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ORIGINAL ARTICLE

Empirical Comparison of the In Situ Methods for Determining Sound Power of Typical Embroidery Machine Located in Industrial Workroom

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ABSTRACT

Sound power is considered as an excellent measure for evaluating the efficiency of noise controls as well as for comparing noise sources in workrooms. This parameter can be determined by sound pressure or intensity based methods in real conditions of workrooms. This paper aims empirically to compare these in situ methods in relation to a typical industrial machine located in workroom in terms of accuracy, applicability. Determination of sound power of a typical model of noisy embroidery machine located in enclosed workroom was performed in the interested frequency range of 125 Hz to 4000 Hz. Field measurement of sound power was conducted using the BSWA sound analyzer according to ISO 9614 and ISO 3746, respectively. The results showed SWL spectrum of the source was relatively high with flat noise spectrum. Operation speed was one of the most important features which could influence the noise of embroidery machine. In regard to uncertainty values, the sound power spectra, obtained using the two methods, showed acceptable agreement from the viewpoint of applicability. The higher value for pressure methods can be due to fluctuations in background noise and method limitations. Direct measurement of reverberation time compared with approximate method could improve the accuracy of the pressure method. Hence, pressure method can be employed by occupational health experts as an alternative to intensity method. Due to its direct and more accurate measurements, intensity method is considered to be a more preferred technique in order to describe any noise sources and to evaluate noise controls at sources.

Keywords: *Sound power, In situ methods, Embroidery machine, Industrial workroom*

INTRODUCTION

Noise pollution control is one of the principal purposes of occupational hygiene programs in workplaces. Due to the growing demand for quietness and acoustic comfort, more attention is being paid to noise control of various sources in workplaces. The main goal of most noise control measures is to reduce the noise level at the worker's location [1, 2]. Noise control at sources is generally considered to be the best solution for reducing noise pollution in workrooms. Components of machines may be adjusted to make an acceptable reduction in noise emission [3]. In order to

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effectively control the noise, it is highly important to identify the sound power of the machines [4].

Sound power quantity 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 sources. Therefore, sound power measurement is employed in order to facilitate machinery noise reduction and to determine whether the operation of a machine is consistent with noise legislations and standards [5]. The increasing interest in determining the sound power level (SWL) is not restricted to noise control professionals. Companies also characterize sound power levels in products documentations [6]. SWL which can be calculated through sound pressure or sound intensity measurements is preferred over SPL, since the SWL is consistent, comparable, and more practical for noise control measures. The selection between pressure and intensity measurements is based on numerous factors such as acoustic nature of environment, ease of application, access to measurement instruments, and speed of experiment [7].

A number of approved methods for the determination of sound power are based on measuring sound pressure close to the noise sources. The choice of these methods is dependent on the acceptable accuracy, the move ability of the source, the presence of other noise sources and the location of measurement [8]. In real situation of workrooms, sound power measurements can be carried out in situ, utilizing the ISO 3746 [9].

However, sound pressure is affected by the acoustic surroundings and is in fact the summation of the sound sources and the acoustic environment. In contrast, 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 regard, sound intensity measurement is now regularly applied to the determination of the sound power of machinery and other sources of noise in any acoustic environment. ISO 9614-X describes the methods for determining the SWL of noise source employing sound intensity measurements [10].

Despite these methods are specific in situ techniques for determining sound power level, scientific literature or even field reports about accuracy, applicability of the mentioned methods in real conditions of industrial equipments located in workrooms are limited.

On the other hand, occupational health experts based on access level to noise measurement instruments need to practical in situ method for determining sound power of any noise sources in workrooms. This paper aims empirically to describe the features of sound intensity based method and compare them, in terms of accuracy, applicability, and speedy with those of traditional sound pressure based method in order to determine the sound power of a typical industrial machine with fully steady state noise emission in unknown acoustic environments as well as typical workrooms.

MATERIALS AND METHODS

Sound intensity based method

Sound power was determined based on the scan method described by ISO 9614-3. In this procedure a surface that fully encloses the machine under test 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. Conventional scanning speeds over the measurement surface were considered roughly 0.5 m/s. Finally, the sound power level Lw is calculated as follow [11].

$$L_W(dB) = \overline{L}_I + 10\log\left[\frac{S}{S_0}\right] \quad (1)$$

Where $\overline{L_I}$ is the spatial-averaged sound intensity level (dB), S is the total surface area (m²) and S0 the reference surface area of 1 m².

Making accurate sound intensity measurements require information about the limitations of the sound intensity analyzer. In order to approve that measurements are truthful and repeatable, two principal indicators i.e. pressure - intensity (PI) index, pressure-residual intensity (PRI) index were assigned. PI index which is the level difference between sound pressure and sound intensity, determines whether measurement has been performed in free or reverberant fields. On the other hand, PRI index shows the phase match as well as accuracy of the intensity probe [12, 13]. According to ISO 9614-3, the value of the A weighted SWL is estimated with confidence interval of 95% to be in the maximum range of ±1.5 dB about the measured value [11].

Characterizing sound intensity analyzer

VA-Lab designed by BSWA Technology Co. Ltd employed for measuring the sound intensity with the intensity probe SI 502. It complies with IEC 1043 class 2 standards. Based on calibration data, response phase mismatch of analyzer was lower than 0.3º for frequency between 45 Hz to 500 Hz and lower than 1º for 500 Hz to 2500 Hz and lower than 2º for 2500 Hz to 6000 Hz. The SPL of each microphone of sound intensity probe was checked with a calibrator and was accurate within ±0.5 dB. In order to reduce the phase mismatch error, a 12 mm spacer was used in the intensity probe, giving a useful range of 160 Hz to 5000 Hz for the intensity scan to achieve approximation error lower than 1dB according to ISO 9614-3.

Sound pressure based method

In order to use sound pressure based method according to ISO 3746, environments are assigned to be

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Fig 1. The studied computerized embroidery machine during operation in the industrial workroom

semi-reverberant room. SPL was measured based on ISO 3746 recommendations using the VA lab sound analyzer. For a source which radiates rather flat noises over the interested frequency band, highest standard deviation of reproducibility according to ISO 3746 is approximately ±3 dB [14].

Surface sound pressure level $\overline{L}_{pf}$ was determined by correcting the value $\overline{L'_p}$ for background noise K_1 and for reflected sound of environment K_2 as follow.

$$\overline{L}_{pf} = \overline{L'_p} - K_1 - K_2 \quad (2)$$

Sound power level L_w was determined as follow.

$$L_W = \overline{L}_{pf} + 10\log\frac{S}{S_0} \quad (dB) \quad (3)$$

S is the area of the measurement surface in m^2, S0 is equal to 1 m^2.

All SPL measurements need to be corrected for background noise, unless the background noise is 10 dB lower than the measured SPL. The correction factor K_1 is calculated as follows [14].

$$K_1 = -10\log\left(1 - 10^{-0.1\Delta L}\right) \; dB \quad (4)$$

$$\Delta L = \overline{L'_p} - \overline{L''_p} \quad (5)$$

where $\overline{L'_p}$ the sound pressure level is averaged over the measurement surface, in decibels, with the source under test in operation; and $\overline{L''_p}$ is the sound pressure level of the background noise averaged over the measurement surface, in decibels.

In the sound pressure method, environment correction factor K_2 can be determined using different methods. The environment correction is an adjustment term for the effect of reflected or absorbed sound at the measured surface SPL. K_2 would be numerically lower than or equal to seven dB. Choice of different methods to determine the environment correction depends on available measuring instruments and existing restrictions. In this study, reverberation time (RT) and approximate method was employed.

Reverberation time method

In reverberation time method, average sound absorption coefficient was determined based on direct measurement of reverberation time of room. In this method, correction value K_2 can be calculated as follow.

$$K_2 = 10\log\left[1 + \left(\frac{C \times RT \times S}{13.816 \times V}\right)\right] \quad (dB) \quad (6)$$

where the C is speed of sound in meter per second, S is the area of the measurement surface in m2, V is volume of room in m3 and RT is reverberation time in second.

In this way, VA-Lab REV module which is developed by BSWA Technology Co. Ltd was employed for measuring reverberation time in one-octave band based on ISO 3382 using interrupted noise method. In this method, decay curves are attained by directly recording the decay of sound pressure level after exciting a room with broadband or band-limited noise. Note that, reverberation time is the time for a 60 dB drop in the sound level after the excitation stops [15].

Approximate method

In approximate method, K_2 was estimated based on approximate value of average sound absorption coefficient for different rooms recommended by ISO 3746. Moreover, the correction value can be calculated as follow.

$$K_2 = 10\log\left[1 + 4\left(S/A\right)\right] \quad (dB) \quad (7)$$

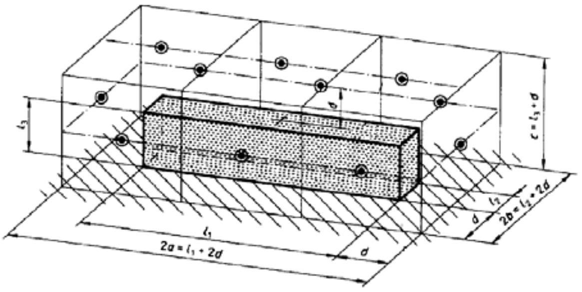

Fig 2. Assigned measurement surface (segments and points) for the embroidery machine
(4d≤l1≤7d, l2≤ d, l3≤2d)

Where A is the equivalent sound absorption area of the room and S is the area of the measurement surface in m2. Note that, the equation (7) is another form of the equation (6) in terms of equivalent sound absorption area.

Characterizing test environments

The noisy process of industrial embroidery in which patterns and designs are imprinted on cloth, is considered to be an important part of the textile industry. Most of modern embroidery processes are controlled by computer and specialized software. The operators in the workrooms plan and monitor the machinery performance, cloth and string characteristics and the patterns. Due to the nature of sewing operations, operators are exposed to noise as a pollutant with some risks of hearing loss. In this regards, in order to effectively control its noise emission, it is highly important to determine the noise characteristics of this machine. Hence, field measurement of sound power level of a typical model of embroidery machine located in enclosed workroom based on mentioned methods was performed in the interested frequency range of 125 Hz to 4000 Hz. The studied embroidery machine during operation in industrial workroom was illustrated in Fig 1. The assigned measurement surface (segments and points) for measuring sound pressure and intensity around the long embroidery machine was a parallelepiped surface based on standard methods according to Fig 2. In sound intensity method, a parallelepiped surface that fully encloses the long embroidery machine under test and separates it in to relevant segments was first assigned. Moreover, in sound pressure method, a minimum of relevant measurement points positioned on the parallelepiped surface at regularly spaced positions was considered. Based on machine dimensions, measurement distance (d) was determined equal to 1 m according to the standard method recommendation as shown in Fig 2.

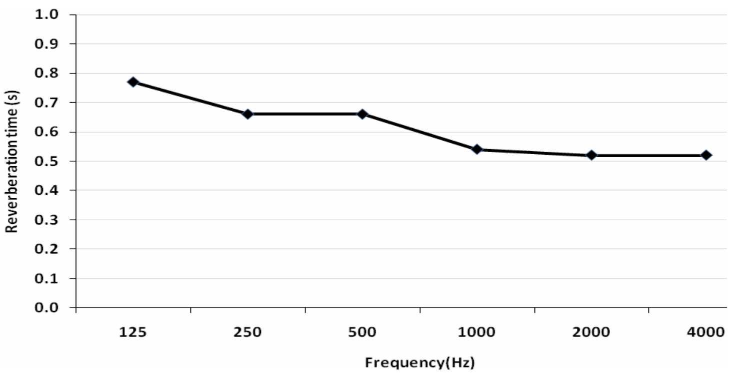

Fig 3. Reverberation time in one octave band in the embroidery workroom

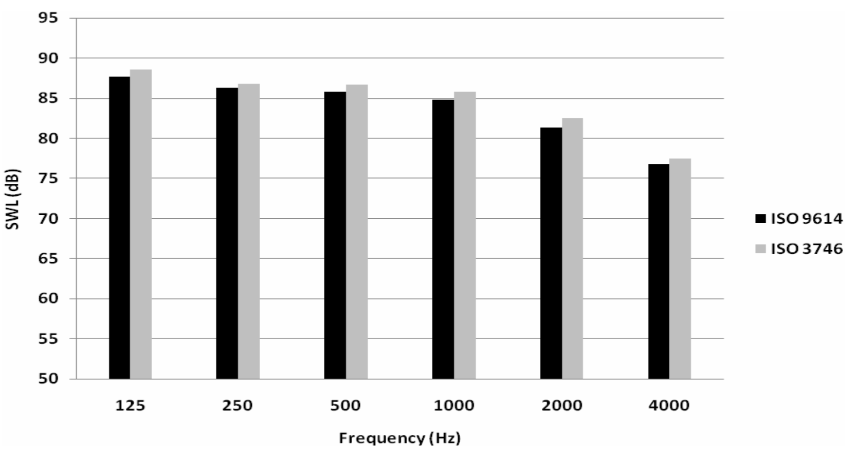

Fig 4. Comparison of the linear SWL of the embroidery machine based on the two methods

RESULTS

Firstly, reverberation time in studied environment was measured using RT instrument. Reverberation time in one octave band in the studied embroidery workroom was presented in Fig 3. The results showed that, reverberation time values in the low frequencies were approximately higher than the medium and high frequencies.

In the next step, for the pressure based method, these values were used to calculate the environment correction factor environments using the equation (6).

Linear sound power spectrum of embroidery machine in normal operation conditions with the operation speed equal to 800 stitches per minute (spm) was estimated based on the sound intensity method (ISO 9614-3) and sound pressure method (ISO 3746) as shown in Fig 4. It was obvious that there was slightly different in sound power spectrum estimated using the two methods. On the other hands, in the approximate method, based on the values recommended by the standard method, the embroidery workroom was considered as nearly empty room with smooth hard walls with average sound absorption coefficient equal to 0.05. In the next step, the environment correction factor calculated for workroom was employed to determine sound power of the embroidery machine based on the sound pressure method using equation (7).

Comparison of linear SWL of the embroidery machine in one octave band based on two different environment correction methods was shown in Fig 5.

The results showed that the sound power level calculated based on approximate method was also slightly different than the sound power level calculated based on reverberation time method over the one octave band. In addition, sound power spectrum of the embroidery machine based on the different operation speeds using the sound intensity method was shown in Fig 6. The results showed that the operation speed of embroidery can influence the sound power of machine. The high speed of needles in striking on the work surface can increase the noise level in workrooms.

DISCUSSION

In order to design machine layout and foundation, industrial engineers need to know the actual SWL of industrial sources in different settings [16]. Using sound intensity, and sound pressure based methods, the sound

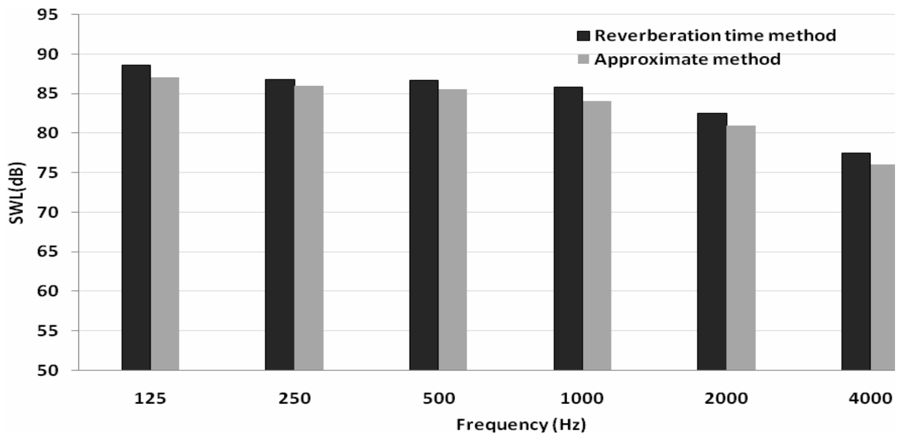

Fig 5. Comparison of linear SWL of the embroidery machine in one octave band based on two different environment correction methods

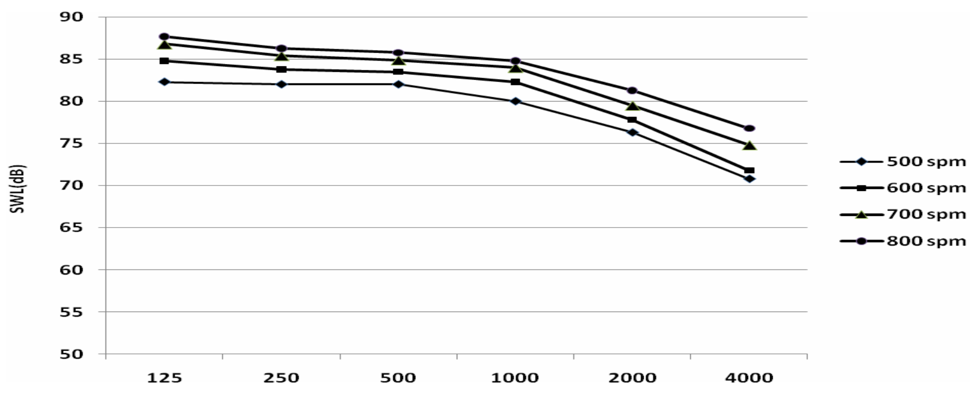

Fig 6. Linear SWL of the embroidery machine based on different opearation speeds

power of typical industrial equipment was determined. The results confirmed that SWL spectrum of the source was relatively high. The embroidery machine has relatively flat noise spectrum over the frequency range of interest. Therefore, noise engineering controls are essential for this type of noisy equipments in order to operate quietly [17]. In order to effectively control the noise at sources, it is highly important to identify the sound power of the machines in different operation conditions. In this regard, the results showed the operation speed of embroidery was one of the most important factors which can influence the sound power of embroidery machine. The high speed of needles (in terms of stitches per minute) in striking on the work surface is effective in increasing the noise emission of machine. Therefore, operators of this type of machines should not increase the needle speeds upper than the recommended values based on instruction manuals. The measurement results did not show pattern of changes in sound power spectrums in terms of different operation speeds. It seems that the range of needles speed changes was not too broad in order to show the pattern of variations in the sound power spectrum.

With regard to measurement uncertainty recommended by two standard methods, it can be said that, there were no significant differences between the results of intensity and pressure methods. However, it was obvious that there were slightly differences in the one octave band between the two methods. The higher value for pressure method was due to fluctuations in background noise of environments and method limitations. The same results were also reported in different studies about in situ methods for sound power determination [18, 9].

It is noted that, knowledge about measurement uncertainty is principally important for experts, particularly when they have to indicate the measurement accuracy. Uncertainty of measurement frequently is influenced by changes in atmospheric condition, indoor's environment, acoustical properties of the reflecting plane, background noise, the type and calibration of instruments, the size and shape of the control surface, sound source location, and integration times [19].

The results demonstrated that the sound intensity method is more practicable and is able to overcome the significant problems of traditional sound pressure method, because it does not need subsequent corrections related to test environments. Moreover, due to the fact that intensity is a vector quantity, a great advantage of using intensity method is that steady external noise sources do not affect the intensity measurement [20, 21]. Note that, sound intensity vector corresponds to the time-averaged outcome of the instantaneous pressure and the corresponding instantaneous particle velocity. This quantity is influenced by the acoustic impedance of the medium and is an indicator of the emission of power through the medium. A sound intensity probe measures the sound intensity traveling aligned to the probe. Hence, the sound intensity probe must be held completely perpendicular to the measurement surface of noise source to avoid an error.

The sound pressure method can not be used in the presence of high levels and fluctuations of background noise caused by sources other than the source under study.

Therefore, the intensity method is a complement to the sound pressure methods and can be used under fewer restricted test conditions [22]. As the number of measurement points of the pressure method is very high and since this requires a long time of measurement, if we want to measure the sound power of a large source, the intensity based method is preferred. However, some common problems with the sound intensity methods are higher demands for the operator's skills, need for accurate equipments, and being more expensive than a basic sound level meter [23]. Moreover, the most significant limitations of this method are frequency limitation due to the pressure approximation gradient settled by the microphone spacing [24]. In pressure based method, one of the simple methods for determining the environment correction is the approximate method. In this way, approximate values of the mean sound absorption coefficient of the room recommended by ISO 3746 were used and therefore, some restrictions of direct method (using RT measurement setup) were removed. However, the results confirmed that we should not expect to achieve very accurate results. In this method, the main cause of error is related to the rough prediction of the effective absorption surface of environments and their furniture. Direct measurement of reverberation time for correcting the acoustic effect of test environment compared with approximate method could improve the accuracy of pressure method. Note that, based on the results, the longer the reverberation time in the low frequency shows the lower sound absorption coefficients of typical materials of room surfaces. However, based on workroom volume, the reverberation time values were lower than the recommended reverberation time for workrooms based on ISO 11690.

Finally, due to the easy arrangement and rapid calculations of the sound power level of noise source located in any acoustic environment, sound intensity method is considered to be a quite speedy direct method and can become the preferred technique for professionals in order to describe and compare noise sources and also to evaluate noise engineering controls.

Conclusions

Accuracy and applicability are two main factors when it comes to selecting the more suitable sound power standard methods according to existing real situations and restrictions of experiment purposes. The sound power spectra empirically obtained using the two methods, showed acceptable agreement from the viewpoint of validity. Direct measurement of reverberation time compared with approximate method could improve the accuracy of the pressure method. Due to its direct and more accurate measurements, intensity method is considered to be a more preferred technique for experts in order to describe noise sources and also to evaluate engineering controls at noise sources. Nevertheless, the sound pressure method along with accurate estimation of environment correction can also be assigned as a practical alternative method.

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