Exhaust Noise Emission Characteristics of Gasoline Engine

D. O. Omondi, R. Kinyua, and A. N. Mayaka

***Abstract*—**The use of[1] internal combustion engines have increased over the years as they are a common prime mover for a variety of tasks including transportation, power generation, and machinery and process operations in industries. Safe work practices require that noise exposure be monitored and controlled and should not exceed set limits. The most common method of engine exhaust noise control is the use of mufflers or silencers. However, depending on the year of manufacture, maintenance and operating environment, loads and operating speeds, these engines emit noise that seriously affect the safety and health of those exposed. Data analysis on noise produced for by engines during operation is not available.In this paper, an analysis of the exhaust noise emissions for different operating speeds of a gasoline engine is presented. It is found that the values of the average noise levels for the frequency components increases by between 6% and 50% with increase in engine speed for both arrangements with and without the exhaust silencer system installed. For the arrangement with the exhaust system the peak average noise level was 84.9 dB(A) at frequency of 31.5 Hzwhile that without the exhaust system the peak average noise level was 106.1 dB(A) at 125 Hz.The former was just about the action limit while the latter was beyond the recommended action level of 85dB(A), both determined at a background noise level of 39.2 dB(A).There was a tendency for the noise levels to reduce at higher frequencies. It was also observed that the average noise levels decreased for each of the centre frequencies with occasional spikes that indicate centre frequencies that could be used for noise control. This analysis provides vital information needed in order to justify technical or management solutions to the noise problem.

***Keywords*—**exhaust noise emission, internal combustion engines, noise exposure, safety and health.

I. Introduction

INTERNALcombustion engines are a common form of energy transfer that has been perfected over the years to make work easier. Models exist that give higher torque performances per joule of fuel consumed irrespective of the size of the engine. For energy to be converted in this form, a number of actions take place including motion of parts, combustion of air-fuel mixture, friction, vibration of structures around the engine, and corresponding generation of heat energy. These are usually accompanied by noise in the form of pressure waves, which if not effectively controlled, may adversely affect the safety and health of persons within boundaries of such arrangements.

The predominant sources of engine noise listed in order of magnitude [1] are that of exhaust, intake and casing. The cooling fan may also contribute some noise [2]. Exhaust noise includes the various noise sources of the exhaust system (expansion joint, piping, and exhaust), whileintake noise includes all noise sources within the intake system (air filter, ducting or piping and the air intake itself)[3, 4]. Casing noise is the result of mechanical and structural propagation of radiated noise [5]. Fuel combustion, engine timing and the extent of component wear also contribute to the casing noise.

Most noise is not a pure tone, but rather consists of many frequencies simultaneously emitted from the source. To properly represent the total noise of a source, it is usually necessary to break it down to its frequency components. One reason for this is that people react differently to low-frequency and high-frequency sounds. Engineering solutions to reduce or control noise are different for low-frequency and high-frequency noise. As a general guideline, low-frequency noise is more difficult to control.

Octave band filters are used to analyze the frequency content of noise. Most frequency band filter sets are designed with 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16000 hertz centre frequencies as specified in [6]. The recommended environmental noise levels aresummarized inTable 1 below.

Table 1: Recommended Noise Exposure Limits

OSHA Standard	
Sound level (dBA)	**Duration (Hours: Minutes: Seconds)**
85	16:00:00
90	8:00:00
95	4:00:00
100	2:00:00
105	1:00:00
110	0:30:00
115	0:15:00
120	0:07:30
125	0:03:45
130	0:01:53
135	0:00:56
140	0:00:28
145	0:00:14
150	0:00:07
155	0:00:03
160	0:00:01

Source: OSHA, 2009

The special signature of any given noise can be obtained by taking sound level meter readings at each of the centre frequency bands. The results indicate octave bands that contain the majority of the total sound power being radiated.

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Sound frequency is perceived as pitch i.e. how high or low a tone is. The frequency range sensed by the ear varies considerably among individuals. A young person with normal hearing can hear frequencies between approximately 20 hertz (Hz) and 20,000 Hz. As a person gets older, the highest frequency that he or she can detect tends to decrease. Human speech frequencies are in the range of 500Hz to 4000 Hz. This is significant since hearing loss in this range will interfere with conversational speech. The portions of the ear that detect frequencies between 3000 and 4000 Hz are the earliest to be affected by exposure to noise.

The objectives of this research is to establish baseline data for subsequent use in the development of appropriate engineering control for the noise problem

II. METHODOLOGY

a. Noise Source

A four-stroke, variable valve timing with intelligence (VVT-i) 1500 cubic centimeters (cm^3) gasoline engine was used for this study (Plate 1). This engine is classified under category M in ISO 5130:2007(E) Section 3.2 i.e. power driven vehicle having at least four wheels and used for the carriage of passengers. It was mounted on a frame structure and installed with all the necessary controls to enable monitoring of test parameters including the engine speed in revolutions per minute. Rotational speed of the engine was determined directly from the revolution counter attached to the engine.

Plate 1: A 1500cc VVT-i gasoline engine noise source

b. Instrumentation for acoustical measurement

A Cirrus CRA 263 Series type 1 integrating sound level meter(Serial Number B22748FE; Certificate Number BS/MET/15/3/4/60; Calibration Date 2015/09/08) fitted with a wind shieldconforming to BS EN 61672was used to sample noise levels.

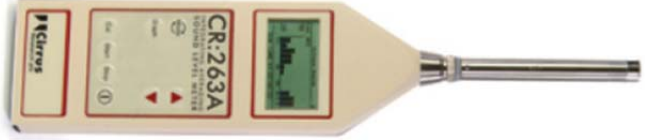

Plate 2: An Integrating Sound Level Meter

The instrument (Plate 2) is a set of Octave Band Filters that allows measurement of frequency content of noise sources. The instrument automatically sweeps through the frequency bands from 31 Hz to 16kHz, followed by a dB(A) L_{eq}, a dB(C) L_{eq} and then a dB(Z) L_{eq} measurement. All frequency band measurements are made as L_{eq} measurements and the Octave Band Filters are automatically weighted with the dB(Z) frequency weighting.

This sweep takes 2 seconds per band, with a total of 26 seconds for a complete sweep. When the sweep is completed, the instrument starts the next sweep, with the L_{eq} for each measurement band being added to the previous value. At the end of the measurement when the stop button is pressed, the instrument calculates and displays the cumulative L_{eq} for each filter band.

At the beginning and at the end of every measurement session, the entire measuring system was calibrated and the configuration for calibration done in accordance with the manufacturer's instruction using a Class 1 sound calibrator in accordance with IEC 60942.

c. Test site

A suitable test site was identified in a level open area away from large reflecting surfaces within a three meter radius from the microphone location and any point of the test engine.The ground was partly covered with grass, though this did not have significant effects on sound reflection since the height of the lowest reference point was about 0.5m.

d. Meteorological conditions

Tests were carried out under metrological conditions without rain and 85% cloud cover. Wind speeds were less than 5 metres per second (m^{-s}). Humidity of 74%, atmospheric pressure of 1013.2mBar, and ambient temperature of $22^{O}C$ were also registered.

e. Background noise level

Readings on the measuring instrument produced by ambient noise and wind was established to ensure that it was at least 10 decibels (dB) below the A-weighted sound pressure level to be measured. The background noise level measured was 39.2 dB(A). A suitable windshield was fitted over the microphone to take care of any possible reflections.

f. Test procedure

i. Positioning and preparation of the engine

The vehicle transmission was set in the "Parking" position, with the engine assembly and supporting auxiliaries including the cooling fan that have automatic actuating mechanisms operating as designed. Before each series of measurements, the engine was brought to its normal operating temperature, as specified by the manufacturer.

ii. Microphone position

The microphone was located at a distance of 0.5m ± 0.01m from the reference point of the exhaust pipe defined in Fig. 1. and at an angle of 45 degrees ± 5 degrees to the vertical plane (Fig. 2) containing the flow axis of the pipe termination. The microphone was maintained at the height of the reference point, but not less than 0.2m from the ground surface. The reference axis of the microphone was maintained in a plane parallel to the ground surface and directed towards the reference point on the exhaust outlet.

iii. Noise measurements were taken for different engine speeds in steps of 500 revolutions per minute (rpm)from 1000 to 4500 rpm first with the exhaust system attached, and later with the exhaust removed.

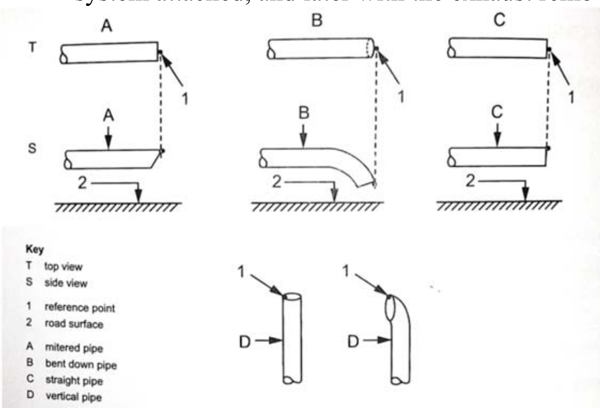

Fig. 1: Location of Reference Points

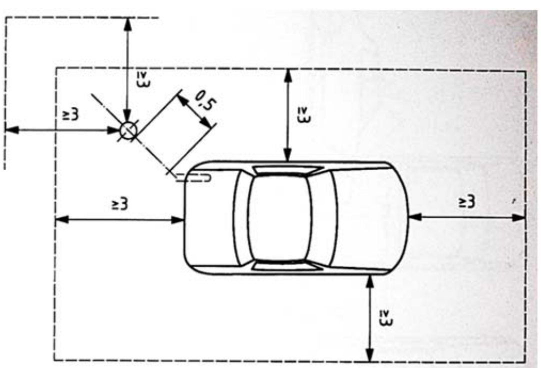

Fig.2: Location of Microphone relative to reference point

This experimental setup was done in accordance with guidelines contained in ISO 5130:2007(E) [6] and illustrated on Plates 3 and 4.

Plate 3: Noise sampling with Exhaust Piping in place

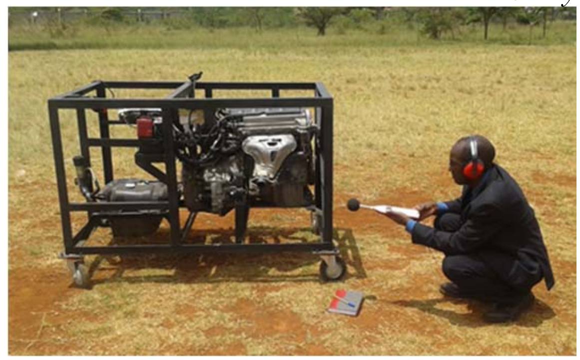

Plate 4: Noise sampling with Exhaust Piping removed

III. RESULTS AND DISCUSSIONS

A VVT-i engine test rig was fabricated and assembled as shown on Plate 1 and used as a source of noise, parameters of control of which were to be identified and studied. The rig was made such that it was possible to remove the exhaust system and replace with other configurations for the purposes of data collection.

There was a clear distinction in the frequency distribution pattern for noise emitted with and without the silencer. Engine exhaust noise varied significantly with increase in engine speed for both cases.

At lower engine speeds (≤ 2500 rpm), the average noise profile acquired an exponentially decaying trendwhile for higher engine speeds (≥2500rpm) results indicated a spike in average noise levels at 125 Hz centre frequency before decaying thereafter – observations being made with the silencer in place. This spike illustrated in Fig. 3 showed that majority of the exhaust noise at higher engine speeds occurred at low frequency of 125 Hz, which was within the Low Frequency range of 20 – 200Hz.

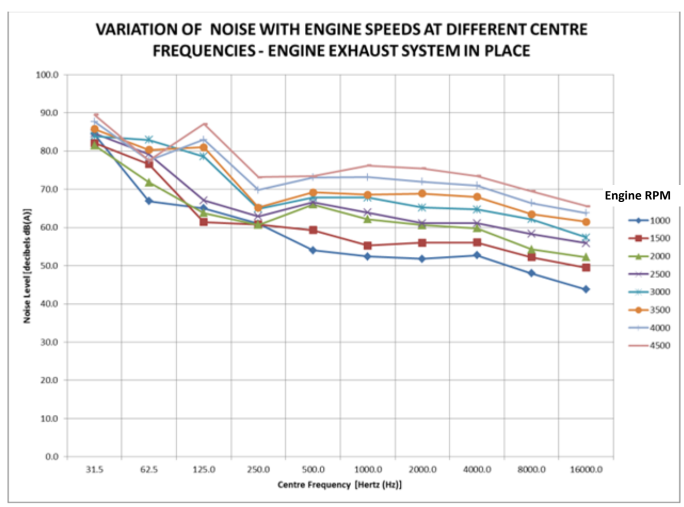

Fig.3: Frequency profile of engine noise with silencer

Noise spectrum for arrangement without the silencer tended to sharply increase from 31.5 to 125 Hz and then gradually decrease at higher frequencies. The most significant change was observed at 1000rpm engine speed, with the lowest noise level occurring at 4000Hz. Higher engine speeds tended to give a uniform decrease in noise level, possibly because the wavelength of sound at higher frequencies becomes shorter.

Unsilenced engine exhaust noise was found to be broadband with the highest levels occurring at lower frequencies.

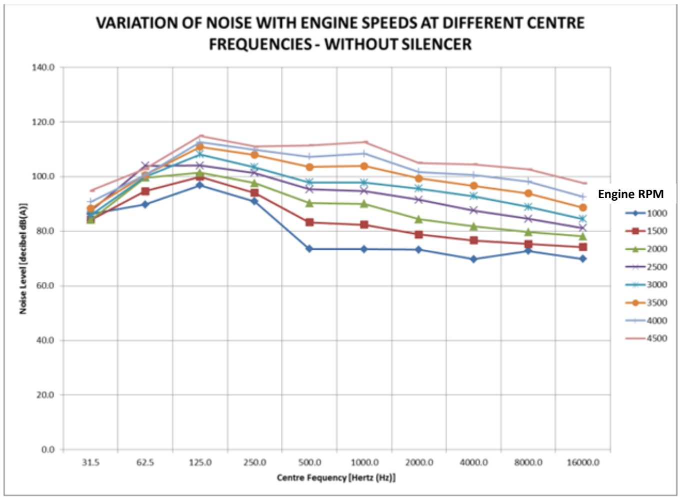

Fig. 3: Frequency profile of engine noise without silencer

For both arrangements with and without the exhaust silencer system installed the values of the average noise levels for the frequency components increases by between 6% and 50% with increase in engine speed.

The noise level for the arrangement with the exhaust system the peak average noise level was 84.9 dB(A) at frequency of 31.5 Hz while that without the exhaust system the peak average noise level was 106.1 dB(A) at 125 Hz.

The former was just about the action limit while the latter was beyond the recommended action level of 85dB(A), both determined at a background noise level of 39.2 dB(A).

IV. CONCLUSION AND RECOMMENDATION

i) Conclusion

A clear distinction in the frequency distribution pattern for noise emitted with and without silencing was observed. The noise levels from the tested engine were found to be higher than the recommended. This will mostly affect young people with normal hearing, who can hear frequencies between approximately 20 hertz (Hz) and 20,000 Hz. There is need to have more effective noise reduction at engine exhaust.

ii) Recommendation

The frequency distribution pattern obtained can be used to inform decisions for the control of noise for various applications, since each of the frequency levels have a corresponding sound wave length that can be modified to control noise.

More study can be done for engines with other capacities in order to obtain a more comprehensive data for noise management produced from engines

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