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A Detailed Study on Various Sources of Cabin Noise and Vibration in Crawler Dozers and Methodology Followed to Reduce the Noise

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ABSTRACT

The major environmental concern in the field of opencast mining industries are the means of controlling and mitigating noise generated from different Heavy earth moving machineries (HEMM) like Excavators, Dozers, Dumpers, Loaders, Graders, etc. Continuous exposure of the operators to excess noise shall result in hearing impairment and other related health issues. Also, for the HEMM manufacturers, it is important to meet the statutory requirement and mine safety norms to qualify for the tenders. Crawler tractors also called Dozers are heavy earth-moving equipment used in open cast mines with metal blades attached in front of it for pushing or dozing of materials. Dozers being one of the major sources of such noise, in this paper we focus on noise control in dozers. The DGMS (Director General of Mine Safety) regulatory requirement specifies the noise generated inside the cabin should be less than 85dB. We present a detailed analysis of major sources of noise generation in dozers, including Structure borne, Air borne and Rattling noise. We also discuss the various stages and methodologies followed to mitigate the noise at different sources and inside the cabin to ensure that the noise level are within the accepted limits. Our study provides a comprehensive understanding of the noise control measures that can be implemented in dozers to reduce noise exposure and ensure safety and well-being of operators in open cast mining industries.

Keywords: Noise, Vibration, Crawler Dozers, Cabin sealing, Sound Proofing

I. INTRODUCTION

Noise and vibration control is of paramount importance in the development of modern earth-moving equipment to meet customer satisfaction and acceptance levels. Heavy earth-moving machinery and equipment used in the mining industry generate high levels of noise and vibration that have adverse effects on human health and the environment. Exposure to high noise levels over an extended period of time can cause permanent damage and health hazards for operators. The generation of noise and vibration is a by-product of almost every industry, opencast mines are of no exception. The equipment and environmental conditions continuously change as the mining activity progresses. Based on their placement, the overall mining noise stemming from the mining equipment differs in quality and level. As a result, noise control has become increasingly important to users of the vehicle and the environment, and vibration is a significant issue closely related to reliability and quality [1]. In opencast mines most of the mining machinery produces noise levels in the range of 90-115 dB(A) [2] USA's National Institute of Occupational Safety & Health estimated that 70-90% of miners would develop hearing loss by age 60 and predicted that one in four mineworkers have hearing issues. The high-level noise caused by heavy machines is one of the most important aspect affecting human health [3]. Most of the time this exposure is more than the mining noise regulations defined by the government and safety agencies. Environmental considerations, safety norms, Improved health, and health awareness are some of the major challenges faced by mining industries nowadays. There are different methods to reduce the exposure of operator to noise on mining sites, One of the method is by using engineering noise controls, which aim to eliminate or minimize the noise at the source.

Based on the study conducted in different parts of the world with respect to harmful consequences of noise exposure, it was realized by DGMS to define noise limits for the mining areas. Accordingly, the following standards and guidelines are recommended vide DGMS Circular No.1 (Tech), 2018 for industrial noise levels. As per the circular, the operators shall not be exposed to noise level that exceeds an eight-hour equivalent continuous sound pressure level of 85dB(A) and wherever it exceeds 85dB(A), personal protection equipment (PPE) of adequate strength shall be used by operators.

TABLE 1

The maximum daily exposure times of the workers for various noise levels. [4]

Noise levels-dB(A)	Daily exposure times(h)
90	4
95	2
100	1
105	0.500
110	0.250
115	0.125

Engineers and scientists continuously work to quantify human vibration tolerance to vehicle vibration [8]. As per international standard test Criteria ISO2631-1, Whole Body vibration values are as shown below. Figure: 1 shows boundary curve for vertical vibrations.

1. Less than 0.315m/s² are "Not Uncomfortable"
2. 0.315 to 0.63m/s² are "a little uncomfortable"
3. 0.5 to 1m/s² are "fairly uncomfortable"
4. 0.8 to 1.6m/s² are "Uncomfortable"
5. 1.25 to 2.5m/s² are "Very uncomfortable
6. Greater than 2.5m/s² are "Extremely Uncomfortable"

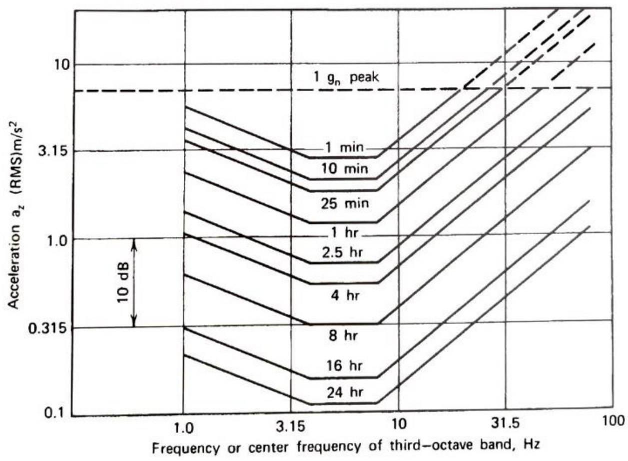

Figure 1: Boundary curve for vertical vibration

In the highly regulated mining industry, Heavy Earth Moving Machinery (HEMM) manufacturers must meet strict safety and statutory requirements in order to qualify for tenders. Implementing engineering controls at the noise-generating point is a very effective way of avoiding exposure to noise. According to the hierarchy of hazard controls, engineering controls isolate workers and others from the noise hazard. Crawler tractors also known as Dozers are heavy earth-moving equipment used in open cast mines with metal blades attached in front of it for pushing or dozing of materials. These Dozers typically have a power rating ranging from 95 Hp to 850 Hp, resulting in high power density that generates significant noise and vibrations during operation. The power train arrangement, including the engine, torque converter, transmission, clutches, and final drive, all comprise numerous mechanical parts that work together at high angular velocities and contribute significantly to noise sources. An experimental study investigating the primary sources of sound from bulldozers found that the exhaust, air inlet for the engines, engine cooling fan, structure-borne noise, and rattling sounds were the main sound sources. The exhaust sound was a significant source of noise at nominal one-third-octave mid-band frequencies from 25 Hz to 250 Hz while the sound from the air inlet was an important contributor in the range of band frequencies from 25 Hz to 500 Hz. The noise from the cooling fan was significant in the frequency range from 315 Hz to 3150 Hz. [5]. As Dozers are a significant source of noise and DGMS (Director General of Mine Safety) regulatory requirements mandate cabin noise levels be kept below 85 dB, reducing noise levels in these machines remains a critical challenge for HEMM manufacturers.

II. INVESTIGATION OF NOISE AND VIBRATION SOURCES IN 850HP CLASS DOZER AND MITIGATION METHODS

The noise and vibration generated by the dozer equipment can be classified into three major categories as

A. Structure Borne Noise
B. Airborne Noise
C. Noise Caused by Rattling

A. Structure Borne Noise:

According to the British Regulations Approved Document E, structure-borne noise is defined as: "sound that is carried via the structure of equipment". For example, The interaction between the track chain and the ground. The sound from the track frame which is integrated with the chassis is classified as one of the structure-borne noise. In technical terms, structure-borne noise can be divided into five distinct processes [6]:

1. Generation: The actual originating source of the oscillation.
2. Transmission: The movement of the oscillation's energy to the equipment from its originating source.
3. Propagation: The mechanism that distributes that energy across the entire structure.
4. Diminution: Indicates to the reflection of sound waves as they bounce off surfaces within the structure, successfully reducing the energy and weakening the sound.
5. Radiation: The production of vibrations from an unprotected surface.

Structure Borne noise in dozers are caused due to following reasons:

1. The interaction between the track chain and the ground.
2. The interaction between track frame and chassis
3. The interaction between engine and chassis
4. The interaction between power train and chassis
5. Major aggregates mounted on equipment like a cabin, fuel tank, hydraulic tank, radiator, etc.,

1) Control of Structure-Borne Noise from Undercarriage: During working of the equipment, the noise generated due to vibration from the undercarriage is transferred to the cabin through the suspension system like cushions & rubber pads. Dozers with a proper suspension system benefit from a quieter cabin with proper anti-vibration mounts. Installation of rubber pads and cushions at critical locations as shown in Fig.02 & Fig.03, where structure-to-structure interaction of undercarriage is predominant, reduces the transfer of noise and vibration inside the cabin efficiently.

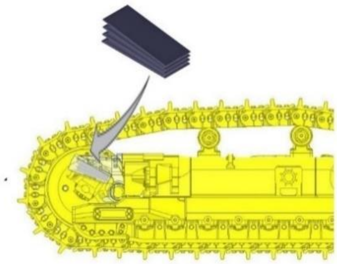

Figure 2: Track frame assembly with track rubber pads

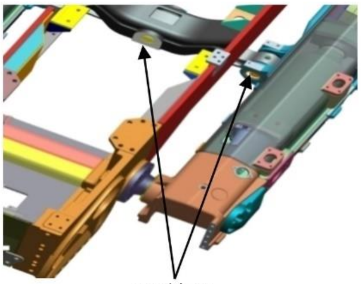

Figure 3: Equalizer bar with cushion mounted

2)Control of Structure Borne Noise from Powertrain: 850Hp Class crawler dozer is powered by diesel engines with robust power train systems and accessories for mobility and function. The Engine and transmission are the main sources of noise and vibration due to a large amount of torque and speeds generated and transferred by their rotating mechanical components.It is necessary to reduce the noise and vibration generated at these sources. Installation of Anti-vibration mounts at critical engine and transmission mounting locations as shown in Fig. 04 effectively suppresses and reduces the noise inside the cabin, considering the axial and radial loads transferred by the Anti-vibration mounts.

Dozer Equipment Specification:

Operating Mass : 100000 Kg

Engine : Diesel engine 4 Stroke and 12 cylinders V type engine

Flywheel Power : 850hp @ 2100 rpm

Max. Torque :4045Nm @ 1300 rpm

Figure 4: Engine & Transmission mounted with anti-vibration mounts

3) Control of Structure-Borne Noise from Radiator, Hydraulic, and Fuel Tanks: Cool pack, hydraulic tank, and fuel tank mounted with isolator cushions & rubbers as shown in Fig. 05 & Fig. 06 provide excellent benefits in suppressing the vibration transfer from the structure thus reducing structure-borne noise.

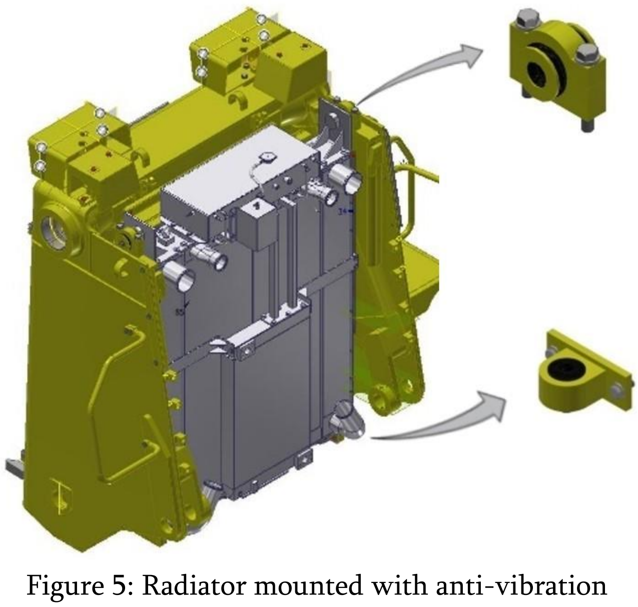

Figure 5: Radiator mounted with anti-vibration mounts

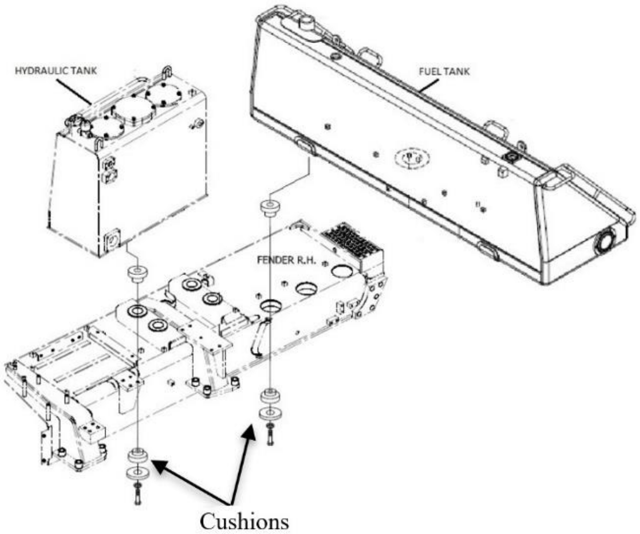

Figure 6: Hydraulic and Fuel Tank with Anti-Vibration Mounts

B. Air Borne Noise:

The noise/sound that is generated from the equipment and travels via the air medium is known as airborne noise. Main examples of airborne noise include sounds from radio and television, talking, and the sound of cars starting or traveling down a road. There are many reasons which cause airborne sound to occur such as Poor workmanship, resulting in openings around structures and doors that allow the sound to travel. These gaps and cracks allow sounds to travel through the air, giving sounds an access point to travel to different parts and inside the cabin.

The acoustic absorption technique is one of the major ways that is used to minimize airborne noise. This decreases the amount of sound that reflects back into the air when hitting a surface within the equipment. Also, the use of sound insulation methods reduces airborne noise effectively. Sound insulation technique is similar to acoustic absorption, except that instead of absorbing sound, the sound is gridlocked from traveling to a related equipment space. The further way by which airborne sound shall be reduced is by ensuring any gaps, holes, and cracks are recognized and eliminated to prevent noise from being able to travel through to other parts of equipment.

Air Borne noises in crawler dozers are caused due to the following reasons:

- Engine exhaust and Air intake system noise
- Fan installation and Fan speed

1) Control of Air-Borne Noise from engine exhausts system and Air intake system: Proper designing of the engine hood system with acoustically treated enclosures as shown in Fig. 07 is effective in controlling and reducing the noise produced from the engine exhausts system and Air intake system. The method involves preventing the path of main noise sources (engine and fan) to the operator, completely closing all openings at floor pedals and operator's seat to reduce secondary noise sources (transmission and final drive), and installation of sound absorption material in the operator's area, primarily on the underside of the floor frame.

Figure 7: Engine Hood

- Proprietary make acoustic foam is used / pasted on engine hood duct, doors, floor frame outer side and floor covers to absorb noise from source (engine, fan, transmission and final drive).
- Proprietary make acoustic foam Gasket is used / pasted on all floor cover and fasteners to avoid metal to metal contact as well as sealing.
- Proprietary make acoustic foam with rubber grip is used as a floor mat to absorb the leakage noise from floor covers.

2) Control of Air-Borne Noise due to Fan Installation and Fan speed: Fan installation methods and noise generated from the high-speed fan is another important factor for airborne noise. In the present improved version of Dozer models the Hydrostatic fan is mounted in front of the cooling system along with a variable speed controller. The main advantage of this installation method as shown in Figure: 8 is that the cooling system will restrict airborne noise transfer to the cabin.

Figure 8: Cooling fan mounted in front of cooling system

Another major improvement in the present version dozer model is the application of a closed-loop electronically controlled variable speed hydraulically driven cooling fan system in place existing conventional fan system. This hydrostatic fan system is gaining momentum worldwide in construction and mining applications due to stringent demand for lower noise from engine cooling fans and a high emphasis on environmental preservation [7]. The fan speed is controlled based on the feedback signal received from the different temperature sensors. The electronic controller receives the signal from three temperature sensors: engine water temperature, CAC, and hydraulic oil temperature. The required fan speed based on the monitoring temperatures is prepared separately and programmed in the controller based on which the target fan revolutions are set. The pump delivery flow is calculated based on the requirement of fan speed. The swash plate angle is adjusted by the pump controller according to the pump flow requirement and also based on the identified engine rpm.

In the previous designed dozer model, the fan is engine mounted and rotates at a constant speed. Due to the above-mentioned change to the hydrostatic fan cooling system, the cabin noise level is reduced significantly compared to conventional version dozer models.

3) Implementation of cabin improvement measures to reduce Noise and Vibration:

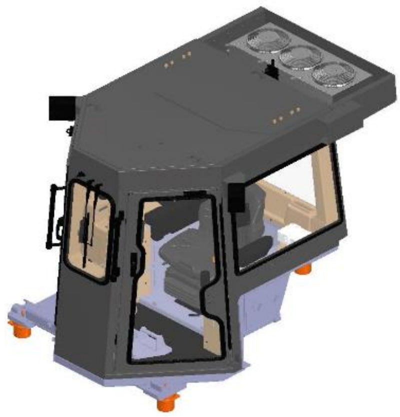

Figure 9: Cabin with Viscous Mounts

- Viscous mounts are introduced in cabin mounting points to absorb shocks and vibrations much more effectively than conventional mounting systems.
- Introduction of the viscous mount and damper spring under the cabin mounting points results in less noise in the cab and a smoother ride over rough terrain.
- Sound proof glass used in windows and doors to avoid airborne noise.
- The cabin and floor frame box section is filled with acoustic material.
- Introduction of dampening paint on internal surfaces of cabin and floor frame.
- Cabin interiors are improved with ABS Garnishing technology.
- AC duct is used to reduce noise coming from the AC unit.

- Pneumatic suspension is introduced below the operator seat to reduce shock and vibration to the operator.

C. Noise Caused by Rattling:

Rattling sound refers to an audible and unwanted noise that spreads through structures and objects mechanically. When an object rattles or is being rattled, it produces short duration sharp knocking sound due to its constant collision with something hard. The primary sources of rattling are, Cabin doors and windows, coupling systems, work attachment, covers, mechanical levers and other similar factors. The noise generated through rattling can add up to structure borne noises and air borne noises, leading to discomfort during equipment operation. Therefore it becomes imperative to reduce the rattling noise for comfortable operation of equipment.

The following measures were implemented to reduce the rattling noises.

- Cabin doors & windows are fixed with rubber beading.
- The Joystick inside the cabin is fixed with acoustic gasket & bellow mountings.
- Control levers inside the cabin are fixed using spring locks.
- Engine hood doors are locked with heavy-duty spring locks.
- Battery boxes are firmly locked with spring locks.
- Side cover doors and radiator cover doors are locked with spring locks.

III. EXPERIMENTAL METHODOLOGY

During development, noise level is measured inside cabin at different exposure. For each test condition, the machine was stationary with the transmission in neutral and engine rpm maintained at "high idle." Sound pressure levels were measured at the ear position of the operator with the operator present in the cabin.

A. Sound Pressure Level Measurement at Operator's Position:

Standard measurement carried out as per ISO 6394-2008, "Earth Moving Machinery – Determination of emission sound pressure level at operator's position – Static Test Conditions"

Figure 10: Sound Pressure Level Measurement at Operator's Position

B. Vibration values Measurement on Operator's seat:

VIBRATION DATA ACQUISITION ON 850HP DOZER	
Test place	Test field
Test facility used	1) OR36 Analyzer (16 channel) OROS make 2) Seat Accelerometer: MMF make 3) NV Gate software VERSION 8.20
Test Condition	1) Cabin mounted with viscous mounts. 2) Duty cycle is carried out in field 3) Forward and reverse travel
Test standard	ISO 2631-1and ISO/TR25398

Figure 11: Vibration values Measurement on Operator's seat

Stage-1 : Equipment with hydrostatic fan mounted in front of cooling system with 2 speed control, cushion mounted cabin and without engine covers.

Stage-2 : Equipment with engine mounted fan, with engine hood covers, acoustic treated floor covers, hood duct, door enclosure, cushion mounted cabin and Pneumatic suspension operator seat.

Stage-3 : Equipment with Fan mounted in front of the cooling system with variable speed controller, with engine hood covers, acoustically treated floor covers, hood duct, door enclosure, Viscous mounted cabin with AC duct, and Pneumatic suspension operator seat.

Figure 12: 850HP Dozer

From the above experimental study from Stage-1 to Stage-3, the overall noise level is reduced by **18%** from 96 dB and the overall vibration level is reduced by **42%** (From stage-2 value of 0.669 m/sec^2)

IV. CONCLUSION

The noise and vibration study conducted out at various stages has provided valuable insights and possible measures for reducing cabin noise and vibration. By analysing the results of the study following measures have been identified as effective in reducing noise and vibration levels inside cabin.

- Mounting of fan in front of cooling system with variable speed controller
- Treating the Engine hood and enclosure with acoustic material
- Treating the Floor frame inside, outside and covers with acoustic material
- Using Viscous mounts for the cabin and floor frame installation
- Ducting of A/C and Garnishing of Cabin interiors with ABS.
- Using Sound proof glass in cabin door and windows
- Using of pneumatically controlled operator seat
- Filling Cabin and floor frame box section with acoustic material.
- Applying Dampening paint on internal surfaces of cabin and floor frame.
- Using Anti-vibration mounts to attenuate the main sources of noise (Engine, Track frame, Power train etc.,)

As a result of these improvements the structure borne noise, Air borne noise, noise caused by rattling and overall noise level have been reduced by 18% and the overall noise level is well within tender and statutory requirement of 85 dB. The overall vibration level has also been reduced by 42%, improving the operator comfort and increasing the equipment lifespan.

Further study is underway to explore the possibility of reducing noise levels by another 5-8 dB. These measures have significant potential to enhance the overall performance of the equipment, and are of interest to engineers and professionals in the field of noise and vibration reduction.

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V. REFERENCES

[1]. Noise in the Mining Industry An Overview

[2]. Noise survey and noise modelling of open cast machineries In mines

[3]. Piccolo A, Plutino D, Cannistraro G (2005). Evaluation and analysis of the environmental noise of Messina, Italy. Appl. Acoust., 66(4): 447-465.

[4]. Noise level analysis of a bulldozer used in constructing a forest road in Mediterranean region of Turkey Hasan Serin* and Abdullah E. Akay Faculty of Forestry, Kahramanmara_ Sütçü _mam University, 46060 Kahramanmaras, Turkey. Accepted 20 April, 2010

[5]. Experimental study of sources of noise from heavy earth-moving machinery. Vardhan, Harsha, Karmakar N.C; Rao Y.V; Noise Control Engineering Journal, Institute of Noise Control Engineering, Vol 53, No.2, Mar 2005, Pg 37-42.

[6]. https://www.novaacoustics.co.uk/blog/what-structure-borne-sound-and-how-can-it-be-reduced.

[7]. Kazuhiro Maruta, Nobumi Yoshida "Low Noise Type Hydraulically Driven Engine Cooling Fan System", KOMATSU technical report 2002, Vol 48.

[8]. Carrol E. Goering, Marvin L. Stone, David W. Smith, Paul K. Turnquist "Off-Road Vehicle Engineering Principles".

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