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Research Article

Design of Barrier to Control the Noise of Fin Tube Heat Exchangers

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Abstract

The today's socio-physical needs demand for conducive acoustical environment for living & working, than never before. In the industrial areas, awareness regarding the noise reduction & control is increasing day by day. According to ASHREA, it's mandatory for all the industries to maintain noise below the certain levels. In this paper, study has been carried out on barrier design to reduce the noise level at the receiver, for any type of fin tube heat exchanger. In this method, noise is treated along the path. The paper includes mathematical calculations for noise in fin tube heat exchanger with and without barrier. A C++ program has been coded to eliminate substantial amount of manual calculations & possibility of error associated with it and to have speedy of calculations. A case study is presented in this study where barrier design results in nearly 15 dB noise reduction.

Keywords: *Noise, Fin tube heat exchanger, noise reduction, sound power, sound pressure, Barrier.*

1. Introduction

A Fin tube heat exchanger is a device used for transfer of thermal energy between two or more fluids or between a solid surface & a fluid. The nature of application of Fin tube heat exchangers leads to its installation in nearest vicinity of buildings; may it be commercial or no commercial. Generally Fin tube heat exchangers are deployed besides the building or on roofs to serve the purpose. A considerable level of noise is generated by the moving parts of the Fin tube heat exchanger, especially by its fan. Now-a-days, production of such noise has become a severe problem because these instruments & appliances need to be installed in the places where people inhabit, work &relax. Therefore, increasing concern about noise from mechanical devices & its consequences led to increasing demand for quieter Fin tube heat exchanger &it has become a necessary requirement for all the Fin tube heat exchangers. During this discussion we will be referring to noise created by fans of all types of Fin tube heat exchangers.

1.1 Noise: 'Sound' is a propagating vibratory disturbance or wave in an elastic medium (solid, liquid or gas). Sound is most commonly thought of as being transmitted in air and detected by a person's ears; Whereas 'Noise' is defined as any unwanted or undesirable sound. While sound in general is not necessarily a problem and may even be desired in certain situations, when it is unwanted or annoying, we refer to it as noise. Whenever mechanical power is generated or transmitted, a fraction of the power is converted into sound power and radiated into the air. Therefore, virtually any major component of a heat exchangers/HVAC system is a potential source of noise, e.g. fans in tube fin heat exchangers.[Colin H Hansen et al]

1.2 Types of noise in Tube fin heat exchanger: Periodic noise' is the noise that has discrete frequency noise emissions related to the rotations of the blades of fans, it is a noise related to some defects in the design of the fan or during the process of construction. The broadband noise is a kind of noise that is produced because the fans operate with air which is entirely governed by aerodynamic conditions. This aerodynamics condition includes the turbulence of the air, its velocity, static pressure etc.[ASHRAE-Handbook-Sound-and-Vibration,2009]

1.3 Fan as a Source Of noise creation in Tube fin heat exchangers: Turbulence generated by 'fan supports' or other upstream obstructions of heat exchangers leads to ingestion of turbulence in the main air flow.

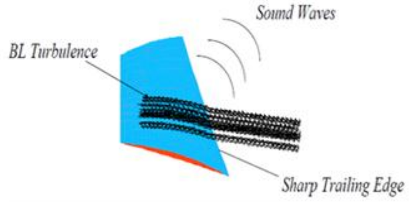

Fig.1: Sound waves creation in fan blade

The turbulence results in random variations in angles of incidence at blade leading edges, causing fluctuating blade loads and surface pressures over a broad range of frequencies. Scattering of BL pressure fluctuations causes propagating acoustic waves.

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Fan Unbalance: Unbalance is one of the leading causes of noise in rotating machinery. Unbalance is simply an unequal distribution of rotor weight along the shaft axis. The forces generated due to an unbalance are proportional to the rotating speed of the rotor squared. Therefore, the balancing of high-speed equipment is especially important. Higher degree of the fan balance will result in less likelihood of noise generation from this source.

Motor Noise: Noise of magnetic origin may be radiated by the fan if the impeller is mounted directly on the motor shaft. [AlexandreLuizAmaranteMesquita, André LuizAmaranteMesquita, Ernesto Arthur MonteiroFilho et al 2005]

1.4 Need of noise control in Fin tube *heat exchangers:* Noise beyond certain levels may lead to, 1) Increase in stress levels, 2) loss of concentration, 3) loss of hearing capacity. The higher noise levels in workplace can act as hurdle in normal communication between occupants. Hence, there is profound need to maintain noise below certain level. Also low noise heat exchangers are beneficial for the industries to increase their market value.

1.5 Possible Methods of noise reduction in Tube fin heat exchangers: The noise control can be achieved through series of actions targeted at the source of the sound waves, modifications on the path or isolating the receiver. A key approach to noise control is to break each problem into its fundamental components. This generated the Source – Path– Receiver concept. Every noise control problem can be broken down into a source creating the noise, a path transmitting the noise, and a receiver hearing the noise. [Silencers Engineering Guide, Price Industries Limited 2011]

Fig. 2: Propagation of Noise

There are possible options available for reducing the noise at each component.

a) At the source: The most desirable & effective option is to mitigate the possibility of noise generation at source. Selection of quieter equipment with best designs can eliminate the noise problems in first place. Design of quieter fan, optimizing fan parameters could be one of the options; but every such action, indirectly has its some or the other retrogressing consequences many a times. Also the space, cost & application requirement prove to be hurdle in perfect design of heat exchangers with no noise.

b) Along the Path: Once the sources are known, receiver's position in relation to the source can be determined. This will allow us to understand the path by which the noise is transmitted. It is important to note that noise typically travels through multiple paths, both airborne and structural, so possible paths must be acknowledged and evaluated appropriately. Treatment options along the path are the next best option and can include silencers, barriers, absorption, lagging, etc.

c) At the Receiver: After the source and path have been identified, it is a matter of assessing the receiver and determining what sound levels are considered acceptable so that the most effective and economical solution to the noise problem can be selected. Calculation of the sound pressure level at the receiver is the final component to the source - path-receiver concept. The main consideration for specifying a target or design sound criteria is the intended use of the space.

2. Barriers- As a Method for Noise Reduction in Tube Fin Heat Exchangers

Due to the above mentioned limitations of noise control at the source; the next best option is to reduce the noise along the path. This leads to two possibilities- place sound-reducing barriers between the source and the working environment or increase the distance between the working environment and the source. Considering cost & space implications, the best solution to reduce the noise is use of barrier. [ASHRAE-Handbook-Sound-and-Vibration-Control, 2009]

A sound barrier is usually a solid material which, by virtue of its mass, acts as an acoustical reflector, interrupting the path of a sound wave. A noise barrier can be defined as any solid obstacle/ acoustical shield that is relatively opaque to sound, that blocks the line-of-sight from sound source to receiver, thus creating a sound shadow. When a noise barrier is located between a noise source and a receiver, the sound attenuation occurs behind the barrier. A barrier may be a rigid structure, such as plywood, concrete wall, or a limp sheet material such as a flexible noise curtain. The aim is to reduce the amount of sound energy released by the noise source, or divert the flow of sound energy away from the receiver and protect the receiver from the sound energy reaching him.

Fig. 3: Pictorial Representation of use of Barriers

3. Barrier Design

3.1Objective of Barrier Design: The primary objective for design of barriers for heat exchangers/HVAC systems &equipment is to ensure that the acoustical environment in a given space is not unacceptably affected by heat exchangers/HVAC system-related noise. The quantified objective of barrier design is to reduce Noise from existing level of 85db to below 70db by holding constant cooling capacity, fan design, Space constraints & location of receiver& source

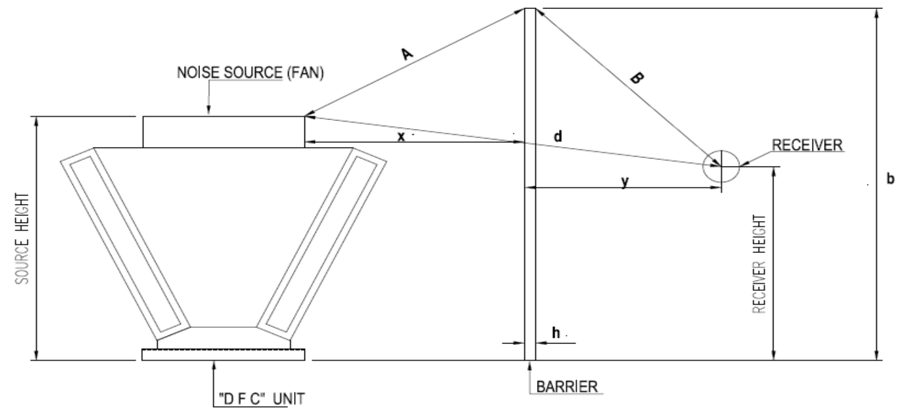

Fig. 4: Schematic Representation of Parameters of Barrier Design

3.2 Methodology followed for barrier design:

3.2.1Diff. Parameters considered for barrier design:

A= distance from the noise source to the top of the barrier (m)

B= distance from the top of the barrier to the receiver (m)

d = direct path of noise between source and receiver.(m)

δ = the difference between the geometrical distance from source to receiver and the shortest path from the source to the top of the wall then to the receiver.(m)

b = height of the barrier (m)

a = width of barrier (m)

h = thickness of barrier (m)

x = distance between source and the barrier.(m)

y = distance between barrier and receiver.(m)

3.2.2 Mathematical procedure to calculate noise levels:[Randall F. Barron et al ,2003] The noise generated internally by each of the fans mentioned previously is composed of two components: broadband noise generated by vortex shedding from the fan blades and a discrete tone (blade tone) noise produced as the blade passes by the inlet or outlet opening of the fan. The sound power level of noise generated by the fan for any octave band may be estimated from the following correlation,

$$L_W = L_W(B) + 10\log(Q) + 20\log(P) + B_T$$

Where,

$L_w(B)$ = basic sound power level (dB)

Q = volumetric flow rate through the fan (cfm)

P = pressure rise through the fan (in H_2O)

B_T = the blade tone component, which is zero except for the octave band in which the blade pass frequency lies

For B_T calculation refer Table No.1

f_B = The blade pass frequency is the number of times a blade passes one of the fan openings and is given by the following expression:

$$f_B = n_r * N_b$$

The quantity n_r is the rotational speed of the fan, rev/sec, and N_b is the number of blades on the fan.

Sound pressure level calculated by:-

$$L_p = L_w + DI - 20\log(r) - 11$$

Where,

Lp = sound pressure level in dB

Lw = sound power in dB

DI = Directivity index

r = distance between noise source and receiver in m.

Using above procedure we have to calculate the sound pressure level for all the bands i.e. for 63,125,250,500,1000,2000,4000,8000 Hz. The next step is to add the all the sound pressure level values of octave bands to get the final value of sound pressure level. The formula for addition of these octave bands is

$$L_P = 10\log\{\sum_{i=1}^{n} 10^{L_{p,i}/10}\}\ \text{dB}$$

Where,

Lp = overall sound pressure level (dB)

Lp,i= sound pressure level calculated for particular octave bands.

3.2.3 Mathematical procedure to calculate noise levels by using Barrier:[Randall F. Barron et al,2003]

First calculate the resonant frequency(F_{11}),

$$F_{11} = 0.4534 * C_L * h\left(\frac{1}{a^2} + \frac{1}{b^2}\right)\ \textbf{Hz} \qquad (1)$$

Where,

C_L = Longitudinal Speed of Sound in m/sec

h = Thickness of barrier (m)

a = Width of barrier (m)

b = Height of barrier (m)

Then, Calculate Specific Mass, $M_S = (\rho_W * h)$ (Kg/m^3) (2)

Where,

]ρ_w= Material Density in kg/m^3

Then, Calculate Critical frequency, $f_c = \frac{M_S f_c}{M_s} in Hz$ (3)

From $f_{11}$and f_c we have to decide the frequency region.

There are three general regions of behavior for the wall or panel & they are,

(a) Region I: stiffness-controlled region

(b) Region II: mass-controlled region

(c)Region III: wave-coincidence region (damping-controlled region)

Table 1: Basic Sound Power Level ($L_W(B)$)

Fan Type	B_T	Octave Band Center Frequency, Hz							
Propeller fan		63	125	250	500	1000	2000	4000	8000
	5-7	51	48	49	47	45	45	43	31

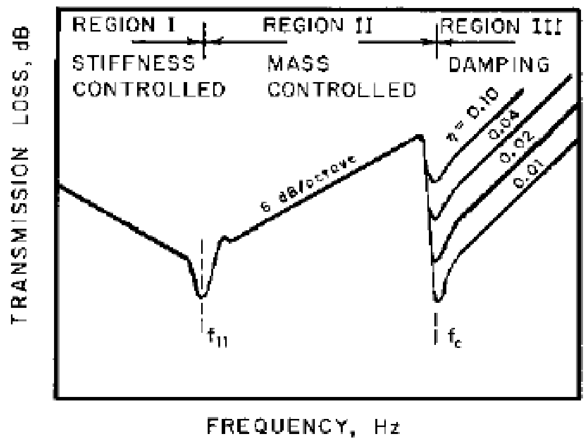

Fig. 5: Variation of Transmission Loss with Frequency

Techniques for prediction of the transmission loss for each of these regions are:-

(A) If the frequency lies between first region i.e. Stiffness Controlled Region then,

i) $$C_S = \frac{768(1-\sigma^2)}{\pi^8 E h^3 (\frac{1}{a^2}+\frac{1}{b^2})^2}$$

ii) $find \quad K_S = 4\pi f Z_1 C_S$

Where,
f = Band Frequency in Hz
$Z_1 = \rho_1 C_1$ = Density * Speed Of Sound
σ = Poison's Ratio

E = Young's Modulus in MPa

iii) Find, Sound power transmission coefficient,

$$a_t = K_S^2 \ln(1 + K_S^{-2})$$

*iv)*Transmission Loss (TL)= $10\log(\frac{1}{a_t})$

(B) If the frequency lies between second region i.e. Mass Control Region then,
For frequencies higher than the first resonant frequency, the transmission loss of the panel is controlled by the mass of the panel and is independent of the stiffness of the panel.
Then, transmission loss can be calculated by,

$$\frac{1}{a_{tn}} = 1 + (\frac{\pi f M_S}{Z_1})^2$$
$$TL_n = 10\log(\frac{1}{a_{tn}})$$
$$TL = TL_n - 5$$

(C) If the frequency lies between third region i.e. Damping Control Region then,
For frequencies above the critical frequency, the transmission loss is strongly dependent on the frequency of the incident sound waves and the internal damping of the panel material.

$$i) TL = TL_n(f_c) + 10\log(\eta) + 33.22\log\left(\frac{f}{f_c}\right) - 5.7$$
$$ii) \quad TL_n(f_c) = 10\log(\,1 + (\frac{\pi M_S f_c}{\rho_1 c_1})^2\,)$$

3.3.3 Sound pressure level calculation: -For transmission of sound across a barrier located outdoors, the following expression has been developed for the sound pressure level Lp at the receiver position due to a point noise source having a sound power level LW on the opposite side of the barrier :

$$L_P = L_W + DI - 20\log(A+B) - 10\log\left(\frac{1}{a_b + a_t}\right) - 10.9$$

Where,
Lp= sound pressure in dB
Lw= sound power in dB
DI= directivity index
A= distance from the noise source to the top of the barrier (m)
B= distance from the top of the barrier to the receiver (m)
a_b= barrier coefficient
a_t= sound power transmission coefficient for the barrier wall
c= sonic velocity in the air around the barrier (m/sec)
d = direct path of noise between source and receiver.
f= frequency of sound wave
N= Fresnel number,

$$N = \frac{2f}{c}(A + B - d) \tag{4}$$
$$a_b = \frac{tanh^2(\sqrt{2\pi N})}{2\pi N * \pi} \quad (N<12.7)$$
$$= 0.004 \quad (N \geq 12.7) \tag{5}$$
$$a_t = 10^{-TL/10} \tag{6}$$

Using above mathematical procedure we can calculate the sound pressure level for eight octave bands. But it is very lengthy& cumbersome procedure for calculation because this calculation procedure comprises of many parameters which are considered as a input parameters like height, width, thickness of barrier, receiver and source height, material selection, path length difference, distance of barrier from noise source and receiver etc. It is very difficult to check the effect of all these parameters on barrier. More time will be required for doing calculations and one need to calculate the value of sound pressure (Lp) for all octave bands i.e. for frequencies 63, 125, 250, 500, 1000,2000,4000,8000 Hz for every set of combination. Henceforth, the program using C++ for performing above calculations was prepared. Using program it is easy to get the value of sound pressure level for eight octave bands. It resulted in saving of ample time.

4. C++ Program Accelerate Calculation Procedures

Program starts with the material selection for barrier. Nearly 20 different materials for barrier have been considered after a detailed study. Out of these 20 materials one can select any material. On the basis of material selection, using switch case, constant values for particular material are selected. In this program by entering all the input values like a, b, h, A,B etc.; values of F_{11} (first resonant frequency) and critical frequency could be calculated.

On the basis of these two frequencies program logic will decide the region and make the Transmission loss calculation for that particular region and directly gives the value. After calculating transmission loss, the next step is to calculate the value of sound pressure (Lp). For calculating Lp values, it is required to find out some parameters like N, a_b, a_t. After calculating these values it will directly give the value of sound pressure (Lp).

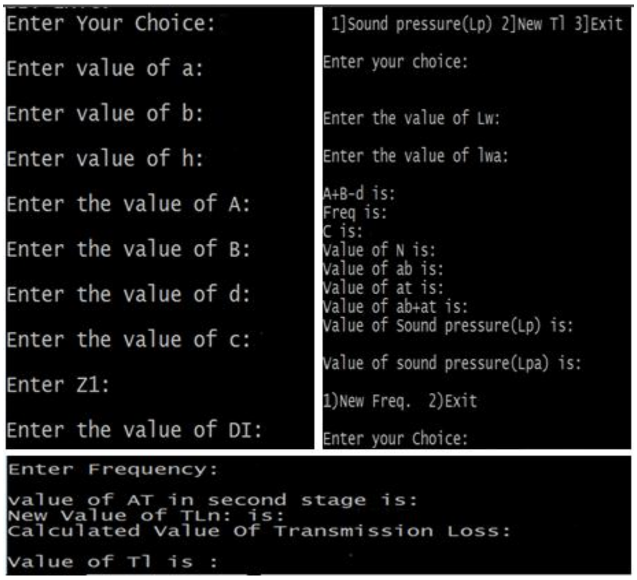

Fig. 6: C++ Programming for Sound Pressure Level Calculation.

5. Case study

Operating points for heat exchanger:-
Source and receiver distance: - 2 m
Air inlet temperature: - 38 °C
Air outlet temperature: - 50.64 °C
Face Velocity: - 3.5 m/sec
Fin spacing: - 10 fpi
Air flow (Q): - 26,930 CFM
Static pressure (P): - 12.71 m^3/sec OR 0.63 in H_2O
Density: - 1.134 kg/m^3
Fan diameter :- 1100 mm
Speed of fan :- 960 rpm
Number of fan blades :- 8
Heat exchanger height and width :- 2 m

5.1 Calculation of Noise Levels for fin tube heat exchanger without barrier:

1) Sound power level calculation:-

A. For B_T calculation refer Table No.1
for speed= 960 rpm and 8 number of fan blades.

$f_B = n_r * N_b$
$F_B = (\frac{960}{60} * 8)$
= 128 Hz

So blade pass frequency (f_B) lies between (88-177)Hz.
Hence we consider the frequency 125 Hz.
So from table No.1, B_T= 5-7 dB

B_T = 0 For Other bands

B. Sound power level

$L_W = L_W(B) + 10\log(Q) + 20\log(P) + B_T$

= 48 + 10 log (26930) + 20 log(0.63)+ 7
= 95 dB

C. Sound Pressure Level Calculation

$L_p = L_w + DI - 20\log(r) - 11$
= 95 + 6 -20 log (2) -11
= 72 dB

Similarly sound power level for other octave bands are calculated & mentioned in the Table No.2 below

Table 2: Mathematically Calculated Sound Power & Sound Pressure Data

Frequency	Lw	LwA	Lp	LpA
63	91	65	80	54
125	95	72	84	68
250	89	81	78	70
500	87	91	76	73
1000	85	85	74	74
2000	85	86	74	75
4000	83	84	72	73
8000	71	70	60	59
Overall	98	94	87	80

D. The overall sound pressure level can be calculated by using above value of Lp,

Overall L_P=10 log$\{\sum_{i=1}^{n} 10^{L_{p,i}/10}\}$ dB

Lp= 10 log $\{10^{80/10} + 10^{84/10} + 10^{78/10} + 10^{76/10} + 10^{74/10} + 10^{74/10} + 10^{72/10} + 10^{60/10}\}$
= 87 dB

5.2 Calculation of Noise Levels for fin tube heat exchanger with barrier: The Factors (or control factors) are the design parameters of a concept or technology that need to be optimized. The objective is to select the control factor levels that minimize the effect of noise factors on the response. For all the factors that are required to be considered in barrier design, diff. levels were selected. These levels are supposed to be bold higher& lower values of parameter at which barrier will perform its function. A pilot study was conducted for deciding these levels.

All dimensions are in meter (m)
Material used for barrier calculations:- Aluminum, Concrete, Plywood
Width of barrier (a):- 2.25, 2.5, 2.75
Height of barrier (b):- 2.5, 2.75, 3
Thickness of barrier (h):- 0.01, 0.02, 0.03
Source to barrier distance (x):- 0.5, 0.75
Barrier to receiver distance (y):- 0.5, 0.75
Source height: - 1.75, 2 (instrument height)
Receiver height: - 0.5, 0.75, 1
Direct distance between source and receiver (d):- 2 m

Then using Taguchi method, a DOE was designed for optimizing these parameters. Taguchi designs are used for robust parameter design, in which the primary goal is to find factor settings that minimize response variation. The goal is to optimize the relationship between the input and the output of the system, includes a signal factor i.e. (length, width, height, thickness, source and receiver height, source to receiver distance from barrier). For every combination obtained from Taguchi design, barrier was designed & corresponding noise levels were calculated with the help of C++ program.

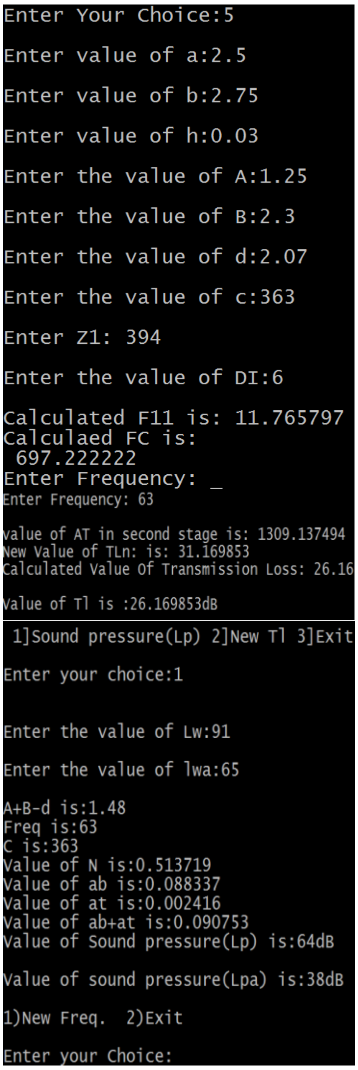

Fig.7: Sound Pressure Calculation using C++ Programming.

Then by substituting these noise levels, Taguchi DOE was analyzed. S/N ratios were obtained from Taguchi DOE, as shown below by fig. no.8

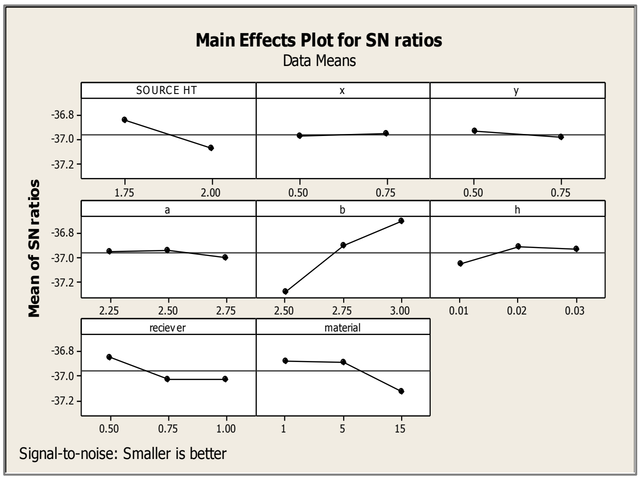

Fig.8: Effect of Parameters on Noise Level

From this graphs, one can understand that Source height, Height of barrier, Thickness of barrier & Height of receiver have significant impact on noise reduction while other factors don't have high influence on noise. From the interpretation of above graph, following optimized values of Parameters were finalized.

Optimized factors:

Material: - Concrete
Width of barrier (a):- 2.5 m
Height of barrier (b):- 3 m
Thickness of barrier (h):- 0.02m
Source to barrier distance (x):- 0.5m
Barrier to receiver distance (y):- 0.5 m
Source height:- 1.75 m (instrument height)
Receiver height:- 0.5 m

5.3 Validation of optimized Parameters: By using these optimized parameters, the sound levels were again calculated to validate the optimized design. The reduced noise level due barrier, designed with optimized parameters, is 67dB.

6. Results

The Noise levels reduced from 87 dB to 67 dB after addition of barrier to the system. This well exceeds the expected reduction of 70dB. Hence we can say that, use of barriers can effectively reduce the noise levels (shown by Fig No.9, 10).

Conclusion

The barriers can be effectively deployed for effective reduction of noise along the path so as to limit the noise levels at receiver & to provide a favorable acoustical environment for receiver to inhabit. A careful observation & interpretation of the results for different barrier materials

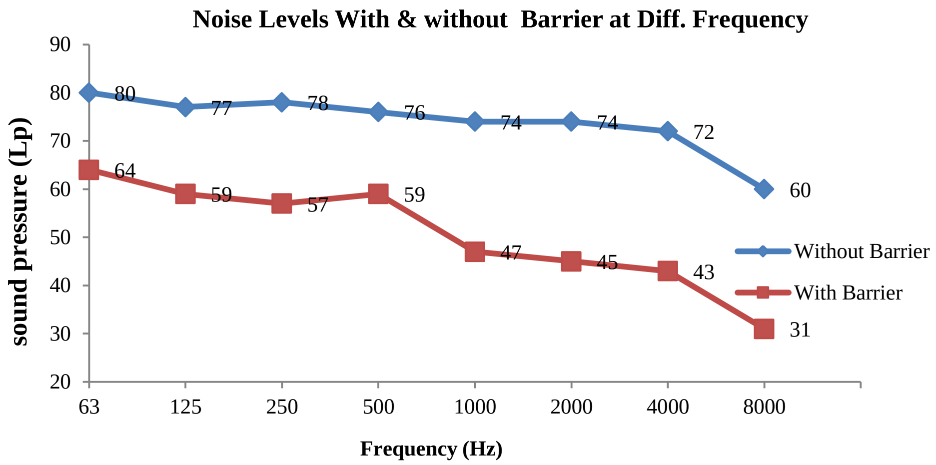

Fig. 9: Comparison of noise levels with & without Barriers

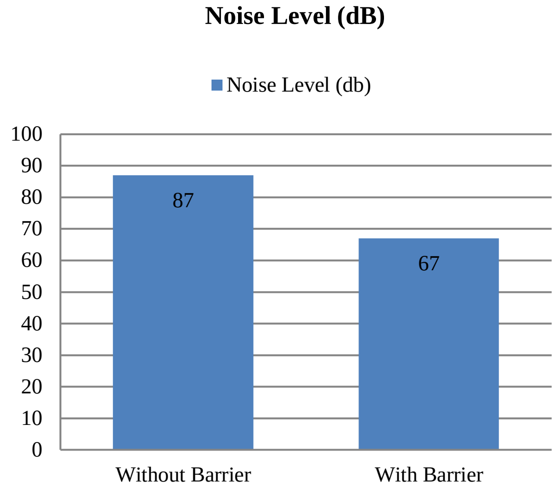

Fig.10: Overall reduction of noise levels with &without barrier.

and all the parameters used for barrier design shows that the height of the barrier has significant influence on noise reduction. Multiple barriers can be used for receivers in multiple directions to serve the purpose. Therefore, one can conclude that using barrier we can achieve nearly 15 dB noise reduction at the receiver position.

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