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Effect of Muffler Design on Amplitude & Sound Frequency of Tractor Noise

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***Abstract*—Noise causes corruption of communication, discomfort and reduction in physical and mental performance of men particularly those who are frequently exposed to high noise like that of farm tractors and machinery. Physically sound is made up of the oscillating waves of different frequencies and amplitudes. Frequencies can be expressed in Hertz (Hz) and amplitudes in decibels (dB). The experiment was carried out to examine the frequency and amplitudes of the sound of tractor noise as influenced by design of the exhaust mufflers. Two muffler designs were conceptualized based on the principle of reactive/reflective kind of muffling technique being low cost and widely used method of suppressing sound of the exhaust of tractor engine. The changes in diverse frequency contents and corresponding amplitude levels as affected by alteration in the exhaust muffler mountings were observed and analyzed in addition to the resulting sound pressure levels (SPLs). Audio spectrum analyzer (Spectrumview) and an acoustic spectrum analyzer (Spek) were employed for analysis of the sound clips to observe the periodical peak amplitude frequency observations, generation of frequency spectra and spectrograms of the tractor noise recorded at different engine speeds (RPM) under different muffler mountings. Frequency spectra indicated presence of higher frequencies in the noise (SPL) recorded at operator's ear level while at 10 m distance away from tractor, higher frequencies reduced considerably. The mean value of the peak amplitude frequencies observed at operator's ear level under no muffler mounted on exhaust outlet of the tractor was found 1502.6 Hz. The mean peak amplitude frequency under standard muffler was found lowest (i.e. 930.6 Hz) while under altered design of muffler (muffler-C), mean of the peak amplitude frequencies was found moderate (i.e. 1134.9 Hz). Statistical analysis of peak amplitude frequency observations under different muffler installation at different engine speed (RPM) revealed minimum values of standard deviation (Hz) and coefficient of variation (%) under muffler-C among peak amplitude frequency observations recorded under all mufflers at each RPM level. Standard deviation (Hz) and coefficient of variation (%) observed under muffler-C, muffler-S and under no muffler mounting were 232.2 Hz & 20.5%, 261.3 Hz & 28.1% and 453.4 Hz & 30.2% respectively. Spectrograms of the tractor noise recorded under no muffler exhibited erratic pattern of different frequency amplitudes over full length recorded sound of tractor noise and also showed presence of higher frequencies in greater amount particularly at higher engine speeds as compared to that of standard muffler and muffler-C viz. at 1000 RPM, higher frequency range such as 7.5-10.0 had respective percent amplitudes of 7.7, 5.1 & 0.4 percent under no muffler, muffler-S and muffler-C. At 1500 RPM, higher frequency range such as 7.5-10.0 had respective percent amplitudes of 10.4, 4.5 & 1.2 percent under no muffler, muffler-S and muffler-C. At 2000 RPM, higher frequency range such as 10-12.5 Hz had respective percent amplitudes of 4.5, 0.4 & 1.1 percent under no muffler, muffler-S and muffler-C. Thus, presence of higher frequencies were noticed in lesser amount under altered design of muffler (muffler-C) in comparison to standard & no muffler mountings.**

Keywords*—Noise; Tractor; Sound; Frequency; Amplitude; Muffler

I. INTRODUCTION

Sound is a common part of our daily life. Many sounds which are unpleasant or unwanted or damaging can be called as "noise". Noise can be generated by men and machines. As stated on website of OSHA, Noise and vibration are both fluctuations in the pressure of air (or other media) which affect the human body. Vibrations that are detected by the human ear are classified as sound. We use the term 'noise' to indicate unwanted sound. Noise exceeding the certain level can cause permanent damage to hearing ability of human beings. However sound is the indispensable medium of communication for the life, when it takes form of "noise" it should be prevented at the source or in the environment where it spreads. Noise causes corruption of communication, discomfort and reduction in physical and mental performance of men who are repetitively exposed to high levels of noise especially to that of machinery which represents most severe form of acoustic dangers. The exhaust mufflers play an important role in mitigation of high noise levels arising out of engine operations of automobiles and farm tractors. Investigating the effect of altered design of mufflers on the noise levels can be helpful for framing the strategy to mitigate the ill effects taking place on human health and comfort due to noise generated out of farm machinery operations at the work place like agricultural farms. The exhaust noise can be reduced appreciably by providing resonance chambers to offset the noise wave effects. Jadhav and Ghatage (2000) reported that the suppression of engine exhaust noise has been a subject of interest for many years. The muffler popularly also known as silencer can be broken into three fundamental types: absorptive (dissipative), reactive (reflective), and combination of reactive & absorptive both. Reactive silencers depend on the basic noise-reduction mechanism of reflection or expansion of sound waves with self-destruction through collision of opposite sound waves.

II. LITERATURE REVIEW

Simpson and DeShayes (1969) reported that tractor operators are subjected to noise and vibration levels that are hazardous to health and deleterious to performance. Mehta et al. (1997) reported that the maximum sound pressure versus octave band frequency curves at rated engine speed indicated that sound pressure level was highest at 4000 Hz frequency. It

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was concluded that the tractor noise was predominant at low and medium frequencies for different mufflers. Jadhav and Ghatage (2000) stated that an engine noise is mainly due to exhaust noise. They stated that exhaust noise is one of the major contributors to noise from vehicles powered by internal combustion engines. For the same power rating, diesel engines are noisier than gasoline engines, since the combustion characteristics of diesel engines produce more harmonics than slower combustion of gasoline. An unmuffled gasoline engine radiates exhaust noise in the range from 90 to 100 dBA while an unmuffled diesel engine under identical conditions radiates exhaust noise in the range from 100 to 125 dBA.

Kumar et al (2005), through audiogram analysis, observed high frequency hearing loss among tractor driving farmers as compared to non-tractor driving farmers. Sam (2006) conducted measurements of sound levels at different forward speeds of power tiller viz. 1.5, 1.8, 2.1 and 2.4 km/hr during field trials and 3.5, 4.0, 4.5 and 5.0 km/hr in transport mode. Each trial was replicated for 3 times with an acquisition period of 30s and the peak value arrived from the noise spectrum was averaged for each selected levels of forward speed. The results were statistically analyzed for making conclusions on safe exposure durations for the power tiller operators. According to

Smith III (2007), in practical signal processing, it is common to choose the maximum signal magnitude as the reference amplitude i.e. the signal is normalized so that the maximum amplitude is defined as 1, or 0 dB. This convention is also used by ``sound level meters" in audio recording. When displaying magnitude spectra, the highest spectral peak is often normalized to 0 dB to facilitate easily read lower peaks as so many dB below the highest peak.

Henderson and Hamernik (2012) stated that sound measurements are made with an A-scale weighting on the sound level meter. Low-frequency sounds (less than 500 Hz) are negatively weighted with the A scale because low-frequency sound energy is not as damaging to the ear as sounds above 500 Hz. Young (2013) stated that when measuring and logging sound levels to help resolve a dispute, both A and C weighted measurements should be provided. The distance from the source and any other detailed notes should be there.

III. METHODOLOGY

A. Sound Pressre Level (SPL) Measurement

The sound pressure level can be calculated using the following formula: they are part of a sentence, as in

$$SL_{pressure} = 20\log_{10}\left(\frac{P}{P_{ref}}\right) \quad (1)$$

Where

$SL_{pressure}$ = Sound pressure level, dB

P = Sound pressure, Pa (N/m^2)

P_{ref} = Reference sound pressure (i.e. equal to 2 x 10^{-5} Pa)

In the above equation, the reference pressure represents the normal threshold of hearing for most human beings. Sound level meters are generally used for measuring sound pressure levels (SPLs), which are equipped with accurate microphones containing flexible membrane or cartridge protected by a grill or screen. When sound waves fall on it they oscillate back and forth which produce electric signal or current from the membrane which is measured and converted into a decibel rating denoting the strength of the sound. Usually sound level meters (SLMs) are able to measure the sound levels to make sure that whether it is within safer limit or not. During the experiment, the sound level meter Lutron SL-4001 was utilized for measuring the noise levels taking place at different RPMs on a farm tractor under different muffler conditions.

B. Test Muffler and Engine Speed of Tractor

Along with company mounted standard muffler (muffler-S), muffler-C was chosen for detailed noise level (SPL) measurements by mounting them on farm tractor. Tractor was operated at three different engine speeds as fixed viz. 1000, 1500 & 2000 RPM. Sound recording was made for three defined muffler conditions namely (i) no muffler, (ii) muffler-S, and (iii) muffler-C.

C. Applications for Frequency and Amplitude Analysis of Tractor Noise

Audio spectrum analyzer as downloaded from http://download.cnet.com/windows/wd6cnf/3260-20_4-10119931.html was employed to find the peak amplitude frequency observations measured over a prefixed period of time. The application also provided FFT displays which are presented at appropriate places. In place of octave band analyzers/filters, the spectrograms of the tractor noise were used to analyze the several frequency bandwidths such as 0-2.5 kHz, 2.5-5.0 kHz, 5-7.5 kHz and so on. An acoustic spectrum analyzer namely *Spek* was employed to generate the spectral representation of the noise audio files in a time-varying graph, usually called spectrogram. For generating the spectrograms of the tractor noise recorded at different places & at different engine speed (RPM). Application used namely *Spek* was downloadable from http://download.cnet.com / Spek / 3000-2170_4 – 75451631.html and also from http://spek. cc/. Spek is free and open source software licensed under GPLv3.

D. Amplitude Ratio

A measure of the strength of a wave is its amplitude which is the vertical distance between the heights of the wave’s peaks and the heights of the troughs. The table given below dscribes how the logarithmic scale can describe very big and very small numbers representing power, energy or amplitude ratios with much shorter notation. The decibel calculating formula is given by

$$dB = 20\ \log_{10}N \quad (1)$$

$$\alpha + \beta = \chi \quad (1) \quad (1)$$

The percent amplitude levels (in percent) were calculated using the comparative amount of the amplitudes of specific frequency ranges as contained in a certain noise clips as recorded during the experimentation on noise (SPL) measurements conducted on farm tractor under different muffler conditions. For this, the spectograms of the noise clips recorded for individual experimental setups (treatments) were analyzed visually to observe the decibel levels followed by their conversion into respective amplitude ratio and finally leading to per cent amplitude levels of the composed frequencies.

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IV. RESULTS

A. Frequency Spectra at Different RPM (Revolutions per Minute)

The frequency spectrum was obtained by inputting the .wav file to the Audio Spectrum Analyzer Application (Spectrumview). Audio Spectrum Analyzer generated Fast Fourier Transform (FFT) display at sample rate of 48000 Hz with 1k transform size. The graphical display represented Frequency (Hz) on horizontal axis and Amplitude (dB) on vertical axis. Frequency spectra generated at different tractor engine speed in revolutions per minute (RPM) and at different places of sound recording viz. operator's ear level of the farm tractor are shown in the figures under following sections.

B. Frequency Spetra of Tractor Noise under No Muffler

Frequency spectrum obtained under no muffler mounting at engine speed of 1000 RPM are presented in the figures (Fig. 1 to Fig. 6).

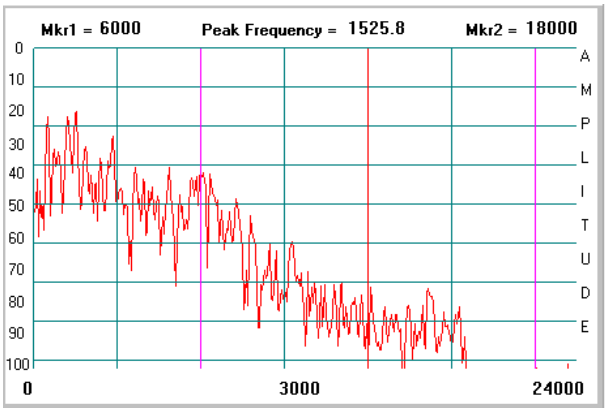

Fig. 1. Frequency spectrum of tractor noise at 1000 RPM under no muffler observed at operator's ear level

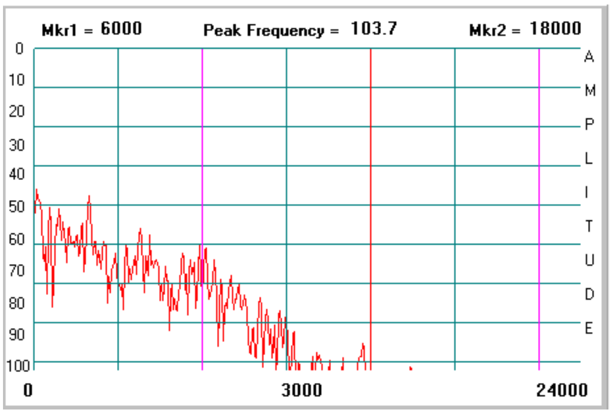

Fig. 2. Frequency spectrum of tractor noise at 1000 RPM under no muffler observed at 10 m distance from farm tractor

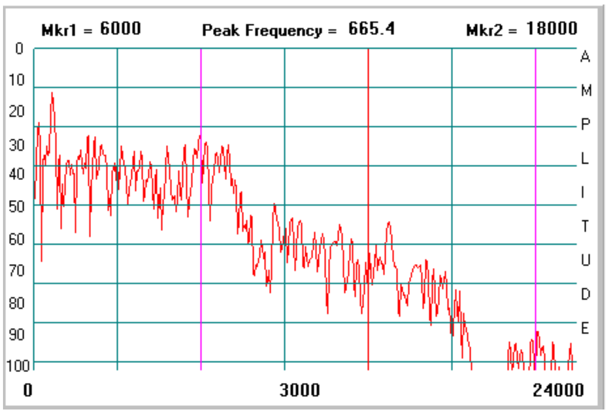

Fig. 3. Frequency spectrum of tractor noise at 1500 RPM under no muffler observed at operator's ear level

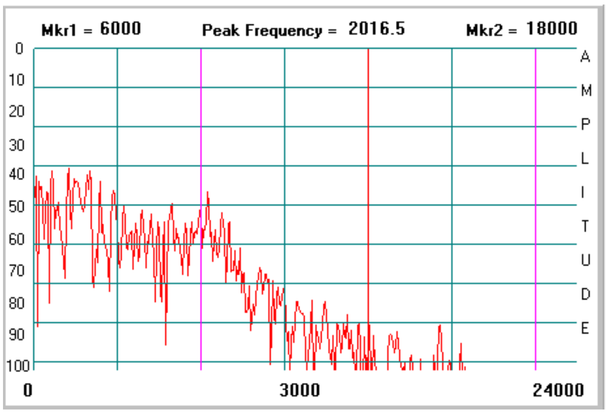

Fig. 4. Frequency spectrum of tractor noise at 1500 RPM under no muffler observed at 10 m distance from farm tractor

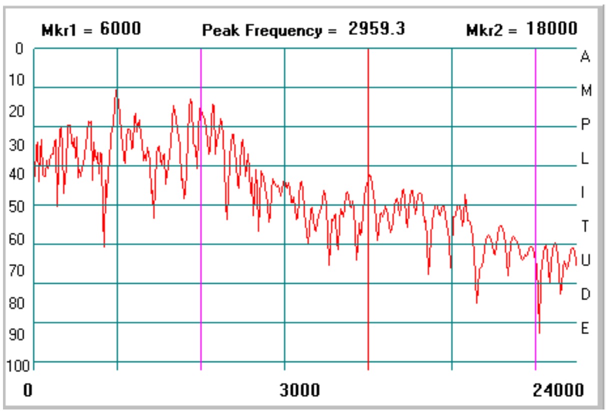

Fig. 5. Frequency spectrum of tractor noise at 2000 RPM under no muffler observed at operator's ear level

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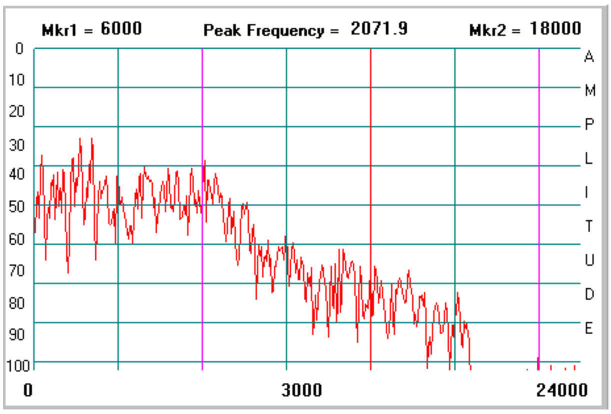

Fig. 6. Frequency spectrum of tractor noise at 2000 RPM under no muffler observed at 10 m distance from farm tractor

C. Frequency Spetra of Tractor Noise under Muffler-S

Frequency spectrum obtained under standard muffler mounting at engine speed of 1000 RPM are presented in the figures (Fig. 7 to Fig. 12).

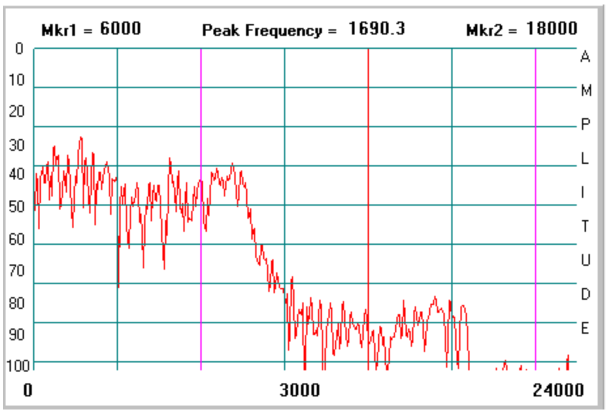

Fig. 7. Frequency spectrum of tractor noise at 1000 RPM under muffler-S observed at operator's ear level

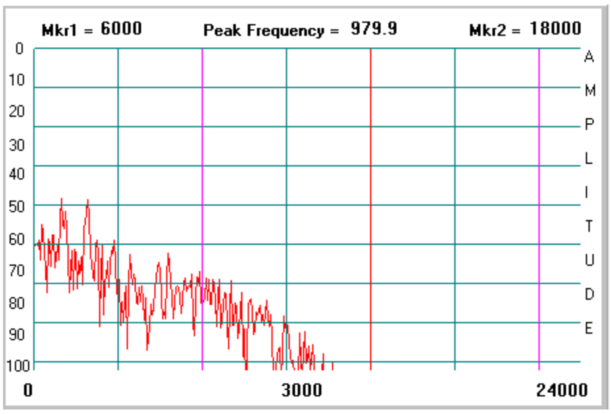

Fig. 8. Frequency spectrum of tractor noise at 1000 RPM under muffler-S observed at 10 m distance from farm tractor

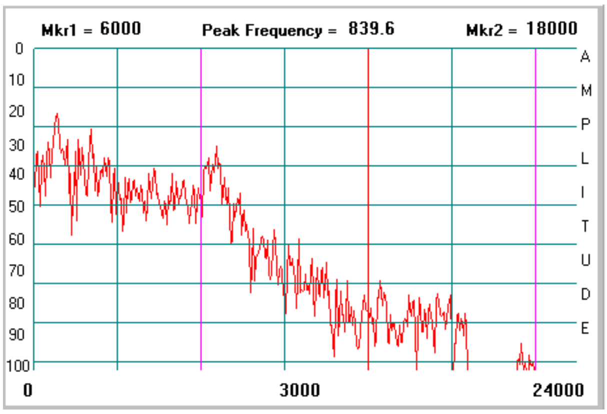

Fig. 9. Frequency spectrum of tractor noise at 1500 RPM under muffler-S observed at operator's ear level

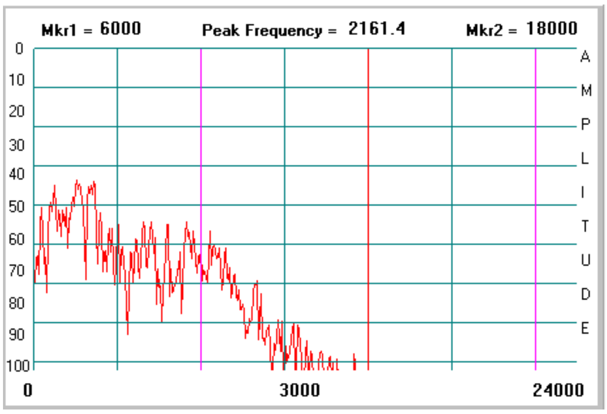

Fig. 10. Frequency spectrum of tractor noise at 1500 RPM under muffler-S observed at 10 m distance

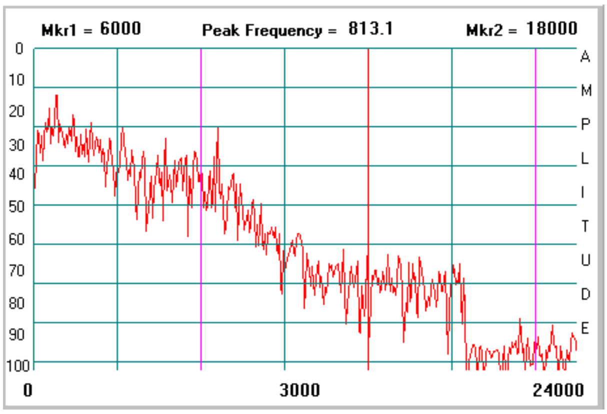

Fig. 11. Frequency spectrum of tractor noise at 2000 RPM under muffler-S observed at operator's ear level

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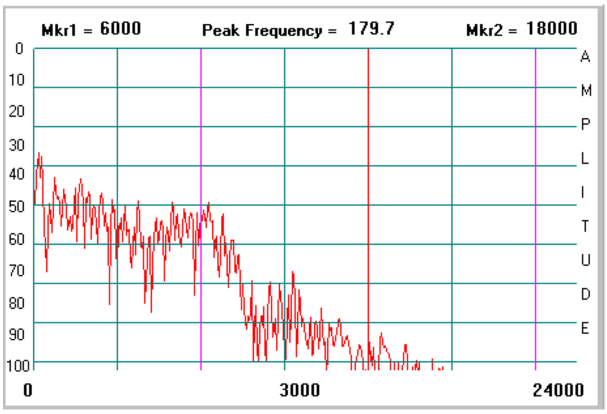

Fig. 12. Frequency spectrum of tractor noise at 2000 RPM under muffler-S observed at 10 m distance from farm tractor

D. Frequency Spetra of Tractor Noise under Muffler-C

Frequency spectrum obtained under muffler-C mounting at engine speed of 1000 RPM are presented in the figures (Fig. 13 to Fig. 18).

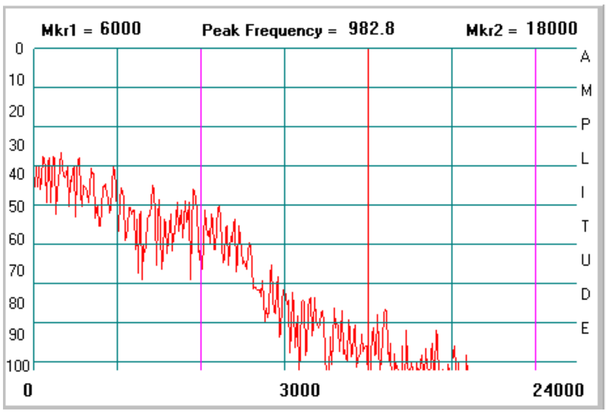

Fig. 13. Frequency spectrum of tractor noise at 1000 RPM under muffler-C observed at operator's ear level

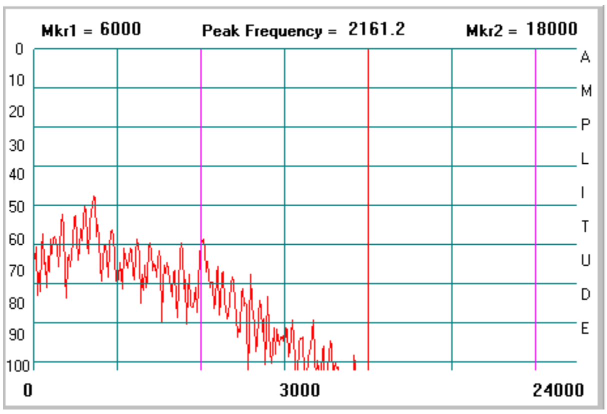

Fig. 14. Frequency spectrum of tractor noise at 1000 RPM under muffler-C observed at 10 m distance from farm tractor

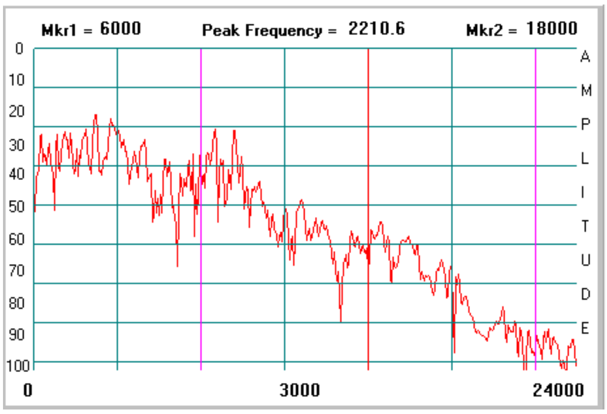

Fig. 15. Frequency spectrum of tractor noise at 1500 RPM under muffler-C observed at operator's ear level

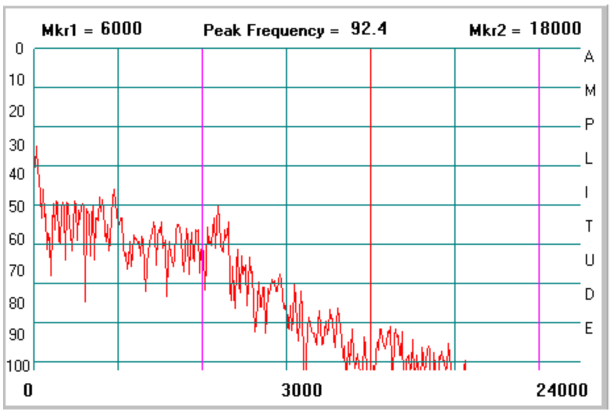

Fig. 16. Frequency spectrum of tractor noise at 1500 RPM under muffler-C observed at 10 m distance from farm tractor

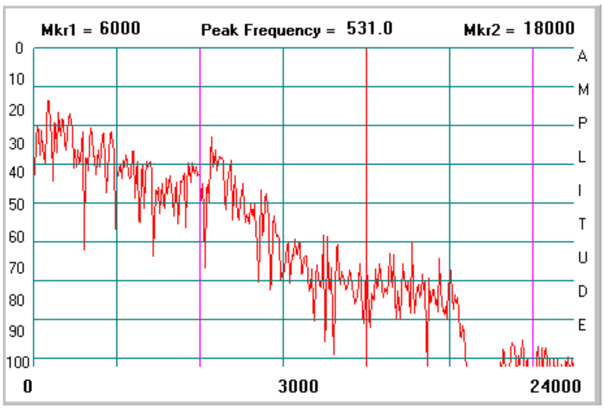

Fig. 17. Frequency spectrum of tractor noise at 2000 RPM under muffler-C observed at operator's ear level

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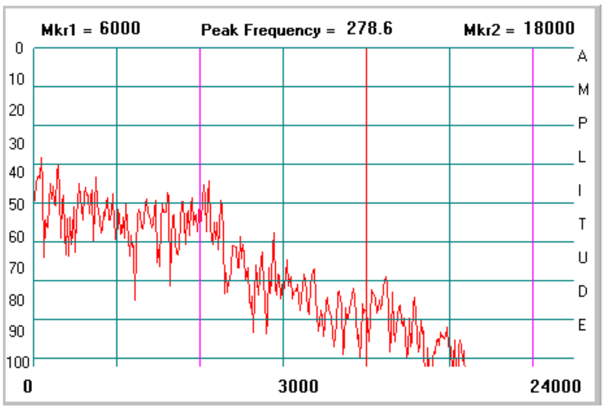

Fig. 18. Frequency spectrum of tractor noise at 2000 RPM under muffler-C observed at 10 m distance from farm tractor

For each muffler mounting and each speed level, the frequency observations of peak amplitudes (also referred as peak frequencies) were recorded and later analyzed for investigating the effect of muffler mounting on the sound frequencies emanated out of it passing through the varying kinds of internal reactive muffler configurations as experimented.

A comparison of mean values of peak amplitude frequencies observed at ear level under three muffler mountings at different engine speeds on Tractor-2 are tabulated (Table I).

TABLE I. MEAN VALUES OF PEAK AMPLITUDE FREQUENCIES OBSERVED AT EAR LEVEL AT DIFFERENT ENGINE SPE EDS ON FARM TRACTOR

	Engine Speed (RPM)			Mean
	1000	1500	2000	
No Muffler	1087.7	1433.5	1986.6	1502.6
Standard Muffler	1079.0	1083.9	628.9	930.6
Muffler-C	1126.0	1371.5	907.3	1134.9

At operator's ear level SPL (Sound Pressure Level) observations on farm tractor revealed lowest (930.6 Hz) and highest (1502.6 Hz) peak frequencies under standard muffler and no muffler mounting respectively in comparison to that observed under muffler-C which exhibited moderate peak frequency viz. 1134.9 Hz.

The mean, standard deviation and coefficient of variation (%) of peak amplitude frequencies observed during the sample noise test at ear level under no-muffler, standard muffler and muffler-C are presented in the Table II.

TABLE II. THE MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIATION IN PEAK AMPLITUDE FREQUENCY OBSERVATIONS

	Mean (Hz)	Standard Deviation (Hz)	Coefficient of variation (%)
No Muffler	1502.6	453.4	30.2
Standard Muffler	930.6	261.3	28.1
Muffler-C	1134.9	232.2	20.5

The mean, standard d The values standard deviation (Hz) and coefficient of variation (%) of ear level peak amplitude frequencies under muffler-C were found 232.2 Hz & 20.5% respectively which were minimum among three muffler mountings under test on farm tractor.

E. *Noise Spectrograms*

The noise clips recorded with the help of a uniform device on farm tractor with & without standard exhaust muffler along with muffler-C were processed to generate the respective spectrograms by using an acoustic spectrum analyzer Spek at different engine speeds which are presented in following sections.

Fig. 19 to Fig. 27 represents the respective spectrograms generated out of the spek application which were further analyzed to determine the amplitude ratio of different frequency bands or segments provisionally classified in eight classes.

F. *Spectrograms of Noise under No Muffler Mounting*

Spectrograms of tractor noise observed at operator's ear level under no muffler mounting on farm tractor are presented in the figures (Fig. 19 to Fig. 21).

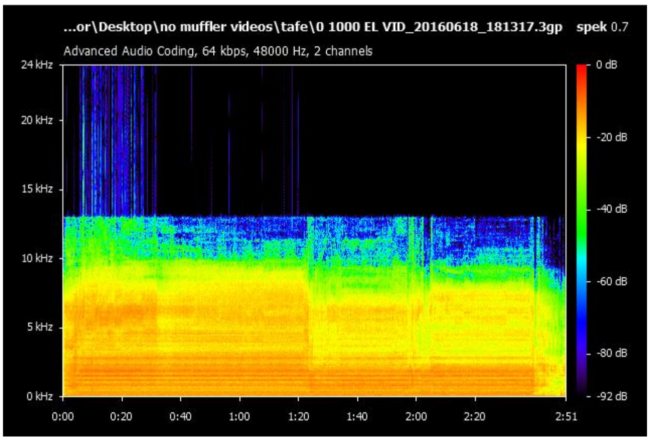

Fig. 19. Spectrogram of noise clips recorded at 1000 RPM under no muffler at operator's ear level on farm tractor

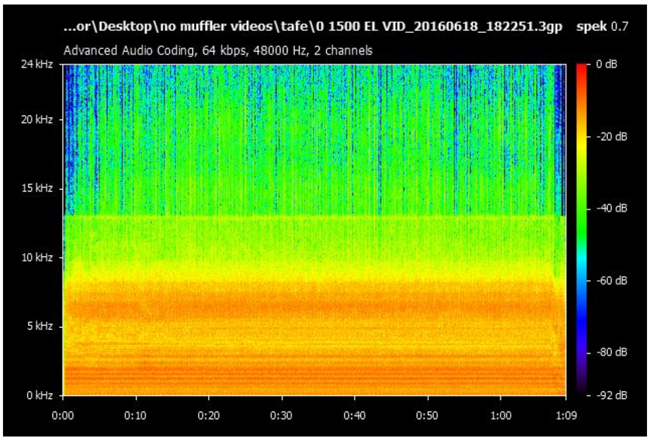

Fig. 20. Spectrogram of noise clips recorded at 1500 RPM under no muffler at operator's ear level on farm tractor

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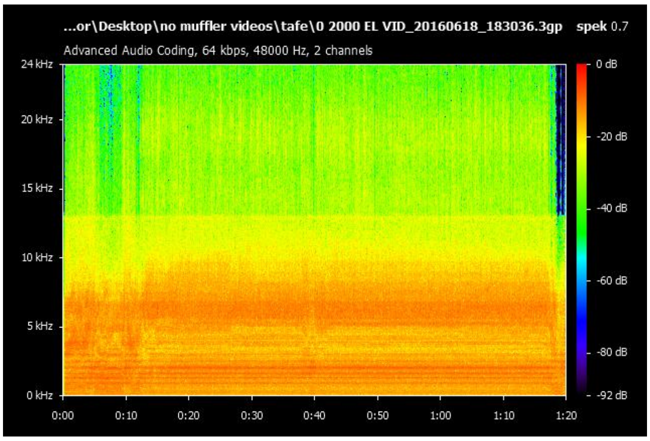

Fig. 21. Spectrogram of noise clips recorded at 2000 RPM under no muffler at operator's ear level on farm tractor

G. Spectrograms of Noise under Muffler-S Mounting

Spectrograms of tractor noise observed at operator's ear level under standard muffler mounting (muffler-S) on farm tractor are presented in the figures (Fig. 22 to Fig. 24).

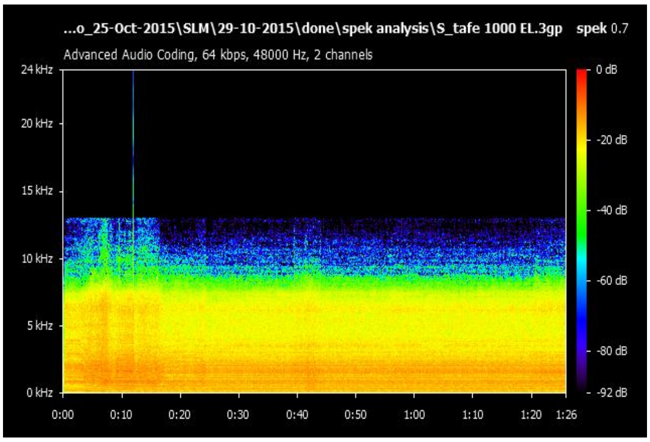

Fig. 22. Spectrogram of noise clips recorded at 1000 RPM under muffler-S at operator's ear level on farm tractor

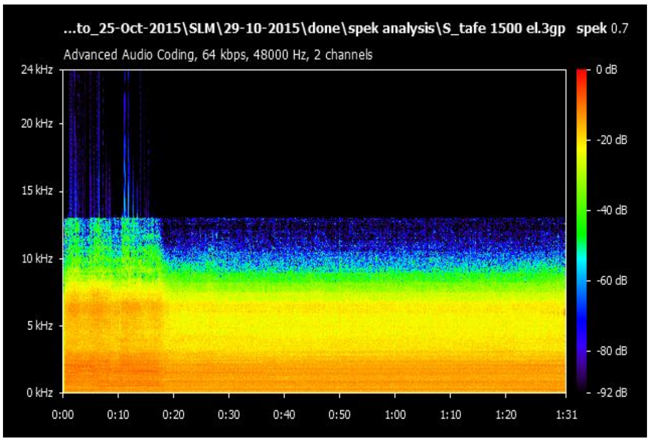

Fig. 23. Spectrogram of noise clips recorded at 1500 RPM under muffler-S at operator's ear level on farm tractor

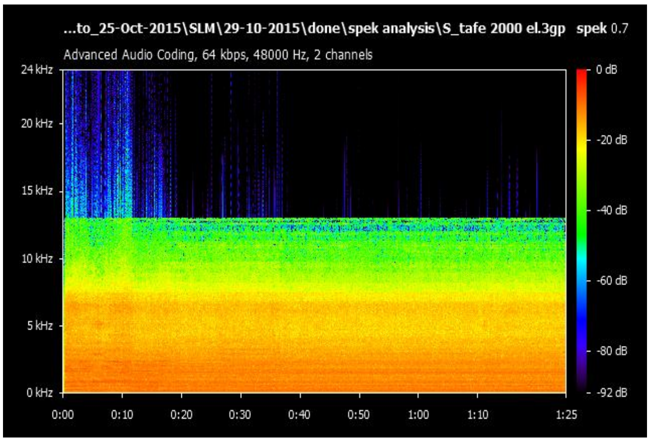

Fig. 24. Spectrogram of noise clips recorded at 2000 RPM under muffler-S at operator's ear level on farm tractor

H. Spectrograms of Noise under Muffler-C Mounting

Spectrograms of tractor noise observed at operator's ear level under muffler-C mounting on farm tractor are presented in the figures (Fig. 25 to Fig. 27).

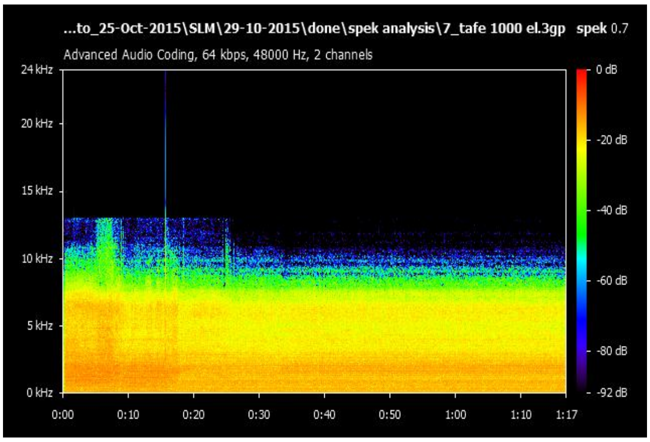

Fig. 25. Spectrogram of noise clips recorded at 1000 RPM under muffler-C at operator's ear level on farm tractor

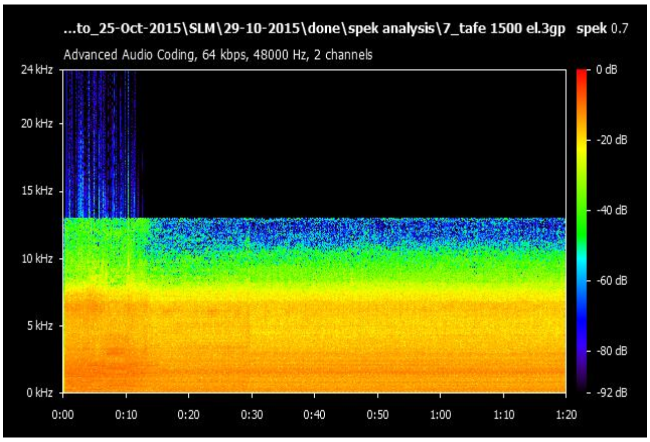

Fig. 26. Spectrogram of noise clips recorded at 1500 RPM under muffler-C at operator's ear level on farm tractor

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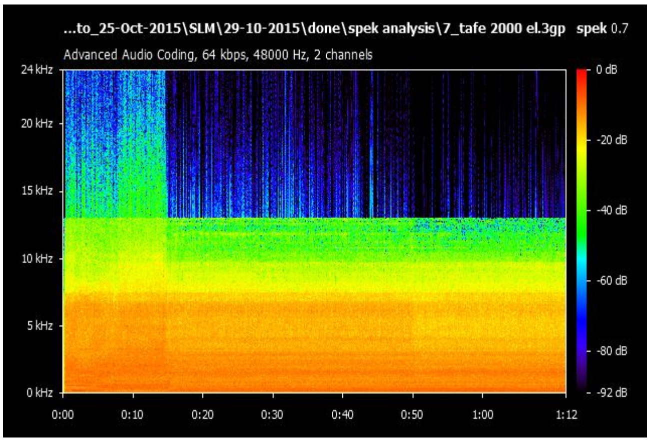

Fig. 27. Spectrogram of noise clips recorded at 2000 RPM under muffler-C at operator's ear level on farm tractor

Manually observed decibel levels and their respective amplitude ratio values of certain frequency ranges based on these graphs are presented in the following tables along with their respective percent level of amplitudes. Mainly four out of eight frequency ranges under different engine speeds demonstrated varying properties of the noise in terms of their proportional amounts as recorded at operator's ear level under different muffler conditions.

The proportional amounts in terms of percent amplitudes of the specified frequency ranges recorded under different muffler installations and under different engine speeds at operator's ear level are presented in the following tables (Table III to V).

TABLE III. PERCENT AMPLITUDES CORRESPONDING TO DIFFERENT FREQUENCY RANGES UNDER DIFFERENT MUFFLERS AT 1000 RPM ON FARM TRACTOR AT EAR LEVEL

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	43.3	50.5	41.2
2.5 – 5.0	24.3	28.4	30.9
5.0 – 7.5	24.3	15.9	27.5
7.5 – 10.0	7.7	5.1	0.4
10.0 – 12.5	0.4	0.1	0
12.5 – 15.0	0.0	0.0	0
15.0 – 17.5	0.0	0.0	0
17.5 – 20.0	0.0	0.0	0

TABLE IV. PERCENT AMPLITUDES CORRESPONDING TO DIFFERENT FREQUENCY RANGES UNDER DIFFERENT MUFFLERS AT 1500 RPM ON FARM TRACTOR AT EAR LEVEL

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	33.0	44.9	39.3
2.5 – 5.0	18.6	25.3	29.5
5.0 – 7.5	33.0	25.3	29.5
7.5 – 10.0	10.4	4.5	1.2
10.0 – 12.5	3.3	0.0	0.4
12.5 – 15.0	1.0	0.0	0
15.0 – 17.5	0.3	0.0	0
17.5 – 20.0	0.3	0.0	0

TABLE V. PERCENT AMPLITUDES CORRESPONDING TO DIFFERENT FREQUENCY RANGES UNDER DIFFERENT MUFFLERS AT 2000 RPM ON FARM TRACTOR AT EAR LEVEL

Frequency Range (kHz)	No Muffler	Standard Muffler	Muffler-C
0.0 – 2.5	33.5	38.3	35.1
2.5 – 5.0	10.6	28.7	26.3
5.0 – 7.5	33.5	28.7	26.3
7.5 – 10.0	10.6	3.8	11.1
10.0 – 12.5	4.5	0.4	1.1
12.5 – 15.0	1.9	0.0	0
15.0 – 17.5	1.9	0.0	0
17.5 – 20.0	3.4	0.0	0

Percent amplitudes corresponding to different frequency ranges under different mufflers at different RPM on the farm tractor at ear level (Table 3 to Table 5) revealed the following outcomes.

(i) At 1000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (43.3%) were increased by 7.2% & reduced by 2.1% under standard muffler (50.5%) & muffler-C (41.2%) respectively. Percent amplitudes of 2.5-5.0 kHz frequencies were found higher (30.9%) under muffler-C.

(ii) At 1250 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (44.3%) were increased by 0.6% & reduced by 4.5% under standard muffler (44.9%) & muffler-C (39.8%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (33.3%) under no muffler mounting.

(iii) At 1500 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (33.0%) were increased by 11.9 & 6.3 % under standard muffler (44.9%) & muffler-C (39.3%) respectively. Percent amplitudes of 5.0-7.5 kHz frequencies found higher (33.0%) under no muffler mounting.

(iv) At 1750 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (26.8%) increased by 11.5% under standard muffler & muffler-C both (38.3%) respectively. Percent amplitudes of 5-7.5 kHz frequencies were found higher (26.8%) under no muffler. Further, 7.5-10.0 frequencies appeared in significant amplitude levels (20.2%) under no muffler.

(v) At 2000 RPM, amplitudes of 0-2.5 kHz frequencies found under no muffler mounting (33.5%) increased by 4.8 & 1.6 % under standard muffler (38.3%) & muffler-C (35.1%) respectively. Percent amplitudes of 5.0-7.5 kHz frequencies found higher (33.5%) under no muffler.

V. CONCLUSIONS

Frequency spectra obtained through software application revealed noticeable presence of higher frequencies (greater than 15 kHz) in the noise (SPL) recorded at operator's ear level while at 10 m distance away from tractor, higher frequencies reduced considerably. The mean value of the peak amplitude frequencies observed at operator's ear level under no muffler mounted on exhaust outlet of the tractor was found 1502.6 Hz. The mean peak amplitude frequency under standard muffler was found lowest (i.e. 930.6 Hz) while under altered design of muffler (muffler-C), mean of the peak amplitude frequencies was found moderate (i.e. 1134.9 Hz). Statistical analysis of peak amplitude frequency observations under different muffler installation at different engine speed (RPM) revealed minimum values of standard deviation (Hz) and coefficient of variation (%) under muffler-C among peak amplitude frequency observations recorded under all mufflers at each RPM level. Standard deviation (Hz) and coefficient of variation (%) observed under muffler-C, muffler-S and under no muffler mounting were 232.2 Hz & 20.5%, 261.3 Hz & 28.1% and 453.4 Hz & 30.2% respectively. Spectrograms of the tractor noise recorded under no muffler exhibited erratic pattern of different frequency amplitudes over full length recorded sound of tractor noise and also showed presence of higher frequencies in greater amount particularly at higher engine speeds as compared to that of standard muffler and muffler-C viz. at 1000 RPM, higher frequency range such as 7.5-10.0 had respective percent amplitudes of 7.7, 5.1 & 0.4 percent under no muffler, muffler-S and muffler-C. At 1500 RPM, higher frequency range such as 7.5-10.0 had respective percent amplitudes of 10.4, 4.5 & 1.2 percent under no muffler, muffler-S and muffler-C. At 2000 RPM, higher frequency range such as 10-12.5 Hz had respective percent amplitudes of 4.5, 0.4 & 1.1 percent under no muffler, muffler-S and muffler-C. The outcomes of experiment were indicative of the greater presence of higher frequencies (percent amplitude values) under no muffler and lowest noticed under altered design of muffler (muffler-C).

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