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A NOVEL FREQUENCY-BASED APPROACH FOR IDENTIFYING INDUSTRIAL MACHINERY NOISE SOURCES AND IMPROVING ANTI-NOISE ENCLOSURE DESIGN

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ABSTRACT

Characterizing noise from machinery in industrial settings can be complex, especially when attempting to isolate and distinguish it from a specific machine among a plethora of other sources. Traditional measurement methods, such as sound pressure level in dB(A) are insufficient for identifying specific noise sources.
In light of this, designing an effective machine enclosure becomes challenging when the noise contribution of a particular machine cannot be clearly distinguished from that of other devices and sources. In this paper, we propose a novel frequency-based approach for identifying the noise spectrum of each device, both with and without an enclosure. The goal of this approach is to support the creation of effective anti-noise enclosures for industrial equipment. The basic principles of the proposed approach are discussed and applied in a real-world industrial case study involving a steel manufacturing plant in India where heavy machineries are in close vicinity. In this case study a motor, blower, and pump very closely spaced are studied. This new approach is more efficient and cost-effective than traditional methods and can be easily implemented in industrial settings to identify specific noise sources and improve the design of machine enclosures for noise control and reduction.

Keywords: *acoustic enclosure, industrial noise mitigation, noisy machines, industrial noise, frequency-based analysis.*

1. INTRODUCTION

Excessive noise in industrial settings can have a negative impact on workers' health and safety, as well as productivity, making noise reduction an important consideration for creating a safe and efficient workplace environment. Reducing noise emissions from industrial machinery can also help to mitigate the environmental impact of industrial activities, by minimizing noise pollution and its effects on local communities and wildlife.
Identifying noise sources from specific machines in industrial settings is not straightforward, as the noise from different machines and devices can overlap and interfere with each other [1-2]. Goal is to identify the most important sub-sources in terms of frequency content and sound power radiation. These sub-sources can then be used to rank and identify where design changes will be most effective to reduce overall noise radiation [3].
Traditional measurement methods, such as sound pressure level (SPL), have been widely used to assess the overall noise level in industrial environments [4-5]. SPL measurement requires a sound level meter to evaluate the total sound pressure level but cannot be used to identify the impact of specific noise sources in a group of them [6-8]. As a result, designing effective anti-noise enclosures remains a challenging task.
Currently there are methods allowing the identification of single noise sources using several transducers such as the Near-field Acoustic Holography and Beamforming [3]. These techniques require expensive instrumentation and an extensive acoustic knowledge.

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In India, the main regulatory body responsible for enforcing noise standards is the Central Pollution Control Board (CPCB), which sets maximum permissible noise levels for different zones and time periods and provides guidelines for noise control measures in industries (e.g., installation of silencers of absorptive materials, noise barriers, and enclosures to reduce noise emissions). The permissible noise limits for industrial areas [9] during the day (6:00 am to 10:00 pm) is 75 dB(A), while during the night (10:00 pm to 6:00 am), it is 70 dB(A). These noise limits apply to all types of industries, including small-scale and large-scale industries, and are intended to prevent noise pollution from reaching levels that could cause hearing damage or other health problems in workers or nearby residents.
Noise reducing enclosures and acoustic hoods are effective methods for controlling noise emissions. According to the CPCB, an acoustic enclosure or acoustic treatment used to control noise emissions from industrial equipment should be designed to achieve a minimum of 25 dB insertion loss [9].
In this study, a novel frequency-based approach that can provide more detailed and accurate information about the noise generated by individual machines in complex industrial settings has been tested in a real power plant in India. The results of its application have been used to guide the design of the anti-noise enclosure and reduce the overall noise levels of the plant and its surrounding area. This also helped to comply with national noise regulations and standards, ensuring that the required levels of noise control and reduction are met.
This paper is an attempt to define a method to analyze signals emitted from machinery, aiming to gain a deeper understanding of their underlying characteristics.

2. PROBLEM STATEMENT

Noise sources of a steel manufacturing power plant (whose name is not disclosed due to privacy reasons) located in India has been studied to evaluate the effectiveness of an acoustic hood in reducing the noise levels of closely spaced machines. The plant layout is illustrated in Figure 1.

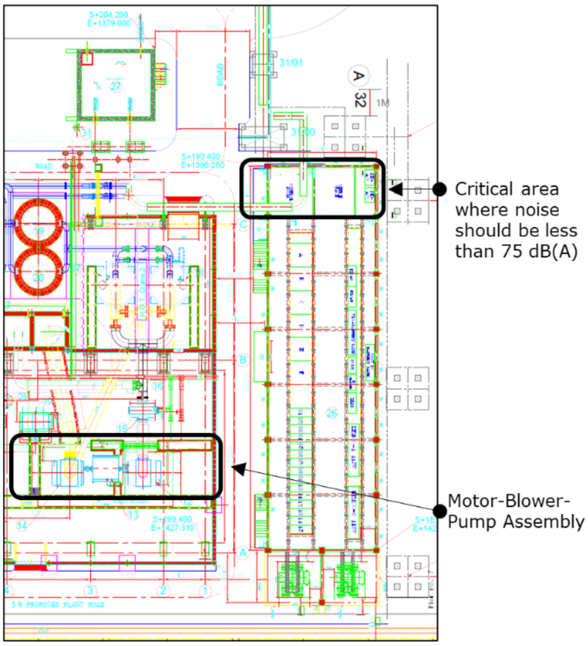

Figure 1. Steel manufacturing power plant layout.

Since these machines are in a confined space, the noise emission of a single piece of equipment cannot be easily distinguished from the others.
The proposed method is based on the recognition that every signal is composed of multiple sound waves, which can be separated using Fourier's superposition theorem. By representing the given signal as a series of sine waves, the relative importance of each component can be determined. The most significant contributions can then be selectively synthesized, allowing for a comparison between the signals emitted with and without an enclosure. This approach enables the assessment of the effectiveness of the enclosure in reducing noise emissions from the source.

3. METHODOLOGY

The SPL measurements obtained using a Class I sound level meter are presented in Table 1, along with some measurements validated using another device to ensure measurement accuracy.

Table 1. Measured sound data at various locations in the case study plant.

Location #	Details	dB (A)
VPSA 1	Blower Front Inside	97
VPSA 2	Motor Front inside	95
VPSA3	Vacuum Pump Front Inside	100
VPSA4	Vacuum Pump Back Inside	102
VPSA5	Motor Back Inside	100
VPSA6	Blower Back inside	111
VPSA7	Blower Front Outside	103
VPSA8	Motor Front Outside	103
VPSA9	Vacuum Pump Front Outside	103
VPSA10	Vacuum Pump Back Outside	107
VPSA11	Motor Back Outside	109
VPSA12	Blower Back Outside	110
VPSA13	Enclosure Left Outside	105
VPSA14	Enclosure right Outside	101
VPSA15	Water I/o	109
VPSA16	suction filter	107
VPSA17	pipe - blower to water i/o	112
VPSA18	pipe zone - water i/o to absorber zone	108
VPSA19	pipe zone - Vacuum pump to silencer tower	107
VPSA20	pipe zone - vacuum pump to absorber / T -joint	112
VPSA21	pipe zone - near silencer tower	110
VPSA22	Absorber Left	110
VPSA23	Absorber Right	114
VPSA24	Absorber Front	115
VPSA25	Absorber Back	112
VPSA26	Absorber Center	115
VPSA27	Near Release Valve	111
VPSA 28	Ouside Absorber Zone at 1m	98
VPSA29	Outside Absorber Zone at 5m	98
VPSA30	Outside Towards Control Room Front Left at 1m	90
VPSA31	Outside Towards Control Room Front Left at control room wall	89
VPSA32	Outside Towards Control Room Front Center at 1m	89
VPSA33	Outside Towards Control Room Front center at control room wall	89
VPSA34	Outside Towards Control Room Front Right at 1m	89
VPSA35	Outside Towards Control Room Front Right at control room wall	87
VPSA36	Ouside shed front right at 1 m	82
VPSA37	Ouside shed front right at 5 m	88
VPSA38	Outside shed double leaf door at front side ---@ 1m	90

A visual representation of the noise levels measured using SPL measurements is presented in Figure 2. Furthermore, the noise map allows to identify the extent of noise interference between two noise sources in proximity.

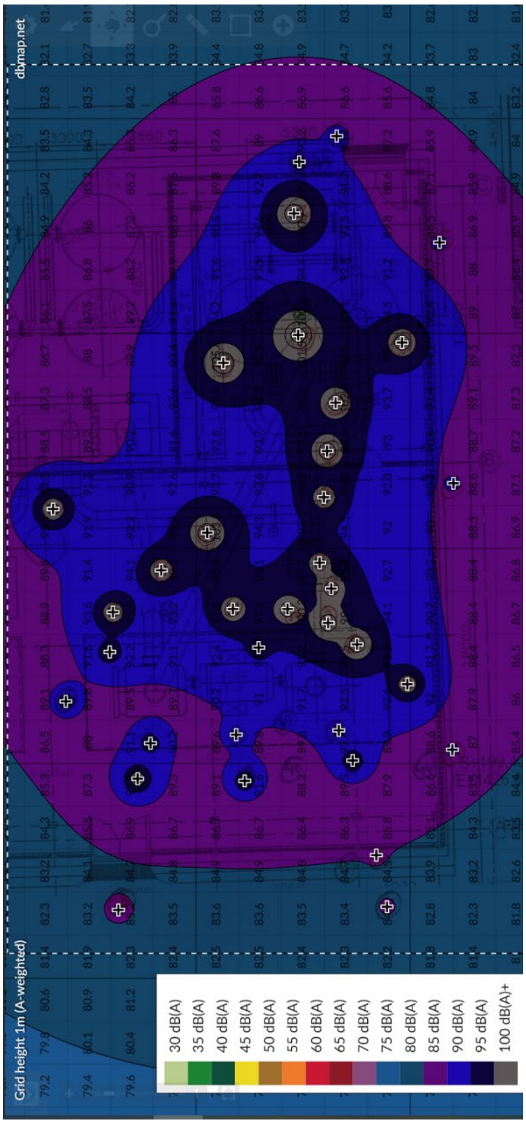

Figure 2. Noise map of the case study plant.

The methodology applied in this study consists of the six main steps:

Step 1: Noise measurements were carried out using a Class 1 sound level meter (Svantek 958A) according to ISO 9612:2009 [10]. Measurements were taken at different locations within the steel manufacturing power plant. The Sound Pressure Level (SPL) measurements were recorded and used to create a noise map.

Step 2: The recorded noise signals were analyzed using a Fast Fourier Transform (FFT) to determine the frequency content of each signal. The FFT analysis helped to identify the dominant frequencies in each noise signal and to separate them from other frequencies that may be due to background noise or interference. The sample size for each location was 2.5 times the maximum frequency (20 kHz). So, the sampling was 50,000 samples per second. A sampling card of 51 kS/sec was used. This was according to Shannon's sampling theory or Nyquist theorem. Linear averaging was performed. Continuous data was collected for at least 30 seconds at each location. The challenge is to collect high frequency data with proper resolution. Data must be free from any leakage and quantization error. While processing data, ensure the data sanctity by properly checking time domain raw data so any unwanted noise is not amplified. Proper averaging of the data can remove any abnormalities or data variants. Processing data with proper filters such as anti-aliasing filter can help.

Step 3: The dominant frequencies of each noise signal were then compared to a database of known noise sources to identify the most likely noise source for each signal. The database was created using a combination of manufacturer's specifications and previous experience with similar equipment.

Step 4: Once the noise sources were identified, anti-noise enclosures were designed for each machine using a devoted software [11]. The enclosures were designed to provide a minimum of 25 dB insertion loss, as per CPCB regulations as shown in Figure 3.

Different layers of materials were used to construct each panel of the enclosure (Layer 1 is outermost):

> Layer 1: Micro perforated sheet with small holes to mitigate low frequency noise content.
>
> Layer 2: Metal perforated layer which makes the structure stable and strong to withhold all the external forces.
>
> Layer 3: Mineral wool 50 mm thick and 60 kg/m3 density is the main layer that absorbs the noise emanating from the three machines.
>
> Layer 4: Acoustic sheet to dampen the noise from the machines.

The effectiveness of the enclosures was then tested by comparing the noise levels before and after enclosure installation.

Step 5: The performance of the anti-noise enclosures was evaluated by measuring the noise levels at the same locations as the initial measurements. The noise levels were then compared to the levels recorded before the installation of the enclosures to determine their effectiveness in reducing noise levels.

Step 6: Finally, statistical analysis was conducted to determine the significance of the results. The data was analyzed using a devoted software to determine the mean, standard deviation, and significance of the results. The analysis helped to determine the effectiveness of the proposed method in identifying noise sources and designing effective anti-noise enclosures.

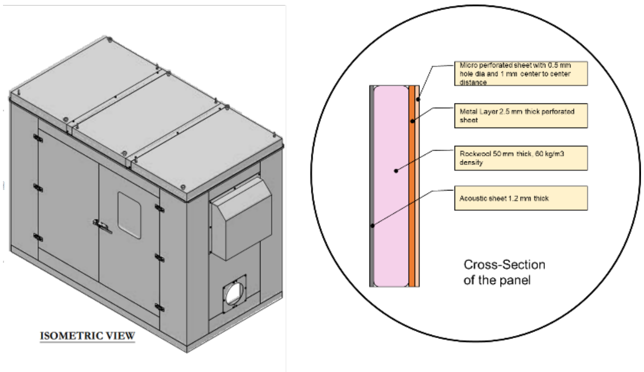

Figure 3. Anti-noise enclosure shown with zoomed in portion of the panel cross-section (inside out from left to right).

4. RESULTS AND DISCUSSION

Noise emissions of three machines (i.e., motor, pump, and blower) were tackled. Figure 4 shows a schematic arrangement of the three machines. Figure 5 shows the frequency response inside and outside the enclosure. As seen, the peaks observed relevant to the motor, pump, and blower equipment have reduced after employing the enclosure. This shows the effectiveness of enclosure in reducing the dB(A) levels emerging from the closely spaced group of three equipment. The noise abatement obtained with the enclosure demonstrated the adequacy of the method developed to study the noise emission of the three different sources. FFT analysis was used successfully to single out noise signature of the machines under investigation in a very noisy environment before and after the enclosure installation.

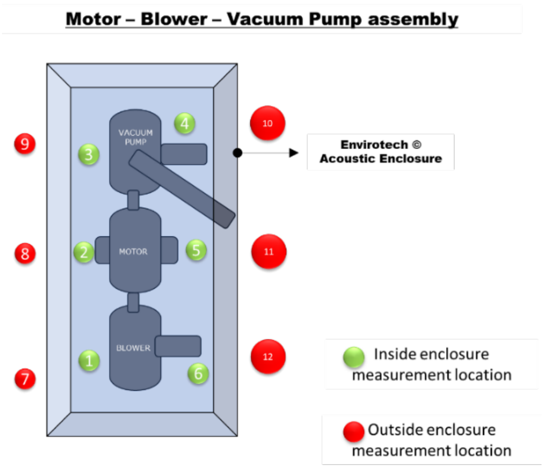

Figure 4. Schematic representation of measurement locations at the group of three equipment (i.e., motor, blower, and vacuum pump from top to bottom) in close vicinity.

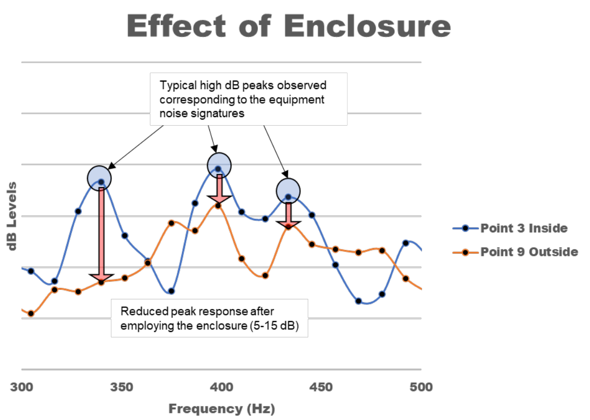

Figure 5. Spectrum contents of closely spaced equipment in power plant acting as noise sources.

5. CONCLUSIONS

Frequency based analysis using FFT algorithm is the most effective way to understand mixed signals. The effectiveness of enclosure to mitigate persistent loud noises emanating from power producing plants was shown in this study by using the frequency-based approach. An enclosure was designed to mitigate noise for closely spaced machinery. A reduction of noise levels up to 15 dB(A) was achieved. The research methodology described in this paper uses a frequency-based approach to identify the quality of anti-noise enclosures designed in a very noisy environment with lot of other background noises. This is a simple technique which requires the user to collect time domain data at various locations in closely spaced machines and process it in frequency domain to identify the effectiveness of an enclosure. This technique was used to identify exactly how much noise levels were reduced from each equipment after observing the noise signature spectrum plots.

6. ACKNOWLEDGMENTS

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