Empirical Study of Noise Characteristics of Typical Centrifugal Fan Based on Special Quantities Using Sound Intensity Based Method

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Abstract

Introduction: In order to identify best treatments at noisy sources, experts must employ special noise quantities. Sound pressure close to sources is usually dependent upon the environments, therefore it is not suitable for determining noise emission of sources. This paper aims to empirically study noise emission characteristics of a typical centrifugal fan located in different layouts based on special quantities using sound intensity based method.

Methods and Materials: In situ determination of noise emission of the fan included sound power, sound intensity and sound pressure was performed using BSWA VA-Lab software according to standard methods in different locations.

Results: The results showed that sound power spectrum of the fan is relatively high and contains predominant diceret tone in 250 Hz equal to 83.5 dB. The sound powers of the fan were similar in different locations. However, notable difference exists in the sound intensities of the fan in different layouts which are near to the values calculated by theorical equation. In order to determine the optimum locations for studied centrifugal fan, sound intensity could also accurately describe the effects of adjacent surfaces on the centrifugal fan noise than sound pressure.

Conclusions: This study empirically showed that sound power of fan is independent of the environments and can help us evaluate noise controls at fan elements. The results confirmed that the sound power and the intensity were excellent quantities for characterizing noisy sources as centrifugal fan compared with the sound pressure. *These results presented details of a scientific approach for analyzing noise in workrooms.*

Keywords: Noise characteristics, sound intensity method, centrifugal fan.

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Introduction

Noise control at sources is principally considered to be the best method for reducing noise effectively. In order to effectively control noise, it is *highly* important to *identify* noise emission characteristics of machines *(1,2)*. *Sound* pressure level *close* to noise sources is *usually dependent up*on the *environments,* therefore this quantity is not suitable for determining actual noise emission of source. However, *sound* power quantity which is used in order to *describe* the noise emitted by sources is independent of the acoustic *surroundings and its value is reproducible for any test conditions* and is *therefore,* an *excellent indicator* for comparing *noise* characteristics of sources *(3)*. *Sound* power values are used in order to *facilitate* machinery noise reduction and to determine whether *the operation of* a *machine is consistent* with noise legislations *(4)*. *Sound* power can be generally calculated through sound intensity measurements according to standard methods (4). Sound intensity is influenced by the acoustic impedance of the medium and is an indicator of the emission of power through the medium. In this regards, sound intensity measurement facilitates the determination of sound power without imposing the need for subsequent corrections (5,6). ISO 9614-X describes the in situ methods for determining the sound power level of noise source employing sound intensity measurements (7). In this regards, ISO 9614-1 describes measurement at discrete points, ISO 9614-2 describes measurement by scanning, and ISO 9614-3 describe precision method for measurement by scanning (7). Nominal sound power of different productions is frequently determined in known acoustic room such as anechoic room (8). However, determination of actual sound power of sources must be performed in situ, in real situations of installation and application.

On the other hands, if a spherical source is positioned near the floor or a wall, a few sounds will be reflected from the surface and will not be emitted in all directions. This event is obtained into account in the expression by the directivity factors (Q). The directivity index (DI) is linked to the directivity factor (Q) as follows (3):

$$DI = 10\log Q \quad (dB) \qquad (1)$$

Therefore, if the source is located at the junction of a floor and wall, the directivity factor in this case is Q = 4 and the directivity index is six dB. In fact, in this location, the sound intensity level (or sound pressure level, if free field exists around the source) of source increases to 3 dB compared with the directivity factor which equals to 2, theorically. This issue must be considered in order to reduce the effect of adjacent surfaces on the noise emission of sources such as industrial machineries in workrooms.

In order to design workplaces and select layouts for machines, occupational health experts need to know about the noise emission of sources in different layouts in actual conditions of applications. In this regards, if willing to empirically determine the noise emission of sources in actual situations of workrooms in further than one position, the intensity method facilitates this purpose, as well (9).

Despite the fact that sound intensity method is a specific in situ technique for determining noise characteristics of sources, empirical studies on accuracy and applicability of the method for characterizing actual industrial noisy sources are limited.

This paper aims to empirically describe the noise characteristics of a typical noisy centrifugal fan based on special quantities in different layouts in an enclosed environment using sound intensity based method.

Methods and Materials

Test object characteristics

A typical centrifugal fan with electric power of 0.25 KW and 1800 rpm which produced fully steady state noise emission was investigated as the test object. Its dimensions were approximately 0.4 m length, 0.4m width and 0.5 m height.

Test environment

The acoustic lab defined as a typical indoor room was selected as test environment. Dimensions of this lab were 14m length, 7m width and 3.3m height with a volume of approximately 325 m^3 and such typical construction material i.e. ceramic tile has been used in the floor and wall and gypsum has been used in the roof surfaces.

It should be noted that based on ISO 9614-3, sound intensity method can be employed for determining noise sourcese characteristics in any acoustic conditions of workrooms. Therefore, any closed rooms can be selected as test environment.

Procedure of sound intensity measurement

Sound intensity is defined as the time-averaged rate of energy flow per unit area. In reality, sound intensity vector corresponds to the time-averaged outcome of the instantaneous pressure and the corresponding instantaneous particle velocity, as follows (10):

$$I = p(t) \times u(t) \qquad (2)$$

where p(t) is the instantaneous pressure, u(t) is the particle velocity and the time averaging is indicated with a bar.

The pressure gradient is approximated as the pressure at one microphone p_B subtracted from the pressure at the other microphone p_A, divided by the separation distance Δr between the two microphones. Therefore, the finite difference equation for the particle velocity u, in the direction r, at a point midway between the two microphones is formulated as below:

$$U = -\frac{1}{\rho \times \Delta r} \int (p_B - p_A) dt$$

(3)

A sound intensity probe usually includes two phases matched microphones mounted along with a definite pre-set space apart. By comparing the differences between the two microphones, it is feasible to compute both the sound pressure and particle velocity between the two microphones. A sound intensity probe measures the sound intensity traveling aligned to the probe. Hence, the probe must be held completely perpendicular to the measurement surface of noise source to avoid an error (10).

In this study, sound intensity was determined based on precision method for measurement through scanning described by ISO 9614-3 (7). In this way, a hypothetical surface that fully encloses the fan located on the floor and separates it into segments is first assigned. The average sound intensity for each segment is subsequently obtained by carrying out two special scans, so that the second scan is orthogonal to the first as shown in Fig 1(A). Conventional scanning speeds over the measurement surface were considered roughly 0.5 m/s. Moreover, sound pressure level of the fan was also measured using VA-Lab. In this regards, average SPL of a minimum of five measurement points positioned on the center of parallelepiped surfaces as shown in Fig 1 (B) at regularly spaced positions was calculated.

In order to determine the effects of fan locations on its noise charateristics, the assigned measurement surface of the fan located on the floor (Q=2) was a parallelepiped with a total surface area of 5 m^2 as shown in Fig 2(A). A frame box, with dimensions Z=1m ,Y= 1m , and X= 1m was used to characterize a parallelepiped surface with five segments surrounding the fan. The assigned measurement surface was considered a parallelepiped with a total

surface area of 2.5 m^2 where the fan was located at the junction of a floor and wall (Q=4) as shown in Fig 2(B). Two locations were considered for the studied fan in the empty space of the lab as shown in Fig 2. Schematic of two locations were considered for the studied fan in the empty space of the lab as shown in Fig 3. The procedure for handling sound intensity probe during measurement is also shown in these figures.
It should be noted that for analyzing the fan noise quantities in the two directivity factors compared with the theorical DI value, types of materials in the adjacent surfaces were considered to be the same. In this way, material type in the floor (Q=2) adjacent surfaces of floor and wall (Q=4) was ceramic tiles. Finally, the sound power level L_w is calculated as below (7):

$$L_W(dB) = \overline{L}_I + 10\log\left[\frac{S}{S_0}\right]$$

(4)

Where $\overline{L}_I$ is the spatial-averaged sound intensity level (dB), S is the total surface area (m²) and S_0 the reference surface area of 1 m².
VA-Lab designed by BSWA Technology Co. Ltd was employed for measuring the sound intensity with the intensity probe SI 502. Based on calibration data, response phase mismatch of analyzer was lower than 0.3° for frequency between 45 Hz to 500 Hz and lower than 1° for 500 Hz to 2500 Hz and lower than 2° for 2500 Hz to 6000 Hz. In order to reduce the phase mismatch error, a 12 mm spacer was used in the intensity probe to achieve approximation error lower than 1dB according to ISO 9614-3 (7). Frequency analysis of noise source was performed in one octave band and one third octave band in the frequency range of 125 Hz to 4000 Hz .

Results

Noise emission characteristics of the fan were measured in the two locations based on standard methods. Comparison between the sound pressure levels and sound intensity levels of the fan located on the floor of the test environment on the hypothetical parallelepiped surface (the same distance from fan) is illustrated in Fig 4. The results showed that sound pressure levels of fan were totally upper than sound intensity levels in one octave band.
Noise emission of the fan in two locations (Q=2, Q=4) was measured based on the sound intensity level. Comparison of sound intensity levels of the fan in octave band in the two locations is illustrated in Fig 5. The result showed that considerable difference exists in the total and the spectrum of sound intensity levels of the fan based on two the directivity factors.
As shown in Fig 5, empirical results showed that the sound intensity level of the fan located at the junction surface of a floor and wall (Q=4) increased approximately to 2.5 dB than the sound intensity level fan located at the floor (Q=2) which was quite similar to the increased theorical DI value (equal to 3 dB).
Sound power levels of the fan in octave band in the two directivity factors was calculated using equation (4) as shown in Fig 6. The result showed that no considerable difference exists based on the two directivity factors. The result showed that the dominant frequency of fan noise emission was near 250 Hz in one octave band in which sound power level was 83.5 dB.

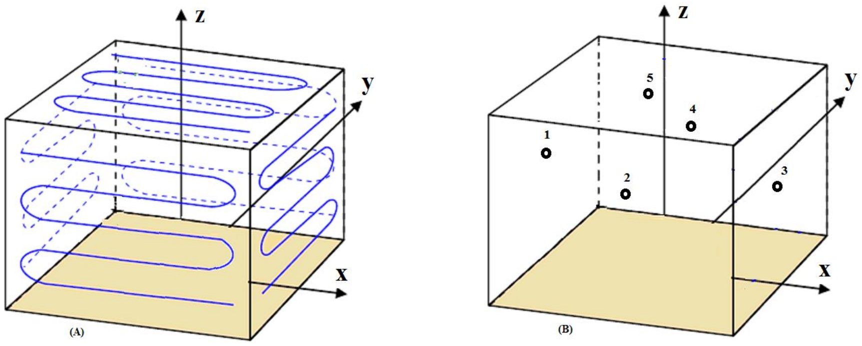

Fig 1: Measuring sound intensity by scanning(A) and measuring sound pressure onthe centers ofparallelepipedsurfaces(B)

Fig 2: The centrifugal fan as test object located in two locations in theacousticlab along with theassignedsurface

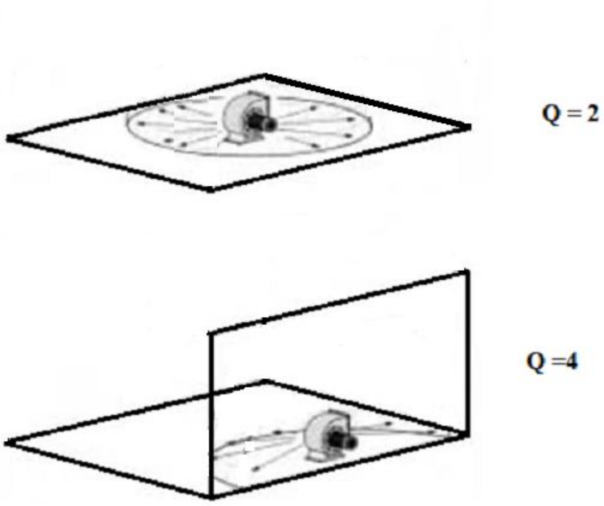

Fig 3: Schematic of two locations of fan in the acoustic lab along with the directivityfactors(Q)

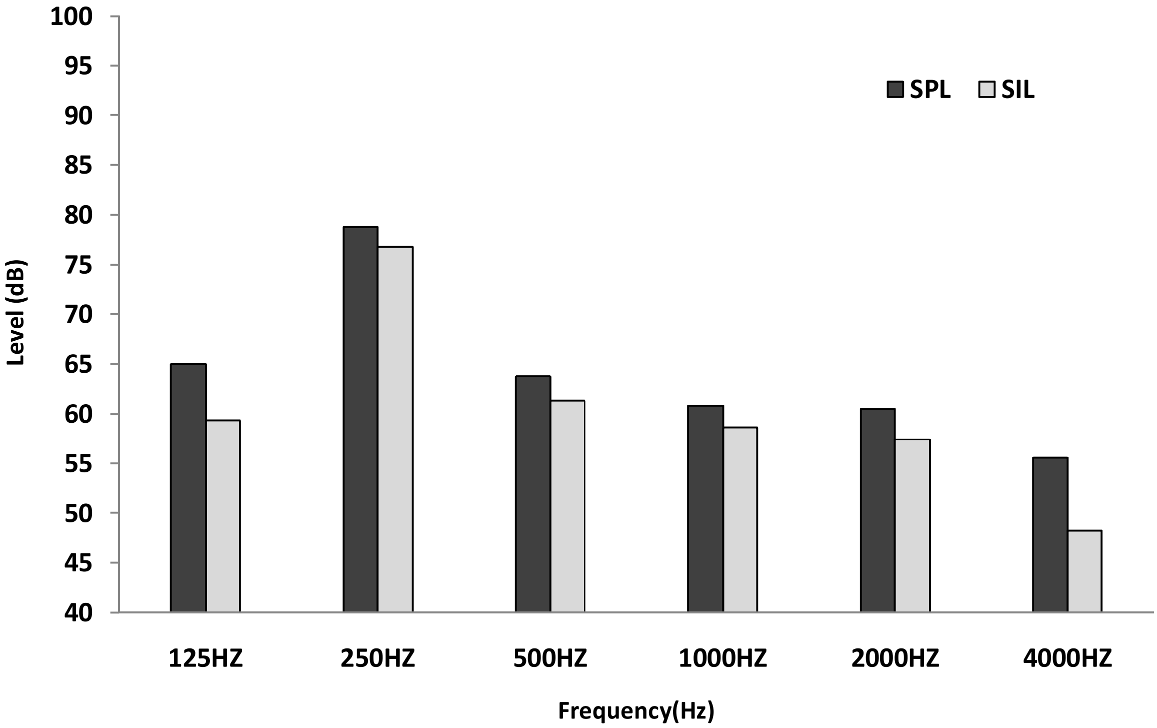

Fig 4: Comparison between the SPL (Linear) and the SIL (linear) of the fan located on the floor of test environment

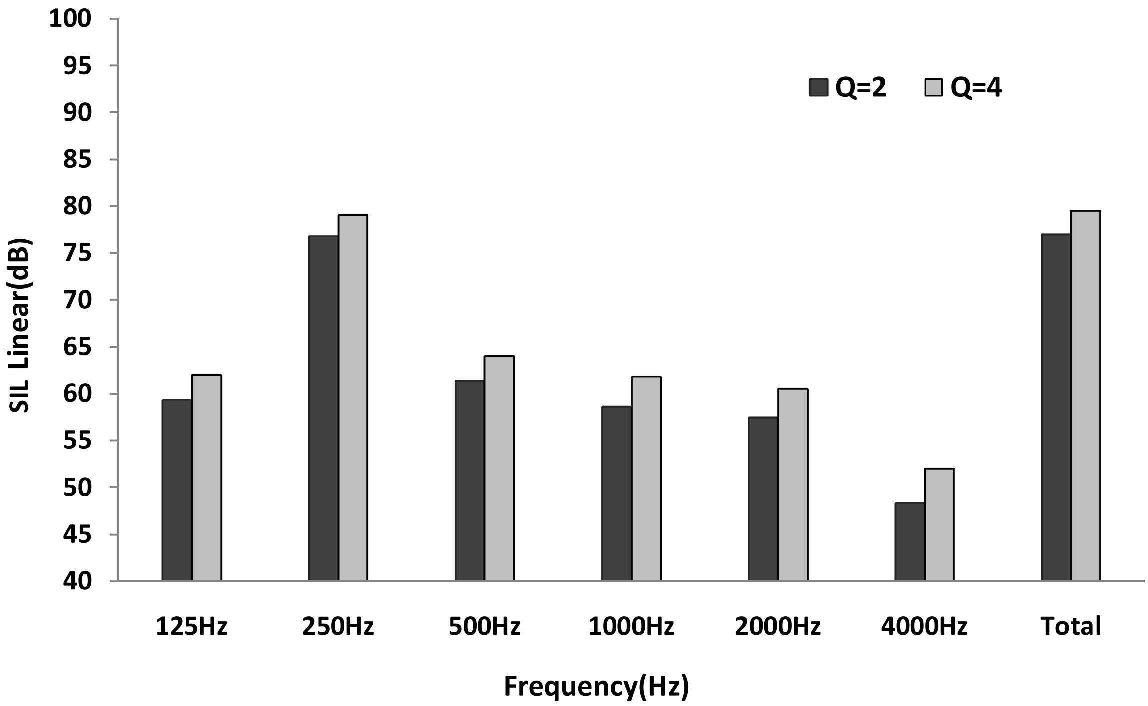

Fig 5: Sound intensity levels of fan in one octave band in two directivity factors

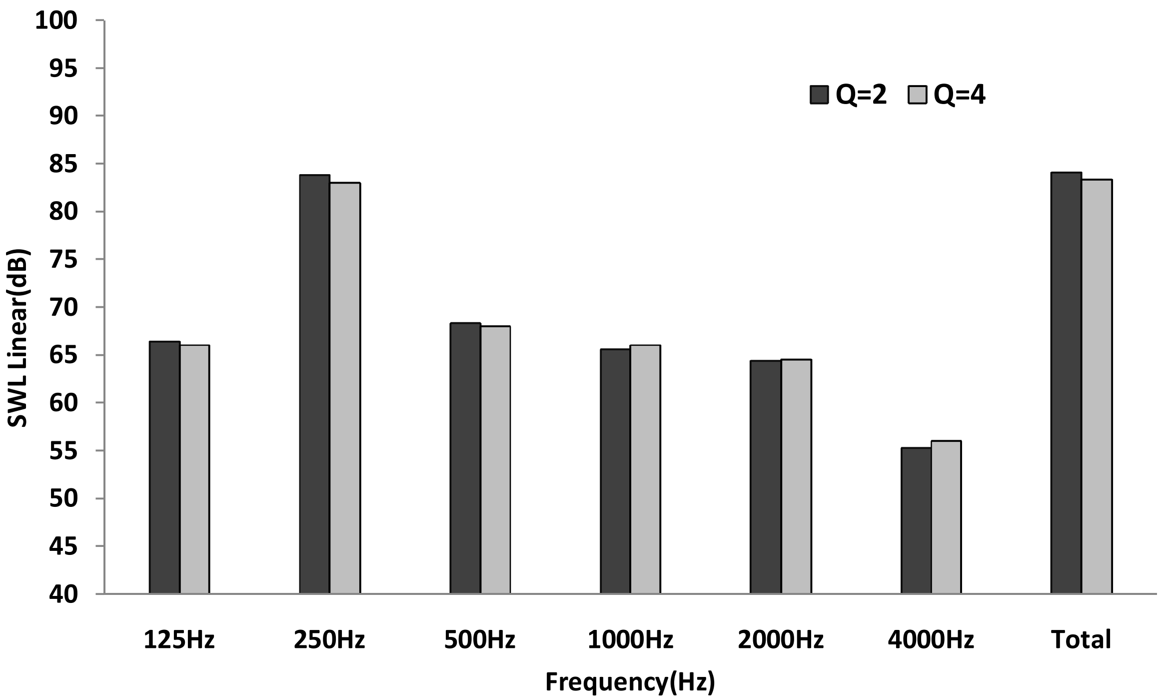

Fig 6: Sound power levels of fan in octave band in two directivity factors

Discussion

The noise emission of the typical centrifugal fan is determined by sound intensity based methods. The result confirmed that SWL spectrum of the fan is relatively high and contains predominant diceret tone. Similar results were found by Nicolinia and Filipponi about fan noise spectrum (11). With regard to measurement uncertainty recommended by standard methods and empirical nature of study, it can be said that there were no significant differences between the results of sound power level in two different locations. Therefore, the results confirmed that the adjacent surfaces of noise sources cannot affect theirs sound power.

However, sound power of sources is affected by installation conditions included type of foundation and vibration control and also maintenance actions as lubricating, replacing the old parts with new ones. Consequently, noise controls at sources elements reduce sound power (a measure of sound energy per time) (12).

On the other hands, the result confirmed that the sound intensity level of the fan is noticeably different based on two directivity factors. Therefore, adjacent surfaces could increase noise emission of sources in form of sound intensity level and consequently, sound pressure level in enclosed environments. In this regards, for reducing the effect of reflecting surfaces on the noise emission of sources such as industrial machineries, industrial experts must position sources on the best locations in workrooms. Using materials with suitable sound absorption can relatively improve the acoustic performance of adjacent surfaces of sources resulting in reduction of noise emission.

Moreover, for evaluating the generality of the theorical DI values, sound intensity levels were measured in the two directivity factors. However, due to similarity between materials of adjacent surfaces of sources (ceramic tile) and also accuracy of measurements, increased empirical DI value (2.5 dB) was approximately near the increased theorical DI value (3 dB).

The results showed that sound pressure levels of fan were totally upper than sound intensity levels in the test environment. In industrial workrooms as semi reverberant rooms, due to acoustic effect of room surfaces which include opposite walls and even roof, SPL values were noticeably different compared with the SIL values (13). However, under fully free field conditions such as outdoor space, the SPL values were completely equal to SIL value in the specific distance from the noise source (3).

In situ measurement of sound power of any sources located in different layouts using portable equipment was the main advantage of sound intensity based method (14).

Due to the easy arrangement and rapid calculations of the sound power level of noise sources located in any acoustic environments, sound intensity method is considered to be a quite speedy direct method and can become the preferred technique for experts in order to describe and compare noise emission of sources and also to evaluate noise engineering controls (15). However, some common problems with the sound intensity methods include higher demands of skills required by operators, need for accurate equipments, and being more expensive than a basic sound level meter (16,17).

In this regards, it seems that the special noise quantities should be considered for analyzing acoustic conditions and noisy sources in industrial workrooms as a scientific approach in future empirical studies.

Conclusions

Due to the fact that sound pressure is dependent upon environments, it cannot be a suitable parameter for determining the share of different acoustic characteristics in noise emission of sources. This study empirically confirmed that sound power of source is independent of any acoustic conditions of workroom and can help evaluate noise controls at fan elements. Moreover, the results confirmed that the sound power and sound intensity are excellent quantities for characterizing noisy sources compared with sound pressure. On the other hand, sound intensity method can be considered to be a more accurate In situ technique for professionals in order to characterize the noise emission of sources. Finally, this study presented the detail of a scientific approach for analyzing noise in workrooms.

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