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Comparative Studies between Reduction of Discrete Frequency Ranges and Radiated Sound Levels (A Case Study of 50 Kva Diesel Engine Cooling Fan)

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Abstract- **Successful efforts in reducing traditional engine noise sources such as the exhaust and intake have heightened the need to device measures to reduce noise produced by engine cooling fan.**

This research work focuses on measuring, analysing and predicting the reduction of discrete frequencies and radiated sound levels from a range of Perkins (50 KVA – 200 KVA) diesel engine cooling fan.

The broadband aerodynamic noise generated by the turbulent flow, discrete tones at the blade passing frequencies and mechanical noise due to mounting, bearing, balancing etc. are the dominant source of noise of the prototype fans.

The digital sound level meter (SLM), frequency analyzer, AC electric motor and Perkins fans were the materials used in carrying out the measurement. The SLM was of the range 30 dB – 130 dB accurate within plus or minus 1.5 dB. This meter was calibrated both before and after measurements. The meter was held 1 m away from the source and 1.2 m above the ground. The axis of maximum sensitivity of the microphone was directed towards the noise source away from extraneous signals. The A-weighted network was used for all sound pressure level (SPL) measurements. The spectrum analyzer was also calibrated to obtain precise results.

A 1hp Tianjin Sida Single-phase AC asynchronous electric motor with fixed speed of 1440 rpm was used to drive the prototype fans for SPL measurements. The radiated sound levels were measured without contributions from engine noise sources. This enabled obtaining of accurate data on the fan noise.

SPL versus frequency of cooling fan was measured within the audio and narrow band ranges using the calibrated TrueRTA spectrum analyzer.

The sound power level (SWL) and sound intensity levels (SIL) of the fans were calculated using the measured SPL values.

Results from the spectrum analyzer were exported to a software program MATLAB where coding, interpolation, extrapolation and analysis of results were done.

The background noise levels (BNL) was between 38.55 dB to 42.36 dB while the noise produced by the motor system (with no load) was 40.89 dB to 44.87 dB. It was observed that the unbanded fans used for 50 KVA generator set had maximum SPL peak value of 84 dB at fundamental blade passing frequency (BPF).

In order to reduce the sound radiated at the blade passing frequency (BPF), the baseline fan was banded with a light-flexible-plastic material. The band was found to effectively reduce the radiated sound levels (BPF tone) for the 50 KVA fan.

11.3 dB SPL reduction was achieved by applying the flexible band on the fan used for the 50 KVA generator set.

Almost all blade rate tone levels were reduced, therefore increasing the acoustical performance of the fans, although slightly affecting its aerodynamic performance. These adverse effect can be mitigated by increasing the size of the radiator.

Keywords: Radiated Sound Level, Discrete Tones, Broadband Aerodynamic Noise, Blade Passing Frequency, Discrete Frequencies.

1. INTRODUCTION

1.1 General Introduction

Noise is generated via many medium, and it can be defined as an unwanted sound. However this definition is subjective in the sense that what one person calls noise might be harmony to the other and therefore has no scientific content. Hence noise can be defined scientifically as a spurious voltage of random nature with little or no periodicity.

Sound on the other hand is generated by objects that vibrates and reaches the ear of the listener as waves in the air or other sound propagating media. Sound can therefore be described as variation of pressure wave in the region near the ear. When the variation in the pressure wave near the ear reaches a very high amplitude, at these point sound can be referred to as noise.

The dynamic range the ear can hear is wide, so the decibel (dB) scale was devised as the de-facto standard to express sound levels. The decibel scale is mostly logarithmic because of its wide range of coverage. In other words, the entire range of human hearing, ranging from (0dB – 140dB) can be described using the logarithmic scale.

There are two dB scales: A and L.

- The dB (L) unit is referred to as a linear scale that expresses a range of audio frequencies as having equal value. The human hear however, does not interpret all sound frequencies as having equal loudness. The human ear is very sensitive to frequencies within the narrow band range (300 Hz - 4 KHz), and not very sensitive to frequencies below 300 Hz and frequencies above 4 KHz.

- The "A-weighting filter," can be described as an approximation of loudness level, it reflects accurately the exact sound pressure levels the ear perceives. It can also be referred to as the dB (A) scale, which was recommended officially as the sound level regulator descriptor.

The reasons for high level of occupational noise in developing countries is the absence of noise regulatory laws.

In Nigeria for instance, frequent interruption of electricity supply, have compelled many individuals, corporate bodies, industries etc. to embark on massive purchase of large generating plants for the generation of electricity. These generators in addition to generating electricity, generates noise.

Sources of noise and vibration in electrical machines are mostly, aero-dynamic, mechanical and electromagnetic in nature. Hence the sources of noise from various components of these machines, must be understood properly.

Specifically, a good understanding of the dominant noise sources, in order of importance is very desirable, so that suitable modifications can be carried-out. In complicated machines however, such information are often difficult to obtain and many noise reduction attempts are based on inadequate data, and in most cases, very expensive.

In most noise problems, it is best practice to use more than one identification method, to ensure greater accuracy in the identification procedure [18].

The cooling fans bring in air from outside to the system for the purposes of ventilation, it blows out dust, from an industrial environment, and it is also used cooling or drying operation, etc.

Successful efforts to reduce known engine noise sources such as the exhaust and intake have giving rise for the need to device measures to reduce noise produced by engine cooling fan. Series of acoustical test performed showed that the cooling fans are the dominant noise sources owing to either the kinds of blades or its arrangement, to the rotational speed of fan and turbulence. A larger distribution of the fan noise was found to depend mainly on the fan shape.

Our concern is on the discrete frequencies and sound radiated from the cooling fan of an industrial diesel engine generator. It is observed under real-world operating conditions, that almost every cooling fan, encounters spatially non-uniform, time averaged inflow and turbulence. Therefore, the sound radiation resulting from the fan blades' is the principal focus of this thesis. More specifically, the objective of this thesis is to measure, analyze and predict the reduction of discrete frequencies and radiated sound levels from a range of Perkins (50 – 200 KVA) diesel engine cooling fan.

2. MATERIALS AND METHODS

2.1 Materials

This work was carried out using the under-listed materials;

2.*1.1 Digital Sound Level Meter*

Mastech Precision Sound Level Meter model MS6700 was used to carry-out sound level measurements. They sound level meter was calibrated. The range of this sound level meter was 30 dB to 130 dB with a frequency response of 31 Hz to 8 kHz. The accuracy of the meter was within ± 1.5 dB. It has two equivalent weighted sound pressure level A and C.

2.1.2 Frequency Analyzer

A spectrum analyzer was used for the measurement of the magnitude of the signal input against frequency taken within the maximum frequency range of the meter. This meter is used to measure the SPL of the spectrum of the sound.

The TrueRTA audio analyzer, is a software based instrument which measures real time data and it is used for evaluating and testing signals within the audio range. This instrument is used with a personal computer that has basic sound input and output capability. The TrueRTA instrument includes a digital sound level meter, a high-resolution real time analyzer, a signal generator with low distortion, a crest factor meter and a dual trace oscilloscope.

This analyzer allows for accurately measuring of the SPL versus frequency, spurious phase noise and modulation analysis of communication signals without sacrificing dynamic range and speed.

The real time spectrum instrument is by far affordable compared to other test instruments and is able to offer an outstanding audio input and output performance.

The spectrum analyzer display has frequency on its horizontal axis and SPL on the vertical axis.

2.1.3 Electric Motor (AC)

A Tianjin Sida single-phase electric motor model YBB3341EA was used to carry out these research. The motor has frequency of 50/60Hz and a voltage of 220/230V. The electric motor is a single phase 1hp asynchronous AC supply motor with 1440 rpm. The motor enclosure is made up of a housing, a front shield, a middle end-shield, and rear end-shield. The end-shield comprises of casting aluminum alloy and a steel housing. A stator, a rotor and a shaft are installed in it. A fan and fan hood are also fixed at the rear end-shield. A cable gland with a sealing is provided. The motor adopts continual running duty (S1) and the insulating is class F.

2.1.4 Diesel Engine Cooling Fan

A 50 KVA diesel engine generator cooling fan was used to carry-out this research. The unbanded and banded 50 KVA cooling fan were properly fitted to the Electric motor at different intervals to determine its discrete frequencies and radiated sound levels.

A flange was fabricated that fits properly to the center of the hub of each of the prototype fans. These was necessary to ensure proper alignment of the fan to the motor system as well as prevent wobbling of the fan.

2.1.5 Computer Application Software (MATLAB)

A computer system with matrix laboratory application software installed (MATLAB) was used for statistical analysis.

***2.2** Method*

2.2.1 Sound Level Meter

A sound level meter is an instrument which responds to sound at a range of frequency and levels comparable to the human ear. The audible range is from 20 Hz to 20 kHz. The sound level meter measures and display acoustical pressure variations in a systematic manner.

A precision sound level meter measures sound pressure level (SPL), and consist of a microphone, a set of frequency response (weighting) network and an indicating meter with logarithmic scale. The sound signal is converted to an identical electrical signal by a high quality microphone, since the signal is usually small, it must be amplified before it can be read on a meter. After the first amplification, the signal may pass through a weighting network. After additional amplification, the signal level will be relatively high for the functionality of the meter after the root mean square (RMS) value has been determined in the root mean square detector.

Root mean square value relates directly to the sound signal energy and it is very important in sound measurement. Peak rectifier can be included to determine the maximum value of impulse signal and a circuit can be used to hold the maximum meter values, or the root mean square value measured with the characteristic of the impulse.

2.2.2 Meter Calibration

Prior to taking sound level measurements, SPL was turned-on for a few minutes to reach room temperature and provision was made to calibrate the meter to obtain accurate results. These meter was calibrated using a portable calibrator placed directly over the microphone.

The Meter was calibrated before sound level measurement was made. A reference source of sound (accurate within plus or minus 1.5 dB) was used both before and after measurements. This was done to monitor the meters performance.

The TrueRTA real-time spectrum analyzer was also calibrated using the SPL value obtained from the calibrated sound level meter. Calibration of the spectrum analyzer enabled accurate measurement of SPL values against frequencies within the full range of the instrument.

2.2.3 Meter Response

Two meter response are employed in practice, “fast” whose fluctuating meter response is reacts fast enabling the measurement of not rapidly fluctuating levels of noise and “slow” whose fluctuating meter response reacts sluggishly. The slow meter response helps average out the fluctuations of the meter fluctuations which would be difficult to read. The slow response characteristics was used in all measurements taken in this work since the fast response is likely to give an erratic reading.

2.2.4 Meter Positioning

The Sound Level Meter was held at about 1 meter away from the noise source and between 0.7 and 1.2 meters above the floor with the microphone connected directly to the instrument. For this measurements, the microphone was placed away from interfering objects and surfaces as these might influence the measured sound levels. It is observed, that sound pressure level measured 0.5 m from a plane reflecting wall can be higher by 3 dB than in the case where there is no wall or in the case where the source of sound was near the ground, the sound radiated near the ground will be reflected by the ground and radiated upward into the hemisphere.

The axis of maximum sensitivity of the microphone was directed towards the noise source(s) and away from extraneous signals, not under consideration, such as wind on the microphone and electrical interference.

2.2.5 Background Noise

The background noise level was determined by simply taking multiple readings of the levels of noise. One was taken when the source of noise was “on” and the other taken when the source of noise was “off”. This method helped determine the extent to which the background noise was either affecting or not affecting the total noise level measured when the source of noise was “on”.

2.2.6 Weighting Network

Four weighting network exist in sound level meter. These are basically A, B, C, and D weighting networks. The network adjust the reading of the instrument to fall within the limits specified by the American Standard Institute.

The A-weighting network is specified for use in estimating the probability of hearing damage in industries. In addition, A-weighting can be correlated with annoyance caused by other noise related sources.

The B-weighting however permits the instrument to have response approximating the 70-phon equal loudness contour.

The C-network is always employed to reduce the high and low frequency response of the sound measuring instrument so that it will not respond easily to sound outside audible range of frequencies. It permits the instruments to have a response approximating the 40-phon equal loudness contour.

The D-network has been standardized for aircraft noise measurement.

For the purpose of this research the A- weighting network was used to carry out all measurements on sound pressure level.

2.2.7 Octave Filter Set

An Octave filter was used for this work, in combination with sound level meter. The octave filter satisfied the requirement of IEC recommendation 225, DIN 45651 and ANSI SLH – 1960 class H. The total frequency coverage is 20 Hz to 20 kHz.

It is thus possible to obtain filter characteristics that match individual noise requirement for the A-weighting curve.

2.2.8 Frequency Analyzer

A plot of SPL against frequency was provided using the TrueRTA audio spectrum analyzing software.

The horizontal and vertical axis of the analyzer is usually calibrated in frequency and SPL respectively. The higher frequency is always laid horizontally at the right hand side of the display while the SPL is always laid vertically. Logarithmic or linear scale can be used depending on the range of frequency. For measurements taken within the audio range, the logarithmic scale is usually selected because it allows a wide range of signal on the display.

A value of 10 dB per division was used on the vertical axis. This scale was calibrated and therefore it was possible to display absolute sound levels as well as allowing comparison between two signal levels. Similarly when the linear scale is employed, this is usually calibrated to enable absolute measurements to be made using the meter. For the purpose of this measurement, both the logarithmic and linear scales were employed. In this way discrete frequency tones were monitored to discover whether they adhere to their required levels.

The first step towards getting TrueRTA audio spectrum analyzer was to install the TrueRTA software in the computer. It was necessary to use a computer with built in microphone (input/output capability). By right clicking on Volume on the computer task bar and selecting “Open Volume mixer” the volume of the microphone was adjusted to its maximum value. Clicking on the recording device option, integrated microphone array was selected.

After the setup was completed, the TrueRTA application software was launched. Under the Spectrum Analyzer menu, the RTA Mode was selected and the resolution set to (1 Octave, 1/3 Octave etc.). To begin real time analysis the start audio I/O analysis option on the menu bar was clicked, while to stop analysis the stop option was selected.

2.2.9 Electric Motor (AC)

A 1hp Tianjin Sida single-phase AC asynchronous electric motor model YBB3341EA which has fixed speed of 1440 and frequency 50/60Hz was used to drive the diesel engine cooling fan. The fan was that used for 50 KVA diesel engine set. The electric motor consist basically of two parts, the stators (a solid block of metal, which contains cylindrical holes, closed by plates at the end) and rotors (a metal cylinder of smaller diameter) with bearing at each ends, joined mechanically to the stator. Both rotors and stators, carry coil windings. A sinusoidal electromotive force is generated, when the coil of an electro dynamo is turned at constant angular velocity in a uniform magnetic field.

The stator, which is a permanent magnet and the rotor which has a pointed edge sits in the middle of the motor, and is subject to the stator’s magnetic field. The rotor moves as a result of attraction between its poles and the poles in the stator repels it.

The motor was used to drive the radiator cooling fan and was properly mounted using a constructed basement made of a solid metal piece and was firmly rooted to the ground to avoid vibration or noise that might be generated when carrying out the sound level measurement. This was to ensure accurate reporting of results.

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2.2.10 *Diesel Engine Cooling Fan*

The fan considered is a radial backward curved fan used for 50 KVA diesel engine generator set. The propeller fan had seven plastic blades, each separated at an angle of 51.4^0. The radius of the fan was 23.5 cm. In normal operations the propeller fan is driven by the engine crankshaft via a belt and runs at a fixed speed of 1500 rpm. However for this study the fan was powered by an AC electric motor with a fixed speed of 1440 rpm and was attached directly to the motor's output with no gears or belts. The motor rotor was hidden in the center of the fan's hub. In this configuration the motor drives the fan mounted on it to cool the radiator of the generator.

A flange was fabricated that fits perfectly on the center hub of the fan, these increased the weight of the fan and allowed proper alignment with the motors’ shaft. The fabrication was perfectly done to avoid wobbling of the fan and possible generation of high frequency noise.

Practice shows that the cooling fans generate noise from the rapid flow of air around blades and obstacles, and sometimes from the motor. In this research, arrangements were made to band the tip of each of the blades using a light and flexible plastic material. These was to determine if the banded fan could reduce the radiated sound levels or blade passing frequency (BPF) tones at the blade tip clearance.

3. RESULTS AND DISCUSSION

3.1 *Results*

The result of the various noise levels obtained in dB(A) are as shown in tables and figures below.

Table 1, shows interpolated results within the audio spectrum. The fields contain the following data; sound pressure level (SPL), sound power level (SWL), and sound intensity level (SIL) of a 50 KVA generator cooling fan (unbanded) while Table 2, depicts data on SPL, SWL, and SIL within the audio spectrum of the same cooling fan (banded). The background noise levels (BNL) and noise of the AC electric motor system were also taken into consideration before undertaking sound level measurements. All measurement were taken 1 meter away from the source and the axis of maximum sensitivity of the microphone directed towards the fan inlet.

FIG.s 1, 2 and 3 show comparison of SPL, SWL and SIL of the unbanded fan with the banded fan in the audio range (20 Hz – 20 KHz).

Tables 3 and 4 show data on SPL, SWL and SIL of 50 KVA unbanded and banded fan within the narrow band range (0 – 2 KHz), with each noise level taken at the various blade passing frequency (BPF). The data obtained was extrapolated from the audio spectrum using the matrix laboratory application software MATLAB.

FIG.s 4, 5 and 6 show comparison of SPL, SWL and SIL of the unbanded fan with the banded fan in the narrow band range (0 – 2 KHz). The plot of noise levels (SPL, SWL and SIL) were done against the harmonics (F_p) of the BPF.

TABLE 1

Interpolated audio Spectrum SPL, SWL, SIL, BNL and motor system noise (With no Load) of 50 KVA Fan (Unbanded)

Unbanded fan (50 KVA) Freq. (Hz)	SPL (dBA)	SWL (dBA)	SIL (dBA)	Ambient Noise (dBA)	Motor System Noise (with no load) (dBA)
15.6	85.81	96.81	65.63	34.32	35.34
31.2	87.52	98.52	67.36	39.39	36.52
62.5	87.27	98.27	67.09	41.73	44.87
125	85.28	96.28	65.10	43.52	38.29
250	81.50	92.50	61.32	25.07	35.40
500	79.31	90.31	59.13	20.49	25.84
1000	70.58	81.58	50.40	22.47	31.46
2000	65.57	76.57	45.41	16.68	24.44
4000	56.35	67.35	36.17	8.72	16.81
8000	43.32	54.32	23.14	4.83	13.43
16000	23.64	34.64	3.46	-10.39	-3.22

TABLE 2

Interpolated audio Spectrum SPL, SWL, SIL, BNL and motor system noise (With no Load) of 50 KVA Fan (Banded)

Banded fan (50 KVA) Freq. (Hz)	SPL (dBA)	SWL (dBA)	SIL (dBA)	Ambient Noise (dBA)	Motor System Noise (with no load) (dBA)
15.6	77.87	88.87	57.69	34.32	35.34
31.2	81.20	92.20	61.02	39.39	36.52
62.5	81.03	92.03	60.85	41.73	44.87
125	74.56	85.56	54.38	43.52	38.29
250	74.25	85.25	54.07	25.07	35.40
500	75.90	86.90	55.72	20.49	25.84
1000	66.54	77.54	46.38	22.47	31.46
2000	63.56	74.56	43.38	16.68	24.44
4000	53.95	64.95	33.77	8.72	16.81
8000	38.21	49.21	18.03	4.83	13.43
16000	21.14	32.14	0.96	-10.39	-3.22

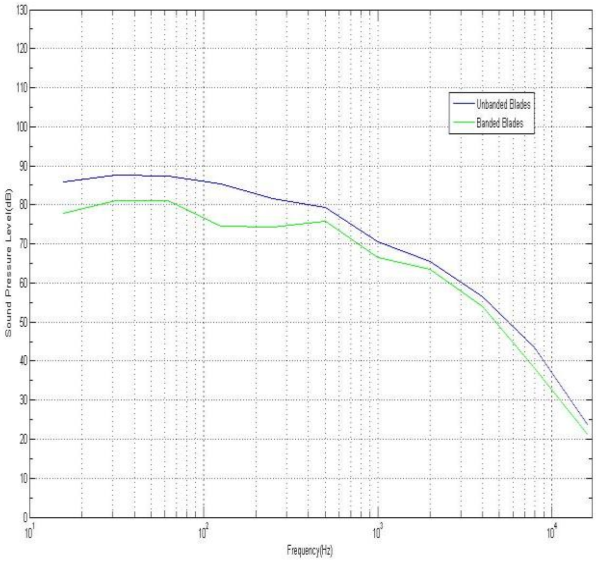

FIG. 1: Comparison between SPL of unbanded and banded 50 KVA generator cooling within the audio spectrum.

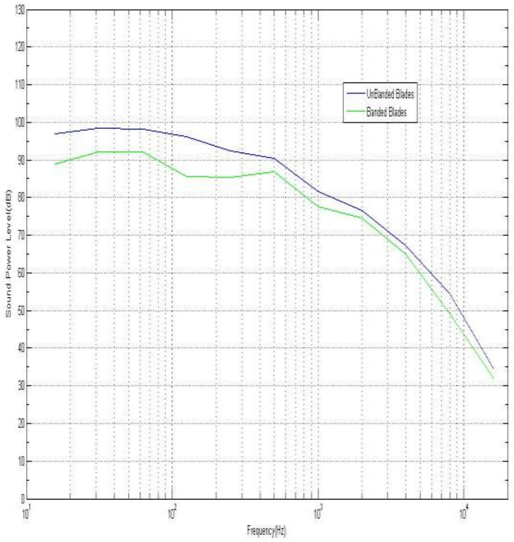

FIG. 2: Comparison between SWL of unbanded and banded 50 KVA generator cooling within the audio spectrum.

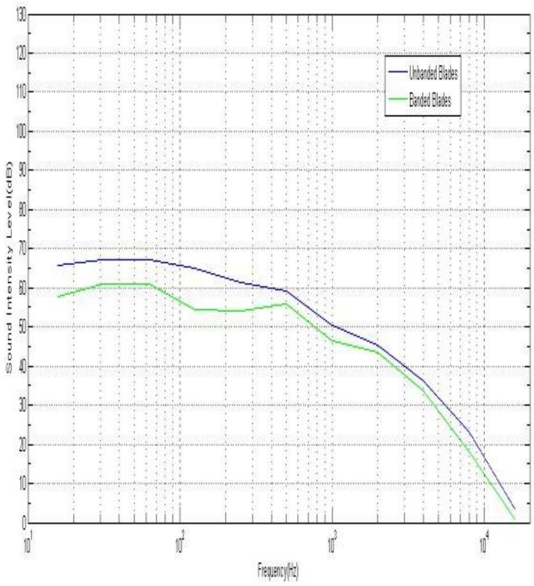

FIG. 3: Comparison between SIL of unbanded and banded 50 KVA generator cooling within the audio spectrum.

TABLE 3

Extrapolated narrow band SPL, SWL, SIL, BNL and motor system noise (With no Load) of 50 KVA Fan (Unbanded)

F_p Unbanded Fan (50 KVA)		SPL (dBA)		SWL (dBA)	SIL (dBA)	Ambient Noise (dBA)	Motor System Noise (with no load) (dBA)
1 F_p		84		95	63.8	40.2	28.0
2 F_p		80		91	59.8	23.8	31.5
3 F_p		79		90	58.8	20.7	26.0
4 F_p		77		88	56.8	21.6	28.1
5 F_p		74		85	53.8	22.0	30.1
6 F_p		70		81	49.8	21.0	31.8
7 F_p		68		79	47.8	21.5	30.0
8F_p		67		78	46.8	20.0	28.4
9F_p		66		77	45.8	19.8	28.0
10 F_p		66		77	45.8	17.0	26.5

TABLE 4:

Extrapolated narrow band SPL, SWL, SIL, BNL and motor system noise (With no Load) of 50 KVA Fan (Banded)

p Banded fan (50 KVA)		SPL (dBA)	SWL (dBA)		SIL (dBA)	Ambient Noise (dBA)	Motor System Noise(with no load) (dBA)
1 F_p		72.67	83.67		52.4	40.2	28.0
2 F_p		76.00	87.00		55.8	23.8	31.5
3 F_p		75.86	86.86		55.6	20.7	26.0
4 F_p		73.27	84.27		53.0	21.6	28.1
5 F_p		69.73	80.73		49.5	22.0	30.1
6 F_p		66.41	77.41		46.2	21.0	31.8
7 F_p		64.21	75.21		44.0	21.5	30.0
8F_p		63.07	74.07		42.8	20.0	28.4
9F_p		62.71	73.71		42.5	19.8	28.0
10 F_p		62.86	73.86		42.6	17.0	26.5

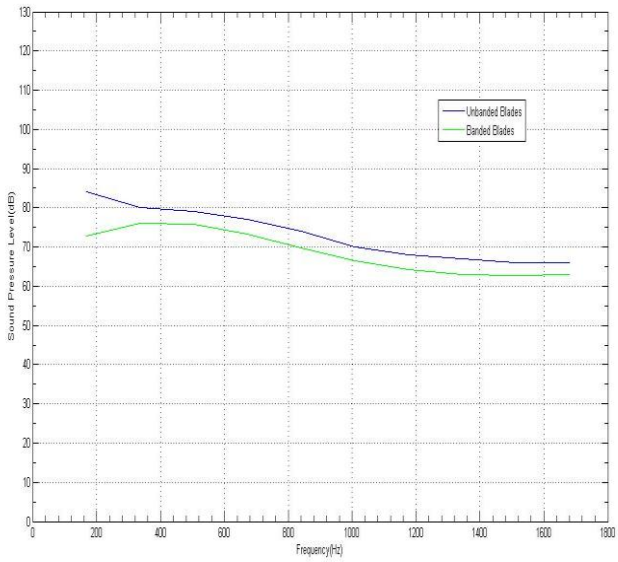

FIG. 4: Comparison between SPL of unbanded and banded 50 KVA generator cooling fan within the narrow band range.

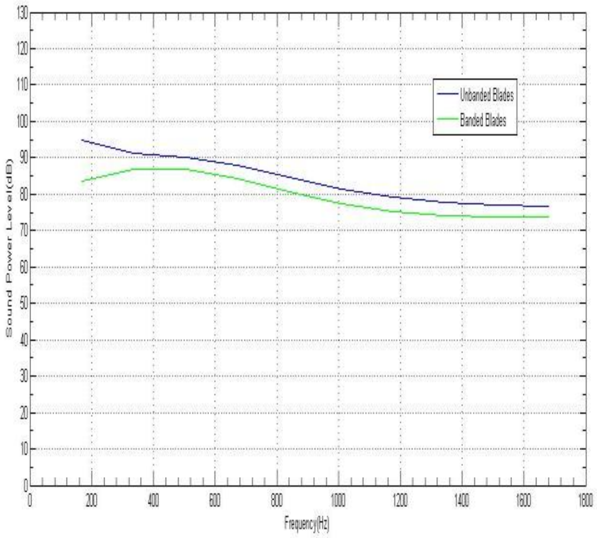

FIG. 5: Comparison between SWL of unbanded and banded 50 KVA generator cooling fan within the narrow band range.

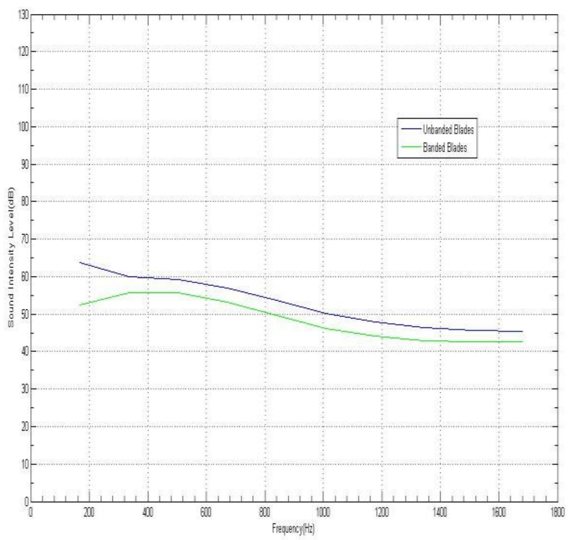

FIG. 6: Comparison between SIL of unbanded and banded 50 KVA generator cooling fan within the narrow band range.

3.2 Discussion

This fan model had seven (7) backward curved plastic blades evenly spaced. Each blade was 0.52mm thick and 14.5 cm long. The fan together with the flange and bolts weighed 1.9kg, and the radius of the circumference of the blades was 23.5cm. The perfectly fabricated flange was suitably fastened to the center of the fan's hub using 11 inch bolts. The fan was then properly affixed to the motor shaft.

The radiated sound level was measured for the prototype fan at a fixed speed of 1440 rpm and the results are as shown in tables 1, 2, 3 and 4 as well as the plots in FIG.s 1, 2, 3, 14, 5 and 6 which displays the comparison between the unbanded and banded fan.

These results were obtained by taking sound level measurement at distances 1 meter away from the fan inlet and 1.2 meter above the ground with the microphone connected directly to the instrument away from interfering objects and surfaces capable of influencing the measured sound levels. Broad band analysis was used to obtain noise spectra in the range 20 Hz – 20 KHz (known as audio band) while narrow band analysis to obtain noise spectra in the range 0 Hz – 2 KHz.

The background noise level of the source was taken into account as well as the noise produced by the motor system (with no load). From experimental results it was observed that the effect of motor system noise, background noise level was insignificant compared to the overall SPL. These results indicate that the blades of the cooling fan is the main contributor to the aero acoustic characteristics of the flow field.

Tables 1 and 3 shows interpolated and extrapolated results obtained from sound level measurements taken within the audio spectrum and narrow band ranges respectively using an unbanded fan. It is observed from table 1, that SPL had a peak value of 87.52 dB at frequency of 31.2 Hz and from table 3, SPL had a peak value of 84 dB at the fundamental BPF (168Hz). Interpolation and extrapolation of results was done using the application software MATLAB.

The SWL and SIL displayed in tables 1 and 3 were calculated using the equations below;

$$SWL\ (dB) = SPL + 20 \times Log(r) + 11\ dB \qquad (1)$$

Where **r** is the distance in meters of the receiving point from the source of sound.

The sound intensity level was also calculated using the formula below;

$$(SIL)\ (dB) = 10 \times Log_{10}(I/I_o) \qquad (2)$$

Where I_o is the threshold of intensity given as 10^{-12} w/m^2 and I, the intensity of sound given as $P^2/\rho c$, the characteristics impedance of sound in air given by 415 Rayls and P is the pressure of sound which can be obtained using the formula:

$$SPL\ (dB) = 20Log\left(\frac{P_{rms}}{P_{ref}}\right) \qquad (3)$$

It was observed that the SWL and SIL taken within the audio and narrow band range also had their peaks at 31.2Hz and fundamental BPF (168) respectively.

From the foregoing experimentation, it was observed that, from the SPL, the SWL of the system increases by 11 dB while the SIL decreases by 20.2 dB, hence a need therefore arises to generate a calibrated equation in which the SIL can be obtained directly.

$$SIL\ (dB) = SPL + 20log_{10}(r) - 20.2\ dB \qquad (4)$$

These formulated equation to the best of my knowledge is novel.

Tables 2 and 4 show results of sound level measurement performed within the audio spectrum and narrow band ranges using a banded 50 KVA cooling fan.

The banded fan was fabricated by mounting a light-flexible-plastic-cylindrical band to the original propeller fan. The flange attached to the hub balanced the fan. The banded blades reduces the flow rate of the fan.

The SPL of the fan as shown in FIG. 1, had a maximum value of 81.2 dB at 31.2 Hz, SWL in FIG. 2, had maximum value of 92.2 dB and SIL in FIG. 3, had maximum value of 61.02 dB at the same frequency within the audio spectrum while for the narrow band range as shown in figure 4, 5 and 6, a maximum SPL value of 76.0 dB was observed at the second harmonic ($2F_P$) and these result also influenced they SWL and SIL obtained.

From experimental results, it is observed that the banded fan reduces the radiated sound levels (BPF tones) by up to 11.3 dB in level. The maximum reduction was observed at the fundamental BPF (168) while several level of reduction were also observed at other frequencies.

The banded fan is found to control the tip clearance noise and offers an improvement in the acoustical performance of the system.

4. SUMMARY AND CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

4.1 Summary and Conclusions

The primary objective of this research was to predict the reduction of discrete-frequencies and radiated sound levels from the diesel engine cooling fan used on a 50KVA generator. This goal was achieved through indebt understanding of the dominant fan noise physics and generator noise reduction methods. SPL, SWL and SIL spectrum was used to represent the radiated sound levels. All sound measurements were taken in line with recommended measurement standards.

The fluatuating force and turbulence on the fan blades' tip are the dominant acoustic source of the investigated subsonic fan noise.

The fan made of plastic blades with a constant radius of curvature were examined. The feasibility of a banded fan was also examined. A banded fan was fabricated by binding a cylindrical band to tips of the propeller fan. The design resulted in significant tonal noise reductions, but unfortunately, the fan had a slight reduction in the aerodynamic performance.

The observation above shows that, the unbanded fan had a better aerodynamic performance than the banded fan while the banded fan had a better acoustical performance than the unbanded fan.

From experimental results, it was confirmed that banded fan used for the 50 KVA generator reduced the radiated sound levels (BPF tones) by up to 11.3 dB. The maximum reduction was observed at the fundamental BPF (168) while several level of reduction were also observed at other frequencies. This observations are in good agreement with the work done by (longhouse, 1978).

This reduction is significant because it was achieved at minimal cost, using methods which could be adopted by any skilled maintenance trades person.

The second objective of this research was to recommend possible fan noise control strategies that may lead to a reduction in the cooling system noise. Discrete-frequency tones at the harmonics of the BPF were successfully reduced, although slightly affecting the aerodynamic performance of the fan. These detrimental effect can be mitigated by increasing the size of the engine radiator.

Banded fan was found to control the tip clearance noise and offered an improvement in the acoustical performance of the system. It was observed that the variation between this work and similar experiments is between 2 dB to 5 dB. This error observed may be largely due to varying environmental factor, noise from electric motor, type and accuracy of sound level meter and spectrum analyzer, vibration due to unbalanced rotating masses etc.

The banded fan is therefore recommended for providing significant BPF tone level reduction.

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