Vibration Isolation Using Neoprene Fabric

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Executive Summary

The goal of this project was to evaluate the vibration isolation properties of neoprene fabric to reduce the transmission of vibrational energy from earthmoving machines through laboratory and field tests. The primary objective was to design and determine the optimal thickness of neoprene fabric necessary to meet the Vibration Dose Value (VDV) criterion for an 8-hour daily exposure action value of 2.5 m/s^2. Through measurements involving excavators and controlled shaker experiments, vibration data were collected using accelerometers and data acquisition devices. Measurements were taken both with and without neoprene fabric to evaluate the performance of neoprene fabric across varying thicknesses. The study confirmed that neoprene fabric significantly reduces transmitted vibration levels and data analysis led to a recommendation for an optimal neoprene thickness to achieve compliance with health and safety guidelines.

Introduction

The goal of this project was to investigate the vibration isolation properties of neoprene fabric in reducing the transmission of vibrational energy, particularly in industrial and laboratory settings. Prolonged exposure to mechanical vibrations can lead to serious health effects, including the hand-arm vibration syndrome (HAVS), spinal disorders, and muscular fatigue [1-3]. Therefore, developing effective vibration isolation solutions is essential to improving worker safety and equipment performance.

This project aimed to design and determine the optimal thickness of neoprene fabric needed to effectively isolate vibrations while satisfying the Vibration Dose Value (VDV) criterion for an 8-hour daily exposure action value of 2.5 m/s^2 per EU Physical Agents Directive [4]. Neoprene fabric was chosen for its excellent energy-absorbing, damping, and elastic properties, making it a strong candidate for vibration mitigation applications.

To achieve this objective, vibration levels were measured using controlled laboratory experiments involving mechanical a shaker and real-world case studies on earthmoving machinery such as excavators. Data acquisition systems, including vibration sensors and LabVIEW software, were utilized to capture vibrational energy with and without neoprene layers under various conditions. This analysis quantified neoprene's performance in isolating vibrational energy and helped establish the optimal material thickness.

The key deliverables for the project included:

- A detailed evaluation of neoprene's vibration isolation capabilities;
- Experimental data analysis for different neoprene thicknesses;
- A recommendation of the optimal thickness required to meet safety standards.

Background

Human beings are inevitably exposed to vibration energy daily. While brief exposure may be harmless, prolonged, or high-intensity exposure can have serious health consequences. The transmission of vibration energy to the human body can be categorized as:

- Whole Body Vibration: This occurs when vibrations are transmitted through the entire body, typically through seating, standing surfaces, or floors, when operating or in contact with vibrating machinery.
- Hand–Transmitted Vibration: This is the exposure of fingers or hands to vibration or repeated shock through hand-held tools and machinery.

Health effects that arise from prolonged exposure to vibration includes:

- Vascular Disorders: Chronic exposure to vibrations damage blood vessels, leading to impaired circulation and causes whitening of the fingers, also called vibration induced whitening.
- Neurological Disorders: Prolonged vibration damages sensory nerves causing numbness, tingling or reduced sensitivity.
- Muscular Disorders: Difficulty of gripping, reduced dexterity, reduced grip strength and locked grip are effects of prolonged exposure. This affects job performance for workers because grip strength is essential, especially for vibrating tools. Additionally, prolonged exposure can induce stress on spinal discs.
- Articular Disorders: Vibration transmitted handheld tools generates low frequency shocks and it has been observed that workers who use these tools develop bone and joint problems.

- On a lower probability scale, the digestive system, urinary system and female productive organs are assumed to be affected by whole body vibration.

To quantify the risks associated with vibration exposure, the Vibration Dose Value (VDV) provides a measure that accounts for both the magnitude and duration of vibration exposure. International guidelines, such as the EU Vibration Directive, specify safe exposure limits for both Whole Body Vibration and Hand–Transmitted Vibration to minimize health risks.

Vibration dose for hand transmitted vibration can be evaluated using the weighted rms acceleration and the time of exposure

$$VDV \propto a_{rms}(t)^{\frac{1}{2}}\,, \qquad (1)$$

where $a_{rms}(t)$ is the time–weighted rms acceleration. The EU Vibration Directive defines an 8-hour equivalent exposure action value of 2.5 m/s², and an 8-hour equivalent exposure limit value of 5.0 m/s², as shown in Figure 1(a) [3].

Vibration dose for whole body vibration can also be evaluated using the weighted rms acceleration and the time of exposure

$$VDV \propto a_{rms}(t)^{\frac{1}{4}}\,. \qquad (2)$$

The EU Vibration Directive whole-body vibration daily exposure limit value is 1.15 m/s² to an eight-hour reference period. In addition, the 0.5 m/s² is a daily exposure action value limit [4]. Figure 1(b) compares health guidelines for whole-body vibration by ISO 2631-1, BS 6841, and the EU Physical Agents (Vibration) Directive [3].

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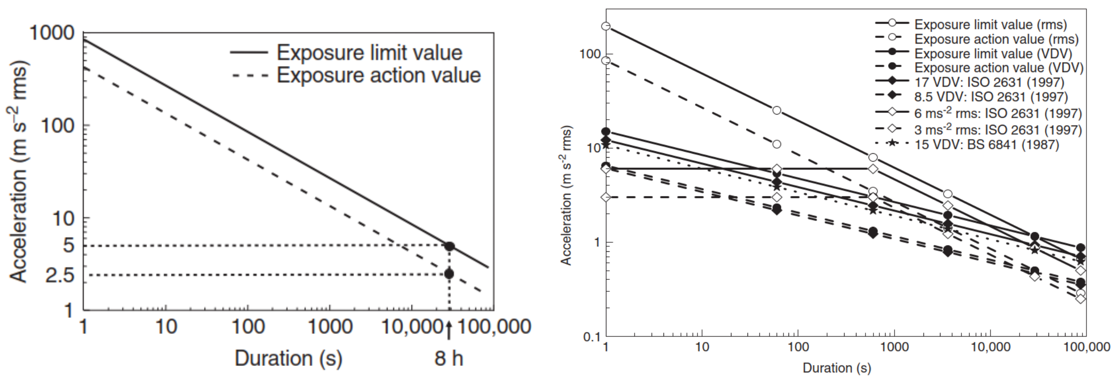

(a) (b)

Figure 1. VDV showing the 8 – hour daily exposure criteria for (a) HTV and (b) WBV

Reducing vibration exposure requires effective vibration isolation, which relies on damping. Damping is the mechanism by which vibrational energy dissipates inside a system, gradually decreasing the oscillations' amplitude. The damping ratio, denoted by ζ, is a measure of how quickly a vibrating system returns to equilibrium after being disturbed. Higher damping ratio systems stabilize more quickly and endure less prolonged vibration. Materials with strong damping properties are essential for vibration isolation applications because they minimize the transmission of harmful vibrations. To calculate the damping ratio, the half-power point method was used. This method involves measuring the frequency response of the system and identifying the bandwidth around the resonance frequency where the amplitude drops to 70.7 % (or –3 dB) of the peak amplitude. The damping ratio ζ can be calculated using the formula:

$$\zeta = \frac{\Delta f_{3\text{dB}}}{2 f_r} \tag{3}$$

where $\Delta f_{3\text{dB}}$ is the bandwidth at the –3 dB points, and f_r is the resonance frequency. This method is straightforward and widely used because it provides a quick estimation of the damping ratio from the frequency response data.

Neoprene, also known as polychloroprene, is a synthetic rubber chosen for its excellent energy-absorbing and damping properties. It also offers strong thermal stability, chemical resistance, and mechanical elasticity, making it ideal for industrial applications. In this project, neoprene fabric was selected as the vibration isolation material due to its ability to absorb and dissipate vibrational energy effectively. By reducing the transmission of vibrations, neoprene improves operator safety, enhances machine performance, and provides a cost-effective solution for minimizing the health risks associated with prolonged vibration exposure.

Project Design and Methods

To research and complete the project, we began with a comprehensive literature review to understand the effects of vibrations on the human body, how much vibrations the human body can withstand, and how neoprene fabric mitigates vibrations [1-4]. This initial phase involved examining various studies and articles that detailed the physiological impacts of prolonged exposure to vibrations, including potential health risks such as musculoskeletal disorders and circulatory issues. We also explored the mechanical properties of neoprene fabric, focusing on its ability to attenuate vibrations, which is done by absorbing and dissipating energy through its elastic and viscoelastic properties, reducing the amplitude of vibrations effectively.

Following the literature review, we proceeded to set up our experimental framework, starting with shaker experiments. These experiments were designed to simulate controlled vibration environments. A Keysight 33500B waveform generator was used to produce white noise, which was then amplified and fed to a Bruel & Kjaer mini shaker 4810 to excite an aluminum beam, as shown in Figure 2. The beam served as the test subject. The shaker excitation force was measured using an impedance head PCB 288D01 and the vibration response was measured using an accelerometer PCB 352C68. The data acquisition and frequency response function (FRF) calculation were conducted using an NI 9234, a USB based device, and the LabVIEW software. The NI 9234 device has four 24-bit synchronous channels and each channel can provide ICP constant current power supply for the sensor. Vibration levels with and without the neoprene fabric were compared. This setup allowed us to quantify the damping effect of neoprene fabric under controlled conditions.

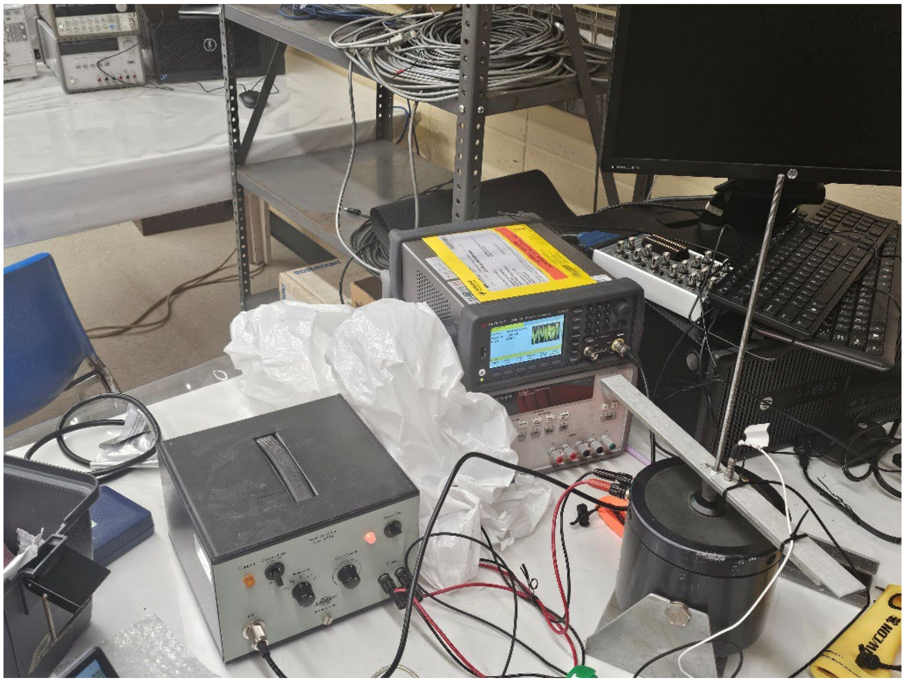

Figure 2. Shaker experiment setup

In addition to the shaker experiments, we conducted field tests to assess the real-world impact of neoprene fabric on vibration levels in the control joysticks of various excavators. These tests were crucial for understanding how neoprene fabric performs in practical applications. Accelerometers were attached to the joysticks to measure the vibrations during normal operation. Figure 3 illustrates two accelerometer setups. For joysticks without the neoprene grip, accelerometers were mounted directly to the joystick using super glue. Since the neoprene layer is soft and flexible, accelerometers were mounted on hose clamps instead. These hose clamps attach the neoprene fabric securely while maintaining the integrity of measurements. In addition, the machinery vibration is mainly in horizontal directions, so the vertical vibration was not measured. The NI 9234 is a four-channel data acquisition device which was used to measure two horizontal directions of each joystick, totally four channels.

This approach enabled us to gather data on the effectiveness of neoprene fabric in reducing vibrations in heavy machinery.

Figure 3. Excavator testing setup

Equipment and Software

1. Waveform Generator (Keysight 33500B): Used to produce white noise for the shaker experiments.

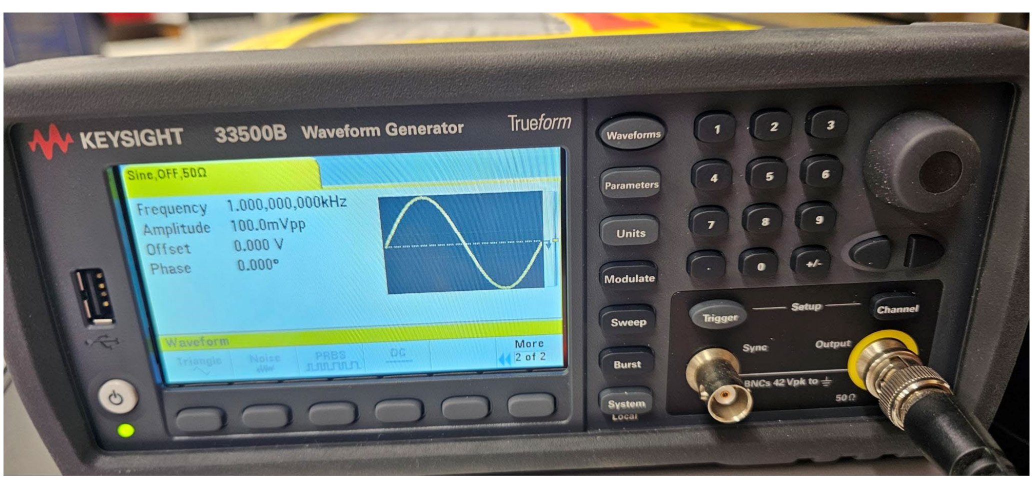

Figure 4. waveform generator

2. Power Amplifier and Shaker (Bruel & Kjaer 2706 and 4809): Amplified the vibrations generated by the waveform generator and converted to mechanical excitation.

Figure 5. Power Amplifier and Shaker

3. Beam: Served as the test subject for vibration transmission.

Figure 6. Beam

4. Neoprene Fabric: Tested for its vibration damping properties.

Figure 7. Neoprene Fabric

5. Accelerometer (PCB 352C68): Measured the vibration levels in both the shaker experiments and field tests.

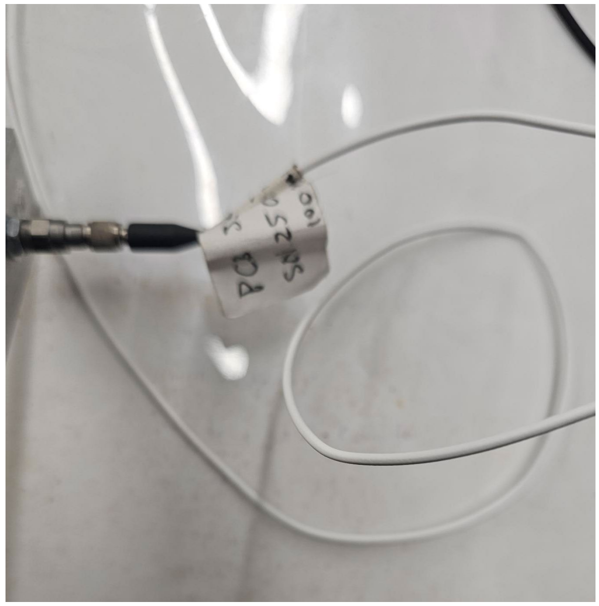

Figure 8. Accelerometer

6. LabVIEW Software: Recorded and analyzed the vibration data.
7. Excavators: Used for field tests to measure real-world impact on control joysticks.

Results of Shaker Tests

To test the effectiveness of the neoprene fabric, the following four cases were tested:

a) No neoprene fabric
b) One layer of neoprene fabric
c) Two layers of neoprene fabric
d) Three layers of neoprene fabric

The fabric is made of 90% polyester and 10% Spandex. Each layer is 2 mm thick. Figure 9 below shows baseband FRFs of these four cases.

(a)
(b)
(c)
(d)

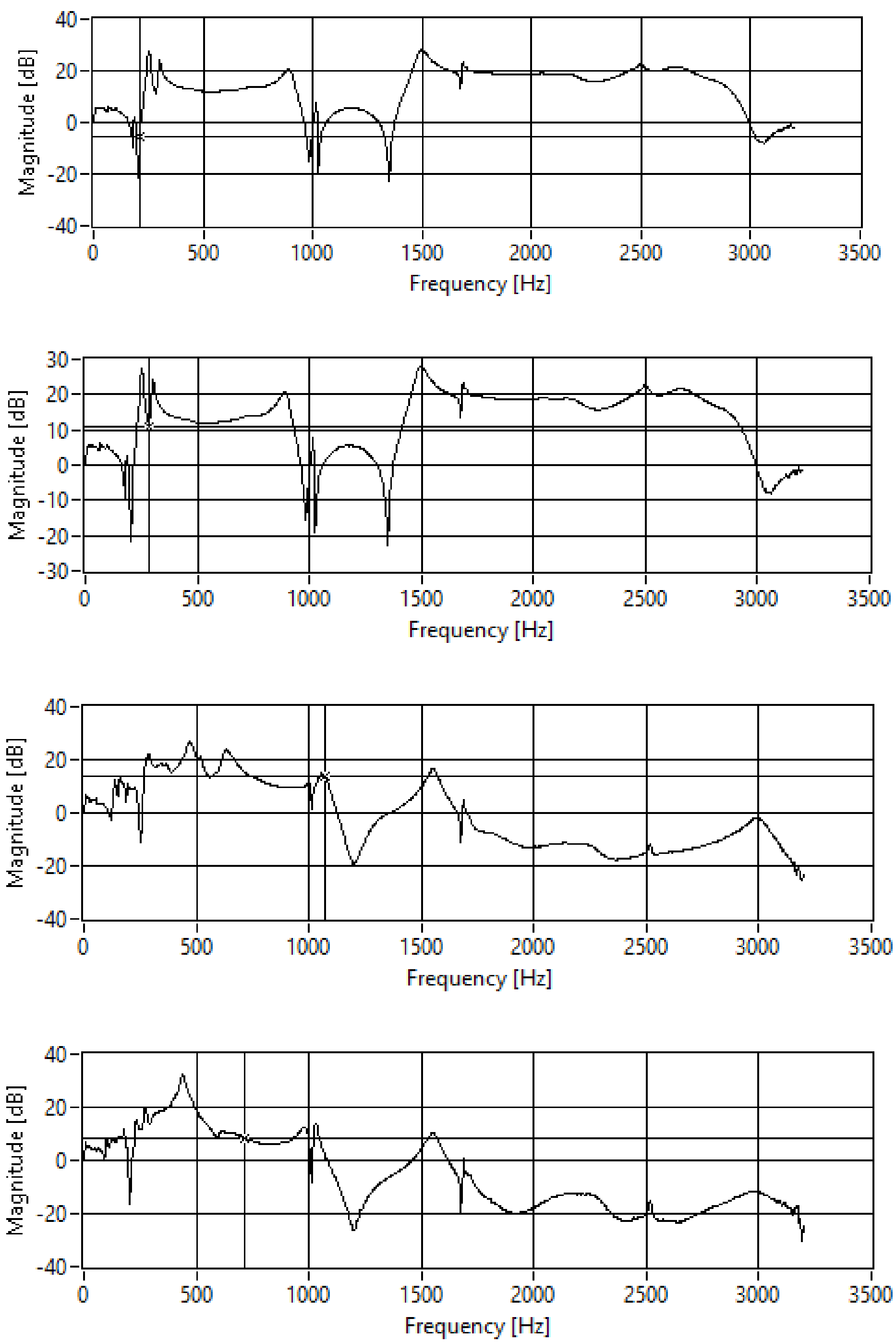

Figure 9. Baseband FRFs of shaker experiment. (a) no neoprene fabric, (b) one layer, (c) two layers, (d) three layers.

From these baseband FRFs, the first two identifiable peak points were selected, and the magnitude in dB, and the frequency were recorded; these peaks were called “modes”. Then zoom FRFs were conducted focusing on the first two vibration modes for the purpose of better frequency resolution. Figure 10 indicates one of the zoom vibration modes and the damping ratio calculation using the half-power point method.

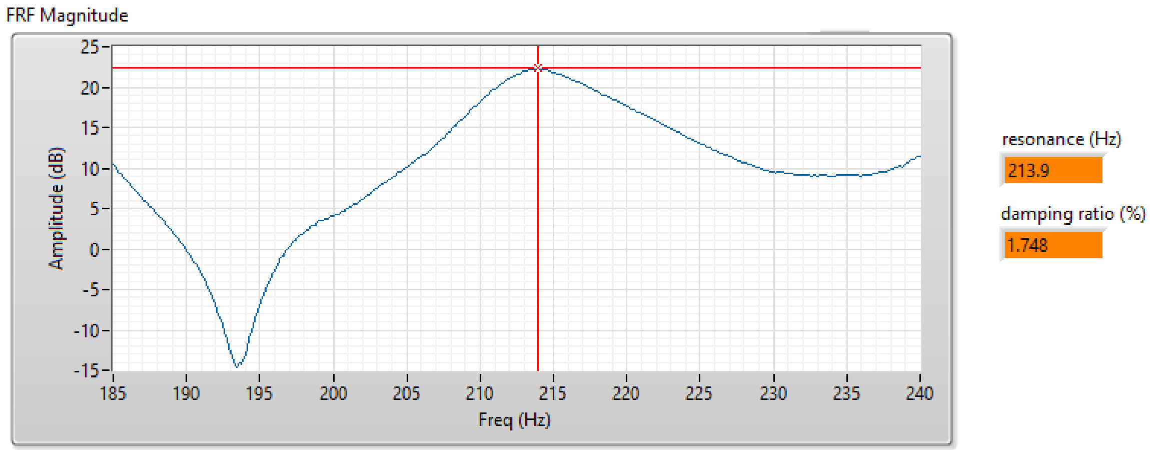

Figure 10 . Zoom FRF and damping calculation

Tables 1 and 2 summarize the frequency, FRF amplitude and damping ratio of each mode for all four cases. Tables 1 and 2 show that with an increase in neoprene fabric layers, the natural frequency would decrease, because the decrease in stiffness. The FRF amplitudes are in the trend of decrease, although the most significant change is between one layer and two-layer cases. The damping ratio is the highest with two layers of neoprene fabric.

Table 1 . Summary of 1st Mode results.

	No grip	**one layer**	**two layers**	**three layers**
frequency (Hz)	183.7	181.4	184.9	102
Amplitude (dB)	23.2	24.4	11.9	9
damping ratio (%)	0.3	0.4	6.5	4.8

Table 2. Summary of 2nd Mode results.

	No grip	**one layer**	**two layers**	**three layers**
frequency (Hz)	251.3	213.9	233.7	193
Amplitude (dB)	30.7	22.2	8.7	7.8
damping ratio (%)	1.3	1.75	4.3	2.3

The lab shaker tests indicate that two layers of neoprene fabric would be optimal to achieve satisfactory vibration reduction and damping.

Field Excavator Test Results

Initial tests were conducted on a John Deere 200D excavator at McNeese Farm on Oct 17, 2024. Nine tests were conducted as listed in Table 3. This table summarizes all the test conditions and the length of each data file. These tests can be categorized into three groups: no grip, one later of grip, and two layers of grip. Three different tests were conducted in each group: idle, throttle wide open, and operation. "Idle" and "throttle wide open" are steady-state conditions in which the excavator was not in operation.

Table 3. Summary of initial excavator test conditions

Test Number	Test Condition		Test Length (sec)
1	No grip	idle	14
2		throttle wide open	25
3		operation	143
4	One layer grip	idle	24
5		throttle wide open	24
6		operation	141
7	Two-layer grip	operation	136
8		throttle wide open	35
9		idle	30

All recorded data were filtered using the frequency-weighting W_h as specified in ISO 5349-1:2001 for hand-transmitted vibration [2]. According to the ISO 5349-1, the primary quantity to describe the magnitude of the hand-transmitted vibration is the root-mean-square (rms) frequency weighted acceleration expressed in m/s^2. The rms values of each channel and the total vibration exposure are presented in this report. Table 4 summarizes the rms values of these tests. Only horizontal directions were measured. “Front-back” and “left-right” refer to the z- and y-directions as in the ISO 5349-1, respectively. These initial tests show that two layers of grips would lead to the most significant vibration reduction, which agrees with the lab shaker tests.

Table 4. Summary of initial excavator tests

		Left joystick			Right joystick		
		front-back	**left-right**	**total**	**front-back**	**left-right**	**total**
idle	**no grip**	0.501	0.418	0.652	0.560	0.77	0.952
	one layer	0.389	0.246	0.460	0.309	0.463	0.557
	two layers	0.117	0.133	0.177	0.311	0.421	0.523
throttle open	**no grip**	0.0763	0.122	0.144	0.213	0.080	0.228
	one layer	0.0792	0.046	0.092	0.074	0.044	0.086
	two layers	0.0943	0.084	0.126	0.088	0.072	0.114
tracking	**no grip**	1.375	0.790	1.586	0.988	0.988	1.397
	one layer	1.220	0.523	1.327	1.01	0.661	1.207
	two layers	0.949	0.428	1.041	1.00	0.548	1.140

Based on lab shaker tests and initial excavator tests, more tests focused on two-layer fabric. A series of field tests were conducted from December 2024 to April 2025.

1) *John Deere 200D*. Table 5 and Figure 11 show the test results on John Deere 200D excavator. The measured results are rms acceleration in m/s^2. The vibration reductions vary from 33% to 62.6%.

Table 5. Summary of John Deere 200D test results

		Left			Right		
		front-back	**left-right**	**total**	**front-back**	**left-right**	**total**
Tracking	**no grip (m/s^2)**	3.583	2.698	4.485	3.175	2.959	4.341
	two layers (m/s^2)	2.031	1.514	2.533	1.284	1.986	2.365
	reduction (%)	43.3	43.9	43.5	59.6	32.9	45.5
Digging	**no grip (m/s^2)**	1.793	1.003	2.054	1.323	1.946	2.353
	two layers (m/s^2)	0.939	0.546	1.086	0.694	0.727	1.006
	reduction (%)	47.6	45.6	47.1	47.5	62.6	57.3

Figure 11 . John Deere 200D test results, (a) tracking, (b) digging.

2) *John Deere 35G*. In this set of tests, the neoprene fabric is made of 92% polyester and 8% spandex. Table 6 and Figure 12 show the test results. Except for the right joystick's *z*-direction which did not exhibit any change, significant vibration reductions up to 50.6% were seen in other channels. The total vibrations of both joysticks with the neoprene grip now satisfy the 2.5 m/s^2 requirement.

Table 6. Summary of John Deere 35G test results

	Left			**Right**		
tracking	**front-back**	**left-right**	**total**	**front-back**	**left-right**	**total**
no grip (m/s^2)	1.177	2.085	2.394	0.862	2.463	2.609
two layers (m/s^2)	0.786	1.107	1.358	0.868	1.218	1.495
reduction	33.2%	46.9%	43.3%	-0.7%	50.6%	42.7%

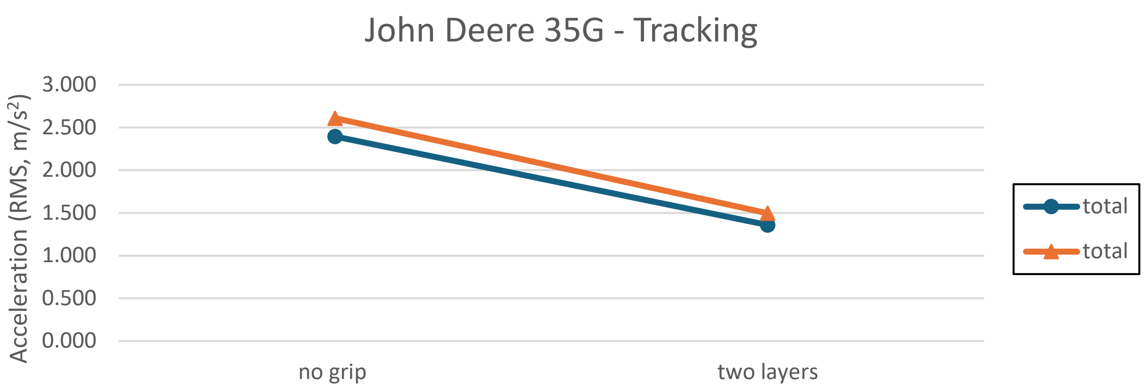

Figure 12 . John Deere 35G test results

3) *Case CV80*. In this set of tests, the neoprene fabric is made of 92% polyester and 8% spandex. Table 7 and Figure 13 show the test results. Except for the left joystick's *y*-direction, which could be due to measurement errors, significant vibration reductions up to 44.2% were seen in other channels. The total vibrations of both joysticks with the neoprene grip now satisfy the 2.5 m/s^2 requirement.

Table 7. Summary of Case CX80 test results

	Left			Right		
tracking	**front-back**	**left-right**	**total**	**front-back**	**left-right**	**total**
no grip (m/s^2)	2.35	0.72	2.459	1.69	2.17	2.751
two layers (m/s^2)	1.31	1.02	2.040	1.06	1.44	1.786
reduction	44.2%	-41.7%	17.1%	37.3%	33.7%	35.1%

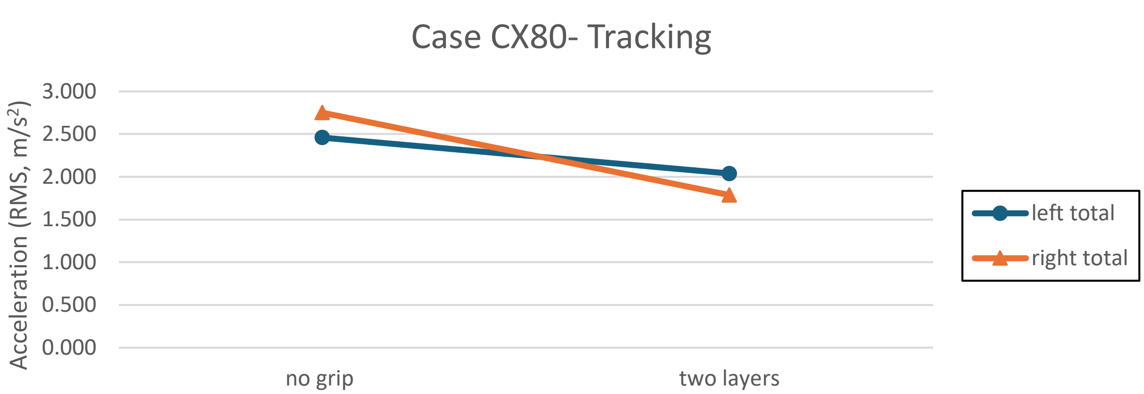

Figure 13 . Case CX80 test results

4) *Volvo ECR58*. In this set of tests, the neoprene fabric is made of 92% polyester and 8% spandex. Table 8 and Figure 14 show the test results. Although consistent decrease in magnitude in both left and right joysticks, the total vibrations are higher than the EU's criterion for 8-hour exposure limit of 5 m/s^2. It was noticed that the engine was running at lower frequencies than other tested excavators. Further investigations are needed to identify the root cause of this Volvo excavator's high vibrations.

Table 8 . Summary of Volve ECR58 test results

	Left			Right		
Tracking	**front-back**	**left-right**	**total**	**front-back**	**left-right**	**total**
no grip (m/s^2)	5.11	4.60	6.876	6.33	3.44	7.206
two layers (m/s^2)	5.03	3.36	6.048	6.10	2.05	6.437
Reduction (%)	1.6%	26.9%	12.0%	3.6%	40.3%	10.7%

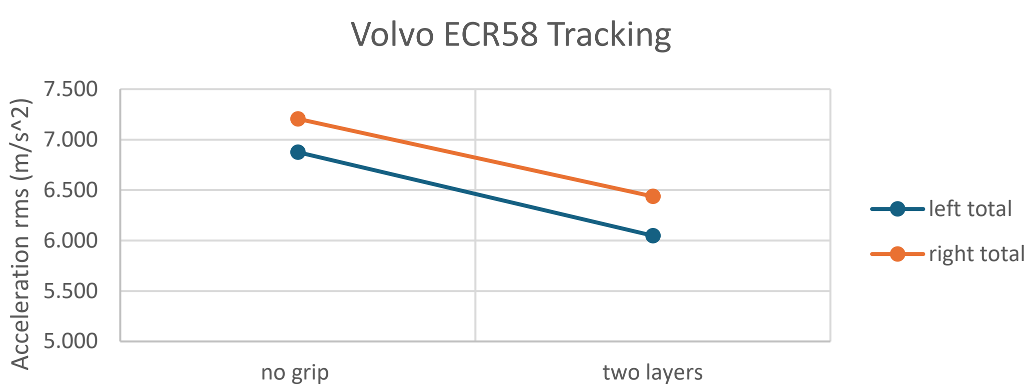

Figure 14 . Volvo ECR58 test results

Conclusions and Recommendations

The purpose of the project was to verify the ability of neoprene fabric to reduce vibrations and to identify the optimal thickness of neoprene fabric that can effectively reduce vibrations to safe levels. The lab test results from the shaker experiments showed consistently that neoprene fabric is good at reducing vibration levels effectively. Based on the lab tests, the thickness of neoprene fabric that attained the most reduction of vibration consistently is 4 mm (two layers of neoprene fabric). Similarly, the field tests were performed on the excavator control joysticks with two layers of neoprene fabric that effectively reduces vibration levels. Overall, the research indicate that neoprene fabric is effective in attenuate vibrations, making it a viable solution for reducing vibration-induced discomfort and potential health risks in various applications, especially those with vibrating parts that are hand held for extended periods.

Future research will be extended to other earthmoving machines including bulldozers and loaders. Another recommendation would be for the sponsoring company would be for there to be a production of neoprene gloves as this would make it more convenient for the user to move from equipment to equipment. In addition, other materials will be tested.

As the testing focused on hand transmitted vibrations, no recommendations can be made for whole body applications. Whole-body vibration reductions at seat and floor will be investigated.

References

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