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Whole Body Vibration Control and Strategies in Open Cast Coal Mines : An Overview

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Abstract : the paper focus on the study of vibration control of Heavy Equipment Mining Machineries (HEMMs) vibration and its effect on the workers involved at mining work. The coal mining workers and the operator of the HEMMs are often exposed to occupational health hazards like Whole Body Vibration (WBV). The effect of these occupational hazards are slow but can be proved to be serious cause for various health hazards like low back pain, spinal problem, and musculoskeletal disorders (MSD). The effort has been made to study the Whole Body Vibration (WBV) in open cast mining based on seat design factors. The mining machineries like blast hole drill machine, excavators, loaders, dumpers, tippers, shovel, and dozers often suffer from the vibration due to lose mechanical parts. The operators of mining machineries are exposed to WBV. Among HEMMs, Dumper are reported to be highly subjected to WBV based on RMS and VDV and hence can be proved to be more hazardous. The evaluation for WBV is done in accordance with ISO 2631-1:1997. Through current study an effort has been made to suggest the innovative measure to reduce the WBV exposure among the HEMMs operator.

Keywords : HEMMs, WBV, HAV, ISO-2631-1:1997

1. INTRODUCTION

A recent mining activity involves the interaction of ore and novel machinery which leads to increase in production. This intense working in order to accomplish the production target set by the mining companies has led to the rise of various occupational health hazards. The machineries such as dumper dozer, excavator, Blast Hole Drilling (BHD) machine experiences vibration at different levels (for instance drilling, excavation, loading, dumping and hauling) of the mining activity. These vibration levels lead to the many job-related health hazards occurring due to the vibration and can be spotted in both on-road and off-road vehicles. WBV occurrence results due to supporting vibrating surface. Vibrating source can be either due to the engine vibration, at the vehicle chassis or due to the seat of the operator. Vibration may enter the body as a result of the contact with the backrest of a seat [1]. These vibrations are most likely to cause the health problems which are associated with human. The principle environment causing whole body vibration include the road transport vehicle, off road vehicle (*e.g* earth moving machinery), marine systems (*e.g* ships, hovercraft, submarines etc), rail transport, aerospace system, buildings, and industrial equipments. The body is highly sensitive to many types of motion and almost any environment can produce sufficient whole body vibration for there to be needed to assess its importance. The nature of vibration and its effects can vary greatly from one environment to another. Hence an appropriate measure is required in order to avoid vibrations. The guidelines for the measurement and the limit value are provided by the International standards. ISO 2631-1:1997 and BS 6841(1987), which is currently followed by most researchers. The whole body vibration regarded

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as significant cause for occurrence of various musculoskeletal disorders. The mining workers involved with HEMMs are most likely to experience such hazardous problem. Hence an effort must be made to reduce the vibration which turn will reduce the whole body vibration exposure among operators of HEMM.

2. WHOLE BODY VIBRATION (WBV): AN OVERVIEW

The works related to mining industry are very intense and hence the operators involved in mining industry are often exposed to whole body vibration (WBV) due to vibration occurring in Heavy Equipment Mining Machineries (HEMMs). The Heavy equipment mining machine in open cast mines such as drill, shovel, road header, rock breaker dumper, & dozers are one of the vibrating sources from mechanical point of view. The Statistical studies in India shows that 1.80 to 18 lakhs of the miners are regularly exposed to the whole body vibration are thus subjected to various Musculoskeletal Disorders (MSD) problems [4]. The characteristic of a machine is that when the vibration occurring due to oscillation as result of internal and external forces, it get transmitted to the operators' bodies through the contact part of the vibrating sources. The mode of transmission can either be due the handle of machine [termed as Hand Arm Vibration (HAV)], or through the surface of machine or seat of the mining machinery [1] [known as whole body Vibration (WBV)]. The greater population of mining workers are reported to suffer from musculoskeletal disorders, spinal problem, and low back problem due to vibration exposure. The problem related to whole body vibration opens to various research work that can still be done based on improving various factors responsible for WBV.

These factors can be classified based upon Environmental condition; personal factors associated with the HEMMs operators; and the machine factors including vehicle condition and service periods, maintenance, vehicle type and design, seat type and seat material, vehicle speed, cab layout, position and design. The studies related to whole body vibration in field mining are very few till date. The works which exist is mainly focused on the evaluation method in accordance with ISO 2631-1:1997 and provides exposure limit value for whole body vibration. The work pointing on strategies and measures for minimising the WBV exposure has not been taken into consideration by many authors. Most of the field work conducted by the authors on the mining machineries especially Load Haul Dump (LHD) machine reported the high level of vibration exposure mainly in vertical axis. However there was the deviation in certain cases which was mainly due to the factors such as road condition, and vehicle speed. The Eger et al.[5] conducted experiment on WBV exposure at the operator-vehicle seat interface of LHD of underground mines based on factors like loading & unloading condition and Mucking tasks. The dominant axis for vibration was found to be along Z-axis between ranges of 0.89-1.18m/s^2. The vibration levels indicated the harmful health effect as per the Health Guidance Caution Zone (HGCZ) mentioned in ISO 2631-1:1997 [8]. Griffin (2002) suggested that vibration exposure level can be minimised by appropriate vehicle selection and their operating condition. An investigation carried out by B.B Mandal et al. (2014)[6] on vibration levels of 157 mining equipment including dumpers, dozers etc in 10 open cast mines depicted that 27 % of the equipment showed minimal health risk, 53% equipment showed moderate and remaining 20% equipment had high health risk to operators. The shovels and excavators that were involved in mining activity had a minimal health while the dumpers and dozers showed high risk potential. Vibrations were measured in three axes among which vibration measurement along the Z-axis was dominant for dumpers and tippers. While X-axis were the dominant axis of vibration for loaders and dozers. The investigation suggested that vibration along Z-axis in Dumpers can be controlled by suitable mechanical control such dampers, seat material and suspension. The operators on WBV exposure undergo musculoskeletal disorders. B.B Mandal & A.K.Srivastava (2010) [7] investigated musculoskeletal disorders in dumper operators on whole body vibration exposure at Indian mines. The investigation was made based on the vibration measurement and exposure time. Vibration along the z-axis was the dominant one ranging from 0.644 to 1.82 m/sec^2(R.M.S acceleration). When measurement were analysed using the international guideline for whole body vibration i.e ISO 2631-1:1997 for an average time exposure of 5 hrs, all dumpers were likely to have high risk for their operators. The paper included forty dumpers operators and 20 controls from the same mines. It was found that 85% of the exposed population were having low back problem as compared to control population. Hence the suitable control measures for minimising vibration and its effect need to be adopted.

3. TECHNIQUES OF WBV ANALYSIS

A. Standards governing Whole Body Vibration and Measurement

The standard that is mostly used and considered to be relevant in measurement of whole body vibration is ISO 2631-1:1997 and BS 6841(1987). BS 6841 (1987) has been used extensively in European countries. ISO 2631 contains vibration exposure limit and defines the technique for vibration evaluation containing high peak values (having high crest factors). The root mean square (*r.m.s*); and the Vibration Dose Value (VDV) are generally used for WBV measurement. [8]

Mathematically *r.m.s* value represented as:

$$A_{w\,r.ms.} = \sqrt{\frac{1}{T}\int_0^T a_w^2(r)dt}$$

Where, $a_w(t)$ – Frequency weighted instantaneous acceleration at time "*t*"

T – Measurement period (*s*)

And VDV can be represented as:

$$VDV = \sqrt[4]{\int_0^T a_w^4(t)dt}$$

$a_w(t)$ – Frequency weighted instantaneous acceleration at time "*t*".

T – Measurement period (**s**).

ISO 2631-1 provide Health Guidance Zone (HGCZ) as shown in fig 1. The exposures above HGCZ indicate no health effect and above HGCZ indicate potential Health risks. The upper and lower limit value is 0.47 m/s^2 and 0.93 m/s^2 (in terms of r.m.s) according to HGCZ. The corresponding VDV value is 8.5 m/$s^{1.75}$ and 17 m/$s^{1.75}$

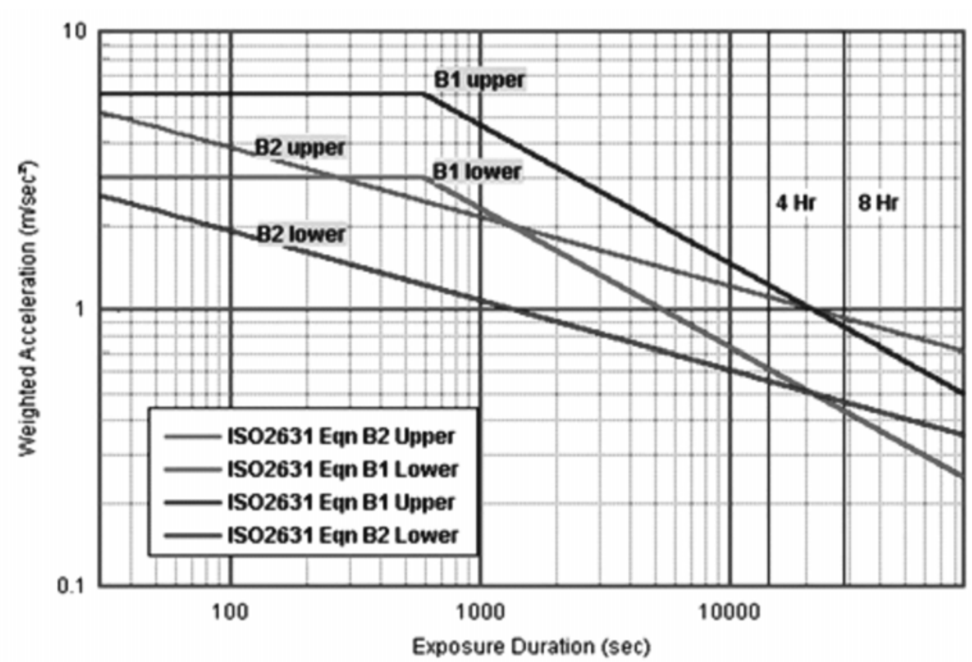

Fig. 1. ISO 2631-1; 1997- Health guidance caution zone, [8].

4. WBV REDUCTION STRATEGIES AND CONTROL:

The vibration of the machine significantly depends on machine factors including vehicle speed, vehicle type, seat type and seat material, maintenance, and service periods, cab layout, position and design. The works related to these factors in mining machineries field are very few.

A. Seat Type : The seat type is an important factor for reducing the vibration. Implication of different seat material has different effect of vibration transmission to the operator. Kolich et al. (2005) obtained the higher vibration extent for less firm and thinner seats and also considered the effect based on different foam deflection and foam density for seat deign as shown in fig 2.

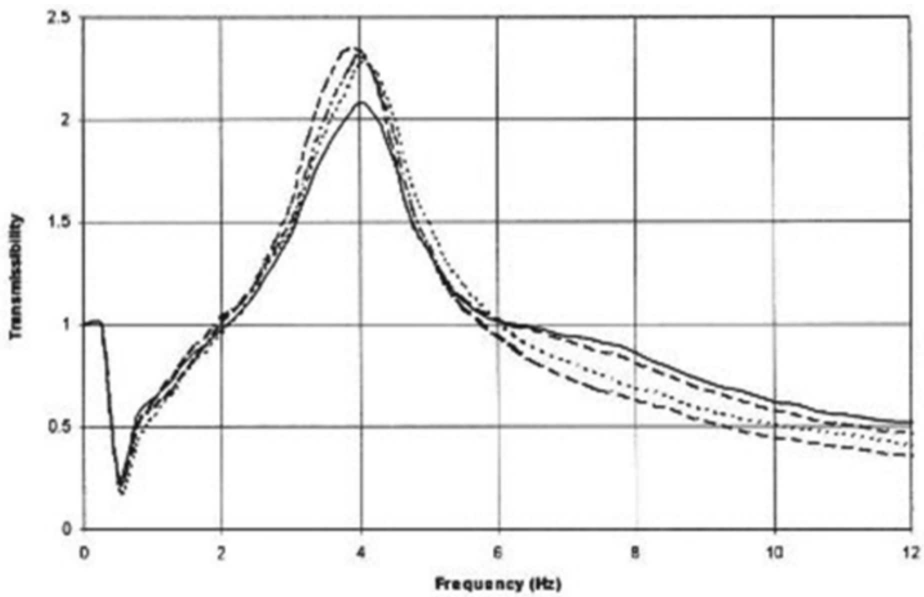

Fig. 2. Foam effects on occupied vertical vibration transmissibility [kolich 2005].

Hinz et al. (2002), vibration effect on Human based on seats without and with a backrest. The r.m.s value noted was higher for without backrest. Therefore there is need for development of proper seat material which will minimize the vibration at operator seat interface and proper adjustment of seat backrest at an angle to minimize the WBV effect at the driver seat interface. The seat can be provided with cushion of suitable material that will act as an additional isolator to dampen vibration.

B. Seat suspension : seat suspension plays a vital role to dampen the vibration effect before it reaches to the operator. The work related to improving the seat suspension in heavy equipment mining machinery in order to reduce WBV is relatively quite less. Selection of suitable suspension seat on basis of vehicle and its work is quite relevant. Most of the mining machineries involved in mining activity have to perform intense work. Hence work on seat suspension can be proved to beneficial in reducing WBV. Application of pneumatic seat suspension can be more efficient as compared to conventional mechanical suspension seat. The work by Bouazara et al., 2006; provide a justification for the suitable seat suspension dampening the vibration effect in vehicle.

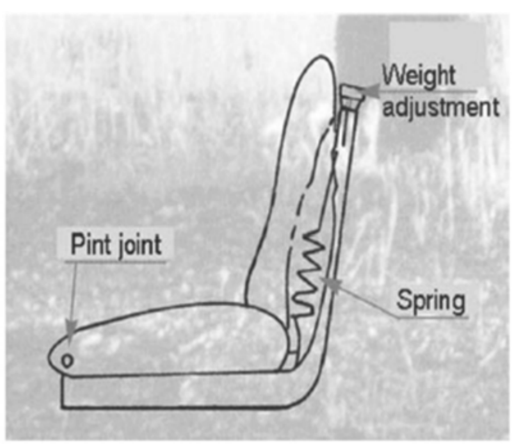

Fig. 3(*a*). Mechanical Suspension (Non Compact)

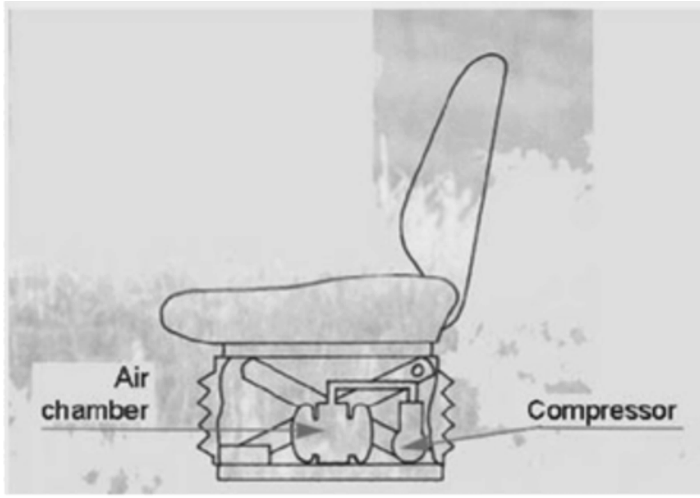

Fig. 3(*b*). Mechanical Suspension (Non Compact)

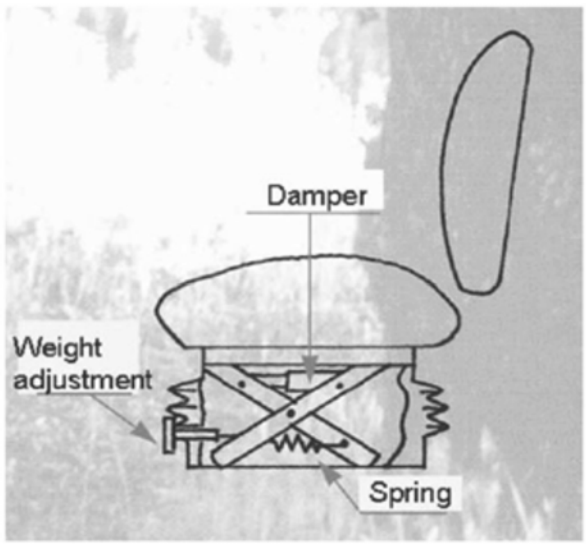

Fig. 3(*c*). Pneumatic Mechanical Suspension

Fig. 3. Different suspension type for dampening Vibration

5. SUMMARY & CONCLUSION

The operators involved with mining machineries are more likely exposed to Whole Body Vibration. The work related to WBV in field of mining machineries mostly related to the measurement side and deciding the appropriate exposure limit of WBV. The works related to minimizing the effect of WBV from mechanical point of view are quite few. According to ISO 2631:1997 exposure limit value is estimated to be 0.90 m/s^2 in terms of r.m.s value and 17 $m/s^{1.75}$ in terms VDV (vibration dose value). An attempt must be made to limit the value within the given range in order to avoid WBV exposure among the operator of HEMMs. These vibration exposure can be reduced with suitable selection and consideration of the mode through which the vibration is transmitted i.e seat material and seat design.

Machinery Directive 89/392/EEC of 1996 suggested the mobile machinery manufacturers to improve the safety regarding physical agents such as noise and vibration. It recommended for information and evaluation of WBV exposure if weighted r.m.s measured at vehicle-operator seat exceeds 0.5 m/s^2. The work related to selection of proper seat material and its analysis in reduction of WBV exposure need to still improve by combination different material and to study their effect. The combination of different suspension system can be done and studied to dampen the vibration effect. There is a need for seat suspension design based on dynamic consideration of the machineries, operating nature of machineries and the vibration characteristics to it will be exposed. The damper and the spring provided is further interesting research work that can be carried on for reducing vibration and hence its effect i.e WBV. The damping effects of different material are different and thus have different effect on vibration. Apart from these there is need for deciding appropriate vehicle speed running in coal mines. The studies show that the machinery in loaded condition has lower vibration magnitude with respect to unloaded condition. This can be justified by the graph obtain from work of Donati (2002)

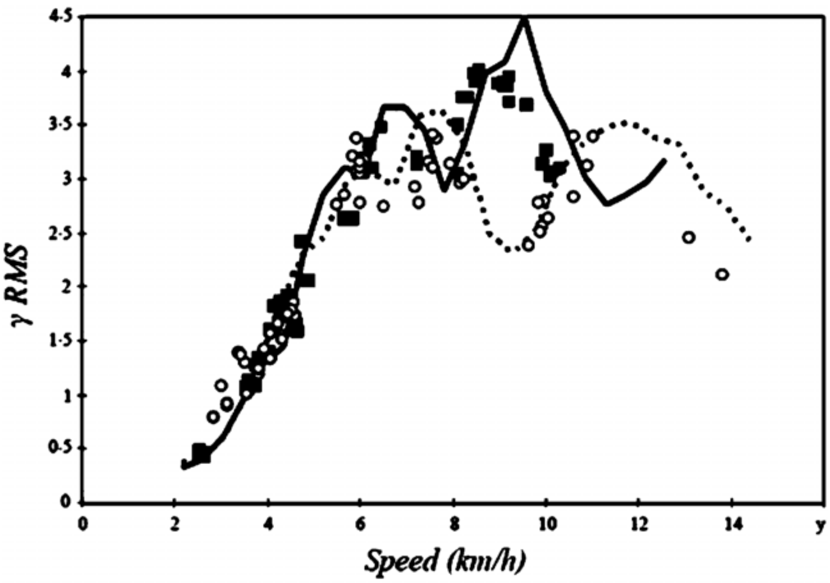

Fig. 4. Comparison of r.m.s acceleration at different speed. [Donati 2002]

Hence in order decrease the WBV exposure among the operator of mining machineries factors including nature of work, design consideration of seat suspension, seat material might be of greater interest of research. These considerations of factors are more likely to provide the preventive measure to reduce vibration and WBV. This in turn will also reduce health hazardous problem such as various musculoskeletal disorders among operators.

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