Noise Cancellation Techniques for Enhancing Speech Communication in Mechanized Mines

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Abstract: *Active Noise Cancellation is an approach to noise reduction in which a secondary noise source that destructively interferes with the unwanted noise is introduced. Unwanted acoustic noise is a by-product of many industrial processes and systems including Surface and Underground mines. The sound level inside the mines are beyond permissible level at most of the places and a solution to it using conventional headphones has failed because of its inefficiency in allowing desirable sounds of person to person communication and the sound of the alarm of the 'Roof Fall'. This paper illustrates a design of special headphone incorporating the techniques of ANC and Band Pass Filters for use in mechanized mines which allows all the desirable sound to pass through but filters out the undesired machine noise.*

1. Introduction

Provision of suitable work environment for the workers is essential for achieving higher production and productivity in both surface and underground mines. Noisy working conditions have negative effects on the workers' morale and adversely affect their safety, health and performance. It is brought to the knowledge of all concerned that Noise is emerging as an important and challenging health hazards for mine workers. With increasing mechanization of mining operations and use of heavy machinery the noise level in mines have increased over the years. Surveys conducted by various institutions have shown that noise levels in majority of the mining operations are higher than the recommended limit of 90 db. Repeated or prolonged exposure to excessive noise levels leads to hearing impairment.

Potential sources of noise emissions include compressors, drilling machines, crushers, and other mechanical equipment used at a mine. Increasing the distance between the noise source and the listener is often a practical method of noise control. Where such noise control measures are not possible, personal hearing protection devices, such as approved ear plugs or ear muffs, should be worn by every person exposed to noise levels exceeding 90 dB.

The results obtained after investigation indicated that the sound pressure levels of various machineries were higher than the acceptable limits i.e. >90dB. In the mines under study, most of the mine workers were exposed to SPL (sound pressure level) beyond 90dB due to machinery noise. Therefore, control measures should be adopted in mines for machinery as well as hearing protection aids should be supplied to the workers in order to protect the mine workers from NIHL (Noise induced hearing loss).

In order to assess the status of noise levels in mines, systematic noise surveys are needed to be conducted using appropriate statutory guidelines so that effective control measures can be taken up in mines. Keeping this in view, this paper elaborates the technical details of the level of exposure of the mine workers to noise. A proposed solution to this hazardous aspect, using the technique of Active Noise Cancellation and Sound Filtration has also been made in this paper. This paper also introduces the fraternity to a headphone for mining workers and mining engineers, which is devised using ANC and Sound Filtration.

2. Indian Standards for noise level in mines

Mine workers are regularly exposed to a sound pressure level much above the level permissible according to the Indian standards in most of the mines. And at a level, above which, Personal protective equipment is must, the workers are found working without the PPE. In DGMS Circular No.18 (Tech), 1975, warning limit of 85 dB may be set as the level below which very little risk to an unprotected ear of hearing impairment exists for an eight-hour exposure.

Table 1: Indian Standards for noise level in mines

Sound Pressure Level (dB)	Protective measures
< 85	Very little risk to unprotected ears
90-115	Danger of hearing impairment and deafness
115-130	Worker shall not be allowed to enter without ear protection
130-140	Person protective equipment is must
>140	No worker shall be allowed to enter

3. Noise survey in mines

In order to assess the status of noise levels in mines, systematic noise surveys are conducted using appropriate statutory guidelines so that effective control measures can be taken up in mines. The main noise sources in a mine are the machineries used. Taking this into account, a detailed tabular format (Table 2) has been prepared of the SPL against the machines. The sound pressure levels of noise sources were taken at different distances from the sources. The noise level was measured at a height of 1.6 m from ground level. While,

the sound pressure level was measured at a distance of 2 meters and 5 meters from the noise source.

Table 2: SPL at various distances from the Noise Sources

Noise Source	SPL (dB) at 2m	SPL (dB) at 5m
SCH 4 Crusher	117	114
Mini Crusher	114	111
JCB 3D Loader	111	107
JCB Loader	110	106
Loader 2021	108	105
Shovel PC 300	108	106
Jack Hammer Drill	119	113
DTH Drill	116	111
Compressor	104	98
Belt Conveyor	87	80

Many machines do not operate constantly or at a constant noise level. Exposure to noise varies due to mobility of workers, mobility of noise sources, variations in noise levels or a combination of these factors. Noise levels less than 80 dB may be ignored. If the survey indicates that worker is exposed to noise more than 115dB then, he should be provided with hearing protection.

3.1. Instrumentation

The instrument used was a standard CEL -283 integrating impulse sound Level meter (U.K). It measured noise levels produced both near the source and the operator's level covering a range of 40-120 dB and had a selectable A/ Flat frequency characteristics, Fast slow time constants and impulsive response. Workplace noise level measurements were taken on SLOW response. The A-network was used in the present work, which approximates the human response. After a detailed analysis and measurement it was found that sound pressure levels of various machineries were higher than the acceptable limits i.e. >90dB. A bar graph representation of sound pressure levels produced by various equipment is shown in the following figure.

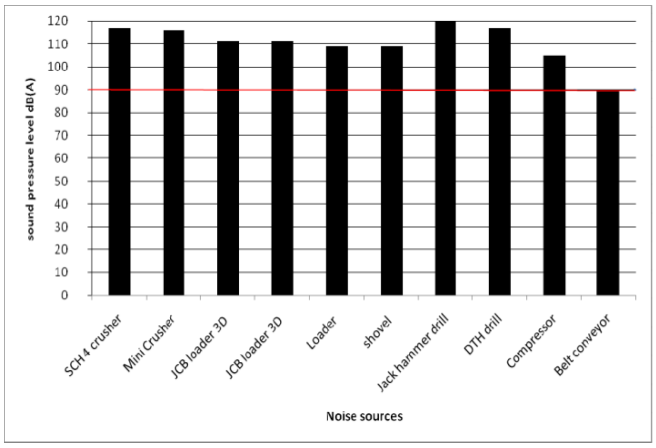

Figure 2 : Bar graph representation of SPL against sources

A red line has been marked to show the permissible Sound pressure level in mines.

4. Exposed Hazards

In an occupational health survey conducted in an below ground metal mine more than 80% of workers showed evidence of Noise Induced Hearing Loss of 27.7% and 13.1% had severe and profound hearing impairment. Noise Induced Hearing Loss was observed among all categories of mine workers but the prevalence was highest among workers engaged in drilling operations. The occurrence and severity of NIHL was related to the degree of exposure to noise and years of service in the mine. More exposed a mine worker is to the noise, more are his chances of NIHL. Apart from this, various other consequences of lesser potential are caused, but are potentially strong to cause a fatal accident in the mine. Some of them are listed in the following sections.

4.1. Inability to hear warnings

Some times because of noisy ambience inside the mines, the primitive indications of a roof fall in the form of bursting sound is neglected by the mine workers unintentionally which proves to be fatal in some cases and highly dangerous the other times. These types of accidents are not directly because of exposure to noise but indirectly a dangerous consequence of noise.

4.2. Inefficient communication

Because of noisy surroundings around the machine operators, it becomes very filthy task for mining engineers to instruct them while on work. The only option left with the engineers remains to instruct them to switch off the equipment first. This regular 'switching off' and 'switching on' of the equipment accounts for a heavy loss to the company in terms of energy consumption. Moreover the efficiency of the manpower also decreases significantly.

5. Action Plan

To its solution, a specially designed headphone is proposed, which is to be used by all the mine workers who are exposed to sounds of SPL >90dB. This headphone will be devised in a special manner to allow only the human voice to reach the ears. So as to filter out all the sounds having frequencies outside the human audible frequency range and will cancel out the undesired noise within human audible range. Basic principles behind the headphone are Active Noise Cancellation to cancel out the undesired noise within the audible frequency range and a Band pass filter to filter out noise which are outside the human audible frequency range.

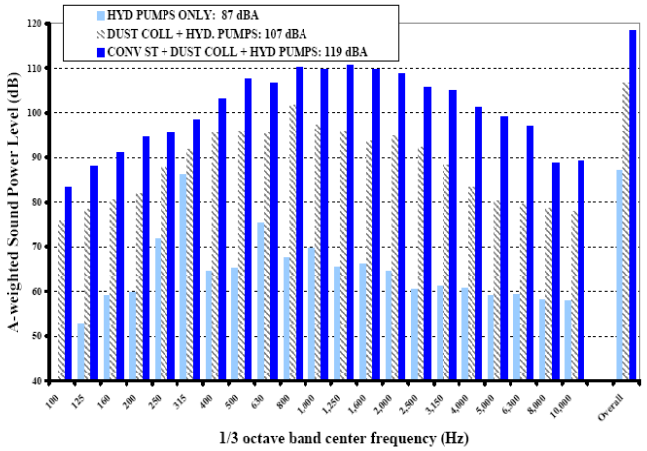

Figure 3: SPL against 1/3 octave band center Frequency (Adam et al, 2007)

A brief idea about the principles on which this device will work is laid down in the subsequent sections.

6.1. Band Pass filter

A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. These filters will be created by combining a low-pass filter with a high-pass filter. An ideal filter would have a completely flat pass band with no gain/attenuation throughout and would completely attenuate all frequencies outside the pass band. This filter will be filtering out the noise produced by the machines reaching the headphones worn by the mine workers.

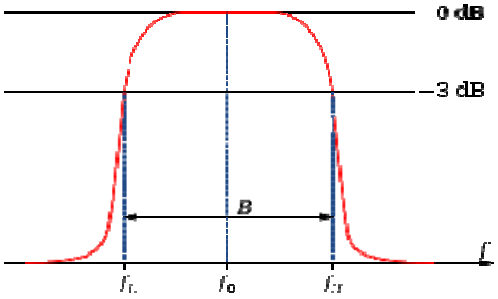

Figure 4: A basic Band pass filter.

6.2. Active Noise Cancellation (ANC)

Active noise cancellation is an approach to noise reduction in which a secondary noise source that destructively interferes with the unwanted noise. ANC is achieved by introducing a cancelling “antinoise” wave through secondary source. Noise Cancellation makes use of the notion of destructive interference. When two sinusoidal waves superimpose, the resulting waveform depends on the frequency amplitude and relative phase of the two waves. If the original wave and the inverse of the original wave encounter at a junction at the same time, total cancellation occur. Thus a sound wave of amplitude and frequency same as that of noise but 180 degrees out of phase cancels out the out of phase machine noise completely.

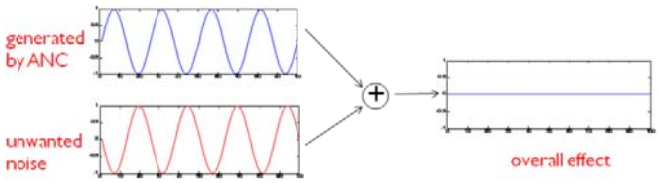

Figure 5: Principle of Active Noise Cancellation.

In other words, Active Noise Cancellation occurs when a microphone fitted on each side of your headphones records the background sound. This recorded signal is processed and played through the headphones in reverse phase. As + 1 and -1 will make 0, the ambient noise along with the reverse phase recording reduces the background sound. This protects the listener to hear only the desired human voice and protects the ears from high sound pressure levels.

We do not tend to think about ourselves as exposed to loud noise in our everyday life, but something as simple as turning up the volume of our music players to drown out the noise on the underground or a busy street may damage our hearing.

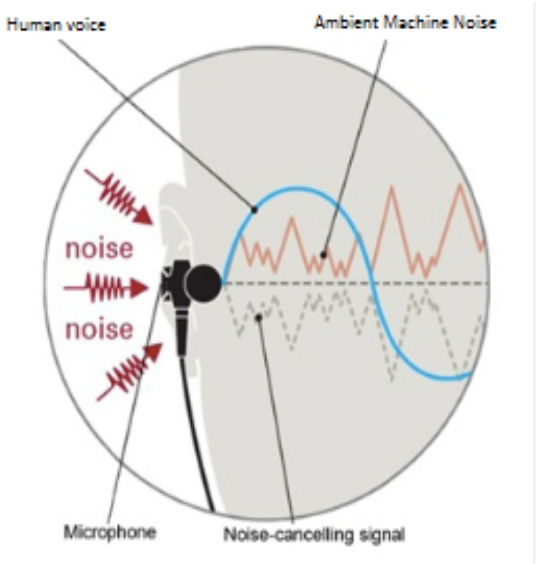

Figure 6: Schematic diagram of ANC equipped headphone

ANC is based on either feed forward control or feedback control. In feed forward control, a reference input coherent with the noise is sensed before it propagates past the secondary source. In feedback control, the active noise controller attempts to cancel the noise without the benefit of an “upstream” reference input.

Structures for feed forward ANC are classified into (1) broadband adaptive feed forward control with a control field reference sensor, (2) narrowband adaptive feed forward control with a reference sensor that is not influenced by control field. Feed forward ANC is generally more robust than feedback ANC particularly when the feed forward system has reference input isolated from the secondary antinoise source.

The goal of active noise cancellation (ANC) is to reduce the amplitude of the sound pressure level of the noise incident on the receiver or ear by "actively" introducing a secondary, out-of-phase acoustic field, “antinoise”. The resulting destructive interference pattern cancels the unwanted sound. Over the past two decades, significant advances in control theory and the development of flexible, programmable, high-speed digital signal processing computers have made it possible to model and implement more complex active noise control systems.

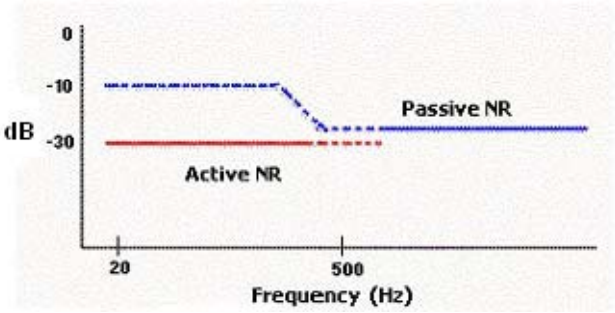

Figure 7: Operational range of active and passive noise reduction

6.2.1. Passive Attenuation

Passive attenuation in an ear cup is a function of the front and rear cavity volumes and the driver compliance below the free air resonance. Increased driver compliance can compensate the reduction of passive attenuation if the front cavity is kept small for maximum efficiency. An ideal cavity is characterized by rigid walls and constant pressure amplitude for wavelengths much larger than the distance across the cavity. The ear cushions should be compliant enough to affect a seal that prevents leaks and as sufficient high density and flow resistance to create such an "ideal" cavity.The diaphragm should be small - less than 1/3 wavelength of the highest audio frequency to be reproduced. There is a trade-off between a small front cavity which will minimize the sound pressure required to cancel low frequencies and a large front cavity which offers superior passive attenuation.

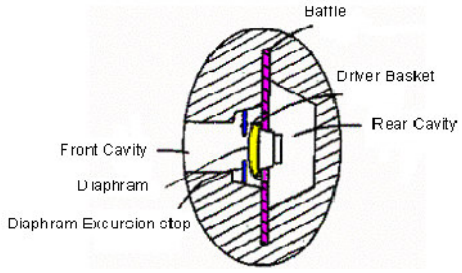

Figure 8: High Compliance Drive for Headphone ANC

The disadvantage with high compliance driver is its sensitivity to overpressure. The pressure waves due to the movement can pull the voice coil outside the gap or distort the diaphragm when the user moves or takes off the headphones. tiny barrier or mesh in front of the diaphragm can prevent its distortion. This diaphragm can also be minimized by indenting it so that it quickly recovers when distorted.

Where passive attenuation begins to weaken in the low frequencies, ANC takes over. Noise cancellation is less effective at high frequencies due to the limitations of ANC filters and headphone transducers to reproduce accurate high-frequency anti-noise. Not all applications require broadband noise attenuation, and some models of NCH reduce low frequency noise only. A noise reducing headphone should have good attenuation at lower as well as higher frequencies.

6.2.2. Feed Forward Control

Digital filters for noise cancellation are called adaptive filters and can correct for both phase and amplitude errors. A NCH using adaptive noise reduction was proposed. A reference microphone at the top of the headband receives a noise signal. The adaptive filter attempts to predict the noise inside the ear cup by passing the signal through a transfer function that models the headphone system. The inverse of the predicted noise is added to the desired audio signal and then sent to the headphone transducer. A second microphone inside the ear cup measures the resulting sound and generates an error signal to converge the filter to zero for more accurate anti-noise

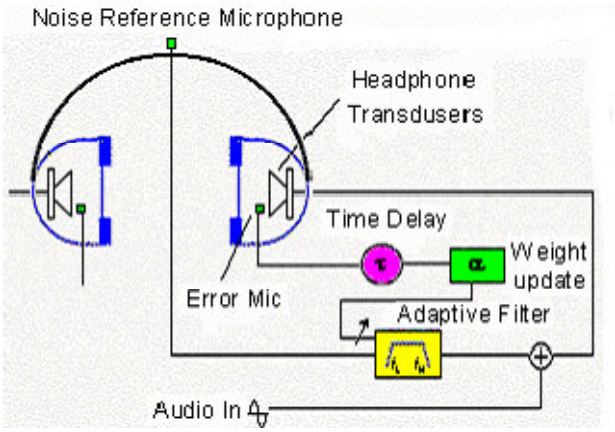

Figure 9: Adaptive Noise Cancellation Headphone

7. Other Practical Applications

Noise canceling headphones are particularly useful for workers, operating or working near heavy machinery and engines. The noise is selectively eliminated thus enabling the reception of the desired sounds, such as speech and warning signals.

Cabin noise in small aircraft is a combination of noise from a variety of sources, the major ones being the engine, wind, and propeller. So plane pilots routinely wear noise attenuating headsets to get rid of the unwanted noise. Such headsets usually employ passive noise attenuation in the form of an annular cushion carried on the rim of each ear cup. But NCH is proved to be worthy in attenuating noise to a further level which makes the pilot as well as passengers to hear warnings and instructions effectively.

In hospitals to diagnose the hearing defects in human ear and speech discrimination, noiseless room is required which is highly expensive. Most of the hospitals cannot afford to procure such rooms. The noise canceling headphone along with audiometry apparatus can be useful in this application.

8. Conclusion

After detailed study of the level of exposure of mine workers to noise and the sound pressure levels of the machine noise, it has been found that most of the mining equipment were observed to be generating the noises exceeding the danger limit set by DGMS. Frequency spectrum analysis revealed low frequency dominant noise situations for almost all-mining equipment. The noise dose of the operators handling noisy equipment, e.g., dozers, dumpers, drills, pay loaders, vibrating screens, mine exhaust fans, compressors, etc. were observed to be quite high.

The Noise Induced Hearing Loss (NHIL) and hearing impairment are prevalent among the mine workers. Moreover, they feel it troublesome to remove and put on their headphones, to talk to their fellow mates inside the mines. The Engineers are also finding it difficult to instruct the operators inside the mine with the headphones on. They need to switch off the machines to facilitate communication, which eventually accounts for heavy loss of energy and manpower. The dire need of the hour has been gauged and so, a headphone has been proposed which can facilitate the communication between persons while blocking the machine noise simultaneously. The proposed solution by means of Active Noise Cancellation Technique and Sound Filters need urgent implementation in mines, particularly in mechanized mines for minimizing the chances of accidents due to unintentional negligence towards oral instructions. It is also proposed to conduct experimental trials on application of Noise Cancelling Headphones in mechanized mines of Singareni Collieries Company Limited.

8. References

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