International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:3, No:3, 2009

Estimation of Individual Power of Noise Sources Operating Simultaneously

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Abstract**—**Noise has adverse effect on human health and comfort. Noise not only cause hearing impairment, but it also acts as a causal factor for stress and raising systolic pressure. Additionally it can be a causal factor in work accidents, both by marking hazards and warning signals and by impeding concentration. Industry workers also suffer psychological and physical stress as well as hearing loss due to industrial noise. This paper proposes an approach to enable engineers to point out quantitatively the noisiest source for modification, while multiple machines are operating simultaneously. The model with the point source and spherical radiation in a free field was adopted to formulate the problem. The procedure works very well in ideal cases (point source and free field). However, most of the industrial noise problems are complicated by the fact that the noise is confined in a room. Reflections from the walls, floor, ceiling, and equipment in a room create a reverberant sound field that alters the sound wave characteristics from those for the free field. So the model was validated for relatively low absorption room at NIT Kurukshetra Central Workshop. The results of validation pointed out that the estimated sound power of noise sources under simultaneous conditions were on lower side, within the error limits 3.56 - 6.35 %. Thus suggesting the use of this methodology for practical implementation in industry. To demonstrate the application of the above analytical procedure for estimating the sound power of noise sources under simultaneous operating conditions, a manufacturing facility (Railway Workshop at Yamunanagar, India) having five sound sources (machines) on its workshop floor is considered in this study. The findings of the case study had identified the two most effective candidates (noise sources) for noise control in the Railway Workshop Yamunanagar, India. The study suggests that the modification in the design and/or replacement of these two identified noisiest sources (machine) would be necessary so as to achieve an effective reduction in noise levels. Further, the estimated data allows engineers to better understand the noise situations of the workplace and to revise the map when changes occur in noise level due to a workplace re-layout.

Keywords**—**Industrial noise, sound power level, multiple noise sources, sources contribution.

I. INTRODUCTION

THERE is a continuous and dynamic interaction between people and their surroundings that produces physiological and psychological strain on the person. This can lead to discomfort, annoyances, subtle and direct effect on performance and productivity, effects on health and safety and death. Discomfort in offices and industries can be due to glare, noisy equipment, draughts or smells [1]. Noise, an unwanted sound, is a phenomenon that has plagued us from the day we were born. It annoys and hurts people both psychologically and physiologically. Hearing loss, as a result of exposure to noisy environment, is one of the top ten occupational injuries [2]. Noise not only cause hearing impairment (at long-term exposures of over 85 dB, known as an exposure action value), but it also acts as a causal factor for stress and raises systolic pressure. Additionally, it can be a causal factor in work accidents, both by making hazards and warning signals, and by impeding concentration. Noise also acts synergistically with other hazards to increase the risk of harm to industrial workers. Reference [3] emphasized in his research to identify factors that affected worker productivity, occupational health and safety in selected industries in a developing country. Fifty production managers participated in the study; fifty-four percent of the managers reported hot environmental conditions, 28% a noisy environment, and 26% a lack of resources and facilities as the major factors that affect worker productivity, occupational health and safety.

Kryter's monograph on noise and noise levels [4] includes definitions of sound, its measurements and concepts of the basic functioning and attributes of the auditory system. It examines the relationship between auditory and non-auditory responses (e.g., work performance, sleep, feelings of pain, vision and blood circulation problems) and noise levels in the workplace and industrial communities. Industrial noise is usually considered mainly from the point of view of environmental health and safety, rather than nuisance, as sustained exposure can cause permanent earring damage. Traditionally, workplace noise has been a hazard linked to heavy industries such as ship building, sheet metal, forging, mining, heavy engineering works and associated only with noise induced hearing loss (NIHL). Modern thinking in occupational safety and health identifies noise as hazardous to worker safety and health in many places of employment and by a variety of means. Reference [5] stated in his research that hearing loss was categorized as a separate illness that accounted for 11% of work related illness. Excessive noise can lead to poor verbal communication and reduce the ability to recognize even the warning signals. These dangerous work conditions can also cause stress and fatigue. Occupational hearing loss is a permanent illness with no recovery currently possible.

More commonly, some types of machines produce noise levels as high as 120 dB(A) or more. This particular level violates National Fire Protection Association guidelines [6], which states that the total sound pressure level produced by the ambient sound pressure and signalling appliances shall not exceed 120 dB(A). In addition, the Occupational Safety and

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Health Administration (OSHA) [7] suggests that all workers must wear hearing protection devices if a noise dose is above 90 dB(A). Generally, the handling of the problem of workplace noise has two phases – noise evaluation and noise control. There are two basic methods of for noise evaluation in an environment - direct and indirect. The direct method consists of continuous measurement/monitoring of noise levels during the whole time of the worker's exposure by using the noise dosimeter. These results precisely describe the worker's risk. The indirect method is based on the noise measurement in shorter time than the one being assessed and the use of mathematical formulae for the estimation of values needed. Only after investigating the workers' noise exposure; the various noise control measures should be considered, which include engineering controls, administrative controls and hearing protection devices. However, engineering controls should be preferred, wherever possible, to control excessive exposure to noise. Although noise source control can be a profound process, but it is the most effective way to eliminate noise level on source. Therefore, identification and reduction of noisiest source should be the first step to overcome the noise problem in industry where more than one noise source is involved in an area, which is often the case in workplaces/industries.

A number of researchers have reported works on reducing noise levels at work places by adopting different methodologies. However, the authors did not find adequate literature on assessing nosiest source at work place where numbers of machines are operating simultaneously. In the present work, an attempt is being made to identify the nosiest source when numbers of machines are operating simultaneously so that effective reduction can be achieved by modifying the design and/or replacement of the noisiest machine, or any other appropriate control measure. The sound power of noise sources (i.e., machines) can be useful information in the identification of noisiest source. Further, if the sound power of noise sources becomes available, the sound pressure level at any locations in the workplace can be calculated as well. So, by estimating the sound power of noise sources, the most effective candidate(s) for noise control can be assessed. The mathematical model proposed by Lu and Hong [8] is used in this study and the least squares method is adopted to solve the problem. The proposed model is first validated in the Central Workshop of National Institute of Technology Kurukshetra, India; and then applied for identification and estimation of noisiest source in a Railway Workshop at Yamunanagar, India.

II. PROBLEM FORMULATION

Industry workers suffer psychological and physical stress as well as hearing loss due to industrial noise. Hearing loss is not the only adverse effect of occupational noise, but also a number of non-auditory effects may endanger worker's safety. Lu and Hong [8] propose an approach enable engineers to point out quantitatively the noisiest source for modification, while multiple machines are operating simultaneously. The model with the point source and spherical radiation in a free field is adopted to formulate the problem. The proposed method requires input data that includes the coordinates (x, y) of the noise sources and the locations where the sound pressure level is measured; and the measured sound pressure levels at the measurement locations. Then, the method of least squares can be applied to estimate system parameters. Finally, a set of solutions that represents the sound power of noise sources can be estimated and these solutions have minimum error in least squares sense. With the help of sound powers thus estimated/obtained, engineers would be able to evaluate noise distribution whenever re-layout of workplace takes place in future.

The theoretical concepts are briefly presented subsequently; however, the detailed discussion can be found in [8]. In general sound reaches the human ear through waves in air, propagating out spherically from a point source. Sound power is the amount of sound radiated by a source. It is independent of distance or environment; and is basically used for the noise rating of machines. The sound power level Lw (dB) radiated by a point source is related to the sound pressure level Lp (dB) at a distance r (m) by the following equation [9] – [11]:

$$Lp = Lw + 10 \log (Q/4\Pi r^2) \qquad (1)$$

where, Q is the directivity factor of the source. Equation (1) is valid for airborne sound at most temperature and pressure condition; and is often referred as spherical radiation in a free field.

In case of multiple noise sources (say m) and measurement locations (say n), the component of Lp_{ij} of each source s_i contributing to the measurement location m_j can determined by using the following equation:

$$Lp_{ij} = Lw_i + 10 \log (Q_i/4\Pi r_{ij}^2) \qquad (2)$$

where, $i = 1, 2,\ldots, m$; $j = 1, 2,\ldots., n$; r_{ij} is distance between the source s_i and the measurement location m_j; and Lw_i is the sound power of the noise source s_j. The travel distances (r_{ij}) can be calculated by Euclidean methods as under:

$$r_{ij}^2 = \left(x_i - x_j\right)^2 - \left(y_i - y_j\right)^2 \qquad (3)$$

The total mean square sound pressure is the sum of component source mean-square pressures for uncorrelated noise sources [9], [11]. So, if the contribution to the sound at j^{th} location be $Prms_{ij}$ (corresponding to s_i contributing to m_j), then the total sound pressure level Lp_j at m_j is given by the following equation:

$$\begin{aligned} Lp_j &= 10 \log \left[\left(\sum_{i=1}^{m} \mathrm{Pr}\, ms_{ij}^2 \right) \Big/ P^2 ref \right] \\ &= 10 \log \left(\sum_{i=1}^{m} 10^{0.1 Lp_{ij}} \right), j = 1,2,\ldots..,n \qquad (4) \end{aligned}$$

where, the reference pressure (P_{ref}) = 20 x 10^{-6} Pa.

Substituting (2) in (3), we get:

$$10^{0.1 Lp_j} = \sum_{i=1}^{m} \left(\frac{Q_i}{4\pi r_{ij}} \times 10^{0.1 Lw_i} \right), j = 1,2,\ldots..,n \qquad (5)$$

Let $10^{0.1Lpj} = b_j$; (Q_i / 4Π r_{ij}^2) = a_{ij} ; $10^{0.1Lwi} = x_i$; then the above equation can be formulated into a set of linear equation. Rewriting in vector notations, we get:

$$B = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_3 \end{pmatrix}, \quad A = \begin{pmatrix} a_{11} & a_{12} & a_{1m} \\ a_{21} & a_{22} & a_{2m} \\ \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & a_{nm} \end{pmatrix}, \quad X = \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_3 \end{pmatrix}$$

Then,

$$B = AX \tag{6}$$

If the measured sound pressure levels at measurement locations are Lp_1, Lp_2, …., Lp_n ; then the sound powers Lw_i (i = 1, 2, …, m) can be determined by solving the set of linear equations.

A. Model Assumption

To develop a method capable of estimating the sound power of noise sources by using sound pressure meter, while there are multiple sound sources being operated simultaneously in workplace, several assumptions should be defined [12] that are as under:

- The factory/workshop is quite large and open.
- The effects of sound reflection and absorption from walls are ignored.
- Noise is produced from the centre of the workstation.
- The noise sources are assumed to be point.
- It is assumed that background sound does not affect our calculations.
- For an ideal (non directional) point source in full space, the directivity factor is Q = 1. If an ideal point source is located on an acoustically hard surface, then Q = 2 for the half-space above surface

B. Computational Procedure

This section describes the computational procedure. The procedure consists of following steps:

Step 1: The layout of the factory/workshop floor is plotted. All the machines (or noise sources) as well as measuring locations are plotted on the layout map. The noise sources (the machine locations) are represented by points on the x-y plane as a pair of x and y coordinates, by selecting one corner of the factory floor as the reference origin (usually the lower left corner). Similarly, the measuring locations are also represented by points on the x-y plane. It is important to pick measurement locations more than the number of noise sources so as to achieve better estimation of the power of the noise sources [8].

Step 2: Measure the distances between all the noise sources and measurement locations by measuring the Euclidean distance by using (3).

Step 3: The ambient noise level dB(A) are measured at each of the measuring locations, when all of the machines are operating simultaneously. In order to obtain reliable data, several measurements are taken at different times for every measuring location, and then the average noise is calculated and used as the measured ambient noise level, that is measured combined sound pressure level (Lp_j), for that particular location of the factory floor.

Step 4: The contribution of individual noise source (Lp_{ij}), in terms of linear equations (in vector notations), to each measurement location is then calculated by using (2). Sum up the all the individual contributions by using (4) and compute the sound pressure level Lp_j at each measurement location.

Step 5: Now by using least square criterion (in which only the errors in Lp_i are considered), compute the sound power of noise sources (Lw_m) through MATLAB statistical software. The computation is similar to the linear regression problems for finding the coefficients of model equations, and these coefficients represent the power of noise sources in the model.

The step by step procedure is explained in later part of this paper under the case study carried out for demonstrating the applied aspect of this paper.

III. Validation Of The Least Square Method For Evaluating The Sound Power Of The Noise Sources

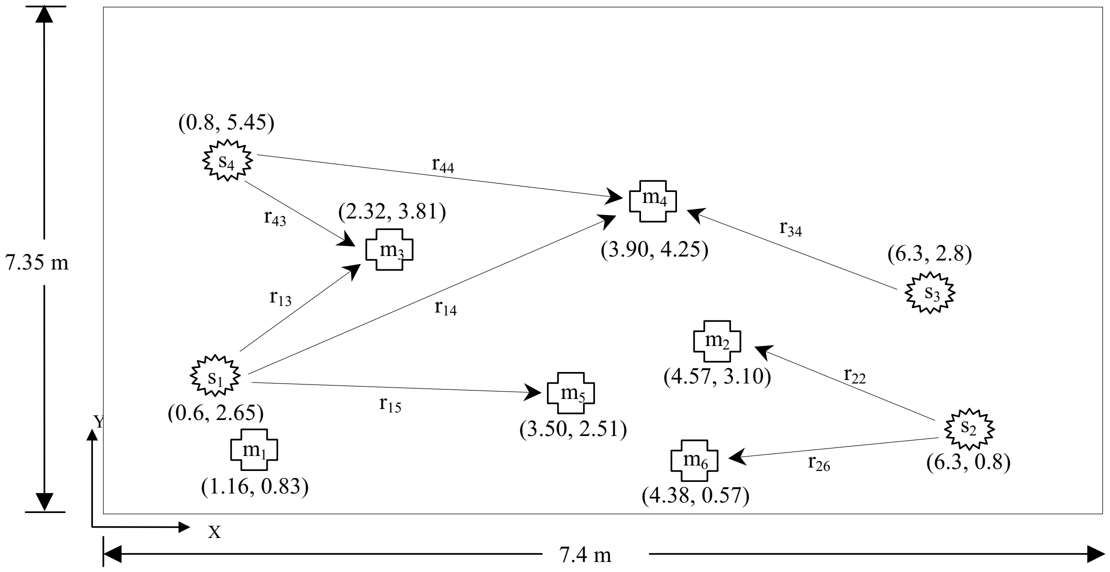

Fig. 1Workshop floor with four noise sources and six measurement locations

Four machines and six measuring locations are considered in the Machine Shop (part of Central Workshop) of National Institute of Technology Kurukshetra to validate the Lu and Hong mathematical model, solved by least square method, for evaluating the sound power of noise sources. Fig.1 shows the layout of four machines and six measuring locations in Machine Shop.

The procedure for validation is as follows:

Step 1: Mark the coordinates (*x, y*) of the four machines/noise sources (s_1, s_2, s_3, and s_4) and the six measuring locations (m_1, m_2, m_3, m_4, m_5 and m_6), in metre, as indicated in Fig. 1.

Step 2: The sound power level of each noise source is measured with sound level meter when only individual noise source is in operation. These measured sound power of individual noise sources obtained for s_1, s_2, s_3, and s_4 are Lw_1, measured = 88.2 dB, Lw_2, measured = 89.8 dB, Lw_3, measured = 91.4 dB, and Lw_4, measured = 90.2 dB respectively.

Step 3: When all the four noise sources are in operation, the measured sound pressure levels at six measured locations are obtained as Lp_1 = 73.1 dB, Lp_2 = 74.8 dB, Lp_3 = 74.5 dB, Lp_4 = 73.2 dB, Lp_5 = 74.0 dB, and Lp_6 = 74.0 dB respectively. Then the sound power levels of noise sources are computed by following the step by step procedure discussed earlier under computational procedure sub-heading. The computed sound power of noise sources for s_1, s_2, s_3, and s_4 comes out to be Lw_1 = 85.06 dB, Lw_2 = 85.35 dB, Lw_3 = 85.59 dB and Lw_4 = 85.66 dB respectively. The step by step computations of this methodology are explained subsequently in the case study carried out for his research paper.

Step 4- The method is validated for practical application, when the sound power levels obtained in Step2 and Step3 lie within the comparable limits. The comparison of the sound power values obtained in Step 2 and Step 3 reveals that the proposed mathematical model solved by least square error method estimates the sound power of noise sources under simultaneous conditions on lower side within the error limits 3.56 - 6.35 %. Thus suggesting the use of this methodology is suitable for practical implementation in industry.

IV. CASE STUDY

To demonstrate the application of the above analytical procedure for estimating the sound power of noise sources under simultaneous operating conditions, a manufacturing facility (Railway Workshop at Yamunanagar, India) having five sound sources (machines) on its workshop floor is considered. The workshop floor layout is shown in Fig. 2. The width and length of the workshop floor are 4.57 m and 9 m respectively and the sound pressure levels are measured at six measurement locations randomly distributed on the floor (Fig. 2). The coordinates (*x*, *y*) of the five machines (noise sources) s_1, s_2, s_3, s_4 and s_5 as well as that of the six measuring locations m_1, m_2, m_3, m_4, m_5 *and* m_6 are also shown in the Fig.2.

The distances between machines (noise sources) and measurement locations are calculated by using (3) as under:

$r_{11}= [(1.48 – 1.75)^2 + (4.05 – 1.00)^2]^{1/2} = 3.0619$ m

$r_{12}= [(1.48 – 1.00)^2 + (4.05 – 3.60)^2]^{1/2} = 0.6580$ m

$r_{13}= [(1.48 – 3.10)^2 + (4.05 – 3.48)^2]^{1/2} = 1.7174$ m

$r_{14}= [(1.48 – 4.05)^2 + (4.05 – 2.40)^2]^{1/2} = 3.0541$ m

$r_{15}= [(1.48 – 4.25)^2 + (4.05 – 5.65)^2]^{1/2} = 3.1989$ m

$r_{16}= [(1.48 – 8.70)^2 + (4.05 – 0.80)^2]^{1/2} = 7.9178$ m

$r_{21}= [(5.04 – 1.75)^2 + (4.05 – 1.00)^2]^{1/2} = 4.4863$ m

$r_{22}= [(5.04 – 1.00)^2 + (4.05 – 3.60)^2]^{1/2} = 4.0650$ m

$r_{23}= [(5.04 – 3.10)^2 + (4.05 – 3.48)^2]^{1/2} = 2.0220$ m

$r_{24}= [(5.04 – 4.05)^2 + (4.05 – 2.40)^2]^{1/2} = 1.9242$ m

$r_{25}= [(5.04 – 4.25)^2 + (4.05 – 5.65)^2]^{1/2} = 1.7844$ m

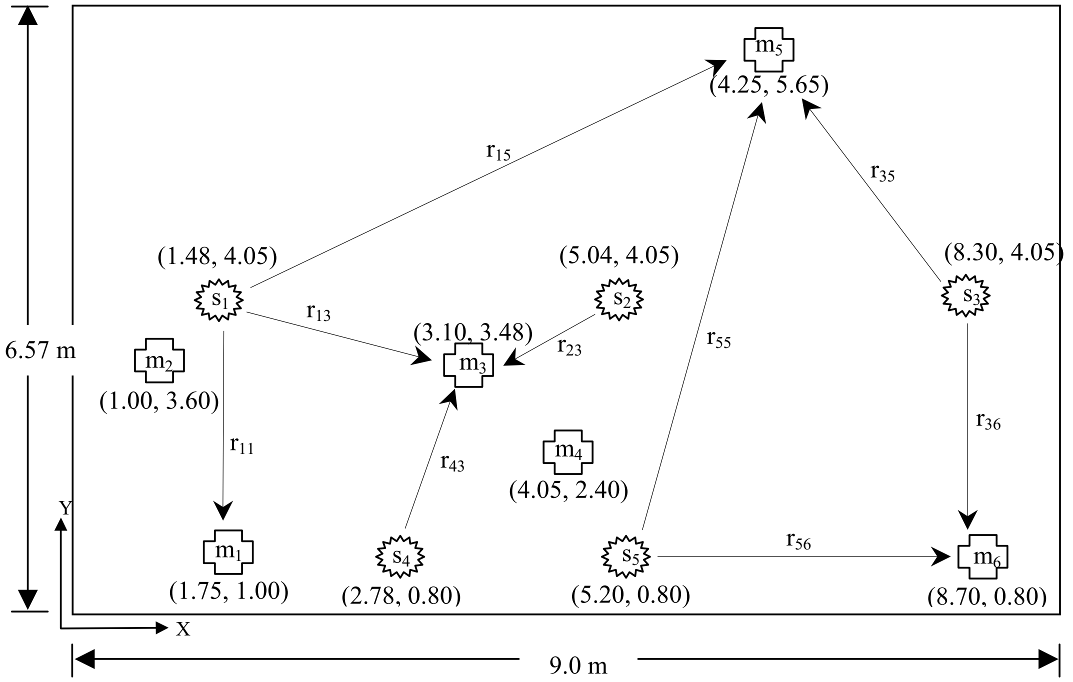

Fig. 2 A workshop floor with five noise sources and six measurement locations

$r_{26} = [(5.04 - 8.70)^2 + (4.05 - 0.80)^2]^{1/2} = 4.8947$ m
$r_{31} = [(8.30 - 1.75)^2 + (4.05 - 1.00)^2]^{1/2} = 7.2253$ m
$r_{32} = [(8.30 - 1.00)^2 + (4.05 - 3.60)^2]^{1/2} = 7.3139$ m
$r_{33} = [(8.30 - 3.10)^2 + (4.05 - 3.48)^2]^{1/2} = 5.2311$ m
$r_{34} = [(8.30 - 4.05)^2 + (4.05 - 2.40)^2]^{1/2} = 4.5591$ m
$r_{35} = [(8.30 - 4.25)^2 + (4.05 - 5.65)^2]^{1/2} = 4.3546$ m
$r_{36} = [(8.30 - 8.70)^2 + (4.05 - 0.80)^2]^{1/2} = 3.2745$ m
$r_{41} = [(2.78 - 1.75)^2 + (0.80 - 1.00)^2]^{1/2} = 1.0492$ m
$r_{42} = [(2.78 - 1.00)^2 + (0.80 - 3.60)^2]^{1/2} = 3.3179$ m
$r_{43} = [(2.78 - 3.10)^2 + (0.80 - 3.48)^2]^{1/2} = 2.6990$ m
$r_{44} = [(2.78 - 4.05)^2 + (0.80 - 2.40)^2]^{1/2} = 1.9242$ m
$r_{45} = [(2.78 - 4.25)^2 + (0.80 - 5.65)^2]^{1/2} = 5.0679$ m
$r_{46} = [(2.78 - 8.70)^2 + (0.80 - 0.80)^2]^{1/2} = 5.9200$ m
$r_{51} = [(5.20 - 1.75)^2 + (0.80 - 1.00)^2]^{1/2} = 3.4558$ m
$r_{52} = [(5.20 - 1.00)^2 + (0.80 - 3.60)^2]^{1/2} = 5.0478$ m
$r_{53} = [(5.20 - 3.10)^2 + (0.80 - 3.48)^2]^{1/2} = 3.4048$ m
$r_{54} = [(5.20 - 4.05)^2 + (0.80 - 2.40)^2]^{1/2} = 1.9704$ m
$r_{55} = [(5.20 - 4.25)^2 + (0.80 - 5.65)^2]^{1/2} = 4.9422$ m
$r_{56} = [(5.20 - 8.70)^2 + (0.80 - 0.80)^2]^{1/2} = 3.5000$ m

The sound pressure levels are measured at all the six measurement locations (m_1, m_2, m_3, m_4, m_5 *and* m_6) and are found to be 76 dB, 80 dB, 75.1 dB, 74.5 dB, 73.7 dB, and 69.1 dB respectively. The contribution of each individual source to each measurement location is then calculated by using (2).

$Lp_{11} = Lw_1 + 10 \log [2/4\pi(3.0619)^2]$
$Lp_{12} = Lw_1 + 10 \log [2/4\pi(0.6580)^2]$
$Lp_{13} = Lw_1 + 10 \log [2/4\pi(1.7174)^2]$
$Lp_{14} = Lw_1 + 10 \log [2/4\pi(3.0541)^2]$
$Lp_{15} = Lw_1 + 10 \log [2/4\pi(3.1989)^2]$
$Lp_{16} = Lw_1 + 10 \log [2/4\pi(7.9178)^2]$
$Lp_{21} = Lw_2 + 10 \log [2/4\pi(4.4863)^2]$
$Lp_{22} = Lw_2 + 10 \log [2/4\pi(4.0650)^2]$
$Lp_{23} = Lw_2 + 10 \log [2/4\pi(2.0220)^2]$
$Lp_{24} = Lw_2 + 10 \log [2/4\pi(1.9242)^2]$
$Lp_{25} = Lw_2 + 10 \log [2/4\pi(1.7844)^2]$
$Lp_{26} = \mathrm{Lw}_2 + 10 \log [2/4\pi(4.8947)^2]$
$Lp_{31} = Lw_3 + 10 \log [2/4\pi(7.2253)^2]$
$Lp_{32} = Lw_3 + 10 \log [2/4\pi(7.3139)^2]$
$Lp_{33} = Lw_3 + 10 \log [2/4\pi(5.2311)^2]$
$Lp_{34} = Lw_3 + 10 \log [2/4\pi(4.5591)^2]$
$Lp_{35} = Lw_3 + 10 \log [2/4\pi(4.3546)^2]$
$Lp_{36} = Lw_3 + 10 \log [2/4\pi(3.2745)^2]$
$Lp_{41} = Lw_4 + 10 \log [2/4\pi(1.0492)^2]$
$Lp_{42} = Lw_4 + 10 \log [2/4\pi(3.3179)^2]$
$Lp_{43} = Lw_4 + 10 \log [2/4\pi(2.6990)^2]$
$Lp_{45} = Lw_4 + 10 \log [2/4\pi(1.9242)^2]$
$Lp_{46} = Lw_4 + 10 \log [2/4\pi(5.9200)^2]$
$Lp_{51} = Lw_5 + 10 \log [2/4\pi(3.4558)^2]$
$Lp_{52} = Lw_5 + 10 \log [2/4\pi(5.0478)^2]$
$Lp_{53} = Lw_5 + 10 \log [2/4\pi(3.4048)^2]$
$\mathrm{Lp}_{54} = Lw_5 + 10 \log [2/4\pi(1.9704)^2]$
$Lp_{55} = Lw_5 + 10 \log [2/4\pi(4.9422)^2]$
$Lp_{56} = Lw_5 + 10 \log [2/4\pi(3.5000)^2]$

Thereafter, summing up all contributions of each source, the combined sound pressure level at measurement location 1, 2,3, 4, 5 and 6 can be denoted by Lp_1, Lp_2, Lp_3, Lp_4, Lp_5 and Lp_6 respectively.

Where $Lp_1 = Lp_{11} + Lp_{21} + Lp_{31} + Lp_{41} + Lp_{51}$

Thus,

$$Lp_1 = 76 \text{ dB} = 10 \log [10^{(Lw1 - 17.6995)/10} + 10^{(Lw2 - 21.0173)/10} + 10^{(Lw3 - 25.1567)/10} + 10^{(Lw4 - 8.397)/10} + 10^{(Lw5 - 18.7505)/10}]$$

Similarly,

$Lp_2 = Lp_{12} + Lp_{22} + Lp_{32} + Lp_{42} + Lp_{52}$

$$\Rightarrow Lp_2 = 80 \text{ dB} = 10 \log [10^{(Lw1 - 4.3435)/10} + 10^{(Lw2 - 20.1608)/10} + 10^{(Lw3 - 25.2625)/10} + 10^{(Lw4 - 18.3968)/10} + 10^{(Lw5 - 22.0416)/10}]$$

$Lp_3 = Lp_{13} + Lp_{23} + Lp_{33} + Lp_{43} + Lp_{53}$

$$\Rightarrow Lp_3 = 75.1 \text{ dB} = 10 \log [10^{(Lw1 - 12.6768)/10} + 10^{(Lw2 - 14.0952)/10} + 10^{(Lw3 - 22.3515)/10} + 10^{(Lw4 - 16.6038)/10} + 10^{(Lw5 - 18.6213)/10}]$$

$Lp_4 = Lp_{14} + Lp_{24} + Lp_{34} + Lp_{44} + Lp_{54}$

$$\Rightarrow Lp_4 = 74.5 \text{ dB} = 10 \log [10^{(Lw1 - 17.6772)/10} + 10^{(Lw2 - 13.6647)/10} + 10^{(Lw3 - 21.1571)/10} + 10^{(Lw4 - 14.1840)/10} + 10^{(Lw5 - 13.8707)/10}]$$

$Lp_5 = Lp_{15} + Lp_{25} + Lp_{35} + Lp_{45} + Lp_{55}$

$$\Rightarrow Lp_5 = 73.7 \text{ dB} = 10 \log [10^{(Lw1 - 18.0796)/10} + 10^{(Lw2 - 13.0095)/10} + 10^{(Lw3 - 20.7586)/10} + 10^{(Lw4 - 22.0761)/10} + 10^{(Lw5 - 21.8579)/10}]\text{, and}$$

$Lp_6 = Lp_{16} + Lp_{26} + Lp_{36} + Lp_{46} + Lp_{56}$

$$\Rightarrow Lp_6 = 69.1 \text{ dB} = 10 \log [10^{(Lw1 - 25.9516)/10} + 10^{(Lw2 - 21.7741)/10} + 10^{(Lw3 - 18.2826)/10} + 10^{(Lw4 - 23.4260)/10} + 10^{(Lw5 - 18.8610)/10}]$$

The least squares criterion and statistical software MATLAB is than adopted to further solve this problem for five unknowns (i.e. sound powers) using above six equations. On solving, we obtain the sound powers Lw_1, Lw_2, Lw_3, Lw_4, and Lw_5 as 84.0 dB, 84.9 dB, 84.7 dB, 83.4 dB, and 69.7 dB for the five machines (noise sources) s_1, s_2, s_3, s_4 and s_5 respectively. The results, therefore, suggest that the most effective candidates for noise control in the Railway Workshop Yamunanagar, India are s_1 and s_2. Any effective reduction in noise levels can be achieved by modifying the design and/or replacement of these two noisiest sources (machine).

V. CONCLUSION

The present paper has evaluated the acoustic characteristics of factory/workshops. The use of the least squared error to identify dominant source from sound pressure measurements on sound field has been presented. The proposed approach provides an objective method to help engineers for finding the noisiest machine in factory/workshop without using complicated instrument or subjective justification. The procedure works very well in ideal cases (point source and free field). However, most of the industrial noise problems are complicated by the fact that the noise is confined in a room. Reflections from the walls, floor, ceiling, and equipment in a room create a reverberant sound field that alters the sound wave characteristics from those for the free field. That is why, we have validated the idea for relatively low absorption room at NIT Kurushetra Central Workshop and the results of validation are quite accurate.

Since corporation with noisy workplace may be held liable for hearing damage which may be occurring outside the workplace, it is essential for facility engineers and plant managers to take the necessary steps to reduce the current noise levels in their facilities and to emphasize protection. With the proposed analytical procedure, the manufacturing industry can quickly evaluate the sound powers of the noise sources and identify the dominant source(s) of noise; and, in turn, helps in overcoming the noise problem and thus enhance the workplace safety.

ACKNOWLEDGMENT

Appreciation is expressed to the Railway Workshop of Yamunanagar, Haryana for their assistance and cooperation in data collection.

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