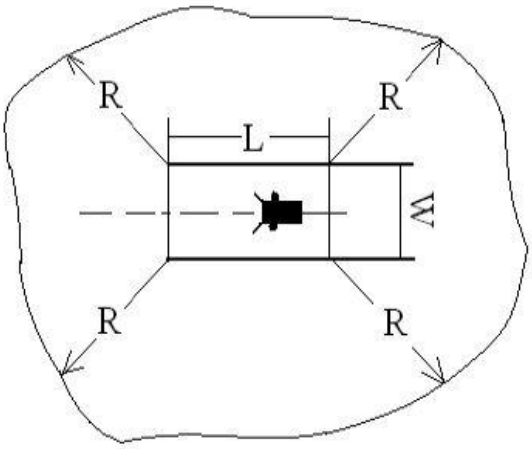

Figure 2 Schematic of the test position for measuring the sound emitted from the combine harvester in position of the around people

The temperature was 10 ℃ and the wind speed was 1.71 m/s in the testing location. For sound assessment, standard level of 85 dB (A) for 8 hour per day was used (Table 2). In table 2, the allowable working time that can be exposed to a certain sound level has been determined by the World Health Organization. According to this standard, when the sound level increases, the working time is reduced. The values of working time were calculated using Equation 1 (NIOSH, 1998; Jalilian Tabbar, 2012).

$$\mathbf{T(hr)} = \frac{\mathbf{8}}{\mathbf{2}\left(\frac{\mathbf{L-85}}{\mathbf{3}}\right)} \qquad (1)$$

Where, T is the allowable hours and L is the measured sound level in 10 cm far from human ear.

Table 2 Suggested hours of exposure to sound (NIOSH, 1998).

Sound level (dB, A)	85	88	91	94	97
Time (h/day)	8	4	2	1	0.5

For measuring the sound level of the combine harvester at the driver's ear position, the microphone was put at a horizontal distance of 10 cm from the driver's left ear. In the around position, the microphone was installed on a holder so that it height was 1.2 m above the ground surface. The holder was put on a line with 7.5 and 20 m distance from central line crossing of the combine harvester. To measure the sound level, an instrument (model: Lutron-SL 4013, Taiwan) was used with accuracy of 0.1 dB and measuring range of 30-130 dB. The sound signals received by microphone were transmitted to the data logger connected to a laptop by RS232 cable. To perform statistical analysis, Excel 2013 and SPSS22 Software were used. The data was analyzed using factorial test based on completely randomized block design. Comparison of the effect of factor levels and their interactions was done according to Duncan's multiple range tests.

In this study, the combine sound signals data was recorded in the time domain. Since the limited information can be obtained in time domain and also the hearing and feeling the sounds in human beings highly depends on frequency, it is necessary to convert sound signals from time domain to frequency domain (Crocker, 1998). For this, firstly it is needed to convert continuous signals in time domain to discrete signals. To convert the obtained sound signals of combine harvester from time domain to frequency domain the Fast Fourier Transform (FFT) method was used in MATLAB 2012a Software environment.

3 Results and discussion

The results of variance analysis of the effects of factors and their interactions on the sound level of JD combine harvester have been presented in Table 3. As seen in this table, the effect of the microphone position, engine rotation speed, gear ratio, interaction of microphone position in engine rotation speed, the microphone position in gear ratio and the microphone position in engine rotation speed in gear ratio on the emitted sound level of the harvester combine were significant at possibility level of 1%. These results showed the significant difference between the averages of the sound levels in different treatments with 0.99 certainties. Reversely, there has been shown that the effect of interaction between engine rotation speed and gear ratio is not significant. The reason of this result can be due to symmetry of the average of treatment (engine rotation speed in gear ratio) around the average of the whole experiment. This can make a small variance of the treatment and therefore cause to non-significantly effect on the interaction (Yazdi Samadi et al, 2000).

Table 3 The results of variance analysis of the average levels of different factors on the harvester sound

Factor	DF	Sum of squares	Mean squares	F
Microphone distance	2	3865.768	1932.884	15094.5**
Engine rotation speed	1	78.457	78.457	612.70**
Gear ratio	2	601.691	300.845	2349.40**
Microphone distance*Engine speed	2	1.962	0.981	7.66**
Microphone distance*Gear ratio	4	6.238	1.559	12.18**
Engine rotation speed*Gear ratio	2	0.797	0.398	3.12n.s
Microphone distance*Engine speed* Gear ratio	4	2.187	0.546	4.27**
Error	36	4.609	0.128	-
Total	53	4561.71	-	-

**significant at 1% probability level, nsnot significant.

Analysis of variance related to the effects of interaction of engine rotation speed in gear ratio factors on the sound level of the combine harvester has been shown in Table 4. The results statistically show significant differences between the factor levels. As shown in this table, the sound levels in different gear ratios were higher than corresponding values of different engine rotation speeds. The highest sound levels were in gear ratio of 3 H and engine rotation speed of 1800 and 2500 r/min with amount of 85.02 and 87.62 dB, respectively, which are higher than the standard allowable level (85 dB, A).

Table 4 The effect of interaction between the engine rotation speed and gear ratio on the harvester sound

Engine rotation speed,r/min	Gear ratio		
	1H	2H	3H
1800	77.12f*	81.37d	85.02b
2500	79.19e	83.94c	87.62a

*Non similar letters in each row indicate non-significant difference.

The average values of sound level at driver's ear position in gear ratio and engine rotation speed has been shown in Figure 2. As can be seen in this figure, the average of sound level was increased by increasing of the engine rotation speed from 1800 to 2500 r/min and changing the gear ratio from 1 to 3 H. The reasons of this trend are the increase of the number of combustion and piston strokes per unit time and consequently the increase of reciprocating speed of sieves and cutting unit, rotation speed of thresher, and rotation speeds of gears in transmission unit that lead to increase of sound production in the combine harvester. These results are similar to the findings of Meyer et al, (1993); Behroozi Lar et al, (2011) and Bacher, (1980).

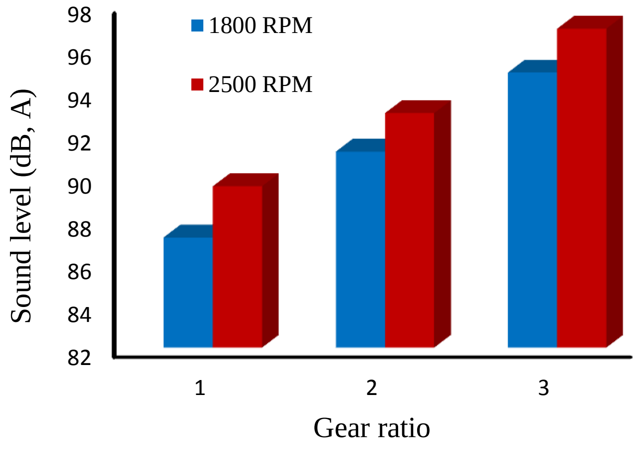

Figure 3 The changes of sound level at the driver's ear position in different engine rotation speeds and gear ratios

Also the effect of different gear ratios on reducing the sound level is higher than the engine rotation speed changes. The mean of sound levels in the operator's ear position and in all gear ratios and engine rotation speeds were either equal to the standard level (85 dB A) or higher. In gear ratio of 1H and engine rotation speed of 1800 r/min, the driver can work for 8 hours per day, but the driver can only work 4 hours per day in same gear ratio and engine rotation speed of 2500 r/min. In gear ratio of 2 H and both engine rotation speed, working only for 2 hours per day is allowable. The working time in gear ratio of 3 H and both engine rotation speed is 1 hour per day. So, some measurements should be considered by the drivers of the combine harvesters to reach the maximum working time standardized by ISO, OSHA and the World Health Organization (8 hours per day). The use of ear protection means, design and construction of the vehicle cabin, reducing the friction of moving parts and the use of hydraulic and pneumatic engineering systems can be of benefit in this regard.

The average values of sound level in different gear ratios and engine rotation speeds at various microphone positions have been shown in Figure 3 and Figure 4. That means sound level of all treatments was reduced by increasing of microphone distance from source of sound production due to attenuation of sound waves in the air. These results are similar to reported results by Crocker (1998) and Suggs (1987). There also can be seen that the effect of gear ratio changes on reducing sound level is higher than engine rotation speed that is against with research results of Hassan Beigi Bidgoli (2004) and Behroozi Lar et al. (2011).

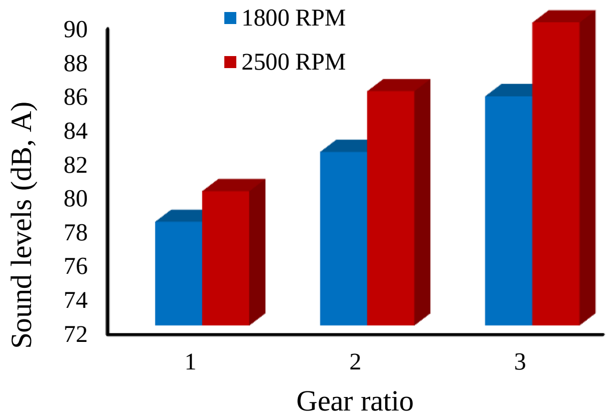

Figure 4 The effect of gear ratio and engine rotation speed on sound level at 7.5 m distance from combine harvester

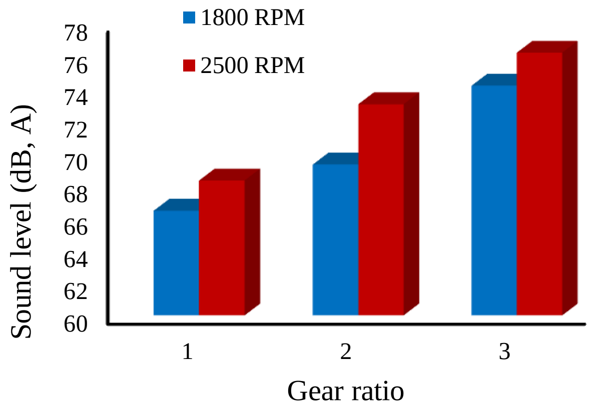

Figure 5 The effect of gear ratio and engine rotation speed on sound level at 20 m distance from combine harvester

Figure 5 shows the average of combine sound level in one third of frequency octave band in different microphone positions. This figure shows great differences in sound level in different microphone positions for all frequencies. Considering the fact that the frequency ranging between 2000-5000 Hz is dangerous for human’s ear (Sabanci, 1999; Sanders and McCormick, 1992), this frequency range can be more taken in to account for designing and development of sound insulation for drivers' ear. With increasing frequency, the sound level of combine harvester was decreased. This result is similar to the findings reported by Sumer et al (2006).

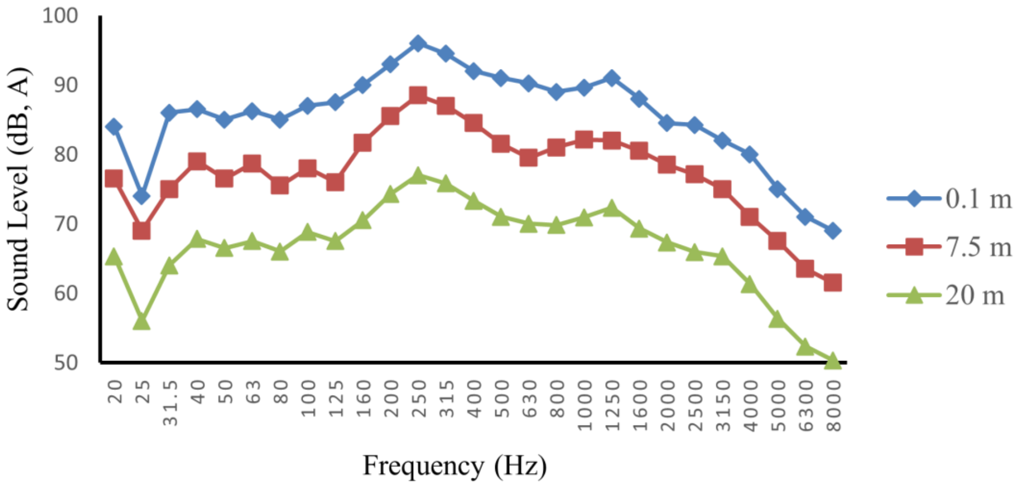

Figure 6 The average sound levels of combine harvester in one third of octave frequency band for different microphone positions

4 Conclusion

In this research, the emitted sound from JD 1055I grain combine harvester at different gear ratios, engine rotation speeds and microphone positions were recorded and analyzed. It was observed that in driver's ear position in all gear ratios and engine rotation speeds the sound level was higher than the standard level, 85 dB (A). To have the maximum working hours (8 hours per day), the drivers must use ear protection or a suitable cabin should be used in the harvester. Also, the sound sources in combine may be carefully studied and then improved to reduce the sound level. Beside this, the combine design can be modified so that the sound level of transmission system minimized by choosing the new power transmission systems such as CVT gearboxes, hydraulic or pneumatic systems. The combine manufacturers can use engineering measurements for driver cabin to reduce emitted signals from combine. The authors suggest a research to study and investigate the sound sources in combine including mechanical resources and combustion noises. It was also observed that with increasing microphone distance from the driver's ear, the sound level was reduced due to effect of ambient sound attenuation. The effects of engine rotation speed and gear ratio at different microphone positions on sound level was significant at possibility level of 1%. The results of data analysis in frequency domain showed that the sound level of combine harvester decreased with increasing frequency.

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