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Performance evaluation of anti-vibration measures for reducing hand transmitted vibration in self-propelled vertical conveyor reaper

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Abstract
Background: Harvesting rice, wheat, and some other grain crops is popular with the Self- Propelled Vertical Conveyor Reaper (SPVCR). It has been known that continuous exposure to hand-transmitted excitations has an adverse influence on operators. It effects on bloodstream, peripheral nervous system, or the musculoskeletal system have indeed been considered as critical occupational hazards.
Methods: Two kinds of anti-vibration measures have been developed to reduce the adverse effects of Hand-Transmitted Vibration (HTV). Styrene-Butadiene Rubber and Neoprene rubber were used to develop anti-vibration measures. The constituents used for these anti-vibration measures were improved into cylinder-shaped isolators based on the load acting on the engine.
Result: To avoid vibration transmission to the handle, cylindrical isolators were situated between the engine and the frame. Maximum vibration in transportation was 27.98 m s^{-2} at 2800 rpm and maximum vibration in wheat harvesting was 19.90 m s^{-2} at 2200 rpm of engine. The vibration magnitudes were reduced more in case of x-direction, however, in y and z direction the vibration magnitudes were also reduced. Maximum vibration reduction was observed with Neoprene isolator at 2200 rpm (1/2 throttle speed). There was no significant difference between SBR and Neoprene at 2800 rpm ($3/4^{th}$ throttle speed), however reduction in vibration was above 80 per cent in both materials for transportation.

Keywords: vibration, SPVCR, HTV, isolators, anti-vibrational measures

Introduction
SPVCR is the most popular machine for harvesting cereal crops in India due to scarcity of labour during peak harvesting season and it was introduced about 15 years ago (Mehta *et al.*, 2014) [10]. It is now popular among the small and medium farming communities due to its size, affordable price, and less maintenance compared with large agricultural machinery. The principal function of vertical conveyor reaper is cutting, conveying and windrowing the crop to a particular side.

The importance of ergonomics has been widely acknowledged in industry and military applications, as well as in agriculture. Agricultural workers are among the most significant sources of farm inputs in majority of the countries. In farming ergonomic applications can correspondingly help in increasing efficiency and productivity, reducing difficulty in work and work-related health problems, and enhancing the protection of labors in various activities. Ergonomics has become extremely relevant since the introduction of contemporary technology. Recognizing that the social consequences of illness and injury are real and significant, ergonomics has been considered a prominent scientific subject for socio-technical development through its assistance in the improvement of farming. Human's discomfort and ache in farm work is induced not just by physical labor, but also by vibration and noise. (Huang and Suggs, 1968) [4].

The vibration that personnel controlling machinery are exposed to throughout their work is among the biggest sources of discomfort. Walking type SPVCR is controlled and operated by human. The operator must walk behind the machine to direct it. Operator exposed to adverse conditions (temperature, humidity, noise, dust, and elevated levels of vibration) induced by active interaction between the element and the working environment while performing different farm activity. Human vibration corresponds to the oscillations that affect the human body and is divided into two sorts. Whole Body Vibration (WBV) and Hand-Transmitted Vibration (HTV) are two types of vibration. HTV exposure during VCR running exceeds the ISO-5349 (1986) [5] allowed limit of 2.9 m s^{-2} for a 4-hour daily exposure time.

In SPVCR, one of the major safety concerns is large amount of HTV. These are induced through the hands into the body and are caused by machine tools or workplaces. Because the VCR's interface is a cantilever beam and the power is coming from a single cylinder diesel engine, hand-transmitted vibration is particularly serious (Ying *et al.*, 1998). The hand arm vibration is conveyed to the operator's hands, arms, and shoulders, causing discomfort and early weariness. In vibratory model of the worker body, the hand, arm, and shoulder are sensitive to a frequency range of 30-50, 5-10, and 20-30 Hz respectively. The hand arm vibration is passed to the administrator's hands, arms, and shoulders, causing discomfort and early fatigue. Fatigue that lasts for months or even a year can result in physical, physiological, and musculoskeletal problems (Waersted and Westgaard, 1991) [14]. The operator was exposed to severe vibration during the operations with vertical conveyor reaper. The magnitude of such vibrations is greater than permissible vibrations.

The vibration is delivered to the hands, arms, and shoulders from the handle. Occupational disease has been characterized for the symptoms, which include impacts on bloodstream, peripheral nervous system, and the skeletal muscles. Therefore, there is need to decrease the amount of vibration of VCR considering the effect of long-term use of machine. Reduction of vibration is one step in the direction of health and safety regulation. In the view of the above an attempt was made to reduce level of vibration of VCR by introducing suitable mechanical measures. This can be break down into two simple steps, those were the main steps involved in the study

- Development of anti-vibrational measures with different materials for decreasing the HTV.
- To determine HTV with different anti-vibrational materials in SPVCR during transportation and wheat harvesting.

Materials and Methods

The present study of performance and evaluation of developed isolator for SPVCR was carried out at Dept. of FMPE, CTAE, Udaipur during months of February and March of 2018. The material and methods followed for evaluation of isolators with different materials for SPVCR has been described under the following subheads.

Selection of material for development of isolator

The synthetic rubber is generally used for development of cylindrical isolators (Binisam and Kathirvel, 2009). In the present study, synthetic rubber that is Styrene-Butadiene Rubber (SBR) and Neoprene Rubber were considered for creating vibration dampening interface. These two materials were also very cost-effective because of abundance availability in various types in local market.

Styrene-Butadiene Rubber was selected because of its inherent properties like elastic reversibility, toughness, permeability, machinability and adhesiveness make it a good anti- vibration material. The selected material is also a water repellent and resistance to alkalis and weak acids. Generally, synthetic rubber outperforms other materials in terms of ageing and weathering, oil, solvents, oxygen, and some chemicals resistance, and dampness resistance.

The second material selected was Neoprene which is also in chloroprene rubbers. Generally, this type of synthetic rubber made from polymerizing chloroprene. Generally, Neoprene is available in two forms: solid rubber and latex, it is widely used in a wide range of applications such as electronic insulation, automotive fan belts, laptop sleeves and isolating pumps and compressors. The properties of two selected isolators in present study are given in Table 1.

Table 1: General properties of SBR and Neoprene

S. No.	Parameters	SBR	Neoprene
1	Hardness, Shore A	50-55	65-70
2	Density, (kg m^{-3})	1.2×10^3	0.8×10^3
3	Tensile strength, (kg m^{-2})	19×10^5	21×10^5
4	Brake elnogation, (%)	Upto750	100-650
5	Deflection compression	2.5 mm for 50 kg	2.1 mm for 50 kg
6	Compression set	Effective	Effective
7	Heat ageing	Satisfactory	Satisfactory
8	Abrasion resistance	Excellent	Very good to excellent

Development of anti-vibration measures

In a vibratory system, vibration isolation is a phenomenon in which mechanical energy is transformed to heat energy and dispersed. In VCR, the power came from a one-cylinder diesel engine. The unbalanced piston movement generate the vibration in engine (Jiao Qunying *et al.*, 1989). This vibration transfers directly to chassis, so finally this accounts for vibration of handle. Various investigations have been carried out in order to minimise HTV. Investigators have recommended various measures to decrease hand-arm oscillations by placing the different materials at different sources of vibration like isolators between engine and chassis, the anti-vibration measures are so located that the vibration transmitted to the handle is minimum to decrease the HTV. In this present study to decrease the transfer of engine vibration to chassis, four cylindrical isolators (Fig 1c) were provided in between engine and chassis.

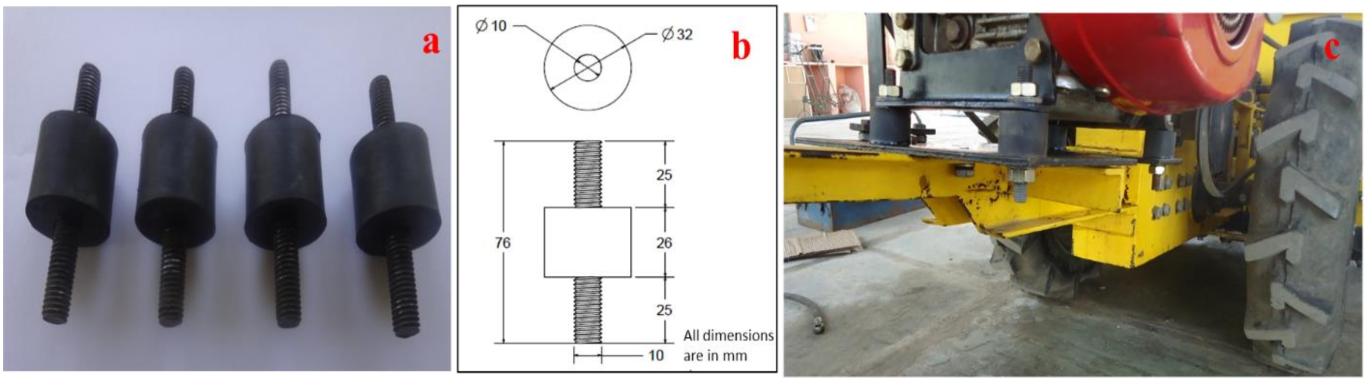

Fig 1: a) Developed four cylindrical isolators b) front view of isolator c) View of cylindrical isolators placed between engine and chassis of SPVCR.

The main elements of the isolator were isomers (SBR and Neoprene Rubber). SBR and neoprene provide a greater level of absorption and compression capabilities than springs. They can operate at a variety of frequencies and with amplification. Because of their great energy storage systems and flexibility of shaping to any shape, isomers, also called as elastomers, were well suited to be used in isolation. In compression, the elastomers must not be repeatedly stretched for more than 10-15%, and in shear, not more than 25-50%. The application of the load dictated the choosing of cylindrical isolators, therefore the engine's weight also taken into account (Tewari and Dewangan, 2009) [13].

The anti-vibration measures were designed as per the requirements of VCR. Both SBR and Neoprene isolators developed with the same dimensions. The engine weight and dimensions of different machine parts were taken for the design of isolators. Based on these data the selected materials were purchased, and the isolators were developed as follows

Four cylindrical isolators were developed to reduce the vibration that is generated from engine. The material adoption and development of interface was dependent on properties of isolator and engine weight. Based on load coming on isolators and diameter of the bolt for fixing the isolators between engine and chassis, the isolator's dimensions were fixed. The dimensions of developed cylindrical isolator are given in Fig 1.

Experimental Design

The experiments were conducted with two operational conditions, each at two different forward speeds. The experiments were designed in two phases. In first phase vibration magnitudes were taken without anti-vibration measures and in second phase the whole experiments were repeated with the developed anti-vibration measures. The experiment design without and with anti-vibration measures is mentioned in Table 1. Dependent Parameter is vibration magnitude in x, y and z axis (m s^{-2}). The experiments were conducted on selected field conditions as per experimental plan given in the following table.

Table 2: Design of experiments for performance evaluation of developed isolators.

S. No.	Independent Parameter	Levels	Particulars
1	Anti-vibration measures	2	I_1 =Isolator for engine and chassis using SBR I_2 =Isolator for engine and chassis using Neoprene
2	Operational conditions	2	X = Transportation (On bitumen road) Y = Wheat Harvesting
3	Engine speed (rpm)	2	A = Half throttle speed (2200 rpm) B = 3/4th throttle speed (2800 rpm)
	Replication	3	

Experimental Procedure for performance evaluation of developed anti-vibration measures

Before performing the experiments, the precautions were taken to suit the conditions for evaluation of anti-vibrations. The road was dry, level, and had a medium finish. Wheat harvesting trials were carried for Raj-4120 was the crop variety, and the moisture content was 33.9 percent (db). It was a dry, undulating field. During the experiment, the average soil moisture content and bulk density were 14.8 percent (db) and 1.62 g/cc, respectively. The average dry bulb temperature, relative humidity, and wind velocity were 36 °C, 19%, and 2.1 m s^{-1}, respectively.

The developed measures perform two tasks; first to create discontinuity in direct contact between the two exteriors and at the same time it provided the rigidity to function the VCR easily in the diverse working situations. The magnitudes of vibration were evaluated after incorporating anti-vibration measures in VCR.

Method for assessment vibration magnitudes during different selected operational conditions

The hand adapter was firmly attached to the VCR's right side. To measure the vibration strength at the handle, the accelerometer was installed on the adapter only with the help of a stud. Whenever the hand grabbed the grip, the metacarpus bone was angled 45^0 degrees to the vertical. To eliminate any relative movement between the point of measurement and the accelerometer, the accelerometer was carefully attached to the adapter. A single subject was used to operate the VCR throughout the experiment.

In this study, a four-channel SVAN 958 vibration analyzer was used which has a frequency range of 0.5 Hz to 20 kHz. Each of the four channels operates at the same time, with input (transducer type), filters, and RMS detector time-constants that are all adjusted separately. Real-time four-channel 1/1 octave or 1/3 octave analysis with statistical computations, real-time four-channel FFT analysis with cross spectra, and sound intensity measurements are all possible with the digital signal processor running in parallel with the metre mode. Vibration analysis satisfies ISO-5349 a.b. (2001) [6, 7] and ISO-2631-1 (1997) criteria. The vibrational meter has two measuring ranges 17.8 m s^{-2} and 316 m s^{-2} respectively. The accelerometer and the vibration analzer are connected via a four-pin cable. At the end of experiment, the vibration analyzer data was transferred into a desktop or laptop for additional examination.

Results And Discussion

Effect of anti-vibration measures on vibration magnitude

After incorporation of Neoprene isolators between engine and chassis the vibration values were reduced from 13.91 to 7.20 m s^{-2} and 19.90 to 8.08 m s^{-2} in transport and wheat harvesting, respectively at 2200 rpm. Subsequently from 27.98 to 5.25 m s^{-2} and 15.55 to 6.98 m s^{-2} in both operational conditions at 2800 rpm. The observed vibration reduction in transportation by isolators made up of Neoprene at 2200 and 2800 rpm were 48.22 percent and 81.2 percent. The observed vibration reduction in wheat harvesting by isolators made up of Neoprene at 2200 and 2800 rpm were 59.39 and 55.11 percent respectively.

After incorporation of SBR isolators between engine and chassis the vibration values were reduced at 2200 rpm from 13.91 to 11.93 m s^{-2} and 19.90 to 10.73 m s^{-2} and at 2800 rpm 27.98 to 5.21 m s^{-2} and 15.55 to 6.08 m s^{-2} in transport and wheat harvesting, respectively. For isolators made up of material SBR the observe vibration reduction in 2200 and 2800 rpm were 46.08 and 60.90 percent respectively. For isolators made up of material SBR the observe vibration reduction in 2200 and 2800 rpm were 18.18 and 81.3 percent respectively, as shown in Fig.2 and 3.

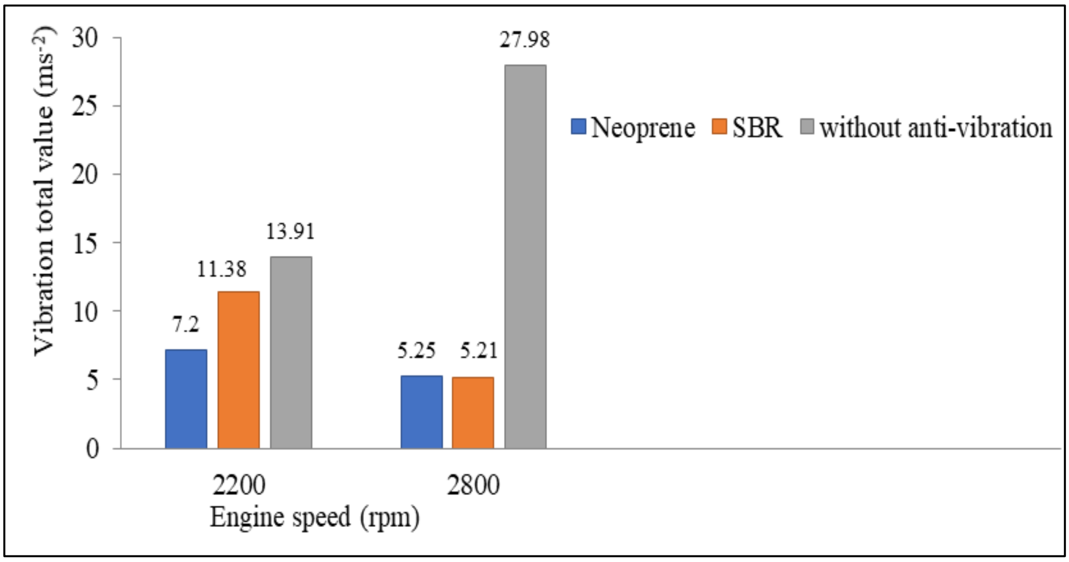

Fig 2: Vibration magnitudes with and without anti-vibration measures in transportation.

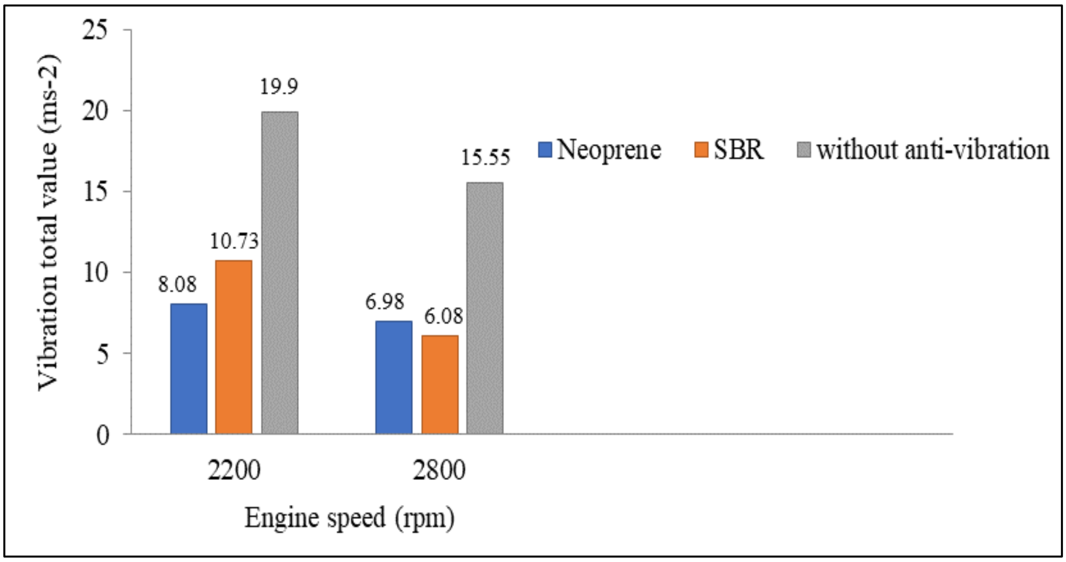

Fig 3: Vibration magnitudes with and without anti-vibration measures in wheat harvesting.

Maximum vibration reduction was observed with Neoprene isolator at 2200 rpm (half throttle speed). There was no significant difference between SBR and Neoprene at 2800 rpm (3/4th throttle speed).

1/3rd octave band frequency spectra of vibrations without anti vibration measures

Without anti-vibration measures, frequency spectra were acquired with all 3 axes in both transport and wheat harvests. The magnitudes of vibrations were measured over a frequency band of 6.3 to 200 Hz. The vibration amplitudes were concentrated in the 0-200 Hz range. It was recorded that the vibration magnitudes were maximum in x-direction and minimum in y-direction for both transportation and wheat harvesting operation. The vibration amounts for all direction were decreased with increase in engine speed for both operations. It is also clear that the vibration magnitudes were maximum in transportation as compared to wheat reaping. Peak acceleration observed in one third octave frequency band spectra for both transport and wheat harvests at engine speeds of 2200 and 2800 rpm.

This could be because the engine in the VCR was the primary source of vibration excitation; its many moving elements oscillate at different frequencies based on their degree of freedom and natural frequencies, contributing to the overall system's vibration. This vibrational interference makes the total system's vibration quite complex, which could be the reason for the appearance of numerous dominant frequencies.

Different researchers have reported on the frequency during which resonance occurs. Reynolds and Angevine (1977) [11], Gurram *et al.*, (1994) [3], Cherian *et al.*, (1996) [1], and Sorensson and Burstrom (1999) reported hand resonance frequencies of 63, 63-100, 20-30, and 40-100 Hz, respectively (Sorrensson and Burstrom. 1997) [12]. Another larger peak acceleration emerged following the initial peak in the current investigation, however this may not be deleterious because weighting has a roll-off rate at higher frequencies (Mansfield, 2004) [9]. Maximum accelerations were also reported to have a similar frequency range (50 Hz) by (Goglia *et al.*, 2006) [2].

The year of manufacture of vertical conveyor reaper used for experimentation was in 2011. The greaves engine model 5520 used in VCR and the age of vertical conveyor reaper used was approximately 6 years. This may be one of the reasons for observing a high vibration during transportation at 2800 engine rpm.

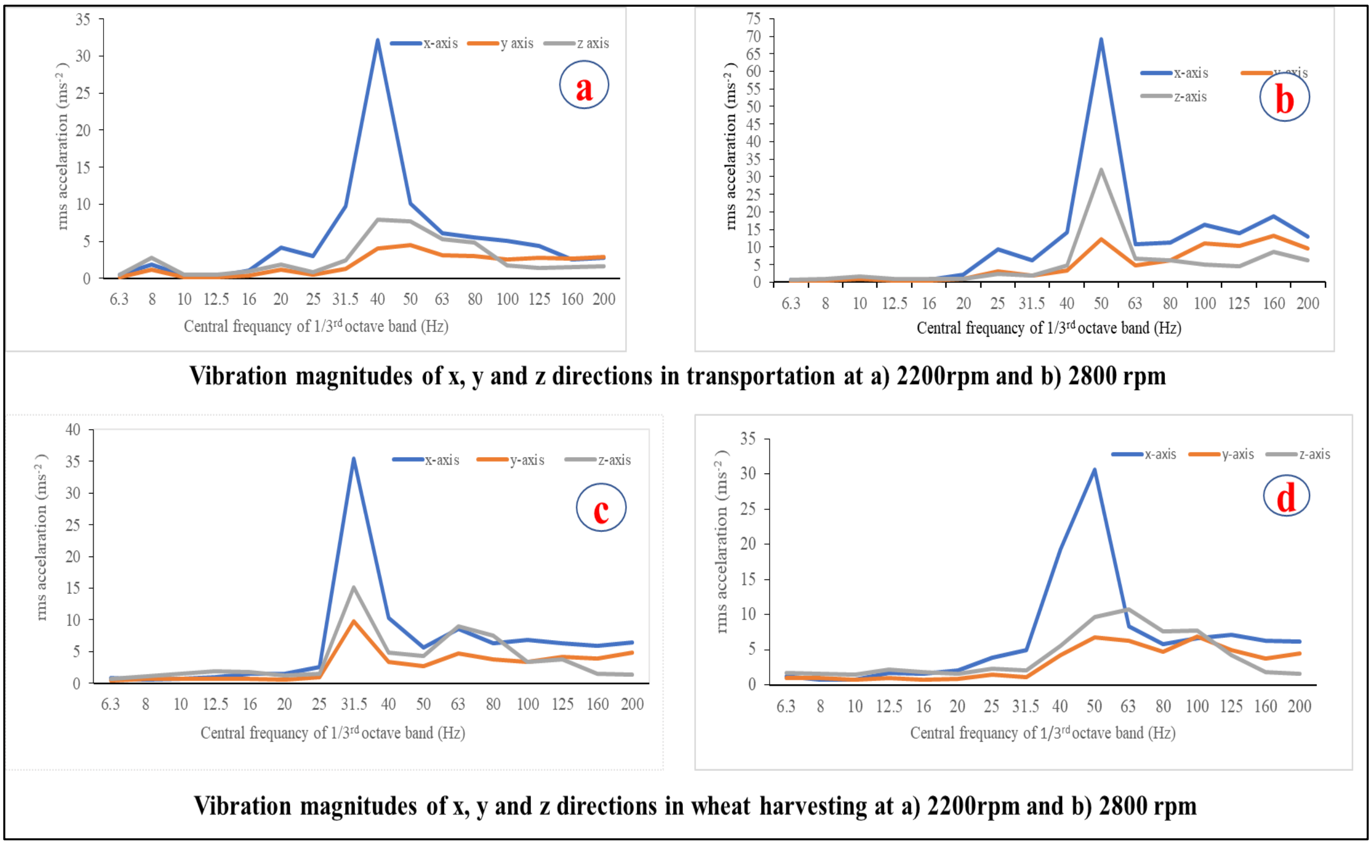

Fig 4: Octave analysis without anti-vibration measures in different operational conditions

1/3rd octave band frequency spectra of vibrations with anti-vibration measures

For each of the three axes, frequency spectra were obtained in both transportation and wheat harvesting with anti-vibration measures. It was clear that the vibration magnitude without anti-vibration measures in x-direction were high for both operational conditions. After application of developed anti-vibration measures the vibration magnitudes were reduced for all operational conditions. The reductions in vibration magnitudes were higher in case of Neoprene at 2200 rpm and at 2800 rpm there is no significant difference between both the isolators. So, Neoprene was better material for reducing the vibration.

The magnitudes of vibrations were also reduced more, as shown in the following figures (Fig. 5) in case of x-direction after application of anti-vibration measures. In y and z direction the vibration magnitudes were also reduced. These reductions indicating higher duration of exposure limit.

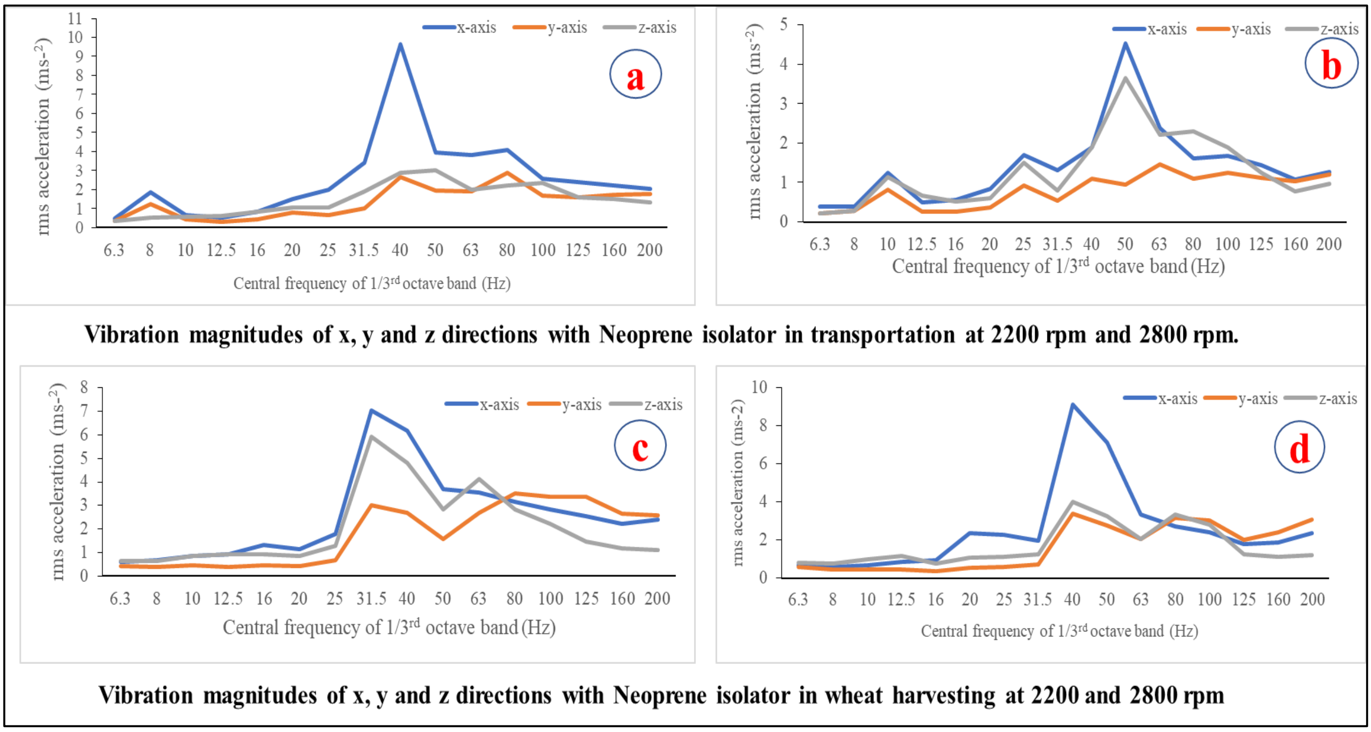

Fig 5: Octave analysis with anti-vibration measures in different operational conditions.

Comparison of 1/3rd octave band frequency spectra examination of vibrations without and with anti-vibration measures

For each of the three axes, frequency spectra were obtained in both transportation and wheat harvesting without anti-vibration measures. The magnitudes of vibrations were measured over a frequency range of 6.3 to 200 Hz. The one-third octave band frequency spectra for both transportation and wheat harvesting operations employing isolators are shown in (Fig 4). Peak acceleration observed in one third octave band frequency spectra for both operational conditions at rpms of 2200 and 2800. During transportation, a high acceleration of 69.26 ms^{-2} was measured in the x-direction at 2800 rpm.

For each of the three axes, frequency spectra were obtained in both transportation and wheat harvesting with anti-vibration measures. The one-third octave band frequency spectra for both transportation and wheat harvesting employing isolators are shown in Figures 5. Peak acceleration observed in one third octave band frequency spectra for both transport and wheat harvest at rpms of 2200 and 2800. The peak acceleration of 9.66 ms^{-2} was observed in x-direction at 2200 rpm during transportation however the reduction in vibration magnitudes were seen in z-direction and y-direction after x-direction.

Analysis of variance for vibration magnitudes without anti-vibration measures

The vibration magnitude analysis was carried out in SPSS statistical software. The vibration magnitude without ant-vibrational measures were carried in analysis of variance (ANOVA) and it was presented in Table 3.

Table 3: ANOVA for vibration magnitudes without anti-vibration measures.

Source of variation	D.F	SS	MSS	F-value	SEm±	CD (p=0.05)
Replication	2	19.911	9.956	2.893	0.927	2.887
Operational condition	1	31.170	31.170	9.058*	0.757	0.5515
Speed	1	70.762	70.762	20.563**	0.757	0.5515
Operational condition * Speed	6	254.657	254.657	74.003**	1.071	0.780
Error	11	20.647	3.441	NA	NA	NA

*, ** indicates 1 and 5 % level of significance respectively

ANOVA Table shows the results of the analysis of variance of the vibration magnitudes with anti-vibration measures at 1 and 5% level of significance. The smaller p-value (prob. < F) and lower F-value indicates more significant. The operational conditions were highly influenced by anti-vibrational measures at 1% level of significance with critical difference (CD) 0.55. the speed and interaction between the operational condition with speed are influencing at 5% level of significance it means that 95% of variation is due to experimental variables and there is only 5% chance only due to other variables.

Analysis of variance for vibration magnitudes with anti-vibration measures

Table 4: ANOVA for vibration magnitudes with anti-vibration measures.

Source of variation	D.F	SS	MSS	F-value	SEm±	CD (p=0.05)
Replication	2	0.047	0.0235	0.050	0.242	0.734
Anti-vibration measures	1	10.218	10.218	21.822**	0.198	0.1414
Operational condition	1	104.584	104.584	223.349**	0.198	0.1767
Speed	1	4.117	4.117	8.791**	0.198	0.1767
Anti-vibration measures * Operational condition	1	10.854	10.854	23.180**	0.279	0.2263
Anti-vibration measures * Speed	1	0.952	0.952	2.033 NS	0.279	0.2263
Operational condition * Speed	1	1.034	1.034	2.207 NS	0.279	0.2498
Anti-vibration measures * Operational condition * Speed	1	4.150	4.150	8.863**	0.395	0.4059
Error	14	6.556	0.468	1.0	-	-

*, ** indicates 1 and 5 % level of significance respectively

The vibration magnitudes with anti-vibration measures were presented in Table 4. It was observed that the anti-vibrational measures, operational conditions and speed were influencing at 5% level of significance. In interactions only anti-vibration measures with operational conditions alone influencing at 5% of level of significance and other variables found as non-significant.

Cost comparison of Neoprene and SBR

The resilience of material depends mainly on its performance and cost. The anti-vibration measures used in the experiment are Neoprene and SBR. Neoprene isolators are costly when compared with SBR isolators. However, the cost of each isolator and total cost for engine-chassis interface of single VCR were given in the below Table 5.

Table 5: Cost comparison of Neoprene and SBR

Isolator Material	Cost per isolator (Rs.)	No. of isolators	Total Cost (Rs.)
Neoprene	175	4	700
SBR	135	4	540

Conclusions

The following conclusions were drawn from present study as follows:

1. Maximum vibration in transportation was 27.98 ms^{-2} at 2800 rpm and maximum vibration in wheat harvesting was 19.90 ms^{-2} at 2200 rpm of engine.
2. The vibration magnitudes were reduced more in case of x-direction. However, in y and z direction the vibration magnitudes were also reduced.
3. Maximum vibration reduction was observed with Neoprene isolator at 2200 rpm (half throttle speed). There was no significant difference between SBR and Neoprene at 2800 rpm (3/4th throttle speed), however reduction in vibration was above 80 per cent in both materials for transportation
4. Neoprene isolators are costly when compared with SBR isolators but vibration reduction was found to be maximum in Neoprene and hence it is recommended.

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