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Optimization of Agriculture Tractor Seat Vibration Using Passive Suspension System and Modelling and Simulating in Ansys

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ABSTRACT

Operators of agricultural tractor perform various tasks at work that expose them to a variety of risk factors. During their work, agricultural tractor operators are exposed to different negative influences, due to which vibrations are especially harmful. Long term exposure of tractor driver to vibrations induced by agricultural tractor operations may lead to various health problems. It is widely recognised that agricultural tractor operators are exposed to high level of whole body vibration (WBV) during specific farm operations. WBV may leads to Low back Pain (LBP) and spinal cord related diseases, therefore the objective of the study is to reduce the level of ride vibrations experienced by tractor seats appear to be necessary and some possible methods of achieving significant improvements. In the present study, The vibration transmitted through the seat of a four-wheel drive tractor equipped with front suspension axle and shock absorber for the implement, were measured using OR34-2, 4 Channel FFT analyser and then analysed in terms of root mean square (RMS) accelerations according to the ISO standard. Several tests were conducted in different conditions considering the type of operation (harrowing, ploughing and cultivating) at different road conditions (on road, sugarcane field and flat field) with two different running speeds. Then we developed a new suspension system for tractors seat using spring and dampers to reduce the vibration energy and frequencies up to a suitable range for the operator. The vehicle dynamics model of tractor with tandem suspension is modelled and simulated in analysis software ANSYS and optimize the parameters of the seat to achieve rms acceleration in the range of 'Health guidance caution zone' (HGCZ) so that it gives the ride comfort for the operator.

KEYWORDS: *Vibration, Low Back Pain, RMS Acceleration, Tractor Seat, Suspension System, Springs, Damper, Frequency, etc*

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INTRODUCTION

Vibration is one of the most commonly investigated ergonomic factors affecting workers health and work efficiency. Human vibration is defined as the effect of mechanical vibration on the human body. Around the world, millions of people are exposed to mechanical vibrations while working. The effect of vibration is critical in terms of human health, working comfort, work productivity, work quality, and work safety. Long-term exposure to whole-body vibration (WBV) may cause serious health issues, including spinal column problems and lower-back pain, depending on the magnitude, frequency, direction, duration, and distribution of the vibration on the human body. In addition to the workers' health, their safety, comfort, and working efficiency are also adversely affected by WBV exposure. Workers from many occupations are exposed to WBV on the road or off-road vehicles. Much research has been done investigating the exposure of farm tractor operators to high levels of WBV. Tractors do not usually have suspensions, thus, vibration levels in tractors are higher than in other road vehicles. The tyre-axle and axle-frame suspensions of road vehicles are not available on tractors; rather, the only suspension is between the frame and cabin and the seat.

India is the largest world market for tractors below 37 kW, due to the small size of farms. The current population of tractors in India is around 1.5 million and more than 0.15 million tractors are added to Indian agricultural field every year. They are being mainly used for primary and secondary tillage operations and for the transportation to haul goods, people and even animals. There is a tractor with a suspension that seats commercially available in Indian models have insufficient vibration protection. With the high degree of mechanisation of farms along with larger size and complexity of farm machinery, a safe comfortable working environment for the driver becomes an important consideration if productivity and customer satisfaction are to be increased. The occupational hazards of tractor driving include deafness, pain, and injury, disorders of the spinal column and stomach, caused by vibration. Besides, these also result in lower quality and work output.

Drivers of agricultural tractors under the whole body vibrations result in human fatigue, causing a driving related accident and other problems. Longer exposure during performing, cultivating, ploughing and harrowing operations may also cause severe discomfort, pain, and injury. These result in increased risks for low back and pain disorders were reported among tractor drivers due to continuous exposure to whole body vibration. The origin of this health problem is vibrations transmitted to the driver caused due to the unevenness of the road surface or soil profile, or moving elements within the machine or implements.

The main design criterion for this study is a minimisation of the root mean square (RMS) acceleration level of the driver in accordance with International Organization for Standardisation (ISO 2631:1997) comfort levels. The suspension system on most commercially available tractor seats consists of a mechanical spring and damper. This type of system responds passively to vibrations transmitted to the driver from the terrain over which the tractor is driven. The performance of passive commercial tractor seats has been widely researched and it was observed that drivers were often subjected to vertical vibration levels that exceed the ISO exposure limits. At present, there is a need for the development of agricultural tractor that enables more comfortable and safe performance of various agricultural tasks. With regard to tractor operations, one of the important points in the design and use of tractors is the invention of comfortable seats that can prevent occupational diseases caused due to whole-body vibration.

A. Whole Body Vibration

Whole body vibration refers to the vibration transmitted to the body from the supporting surface like feet, buttock of a person driving a vehicle; vehicles which drive over rough terrain have vibrations induced in them by the uneven surfaces over which they travel. If these vehicles had no suspension system every bump over which the vehicle travelled produced vibration which is directly transmitted to the vehicle's operator.

B. Harmful Frequency Range

Whole-body vibration is harmful to human because it excites the natural frequency of the body. The dynamics of the human body has been researched to determine which frequencies are most harmful. Gniady's and Bauman from Aura Systems determined the natural frequencies of the human body in the sitting position. The human body usually has a natural frequency between 4 and 5 Hz. Table shows a number of vital body parts and the corresponding natural frequencies. Most of the vital organs of the body, such as the stomach, spine and heart have a natural frequency around the 4 to 5 Hz range, as suggested by Gniady's research. Knowledge of the most harmful frequency range of the sitting human body dictates the necessary frequency range of a vibration cancellation device.

Table -1: Natural Frequencies of the Human Body

Body Part	Natural Frequency	Body Part	Natural Frequency
Trunk	3-6 Hz	Heart	4-5 Hz
Eyeball	20-25 Hz	Shoulders	2-6 Hz
Chest	4-6 Hz	Head	30 Hz
Thorax	3 Hz	Stomach	4-7 Hz
Spine	3-5 Hz	Colon	20-25 Hz

C. Effect of Whole Body Vibration

Vibration is one of the most commonly investigated ergonomic factors affecting workers' health and work efficiency. Around the world, millions of people are exposed to mechanical vibrations while working. Vibration in a working environment may produce a wide range of effects.

The effect of vibration is critical in terms of human health, working comfort, work productivity, work quality, and work safety. Long-term exposure to whole-body vibration (WBV) may cause serious health issues, including spinal column problems and lower-back pain, depending on the magnitude, frequency, direction, duration, and distribution of the vibration on the human body. In addition to the workers' health, their safety, comfort, and working efficiency are also adversely affected by WBV exposure. Workers from many occupations are exposed to WBV on the road or off-road vehicles. Much research has been done investigating the exposure of farm tractor operators to high levels of WBV. Tractors do not usually have suspensions, thus, vibration levels in tractors are higher than in another road vehicle. The tyre-axle and axle-frame suspensions of road vehicles are not available on tractors; rather, the only suspension is between the frame and cabin and the seat.

D. Types of Seat Suspension System

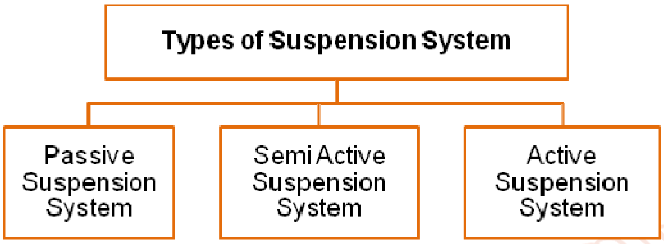


Fig -1: Types of Seat Suspension System

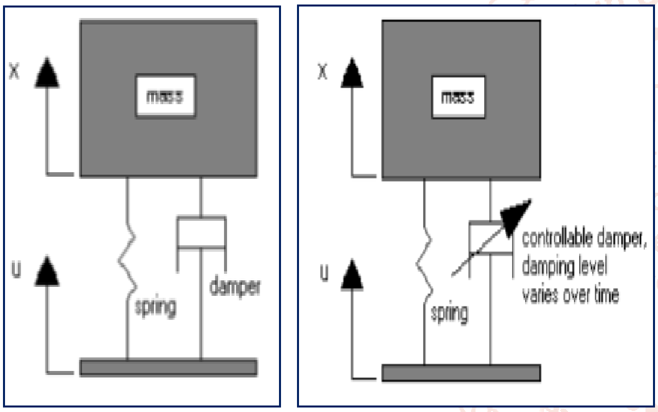


Fig -2: Passive and Semi Active Suspension System

2. RESEARCH METHODOLOGY

A. Aim of the Study

The main aim of this dissertation work is to reduce the vibration in tractor seat up to the operators comfort level, by developing a new suspension system.

B. Problem Statement

From the critical discussion on literature survey and gaps identified from the literature, the problem statement for the current project will be, to reduce the vibration of tractor seat by using a new spring damper passive suspension system so as to get comfort to the operator and analyse with the current suspension system.

C. Objectives of the Study

1. Measurement of dimensions of the conventional tractor seat and the consideration of specification of the tractor. Take the readings of accelerations by using FFT analyser.
2. Comparison of measured data with ISO standards.
3. Develop and design a new suspension system with the existing system for reducing the vibration transmitted through the seat.
4. Take the reading on the modified seat to check the ride comfort thereby increasing the potential of the operator and finding out the parameters for modified seat.
5. Compare the results obtained from the existing seat suspension and modified seat suspension.

D. Scope of the Study

The scope of the project is to minimize the vibration of the tractor seat with the help of a modified spring damper seat suspension system combined with the current suspension system. So that the comfort level of the driver will be increased.

E. Methodology of the Study

1. Carry out physical experimentation for data acquisition regarding vibration levels of existing seat.
2. Study and identify the vibration level and frequency range of conventional tractor seat.
3. Review the existing seat design and for improvement design and develop new suspension system.
4. Carry out physical experimentation on modified tractor seat.
5. Compare the new design system with the existing seat.
6. Validate the result with ISO 2631-1 'Health guidance caution zone' limits.
7. Modeled and optimize the system to achieve results in 'Health guidance caution zone' limits.

3. MODELLING AND DATA ACQUITION

A. Tractor Specifications

Table -2: Tractors Specifications

Model	RV-3 XM + 3A
HP Category	35 HP
Type	4 Stroke, Direct injection Diesel engine
No. of cylinders	3
Bore and stroke	100 X 116 mm
Displacement	2734 cc
Max torque	469 Nm @1400-1600 rpm
Rated engine speed	1800 rev/min
Air cleaner	3- Stage oil bath type
Cooling System	Water Cooled with no loss tank
Clutch	Duel-280mm diameter
No. of gears	8 forward, 2 Reverse speeds
Brake	Dry disc brakes
Gear speeds (km/hr)	Forward: 2.30-27.80 Reverse: 2.73-10.74
Total length	3470 mm
Total width	1695 mm
Wheel Base	1950 mm
Total Height	2255 mm
Ground clearance	395 mm
Weight of Tractor	1895 kg
Tires	Front:1300 mm Rear:1350 mm

B. Tractor Seat

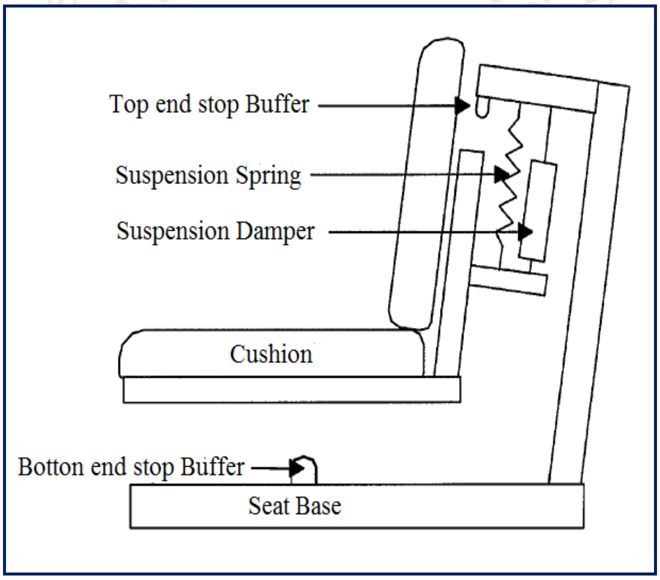


Fig -3: Conventional Tractor Seat

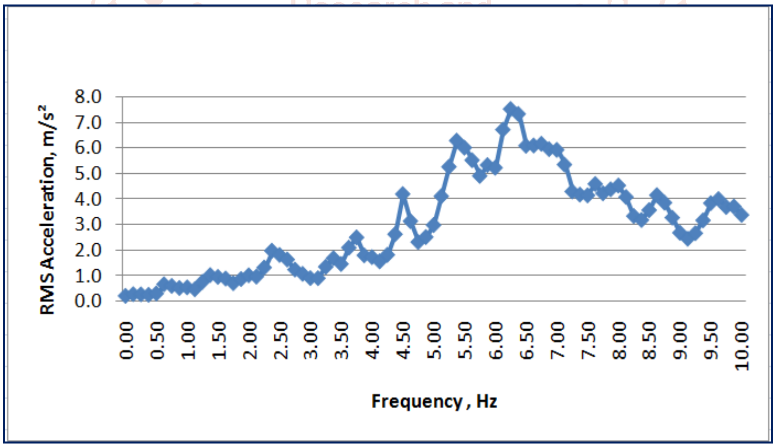
Two conventional seats in current production were used for this investigation is shown in the fig. The seat was a compact design for use in farm tractors with the suspension components mounted behind the backrest. Seats had covered with foam cushions, steel coil springs, oil dampers and rubber end-stop buffers. The seat is directly attached to the chassis. Therefore most of the forces transmitted to the driver through seat suspension. The seats are considered representative of seats mounted on many off-road machines. The design of seats mounted on tractors, earthmovers, and industrial trucks are similar and consist of a suspension (springs, damper, guiding system), a cushion, and two sets of end-stop buffers, one to limit the free upward travel and the other to limit the downward travel.

C. Measurement of RMS Acceleration on Conventional Tractor Seat

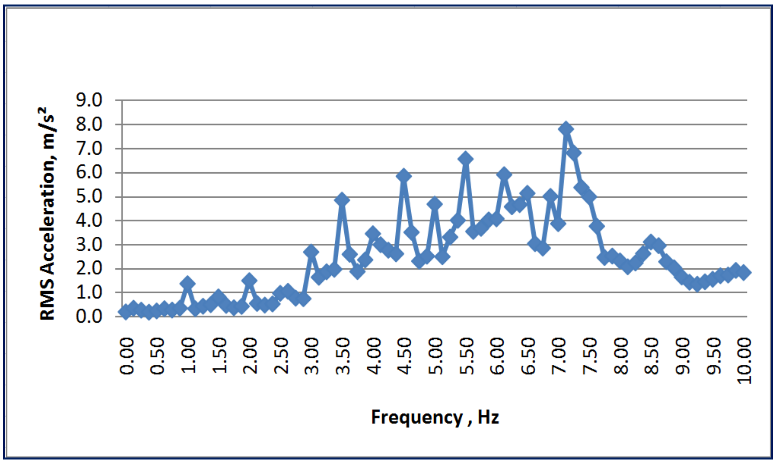
Table -3: Plough Connected to Tractor

Frequency Hz	Ploughing flat field RMS acceleration m/s^2		Ploughing sugarcane field RMS acceleration m/s^2		Plough Transport (on road) RMS acceleration m/s^2	
	05 km/hr	08 km/hr	05 km/hr	08 km/hr	05 km/hr	08 km/hr
0.50	0.318	0.267	0.2322	0.208	0.421	1.3410
1.00	0.556	1.066	1.3620	0.811	0.3655	0.9251
1.50	0.965	1.136	0.8151	1.324	0.5596	0.5485
2.00	1.029	2.698	1.4892	1.070	1.4498	1.6002
2.50	1.828	2.468	0.9619	0.553	2.3595	1.7655
3.00	0.919	2.961	2.6771	0.968	1.5545	0.9130
3.50	1.473	2.477	4.8305	3.369	2.5539	2.4014
4.00	1.744	2.494	3.4370	3.064	1.5821	1.4168
4.50	4.215	3.491	5.8236	7.623	3.0482	2.3105
5.00	3.000	3.164	4.6656	4.709	2.4865	1.7255
5.50	6.034	4.351	6.5383	7.183	2.9558	3.0477
6.00	5.248	4.473	4.0548	6.188	2.5662	3.9624
6.50	6.109	3.513	5.1141	6.703	2.8350	3.2391
7.00	5.948	4.085	3.8538	5.688	3.3865	3.7425
7.50	4.165	3.096	4.9715	3.528	1.5436	2.6596
8.00	4.549	1.830	2.3069	3.910	1.7379	3.6449
8.50	3.584	2.450	3.0931	3.39	1.2308	2.4116
9.00	2.699	1.916	1.6413	2.564	0.9195	1.4031
9.50	3.859	1.758	1.5473	2.761	1.6524	1.8307
10.0	3.399	1.559	1.8258	3.580	1.7939	1.3791

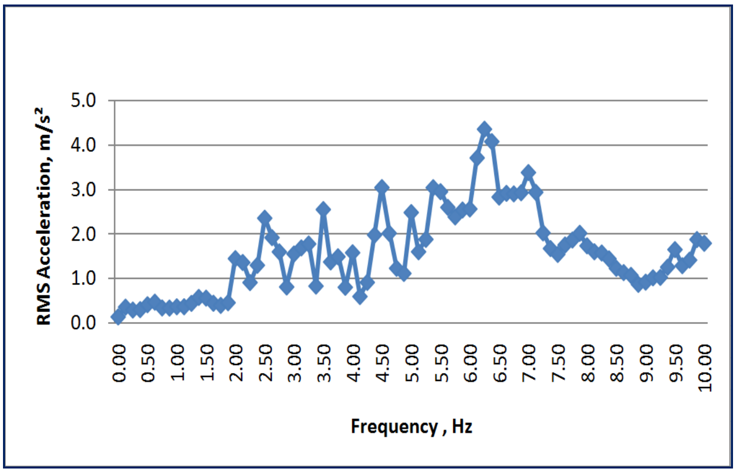
D. Measurement of Vertical RMS Acceleration at 05 Km/Hr and 08 Km/Hr for Conventional Tractor Seat



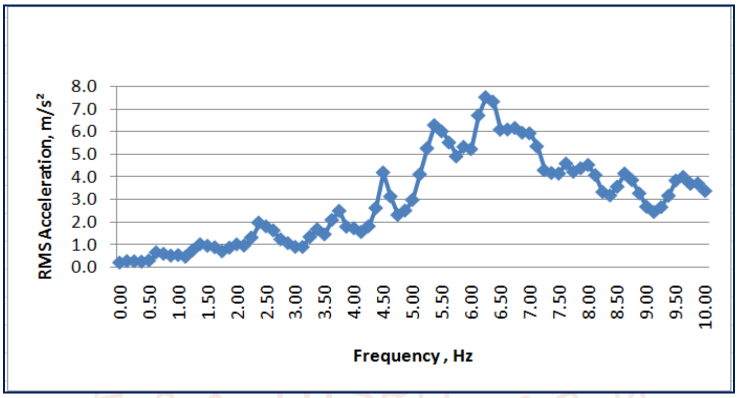
Graph -1: Ploughing Flat Field with conventional tractor seat at 05 km/hr



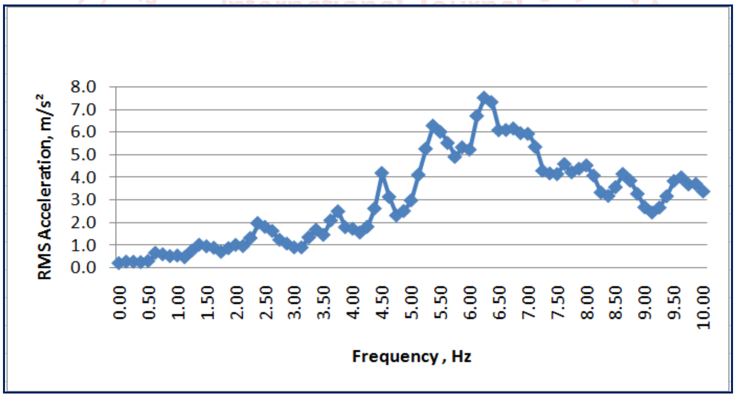
Graph -2: Ploughing Sugarcane Field with conventional tractor seat at 05 km/hr



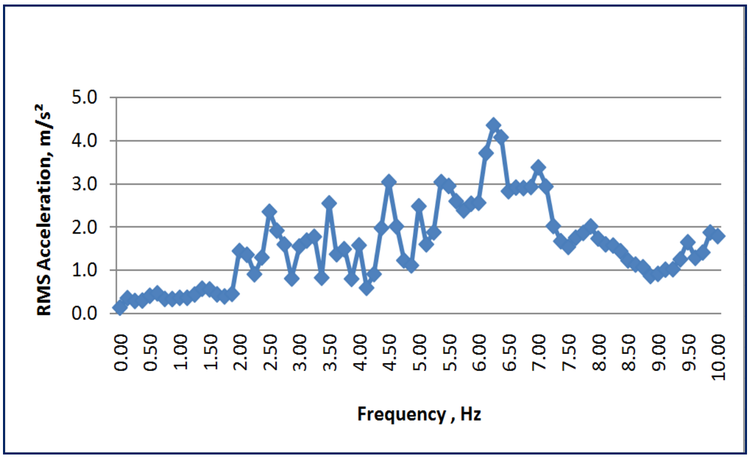
Graph -3: Plough on road with conventional tractor seat at 05 km/hr



Graph -4: Ploughing Flat Field with conventional tractor seat at 08 km/hr



Graph -5: Ploughing Sugarcane Field with conventional tractor seat at 08 km/hr



Graph -6: Plough on road with conventional tractor seat at 08 km/hr

From the above graphs it can be seen that the measured values of root mean square (rms) acceleration on conventional tractor seat at two different speeds 05 km/hr and 08 km/hr on flat field, sugarcane field and on road is much higher than the ISO standard comfortable range for the tractor operator health shown in the following table.

Table -4: Plough Connected to Tractor

Sr. No.	Case	Values of rms accelerations in m/s^2
1	Plough on flat field at 05 km/hr	7.5
2	Plough on Sugarcane field at 08 km/hr	10
3	Cultivator on flat field at 05 km/hr	5.5
4	Cultivator on Road at 08 km/hr	7
5	Harrow on Sugarcane field at 05 km/hr	11.25
6	Harrow on Sugarcane field at 08 km/hr	9.75

From the table, it can be seen that the values of rms accelerations were not in the range specified by ISO 2631-1 ($1.6 m/s^2$ to $1.15 m/s^2$) for the frequency range of 03-07 Hz. So there should be some modifications can be done in existing tractor seat suspension system for meeting the accelerations specified by ISO standards.

Ride vibration was measured by a human vibration Unit. Triaxial seat accelerometer type was used as a transducer. The triaxial seat accelerometer was mounted on the operator's seat at a point on the interface between the operator and his seat to measure ISO weighted rms acceleration levels along the vertical direction as per International Standard (ISO 2631/1, 1985). The precision sound level meter was frequency weighted for the frequency range of 1-10 Hz.

The tests were conducted on three different surfaces, on road, a Grain field and a sugarcane field during the ploughing, harrowing and cultivator operation for the tractor.

4. MODIFIED TRACTOR SEAT

A. Modified Tractor Seat

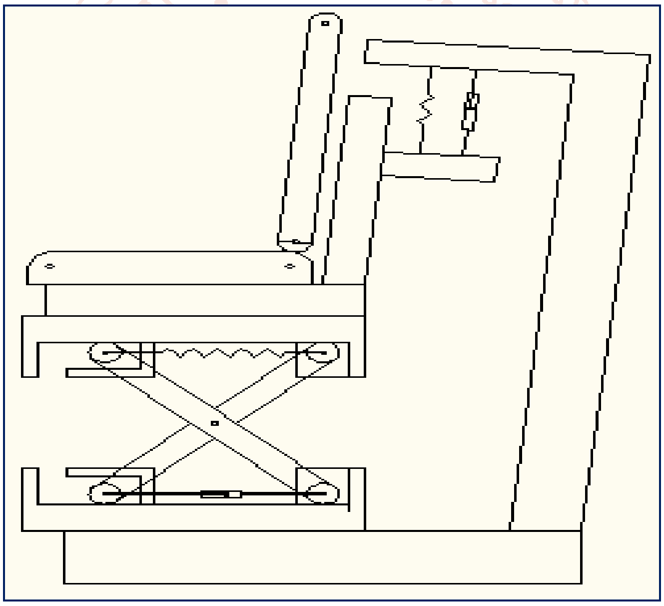


Fig -4: Modified Tractor Seat

The vibration measured on a conventional tractor seat, the value of RMS acceleration on all terrain tractors it was observed that drivers were often subjected to vertical vibration levels that exceed the ISO exposure limits. So there is a need for the development of agricultural tractor that enables more comfortable and safe performance of various agricultural tasks. With regard to tractor operations, one of the important points in the design and use of tractors is the invention of comfortable seats that can prevent the effect of vibration on the human body and gives comfort to tractor operator.

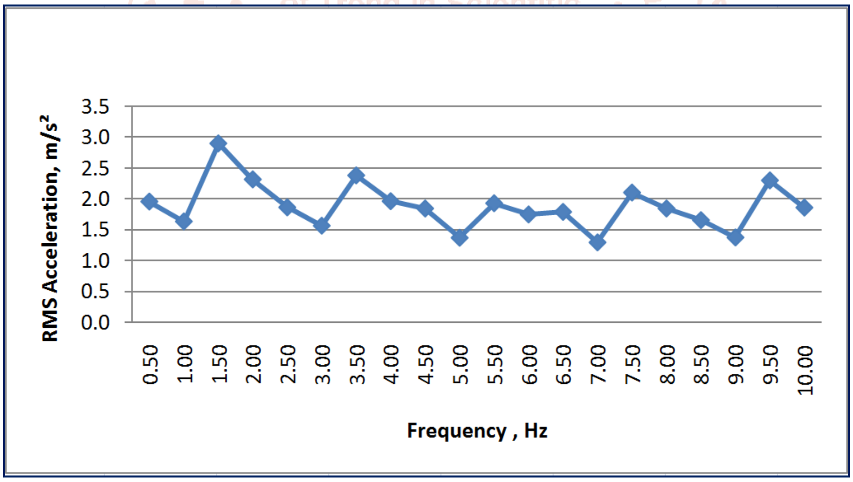
The modified seat configuration is shown in fig. It consists of a spring and damper system. The spring and damper are connected parallel to each other. The spring and damper are connected to each other by using cross bars which are hinged at the center. One end of the spring is hinged to one end of the bar and is fixed to the seat of the tractor, where the other end of the spring is hinged to the one end of the other bar by using the roller. Similarly, the damper one end is hinged to one end of the bar which is fixed to the chassis, where another end is hinged to bar using a roller. The system consists of an end stop as shown in figure.

B. Measurement of Acceleration on Modified Tractor Seat

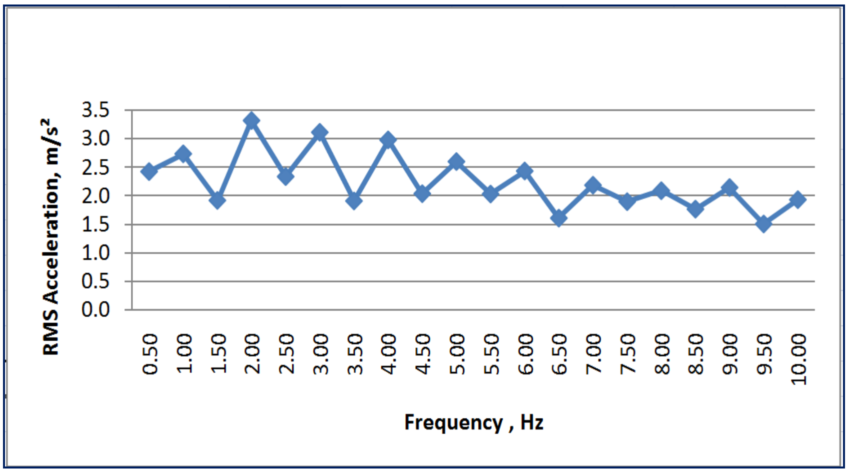
Table -5: Plough Connected to Tractor

Frequency Hz	Ploughing flat field RMS acceleration m/s^2		Ploughing sugarcane field RMS acceleration m/s^2		Plough Transport (on road) RMS acceleration m/s^2	
	05 km/hr	08 km/hr	05 km/hr	08 km/hr	05 km/hr	08 km/hr
0.50	1.963	1.512	2.428	2.302	1.958	2.292
1.00	1.642	2.017	2.740	2.566	1.885	2.113
1.50	2.903	1.962	1.921	2.401	1.629	1.848
2.00	2.322	2.515	3.325	2.494	1.532	1.782
2.50	1.870	1.666	2.340	2.254	1.837	1.685
3.00	1.573	1.927	3.118	2.262	1.935	1.752
3.50	2.386	1.677	1.911	2.442	1.487	1.615
4.00	1.969	2.152	2.984	2.199	1.548	1.596
4.50	1.851	1.60	2.039	2.215	1.488	1.766
5.00	1.380	1.908	2.600	2.110	2.332	2.184
5.50	1.930	1.529	2.030	2.049	1.155	1.974
6.00	1.755	1.701	2.430	1.859	1.879	1.759
6.50	1.796	1.331	1.610	2.077	1.147	1.813
7.00	1.303	1.844	2.188	2.137	2.182	2.064
7.50	2.109	1.585	1.899	2.251	0.987	1.898
8.00	1.851	1.73	2.092	1.874	1.631	1.793
8.50	1.663	1.214	1.768	1.899	1.068	1.817
9.00	1.383	1.712	2.148	2.046	1.686	1.883
9.50	2.305	1.561	1.507	2.337	1.193	1.499
10.0	1.866	1.949	1.934	1.979	1.165	1.244

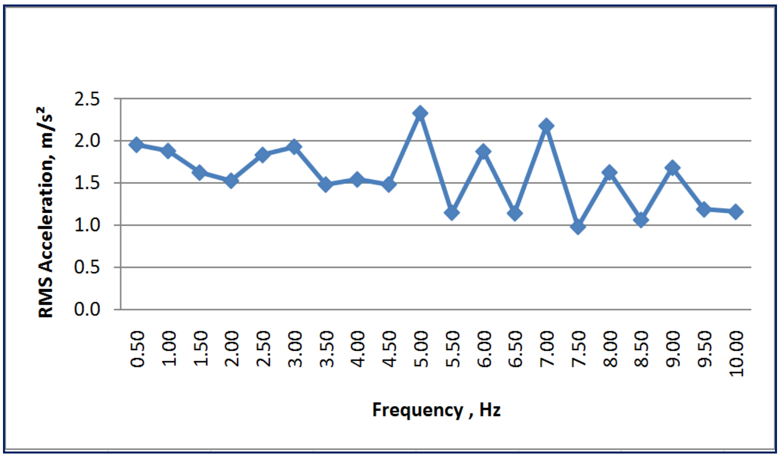
C. Measurement of Vertical RMS Acceleration at 05 Km/Hr and 08 Km/Hr for Modified Tractor Seat



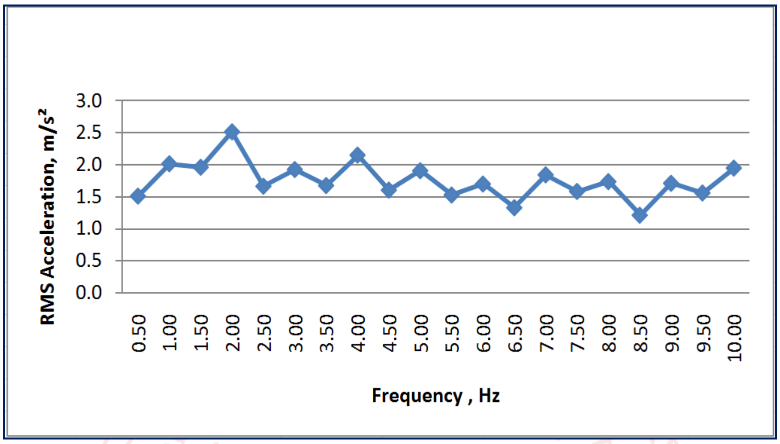
Graph -7: Ploughing Flat Field with Modified Tractor Seat at 05 km/hr



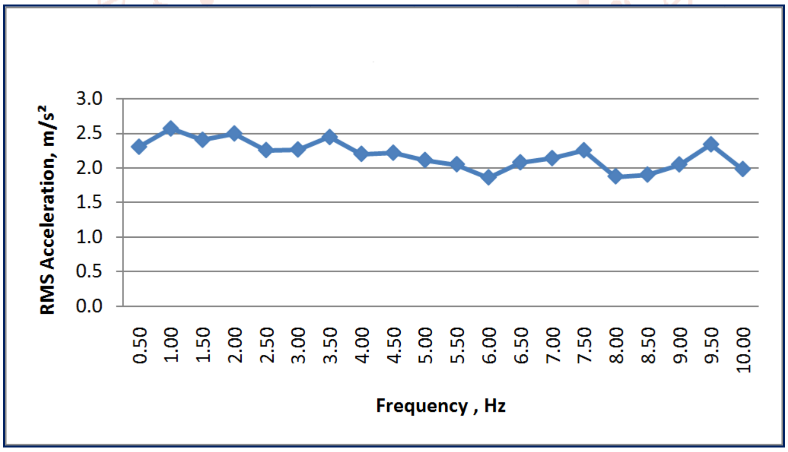
Graph -8: Ploughing Sugarcane Field with Modified Tractor Seat at 05 km/hr



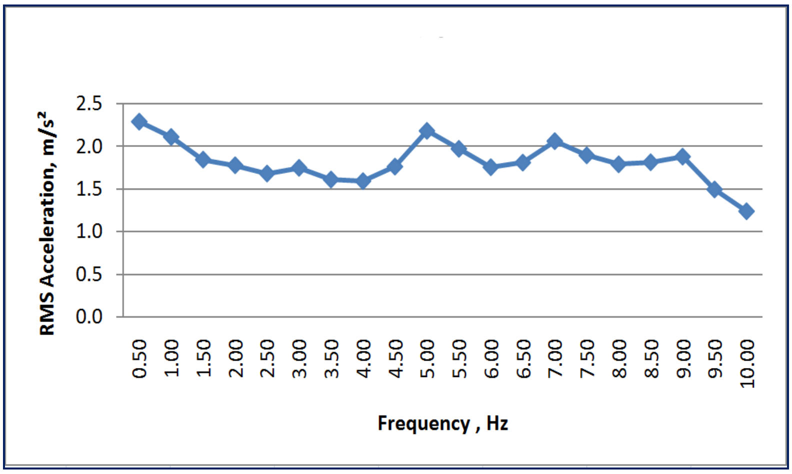
Graph -9: Plough on road with Modified Tractor Seat at 05 km/hr



Graph -10: Ploughing Flat Field with Modified Tractor Seat at 08 km/hr



Graph -11: Ploughing Sugarcane Field with Modified Tractor Seat at 08 km/hr



Graph -12: Plough on road with Modified Tractor Seat at 08 km/hr

5. RESULTS AND DISCUSSION

A. Comparison of measured vertical RMS Acceleration between Conventional and Modified Tractor Seat

The vibration measurement was taken on the conventional tractor seat and it is compared with the modified tractor seat on flat field, sugarcane field and on road at 05 km/hr and 08 km/hr which is tabulated below,

Table -6: Comparison of measured vertical RMS acceleration between conventional and modified tractor seat

Speed of Tractor	Ploughing flat field RMS acceleration m/s^2	
	Conventional Tractor Seat	Modified Tractor Seat
5 km/hr	3.0825	1.89121
8 km/hr	2.5631	1.7553

Table -7: Comparison of measured vertical RMS acceleration between conventional and modified tractor seat

Speed of Tractor	Ploughing on Sugarcane Field RMS acceleration m/s^2	
	Conventional Tractor Seat	Modified Tractor Seat
5 km/hr	3.0620	2.2513
8 km/hr	3.4615	2.1876

Table -8: Comparison of measured vertical RMS acceleration between conventional and modified tractor seat

Speed of Tractor	Ploughing on Road RMS acceleration m/s^2	
	Conventional Tractor Seat	Modified Tractor Seat
5 km/hr	1.8496	1.5662
8 km/hr	2.1134	1.8188

The comparison between conventional tractor seat and modified tractor seat with Harrow connected to tractor shows that, the maximum rms acceleration for the frequency range 1-10 Hz on conventional tractor seat is 6.7 m/s^2 on flat field and 10.75 m/s^2 on sugarcane field, however on modified tractor seat the rms acceleration was 2.9 m/s^2 for flat field and 3 m/s^2 on sugarcane field, reducing the vibration to considerable limit.

6. MODELLING AND OPTIMIZATION

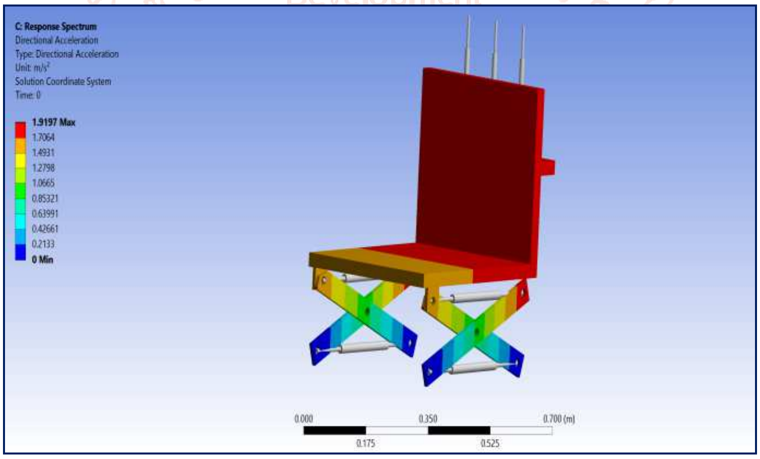


Fig -5: RMS acceleration with plough on flat field

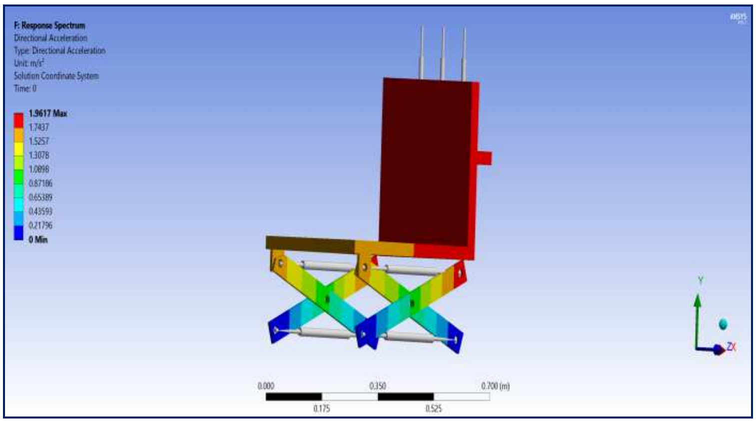


Fig -6: RMS acceleration with plough on Sugarcane field

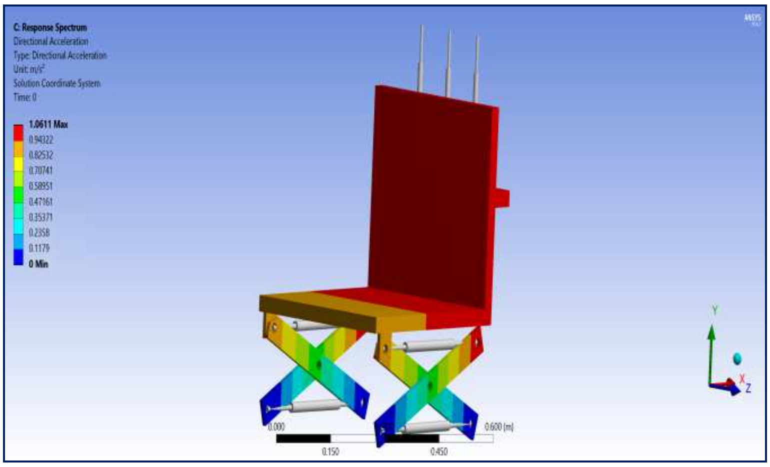


Fig -7: RMS acceleration with plough on Road

7. CONCLUSIONS

The several tests were carried out on present agricultural tractor seat on different conditions at two different speeds 5 km/hr and 8 km/hr and comparison of measured values of conventional tractor seat root mean square (rms) acceleration with ISO 2631-1 indicates the magnitude of frequency weighted rms acceleration in vertical direction have been exceeded the upper limit of 'Health guiding caution zone' in all terrain tractors. The acceleration was in the range of 1.5 - 7.5 m/s^2 with plough, with 1 - 6.5 m/s^2 cultivator and 2 - 10.75 m/s^2 with harrow. The vibration level compared with the ISO 2631-1, there was a significant increase in discomfort to the operator's low back, trunk, shoulder hip and adverse effect on the spine. Using spring and damper below the seat an equivalent suspension system is designed for and rms acceleration on the seat is measured using FFT analyser. The measured values of modified tractor seat shows that the vibration is able to reduce from harmful frequency range to near safe zone of 'Health guiding caution zone' in the range of 1.5 - 3.3 m/s^2 with plough, 1 - 1.8 m/s^2 with cultivator and 1.5 - 3 m/s^2 with harrow. Tractor seat with conventional suspension system identified to be above the HGCZ and with the modified suspension system was identified to be near the HGCZ as per the ISO 2631 standards.

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