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THE EVALUATION OF HUMAN VIBRATION MEASUREMENTS AND THE EFFECTIVENESS OF DIFFERENT VIBRATION REDUCTION STRATEGIES IN A SAWMILL

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(97FS-34)

The Evaluation of Human Vibration Measurements and the Effectiveness of Different Vibration Reduction Strategies in a Sawmill

Issue:	Measurement of structural vibration in a sawmill and in related power hand tools; evaluation of vibration reduction methods for sawmill and power hand tools including chain saws; comparison of subjective and physical measures of vibration.
Agency:	Canadian Forest Products Ltd.
Representative:	Ms. Kimberly D. Zinck
Funding:	$15,800

Long term vibration exposure has been linked to musculoskeletal disorders. The purpose of this project was to:

1. Quantify the levels of hand-arm and whole-body vibration exposure of workers at the Canadian Forest Products Ltd. (Canfor), Fort St. John operation.
2. Identify specific jobs/workers who may be at risk of developing vibration-related disorders.
3. Determine the effectiveness of specific vibration reduction interventions and their practicability.
4. Develop a training program to educate workers on the importance and use of vibration reduction techniques.

Specific vibration interventions such as airbags, seat adjustment and/or cushions, matting, workstation isolation, insoles, vibration dampening gloves and hand tool wraps were used to determine if vibration levels could be significantly reduced. Measurements were made in accordance with ISO, and questionnaires were used to obtain pre/post intervention worker feedback.

Vibration exposure was high in planer infeed areas. Workstation isolation provided most effective for reducing whole-body vibration levels. Use of vibration gloves and tool wraps were beneficial in reducing chainsaw but not grinder (ie., 7 and 5 inch Makita grinder) vibration. Gel cushions (ie., sorbothane or t-gel) were not found to significantly reduce vibration. In kiln areas gel cushions were found to amplify vibration to levels linked to health-risk. Potential benefits from matting and tool wraps may not have been realized due to r.m.s. weightings neglect of high frequency ranges. A low relationship between subjective and objective vibration ratings were found.
From this study we make the following recommendations for reducing risks associated with mobile equipment use:

1. Eliminate pot holes from work yards.
2. Use air rides where possible.
3. When suspension systems fail, operator seats should be replaced at the same time.
4. Encourage frequent mini breaks where operators stretch and walk around.
5. Rotate machinery operators through sitting and standing jobs throughout their shifts.

Further research is necessary to determine interventions that will be effective at low vibration frequencies.

The Evaluation of Human Vibration Measurements and the Effectiveness of Different Vibration Reduction Strategies in a Sawmill

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The Evaluation of Human Vibration Measurements and the Effectiveness of Different Vibration Reduction Strategies in a Sawmill

Executive Summary and Key Findings

Long term exposure to either hand-arm or whole-body vibration has been associated with the development of certain musculoskeletal disorders. Many sawmill employees are exposed to vibration on a daily basis. The purpose of this project was to reduce exposure to human vibration and to prevent future musculoskeletal disorders. The main objectives of this project included:

- To quantify the levels of both hand-arm and whole-body vibration that employees are exposed to on the job at Canfor
- To determine if certain jobs/employees are at risk of developing vibration related disorders
- To evaluate the effectiveness of different vibration reduction interventions and determine which methods are most effective/practicable
- Develop a training program to educate employees, who are exposed to high levels of vibration, on the importance and proper use of vibration interventions when at work.

This project was carried out at Canadian Forest Products Ltd – Fort St John division. Frequency weighted measurements for both whole-body and hand-arm vibrations were evaluated through out the mill under regular working conditions. Specific vibration interventions (including airbags, workstation isolation, seat cushions, seat adjustment, matting, plywood, insoles, vibration dampening gloves, and hand tool wrap) were put in place and the vibration levels re-examined to determine if there was any reduction in the level of vibration. All measurements were made in accordance with ISO 2631-1:1997. Questionnaires were used to provide feedback from employees on their perceived level of vibration experienced before and after interventions were in place, and on the practicability of interventions used.

Mobile equipment operation is of most concern in the sawmill with many baseline values greater than .2 m/s^2. Based on the results from this study, use of sorbothane or t-gel cushions are not recommended as they did not show a significant reduction. In some

areas, such as the kiln forklift route, the sorbothane cushion amplified levels to within the health risk caution zones. The following recommendations should be considered to help reduce the risks associated with operation of mobile equipment:

- maintain yard conditions free of pot holes,
- use air ride seats where possible,
- replace seats when the suspension system is no longer effective,
- take frequent mini breaks to get out of equipment and walk around,
- job rotate operators onto a standing job,
- enlarge job with duties that allow operators to get out of equipment for short periods.

Several factors, such as the life span of the seats, different style seats, age and make of equipment, were not considered in this study and are worthy of further study.

In evaluation of whole-body vibration, some areas of the mill may have an affect on employee comfort and fatigue decreased proficiency but no areas present an actual health risk. This study showed the baseline planer infeed areas (floors not isolated) to be of most concern out of the sawmill and planer. Isolating the workstations completely from the surrounding area has proven to be the most effective method of reducing whole-body vibration. More cost-effective interventions like plywood, matting, and insoles are marginally effective in some areas. These interventions, in addition to isolation, play a large role in improving the overall comfort perceived by employees while working, and are therefore well worth using.

There are potential long-term health risks for employees using chainsaws and the 7” Makita grinder for more than 10-years. Use of the 5” grinder poses much less health risk for operators and should be used for day to day functions, instead of the larger grinders. Use of the vibration gloves or tool wrap would be beneficial for the chainsaw but appear to be ineffective with the grinders. Unfortunately employees find these interventions are uncomfortable to work with and compromise their ability to grip the tool, resulting in more grip force, which in turn can increase risk of developing musculoskeletal disorder symptoms.

Looking at the weighted r.m.s. value alone for hand-arm and whole-body vibration does not consider the beneficial effects that some of the interventions, matting and tool wrap for example, had on the higher frequencies, which are not concerned with human vibration weightings. It is possible that the comfort perceived by people is related more to these higher frequencies. Only a small relationship between linear values and subjective response was noticed in this study; further study in this area would be worthwhile.

As previously mentioned, this study tested the interventions under regular working conditions and therefore provided less control for testing. Interventions that worked well in some locations and not in others may have been a result of the different environment and work processes. In areas where the intervention was not very effective, it is important to consider that the baseline r.m.s. may have been low to begin with. At the sawmill stacker for example, the addition of matting does not amplify the vibration to levels of concern, so if the operator feels it is more comfortable for his feet and legs with the matting, then it is worthwhile to use. Further research is necessary to find interventions effective at the lower frequencies concerned with human vibration, especially hand-arm vibration

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1.0 Introduction

Each day thousands of workers are exposed to high repetition, awkward postures, and forceful exertions in their jobs. These factors all contribute to the rising costs of claims for musculoskeletal disorders such as low back pain and carpal tunnel syndrome. In industrial settings workers may also be exposed to varying levels of two different types of vibration, whole-body and/or hand-arm. Exposure to vibration has also been associated with the development of certain musculoskeletal disorders (Seidel, 1993; Bovenzi et al., 1991).

There are two different types of vibration workers can be exposed to while operating equipment, tools and vehicles, that are transmitted into the body and have different effects on the tissues and joints. *Hand-arm vibration* is transmitted to the hands and arms when operating vibrating tools (chain saws, hand grinders) and vibrating controls (steering wheels, levers). Exposure to hand-arm vibrations over a number of years can result in permanent physical damage commonly known as ‘raynauds disease’ or ‘white finger syndrome’, or the vibration can damage the muscles and joints of the wrist and elbow. Early symptoms of raynauds disease include pain, tingling, numbness, and loss of feeling and control in the fingers, followed by blanching of the fingers caused by damage to the arteries and nerves in the hands. After a time, these symptoms may be irreversible. Vibrations occurring between 8 Hz - 1000 Hz are of concern when measuring hand-arm vibration, with frequencies in the range of 25 Hz - 150 Hz associated with the development of raynauds disease.

Whole-body vibration is transmitted through the feet (standing on vibrating surface), buttocks or back (through the seat or backrest). Long term exposure can result in serious physical damage to the low back or it can disturb the nervous system. Vibration levels occurring between 1 Hz - 80 Hz are of most concern when measuring whole-body vibration.

A majority of the employees at Canfor - Fort St. John division are exposed to varying levels of vibration. Most workstations in the sawmill and planer, including mill offices, experience whole-body vibration. Since all of the machinery, workstation platforms, and operators booths are connected with steel catwalks, the vibration easily transmits throughout the mill. A majority of the millworkers stand or sit in one general area throughout their shift. A common complaint is the development of soreness and fatigue in their feet, legs, and back. In a couple areas of the mill some interventions have been implemented to help reduce the amount of vibration the operators are exposed to. For example, antifatigue matting, isolated work platforms, place operator booths on air bags. Many of the workers report a noticeable reduction or absence in vibration and symptoms experienced when working in these areas with the vibration reduction interventions implemented. A large part of tradespeoples work involves the use of vibrating hand tools. This group includes welders, sawfilers, buckers, and millwrights who have been exposing their hands and arms to the negative effects of vibration. Some of these workers currently experience symptoms of hand-arm vibration while many others want to prevent these symptoms from occurring. Vibration absorbing gloves and vibration absorbing material, that is wrapped around the handles of power tools, have been tried by some workers frequently using power hand tools. The worker's responses as to the how effective these interventions are at reducing vibration vary. Some people notice an improvement, while others do not.

Mobile Equipment operators are a group of employees who are exposed to both hand-arm and whole-body vibration. An ergonomics study was recently performed throughout Canfor, Fort St. John being part of it, to address the problems with the mobile equipment used and to recommend changes to decrease the rate of injury. After questioning 78 mobile equipment operators it was found that many operators experience symptoms associated with musculoskeletal disorders (West Coast Industrial Ergonomics - Mobile Equipment Project). 58% of all mobile equipment operators in all Canfor divisions were found to experience back pain of which 77% rated their discomfort as moderate to severe. Additionally, 22% of operators experience discomfort in their shoulders. West Coast Industrial Ergonomics (1996) concluded that this was likely due to the combination of continual forceful gripping of controls and the effects of segmental vibration from the controls and the steering wheel. The results were not broken down by division to determine what the prevalence of musculoskeletal disorders were in Fort St. John, but a review of the first aid records shows a high incidence of symptoms, especially among forklift operators, similar to the results reported in the mobile study.

Even though a lot of the work on human vibration is inconclusive, many studies suggest exposure to vibration is associated with musculoskeletal disorders (Bovenzi et al., 1987; Burdorf and Zondervan, 1990; Boshuizen et al., 1992; Seidel, 1993; Wilder, 1993) and decreased work performance (Bovenzi et al., 1991, Lewis et al., 1978). A review of the literature suggests that long term exposure to whole-body vibration is related to degenerative changes of the spine and likely contribute to pathogenesis of disorders of female reproductive disorders (Seidel, 1993).

The seated environment is commonly associated with back pain since the spine is forced into flexion and the optimal line of force is shifted. There is an increase in internal pressure of the intervertebral disc and, the posterior part of the disc is stressed in the seated position. In a sitting position the spine is unable to absorb and dampen the shocks and vibration as effectively as it does in a standing position. Many employees in Fort St. John who have experienced back pain on the job have been exposed to long hours of whole-body vibration while driving mobile equipment or sitting in operators booths. There is evidence to support this trend of back pain occurrence among sedentary workers in a vibration environment (Burdorf and Zondervan, 1990; Boshuizen et al., 1992; Wilder, 1993).

Wilder (1993), reviewed the mechanical factors associated with low back pain in a vibration environment. It was found that vibrated spinal motion segments are at a greater risk of sudden buckling in response to vibration loading. Wilder (1993) suggested that preventative measures should be taken to minimize the vibration reaching the driver, to help reduce the risk of low back pain.

Burdorf and Zondervan (1990), conducted a survey among workers in a steel factory to evaluate the risk for low back pain among crane operators. Based on their results, which demonstrate that workers in a sedentary position are at a risk for low back pain when exposed to whole-body vibration, Burdorf and Zondervan (1990) recommend that persons with a history of low back pain should not be employed as crane operators.

A study on the long term health effects of whole-body vibration was completed with forklift and freight container drivers (Boshuizen et al., 1992). Results of this study indicate that drivers will tend to develop back pain within the first five years of driving. This correlates with the Fort St. John workplace where reports of back pain are high among the forklift drivers, a majority of them having less than five years experience driving the forklifts. West Coast Industrial Ergonomics (1996), also had similar findings reporting a large amount of back discomfort experienced by operators in their early twenties with minimal experience.

In addition to whole-body vibration, studies on hand-arm vibration exposure also show the occurrence of musculoskeletal disorders in the workplace (Bovenzi et al., 1991; BCRI, 1994). In an epidemiological and clinical study, Bovenzi et al. (1991), examined musculoskeletal disorders occurring in the neck and upper limbs of forestry workers using chain saws. Musculoskeletal impairment was found to be more prevalent in the vibration exposed forestry workers than the non-exposed control group. The vibration exposure was related to a decrease in joint function and grip strength and an increase in interphalangeal joint size and carpal tunnel syndrome occurrence (Bovenzi et al., 1991).

In an ergonomic review of repetitive strain injuries in the wood products industry, BCRI (1994) found that one third of the workers experienced hand-arm vibration from equipment or tools, and that 25% of workers experience symptoms of numbness and tingling when using equipment or tools. Forklift operators, millwrights, maintenance workers and loader operators reported the highest amount of hand vibration.

A review of the literature shows that vibration exposure may also have an effect on work performance (Bovenzi et al., 1991; Lewis and Griffin, 1978). In addition to concluding that musculoskeletal disorders of the upper limb are associated with vibration exposure, Bovenzi et al. (1991), also reported that musculoskeletal disorders are linked with disability and decreased work performance. Lewis and Griffin (1978), reviewed measurements of tracking performance in vibration environments and found that an increase in whole-body vibration levels will result in an increase in manual performance errors.

In contrast to the above studies, Nakamura and Haverkam (1991), found no correlation between vibration and performance. The effects of whole-body shock vibration on manual performance were examined by exposing male subjects to vibration while sitting on a rigid seat. Based on their results, Nakamura and Haverkam (1991) concluded that fine manual control was not affected by vibration.

Little information was found regarding different types of vibration reduction strategies and if exposure levels could be reduced successfully. Wilder (1993), suggested that to minimize the risk of low back pain when driving; minimize the vibration reaching the driver, after driving walk around for 5 - 10 minutes, and avoid lifting or bending immediately following driving. Suzuki and Iwasaki (1990) studied the effects of reducing the vibration intensity of chain saws and the prevalence of vibration syndrome among forestry workers. It was found that the reduction in the prevalence of vibration syndrome over a 10-year period was attributed to a decrease in chain saw intensity levels and the total time the tools were used. BCRI (1994) recommended that segmental vibration levels should be evaluated and ensured not to exceed 5 to 16 Hz.

It would be useful to measure the vibration levels of the different workstations and tools used so as to evaluate the levels that employees are exposed to on the job and determine if certain jobs are at risk of developing vibration related disorders. Any high-risk jobs or tools that are identified can then be evaluated. If the vibration levels are again measured after different vibration reduction interventions it can be determined what methods are most effective and practicable for reducing vibration. If it can be objectively shown that that certain things successfully reduce the exposure of vibration to the employee, then implementation can be enforced. Management will be more willing to reorganize high-risk jobs or tasks, and employees will more readily accept the use of vibration controls when working with vibrating tools.

The average age population at this division is young and back pain is already experienced throughout the mill, as well as symptoms of numbness and tingling in the hands among some tradespeople. There have been cases where employees who experience back pain are unable to work in certain jobs as the vibration levels aggravate their condition. Since there is evidence showing that long term exposure to vibration can contributes to musculoskeletal disorders it is important that preventative measures be implemented now while the work force is still young. Musculoskeletal disorders of this nature are costly and can result in many days of lost time. Since many of the workers in the mill either sit or stand in one spot for 8 hours it is important that whole body vibration be reduced Evaluating the vibration levels and finding effective methods to reduce exposure is crucial. The aim is to find effective methods to help reduce any symptoms people currently experience and prevent any vibration related disorders from occurring in the future. The objectives of this study are:

- To quantify the levels of both hand-arm and whole-body vibration, through overall weighted measurements, that employees are exposed to on the job at Canfor.
- Determine if certain jobs/employees are at risk of developing vibration-related disorders.
- Evaluate the effectiveness of different vibration reduction interventions and determine which methods are most effective/practicable.
- Develop a training program to educate employees, who are exposed to high levels of vibration, on the importance and proper use of vibration interventions when at work.

1.1 HYPOTHESIS

The following statements outline the expected outcomes of this study:

- The mobile equipment vibration will be the highest in the mill and of most concern for whole-body vibration.
- Proper weight adjustment on suspension seats in the operator’s booths and mobile equipment will help reduce vibration.
- Use of t-gel and sorbothane cushions in seated operations will provide dampening of vibration.
- Workstation isolation will be the most effective intervention
- The airbags on the Cut-off-saw shacks will significantly reduce vibration.
- Insoles and matting will have some effect in attenuating vibration.
- Use of sorbothane wrap and gel foam on the hand tools will be noticeably effective in reducing vibration

2.0 METHODS AND MATERIALS

The vibration testing, performed by Navajo Technical Sales Inc, took place at Canadian Forest Product Ltd - Fort St. John division, from February 23 - 27, 1998. Data collection for this project comprised of both whole-body and hand-arm measures. The whole-body measurements assessed 'seated' and 'standing' tasks throughout the sawmill. Hand-arm vibration was measured in two different areas where there is regular daily exposure to vibration. Specific vibration interventions were implemented in each area and the vibration levels re-examined to determine if there was any reduction in the level of vibration. Table 1 lists all the job areas and the different interventions that were tested in each area.

Table 1 - Conditions Measured at each Mill Location.

	Whole Body Vibration																				**Hand Arm Vibration**			
	Seated Locations												Standing Locations											
	Cut-Off-Saw #1	Cut-Off-Saw #2	Chip-n-saw 18"	Chip-n-saw 30"	Debarker	Kiln Forklift AR12 Patrick Forklift	Planer Feeder AR12 Patrick Forklift	Sawmill Takeaway WA250 Komatsu Forklift	Shipping Forklift WA180 Komatsu	Planer Takeaway AR10 Patrick Forklift	Taylor Towmotor FG40Komatsu Forklift	Loader WA450 Komatsu	Mcgehee Edger	Trimmer	Tilthoist	Planer Feeder	Grader	Stacker - Planer	Drop Sort	Edger Optimixer	Stacker - Sawmill	Welder (5" makita grinder)	Welder (7" Makita grinder)	Welder (10" Walter Grinder)	Bucker (Husquvarna 272XP Chainsaw)
Baseline Conditions																									
No airbags/ wt not ok	X	X																							
Adjacent Floor														X	X	X	X	X							
Reconnected Floor/shack			X										X	X	X		X	X							
Reconnected Floor + Plywood																X									
Non suspension seat											X														
Seat - wt not ok				X	X				X																
Premeasure/no interv						X	X	X		X		X							X	X	X	X	X	X	X
Interventions																									
Airbags	X	X																							
T-Gel cushion				X	X	X	X	X	X	X	X	X													
Sorbothane Cushion						X	X	X	X	X	X	X													
Seat - wt ok				X	X				X																
Suspension Seat																									
Isolation			X										X	X	X		X	X							
Matting													X	X		X	X	X	X		X				
Insoles													X	X			X	X							
Gel Foam Material																						X	X	X	X
Sorbothane Material																						X	X	X	X
Plywood															X					X					
Combined Interventions																									
Plywood + matting															X					X					
Isolation + Plywood																X									
Airbags + wt ok	X	X																							
Wt Ok + T-gel cushion																									

2.1 EQUIPMENT

All of the equipment used for the testing and analysis was supplied and operated by NAVAJO Technical Sales Inc. For whole-body vibration data acquisition, the following equipment was used: *Signal Conditioning* - 4 Channel Nexus Type 2690 Conditioning Amplifier [serial # 2069373] with user selectable input sensitivity at 1pC/m/s/s and output gain set to 100mV/Unit. *Data Storage* - Sony 16 Channel DAT Recorder [serial # PC216AX]. Type 4322 Triaxial Seat Accelerometer [serial # 1854694]. Analysis of the whole-body vibration data was performed using the Type 2143 Single Channel Digital Filter Real Time Analyzer [serial # 1566296]. All measurements were made in accordance with IS0 2631-1: 1997.

The overall weighted numbers for whole-body vibration were measured in some areas using the Type 2231Precision Modular Sound Level Meter [serial #1574994] and the Type 2522 Human Response Unit [serial # 1815366]. The software program used with this Human Response System was the BZ7104 Application Module. All measurements were made in accordance with ISO 2631-1: 1985.

Overall weighted measures for hand-arm vibration were taken with the Type 2237B Integrating Sound Level Meter & Hand Arm Vibration Meter [serial #2049928]. The accelerometer used was Type 4505 [serial #2060466]. The system included a hand-tool adapter for mounting the accelerometer. All measurements were made in accordance with ISO 5349:1986.

The interventions used for this project are examples of methods that are currently being tried in Canfor Fort St. John to reduce employee exposure to vibration. The following is a description of the different interventions and how they were used in this project:

Airbags	Rubber cushion mounts filled with air designed to isolate the operator shack from the rest of the mill. The airbags are located in all four corners underneath the Cut-off-Saw shacks. The airbags are filled with air to 40 psi. When the air is let out of the air bags the shack lowers down onto the base.
T-Gel Cushion	Whole-body vibration cushion that combines space age T-foam with a layer of elastomeric T-gel, covered with a vinyl cover. The cushion was placed on top of the seat with the accelerometer between the cushion and ischial tuberosities of employee.

Sorbothane Cushion	Whole body vibration cushion made up of high resiliency foam and sorbothane. The cushion was placed on top of the seat with the accelerometer between the cushion and ischial tuberosities of employee.
Non-Suspension Seat	Non-suspension factory seat found in the 1994 WA450 Komatsu forklift.
Suspension Seat	KAB 211 Seat featuring a self contained suspension unit. This seat was installed in the FG40 Komatsu forklift only during the testing period. Daewoo A151762 Seat featuring a suspension unit. This seat was installed in the FG40 Komatsu Forklift for the operator to use and respond to the questionnaire.
Isolated Floor/Shack	A section of the workstation floor, or operators booth, cut free from the structure surrounding it. A series of 6-8" tubing were used to mount the isolated section directly down to the basement floor. See Fig 4.
Adjacent Floor	The catwalk floor surrounding the isolated section of catwalk. Measures were taken here to simulate the workstation before it had been isolated.
Insoles	Cambion insoles consisting of a top layer of foam with a viscoelastic polymer underlayer. For testing purposes, the insoles were placed on the catwalk with the accelerometer directly on top.
Plywood	3/4" plywood screwed into the steel catwalk flooring.
Gel Foam	A material found in Gel Foam gloves intended to reduce hand arm vibrations. Gel (1/8”) foam (1/8”)
Sorbothane	A viscoelastic material (1/8”) that is used in gloves and a tool wrap kit. The material is intended to reduce hand arm vibrations.
Matting	Wearwell antifatigue matting 7/8" thick rubber.

2.2 DATA ACQUISITION

Measurement data was collected using two fundamental methods:

1) *DAT Recording* – a multichannel instrumentation Digital Audio Tape recorder is used to store the original analog vibration signals for post-analysis using a 1/3 Octave digital Filter Real-time Analyzer.

2) *Weighted Acceleration* – dedicated instrumentation provides a single number value representing the frequency weighted, linearly integrated r.m.s. acceleration over the measurement period.

The weighted acceleration measurements were taken in three whole-body vibration locations, in parallel with the DAT recording, for two purposes;

- to aquaint the person conducting the measurements with typical vibrations – by providing immediate display of acceleration levels
- To provide a cross-reference to the DAT measurements.

The weighted acceleration method was used for hand-arm applications for the following reasons:

- Daily operation of hand tools, including grinders, is comprised of relatively short periods lasting only seconds to a minute or two.
- The mobility of both the operator and the hand tool imposed instrument set-up/placement restrictions
- A tri-axial hand-arm accelerometer was not available.

For all whole-body and hand-arm vibration measurements, placement of the transducer (accelerometer) was in the basicentric co-ordinate system, the immediate interface between the body and vibrating surface, in accordance with ISO standards. When measuring various interventions, the accelerometer was again placed immediately between the material and the body. Measurements were recorded over a sample period of time representative of a regular work cycle for each job.

Whole Body Vibration

The DAT recording method was used for all whole-body vibration applications and was the principal data acquisition technique. The actual sample periods varied from 2-minutes for some standing positions to 25-minutes for some seated mobile equipment operations. Weighted acceleration measurements were taken at the 18” and 30” Chip-n-saw, and the Debarker. The instrument was set up to measure and store contiguous one-minute samples over a period of fifteen minutes.

A baseline measure of the vibration was taken at each location. The interventions were then put in place and the vibration measured again for each intervention. Table 2 outlines what conditions were measured at each job location.

Table 2 – Conditions Measured at each Whole-Body Vibration Location

Cut-Off-Saw #1 & 2 No airbags/wt not ok * With airbags/wt not ok ✠ With airbags/wt ok	**Debarker** Wt not ok* ✠ Wt ok Wt ok + t-gel cushion
CNS 30" Wt not ok * ✠ Wt not ok + t-gel cushion Wt ok Weighted Measurements	**Trimmer** Adjacent Floor * Isolated floor ✠ Reconnected floor* Reconnected floor + matting Reconnected floor + insoles
CNS 18" Reconnected shack * Isolated shack ✠ Weighted measurements	**Tilthoist** Adjacent Floor * Isolated floor ✠ Reconnected floor* Reconnected floor + plywood Reconnected floor + plywood + matting
Kiln Forklift **Patrick AR12** Baseline * ✠ Sorbothane cushion T-gel cushion	**Planer Feeder** Adjacent Floor * Isolated floor + wood platform ✠ Reconnected floor + wood platform* Reconnected floor + wood platform + matting
Planer Feeder Route **Patrick AR12** Baseline * ✠ Sorbathane cushion T-gel cushion	**Grader** Adjacent floor * Isolated floor ✠ Reconnected floor * Reconnected floor + matting Reconnected floor + insoles
Sawmill Takeaway Forklift Komatsu Baseline * ✠ T-gel cushion Sorbothane cushion	**Stacker - planer** Adjacent Floor * Isolated floor ✠ Reconnected floor * Reconnected floor + matting Reconnected floor + insoles
Shipping Forklift Komatsu Wt not ok * ✠ Sorbothane cushion T-gel cushion Wt ok	**Edger Optimizer** Baseline – no isloation * Plywood Plywood + matting ✠
Planer Takeaway Forklift Patrick AR10 Baseline * ✠ Sorbothane cushion T-gel cushion	**DropSort** Baseline - No isolation * Matting ✠
Komatsu Loader Baseline * ✠ Sorbothane cushion T-gel cushion	**Stacker - sawmill** Baseline - No isolation * Matting ✠

Komatsu Forklift	**Mcgehee**
Non-suspension seat * ✠	Reconnected floor*
Non-suspension seat + Sorbothane cushion	Reconnect floor + matting
Non-suspension seat + T-gel cushion	Reconnect + insoles
Suspension Seat (Kab 211)	Isolated floor ✠

* - Baseline condition ✠ - Current conditions of job area

In the seated workstations the accelerometer was placed on the seat between the seat surface and ischial tuberosities. See figure 1. The seats have a weight adjustment suspension that must be set to the weight of the operator to provide proper suspension. For some of the tests, the suspension on the seat was adjusted to the proper weight (wt ok) and the incorrect weight – 110 kg (wt not ok) so that both conditions could be measured. The suspension systems were broken in the seats in some of the mobile equipment and therefore incorrect versus correct seat adjustment could only be measured in the shipping forklift. The measuring equipment was secured in the mobile equipment during the data collection to allow for measurements of actual working conditions.

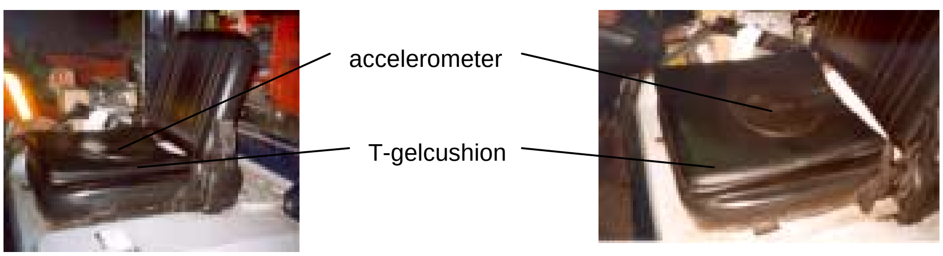


Figure 1 – Towmotor non-suspension seat

In all standing areas, the accelerometer was placed on the catwalk either directly beside or behind where the operator stands. A 10kg bag of safe-t-salt was placed on the accelerometer to weight it down. To test the vibration of the workstation with the different interventions in place, the accelerometer was placed on top of the material (insoles, matting, plywood) and the bag of safe-t-salt was placed on top of the accelerometer. Figures 2 and 3 illustrate the testing conditions. At some of the workstations, a section of the catwalk that the worker stands on had previously been isolated. To determine what the level of vibration at the standing workstations was before the floor sections were isolated, a small 2"x5" piece of steel was welded onto each corner of the isolated platform and the surrounding catwalk. This allowed the vibration to transfer back onto the platform. See figure 4. A measure was also taken on the catwalk adjacent to the isolated platform, because when the floor was reconnected it was observed that it did not vibrate as much as the area beside it. This was likely due to the added structural support of the isolated platform.

Figure 2 - Accelerometer on catwalk

Figure 3 - Accelerometer placed on insoles

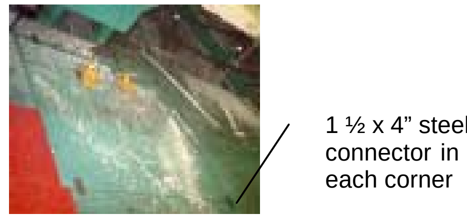


Figure 4 – Reconnected Catwalk

Hand-Arm Vibration

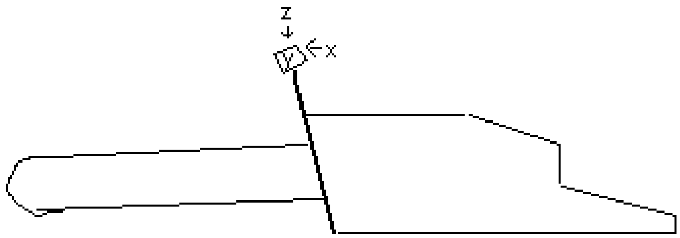
The weighted acceleration method was the only measurement technique used for hand-arm applications.

Hand arm vibration results will be given for the grinders and chainsaw, but not for the tools used in the following areas: sawfilers, paperwrap, forklifts, and millwrights. Due to time restraints not all originally proposed areas were tested. Table 3 outlines the tools that were evaluated and the interventions used.

Table 3 - Hand-arm Vibration Testing Conditions

Job Title	Tool Evaluated	Testing Conditions
welder	5" Makita Grinder 7 " Makita Grinder 9" Walter Grinder	1. *Baseline.* Transducer attached directly to handle 2. *Intervention:* Gel Foam placed between handle and transducer 3. *Intervention*: sorbothane placed between the handle and transducer
Yard Clean Up (Bucker)	Husquvarna 272XP Chainsaw	

All tools were measured under the same three conditions. The *baseline measure* involved no intervention. The transducer was attached directly to the bare handle of the tool in a position relative to where the hand grips the handle. The measuring equipment was hooked into the transducer in the x-axis, the y-axis, and the z-axis. Separate readings were taken in all three axes. See figure 5 to see the position of each axis measured.   Figures 6 and 7 show the position of the transducer on the tools as they were being measured. The transducer was placed on the side handle of the 5" Makita & 10" Walter grinders, and the top handle of the Husquvarna 272XP chainsaw. The transducer was positioned on the main handle of the 7" Makita grinder.



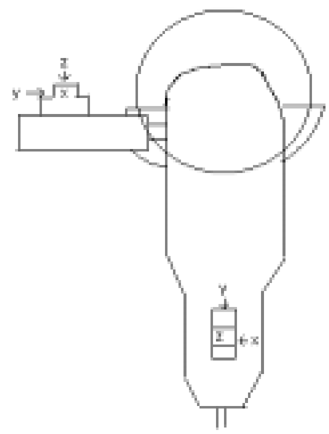


Figure 5 – Measurement location of x-, y-, and z-axis on the chainsaw and grinders.

Figure 6 – Mesurement of x-axis on the chainsaw – no intervention

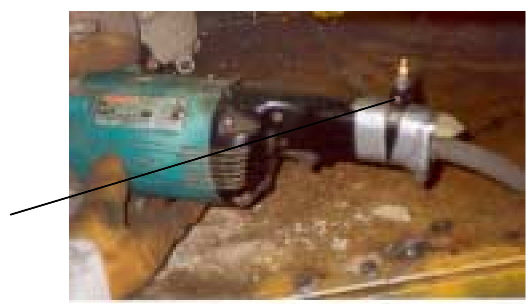


Figure 7 – Measurement of z-axis on the 7" Makita grinder – gel foam

Two different materials were used as interventions: *gel foam* and *sorbothane*. Both of these materials are used in several different styles of vibration reducing gloves and the sorbothane is also used in a wrap kit - to wrap around the handle of the tools. A piece of the material approximately 1"x2" was placed on the handle in the same location used in the baseline measure. The transducer was placed on top of the material and duct tape wrapped tightly around the transducer to secure it in place. Readings were again taken in all 3 axes.

The *chainsaw* measures were taken while the operator was bucking logs. Between four to ten 1-minute readings were taken in the x, y, & z-axes for the baseline measures and the gel foam intervention measures, while only the x-axis was measured for the sorbothane intervention. Due to time restraints, the y & z-axis were not measured on the chainsaw with the sorbothane intervention. Hand arm vibration measures for the three grinders were taken with a disk attachment while grinding a piece of steel. One 10-second reading was taken in each of the x, y, & z axes under all three conditions.

Vibration Questionnaire

Participation for this part of the study was voluntary, and each individual was ensured confidentiality. To ensure this confidentiality results will not be displayed by job location of the mill as certain employees are associated with specific jobs. Fourty-eight employees who are exposed to vibration on the job were given a questionnaire to fill out regarding the amount of vibration they experience. Thirty-one of these employees were given different interventions to work with for at least one week. These thirty-one employees were then given another questionnaire pertaining to the amount of vibration experienced with the intervention in place, and the overall comfort of the intervention. Some of the thirty-one people tried out more than one intervention for a total of fourty-nine interventions tried The following eleven different interventions were given to the employees to use: matting, insoles, airbags, suspension seat, plywood, isolated workstation, T-gel cushion, sorbothane cushion, sorbothane tool wrap, impacto gloves, and ergotech gloves. Questionnaires that were filled out regarding the use of the airbags, isolated floor, and plywood, were based on the employee remembering what the conditions were like before, as these interventions were implemented prior to this project.

Both the impacto and ergotech gloves are made of sorbothane. None of the operators would use the gel foam gloves, which were used in the actual testing, as they were too bulky and uncomfortable to work with.

The KAB 211 suspension seat would not fit in the forklift due to structural reasons, so after the vibration measures were gathered, a different suspension seat was installed. Therefore, the suspension seat used for the questionnaire is a Daewoo A151762 suspension seat and is different than the seat used for testing. The non-suspension seat was the same for both the testing and questionnaire baseline reference.

The sorbothane tool wrap was wrapped around both handles of the grinders and chainsaw. A heat shrink tubing is wrapped around over top of the sorbothane sheet. In the case of the grinders, a new side handle was made in house 3/8" smaller in diameter to account for the added thickness of the wrap (1/8").

Employee Training

Individual training sessions were performed with the mobile equipment operators, Welders, Buckers, and the Debarker and Dropsort operators, once it was determined that these areas showed the highest levels of vibration. The following things were covered with each operator: definition, causes, and possible symptoms of whole-body and hand-arm vibration, and prevention strategies to use when exposed to vibration. An outline of topics to include when educating employees about human vibration is provided in Appendix D. Additionally, this information was included into the competency based training manuals for the Welder and Bucker.

2.3 ANALYSIS

Analysis of the DAT recording was performed with the Type 2143 single channel Digital filter Realtime analyzer. The analyzer was set up for 1/3 Octave band analysis with the frequency range limited to 0.4 Hz to 400 Hz for human vibration purposes. Additionally, the linear overall acceleration values and the weighted acceleration values were displayed. The actual freqency weightings were entered manually into the analyzer and are W_k and W_d from table 3 of ISO 2631-1:1997.

All recorded data was analyzed a minimum of twice to a)ensure the validity of the recorded signal and to select a suitable portion of the taped section (ie., initial recording levels may be high as the vehicle operator "bounces" back into his seat and resumes work), and b)actually analyze the data via the real time analyzer.

Whole-body Vibration

Measured and included in appendix B, is all of the data, for the x, y, and z-axes, in the frequency spectra .4 Hz to 400 Hz. Overall weighted (W) and Linear (L) acceleration values are also included. The linear value is presented in addition to the weighted value because in many cases there was only a marginal improvement when looking at W, but a significant improvement when looking at L. The z-axis (head to seat, head to feet) is the dominant vibration at all the locations and therefore is the principle axis for consideration for analysis purposes as outlined in 7.2.2 of ISO 2631-1:1997. A ratio analysis of the interventions was also performed to demonstrate what parts of the frequency spectra the interventions had attenuation.

Assessment on the effects of the vibration on health is based on ISO Standard 2631-1:1985 & 1997. The new ISO raises the standards on vibration exposure and so analysis of the data for possible health risks is based on the old standard, where a level of .1 m/s^2 affects personal comfort, and .32 m/s^2 affects fatigue decreased proficiency level. Absolute exposure limits are in the range of .6-1.2 m/s^2 as outlined in both standards.

Hand-Arm Vibration

The instrumentation used provided a single number value (Aeq) representing the frequency weighted, linearly integrated rms acceleration over the measurement period. This value was converted into an Aeq4 value. The Aeq4 is based on 4-hours/day use for the chainsaw and 2-hours/day use for the grinders. As with whole-body vibration, it is the axis of dominant vibration that is the principle axis for consideration. The results of all axes are displayed in the results section with the primary axis of consideration highlighted for each tool. These values were compared to ISO 5349:1986 to determine the chance of our employees developing symptoms of vibration disorders. The exposure time for chainsaw operators was 10 years based on the fact that this is a good job to have and may be the average time somebody stays in this position. The exposure time for welders using the grinder was set at 15 years since being a welder is a trade and people will likely be in that trade for at least 15 years.

Questionnaire

To ensure confidentiality, all raw data will not be reported since the association of response by job location would identify the response of a specific operator. Permission has been given by the welders to associate by intervention, as it is more obvious who answered these questions.

There are statistical analysis issues that are hard to satisfy in a field study of this type for a couple reasons; there is non-random assignment of employees to jobs, and some employees used more than one intervention and therefore it is not an independent sample.

Pearson correlation was performed to see if there was any association between subjective rating of vibration (value 1-7) and actual rms values of vibration. Actual responses to question 1 (baseline and intervention questionnaires) were plotted against the actual weighted and linear z-axis values for whole-body vibration. Only the Aeq4 dominant axis values for hand-arm vibration were assessed since only weighted measures were collected. Additionally, percent change in the questionnaire rating was compared with the percent change in the actual r.m.s. values after interventions were in place.

3.0 RESULTS

3.1 RESULTS - VIBRATION MEASUREMENTS

Whole-Body Vibration

Tables 4 - 20 include only the overall linear broadband "L" and weighted "W" r.m.s. acceleration values for the z-axis as this is the dominant axis of vibration. Results are included for all conditions measured. Included in these tables is the change in L and W when comparing the interventions to the baseline. At the 'isolated' locations where the adjacent floor was measured, two baseline measures are used. Ratio analysis graphs are provided for most of the data. The vector sum is not included, as it will be strongly related to the z-axis. All values are expressed in m/s^2. Note that the weightings are taken from the current ISO Standard 2631-1:1997 Table 3 - W_k for all z-axis measurements and W_d for x & y-axis measurements. Researchers wishing to further analyze this data in detail, refer to Appendix B.

Table 4 - r.m.s. Values for Seated Operators Booths in the Sawmill

	Z-Axis		CHANGE (L)		CHANGE (W)	
MEASUREMENT	**L (rms)**	**W (rms)**	**rms**	**%**	**rms**	**%**
Cut-off-saw #1						
Baseline-No AB,Wt not Ok	0.071	0.046				
AB,Wt-OK	0.098	0.065	0.027	38.0	0.019	40.9
AB,Wt not Ok	0.051	0.038	-0.020	-28.0	-0.008	-16.4
Cut-off-saw #2						
Baseline-No AB,Wt not Ok	0.077	0.054				
AB,Wt-OK	0.086	0.064	0.009	12.1	0.010	18.7
AB,Wt not Ok	0.071	0.049	-0.005	-6.8	-0.005	-8.8
Chip-n-saw 30"						
Baseline - Wt not OK	0.103	0.089				
Wt not Ok + T-gel Cushion	0.113	0.101	0.010	9.3	0.012	13.5
Wt-Ok	0.107	0.094	0.004	3.9	0.004	5.0
Chip-n-saw 18"						
Baseline - Reconnected	0.112	0.089				
Isolation	0.094	0.064	-0.018	-16.3	-0.026	-28.9
Debarker						
Baseline - Wt not OK	0.187	0.118				
Wt-OK	0.071	0.054	-0.116	-61.9	-0.063	-53.8
Wt Ok + T-gel Cushion	0.078	0.064	-0.109	-58.3	-0.054	-45.6

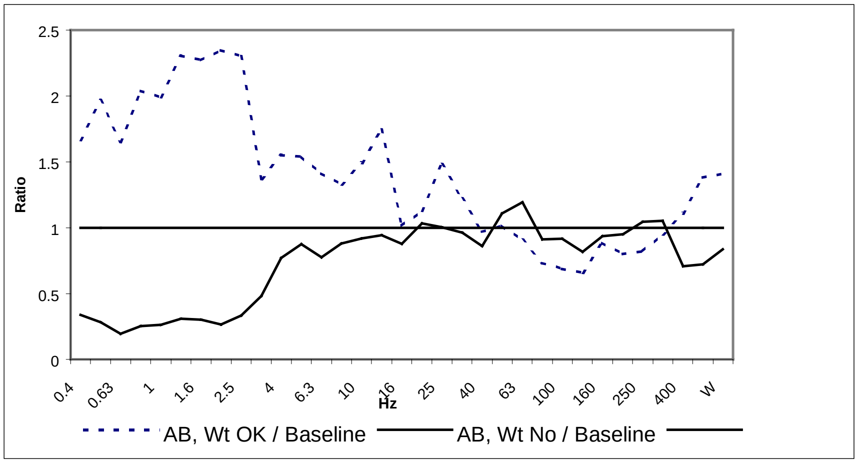


Figure 8 – Isolation Ratio Graph of Interventions for Cut-Off-Saw #1

- Improper Debarker seat adjustment produced vibration of .118 m/s^2 which could be associated with risk of decrease comfort for operator. The T-gel cushion in 30" chip-n-saw produced minimal increase of vibration of 12%, but to within a level that could cause operator discomfort at .101 m/s^2.
- Airbags on cut-off-saws shacks #1 & 2 only minimally reduced vibration, 16.4% and 8.8% respectively.
- Proper weight adjustment on the seats in the cut-off-saws and 30" chip-n-saw resulted in an increase in vibration (40% in cut-off-saw #1). The debarker is the only area that showed a reduction (53.8%) in vibration with proper seat adjustment.
- Isolation of the 18" chip-n-saw shack reduced vibration by 28.9%.

Table 5 – McGehee r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
McGehee						
Baseline - Reconnected Floor	2.066	0.142				
Reconnected Floor + Matting	0.788	0.134	-1.278	-61.9	-0.007	-5.3
Reconnected Floor + Insoles	0.583	0.110	-1.483	-71.8	-0.032	-22.5
Isolated Floor	0.302	0.052	-1.764	-85.4	-0.089	-63.2

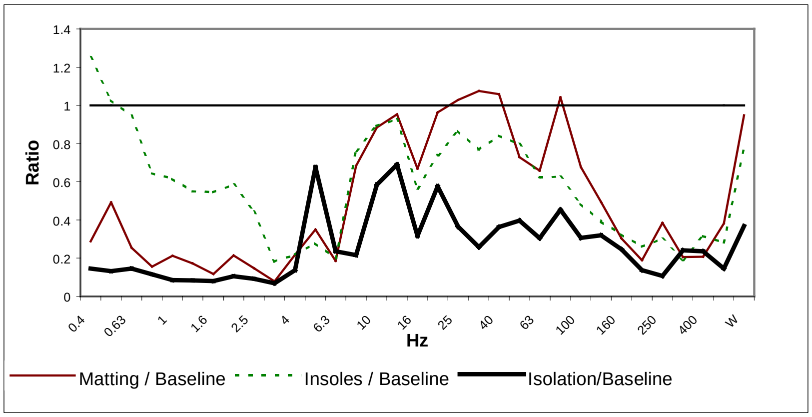


Figure 9 – Isolation Ratio for Interventions at McGehee

- The weighted baseline value of .142 m/s^2 was at a high enough level to cause personal discomfort while working, based on the old ISO guidelines. Isolation of this workstation has reduced the level of vibration by 63%.
- The interventions, matting and insoles marginally reduce the vibration, 5.3% and 22.5% respectively, when looking at the weighted values.
- When assessing the linear values, the two interventions matting and insoles have a high impact in reducing vibration, 61.9% and 71.8% respectively.

Table 6 – Trimmer r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Trimmer						
Baseline 1 – Adjacent Floor	1.286	0.148				
Isolated Floor	0.382	0.103	-0.904	-70.3	-0.046	-30.8
Baseline 2 – Reconnected floor	0.688	0.093				
Reconnected floor + Matting	0.404	0.162	-0.284	-41.3	0.068	73.3
Reconnected Floor + Insoles	0.318	0.079	-0.370	-53.8	-0.014	-15.0

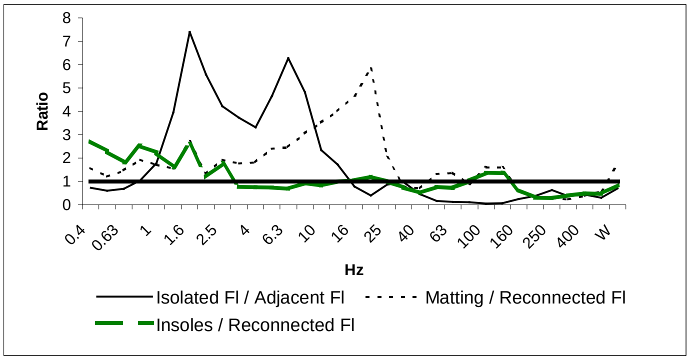


Figure 10 – Isolation Ratio for Interventions at Trimmer

- While isolation reduced vibration by 30.8% when compared to the adjacent floor, both measures were high enough to affect operator's comfort, at .103 m/s^2 and .148 m/s^2 respectively. Implementation of matting also caused levels for caution at .162 m/s^2.
- Insoles helped to reduce vibration by 15%, while matting increased vibration by 73%. In contrast, overall linear values show that matting reduces vibration by 41%

Table 7 – Tilthoist r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Tilthoist						
Baseline 1 - Adjacent Floor	1.283	0.211				
Isolated Floor	0.456	0.071	-0.827	-64.5	-0.141	-66.5
Baseline 2 - Reconnected floor	0.876	0.154				
Reconnected Floor + Plywood	0.503	0.137	-0.373	-42.6	-0.017	-11.0
Reconnected Floor + Plywood + Matting	0.344	0.102	-0.532	-60.7	-0.052	-33.6

- Vibration levels of both the adjacent floor and reconnected floor are high enough to cause operator discomfort at .211 m/s^2 and .154 m/s^2 respectively. Isolation resulted in a 66.5% reduction in vibration.
- The interventions plywood, and plywood + matting, reduced vibration by 11% and 33.6% respectively.

Table 8 – Planer Feeder r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Planer Feeder						
Baseline 1 - Adjacent Floor	3.059	0.244				
Isolated Foor + Plywood	0.522	0.090	-2.537	-82.9	-0.154	-63.1
Baseline 2 - Reconnected floor + plywood	0.606	0.090				
Reconnected Floor + plywood + Matting	0.354	0.084	-0.251	-41.5	-0.005	-6.0

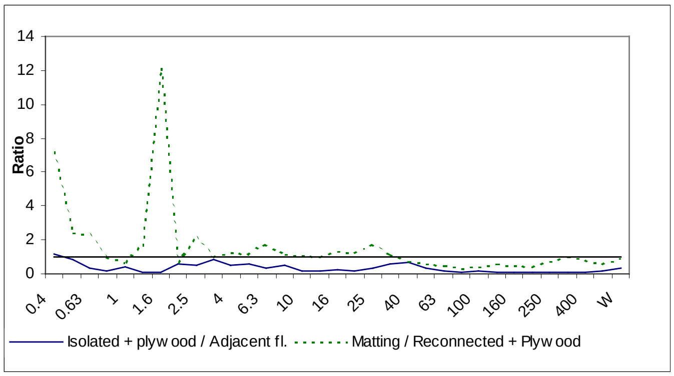


Figure 11 – Isolation Ratio for Interventions at Planer Feeder

- The adjacent floor showed a high level of vibration of .244 m/s^2. Based on the old ISO guidelines, this would cause discomfort for the operator and would be close to affecting work performance. Floor isolation attenuated vibration by 63.1%
- Weighted values for matting showed a 6% reduction in vibration, while the Linear values show a larger reduction of 41.5%.

Table 9 – Grader r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Grader						
Baseline 1 - Adjacent Floor	1.033	0.087				
Isolated Floor	0.329	0.019	-0.703	-68.1	-0.068	-78.4
Baseline 2 - Reconnected floor	0.740	0.025				
Reconnected Floor + Matting	0.151	0.034	-0.589	-79.5	0.009	34.3
Reconnected Floor + Insoles	0.160	0.046	-0.580	-78.4	0.021	82.4

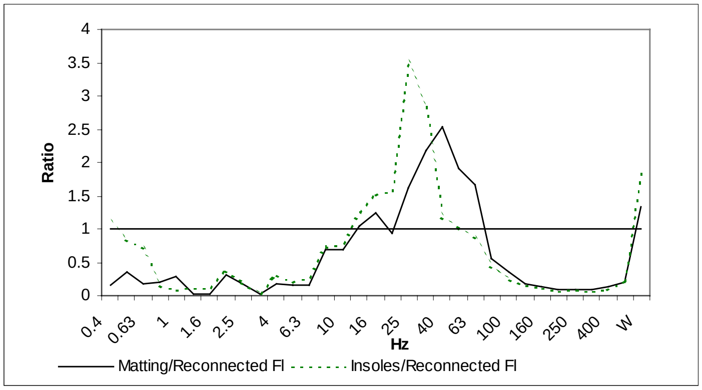


Figure 12 – Isolation Ratio for Interventions at the Grader Station

- The isolated floor helped to reduce vibration by 78.4%
- Evaluation of the weighted measure showed an increase in vibrtion of 34% and 82% for both matting and insoles respectively, while evaluation of the linear value shows a significant reduction of vibration by 79.5% and 78% respectively.

Table 10 – Planer Stacker r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Planer Stacker						
Baseline 1 - Adjacent Floor	0.444	0.060				
Isolated Floor	0.260	0.019	-0.183	-41.3	-0.041	-68.7
Baseline 2 - Reconnected floor	0.292	0.022				
Reconnected Floor + Matting	0.224	0.036	-0.067	-23.1	0.014	60.6
Reconnected Floor + Insoles	0.161	0.021	-0.131	-44.9	-0.001	-6.3

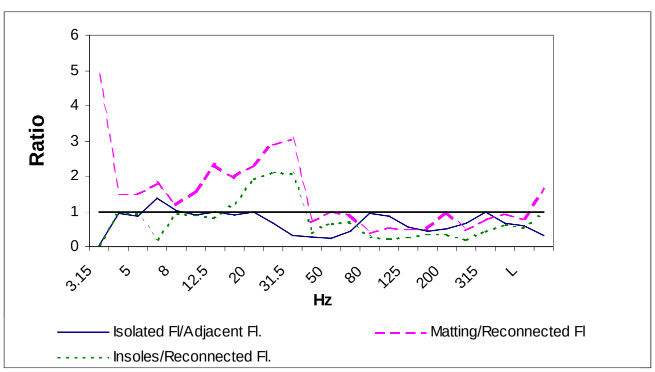


Figure 13 – Isolation Ratio for Interventions at Planer Stacker

- The isolated floor reduced the vibration by 68.7%.
- Matting increased vibration by 60.6% whereas, insoles minimally reduced vibration by 6.3%. Linear values showed that both interventions attenuated vibration by 23% - matting, and 45% - insoles.

Table 11 – Drop Sort r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		CHANGE (W)	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Drop Sort						
Baseline	2.158	0.147				
Matting	0.467	0.169	-1.691	-78.3	0.022	15.1

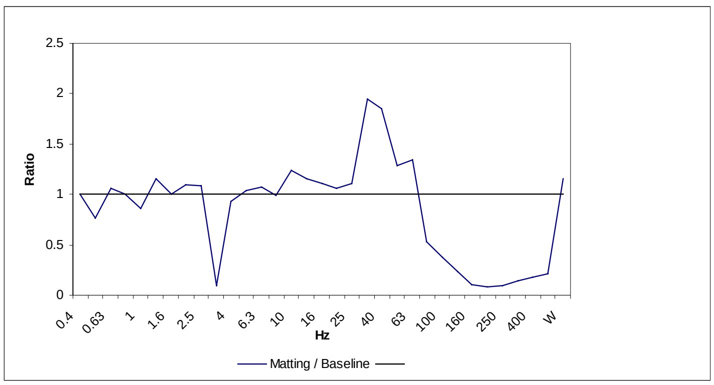


Figure 14 – Isolation Ratio for Interventions at the Drop Sort

- The baseline level of vibration was at 0.147 m/s^2 which may have an effect on operator comfort.
- The weighted value showed an increase in vibration by 15%, while the linear value showed a large reduction in vibration of 78%.

Table 12 – Edger Optimizer r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		CHANGE (W)	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Edger Optimizer						
Baseline	0.521	0.136				
Plywood	0.386	0.083	-0.134	-25.8	-0.052	-38.6
Plywood + Matting	0.243	0.079	-0.278	-53.4	-0.057	-42.1

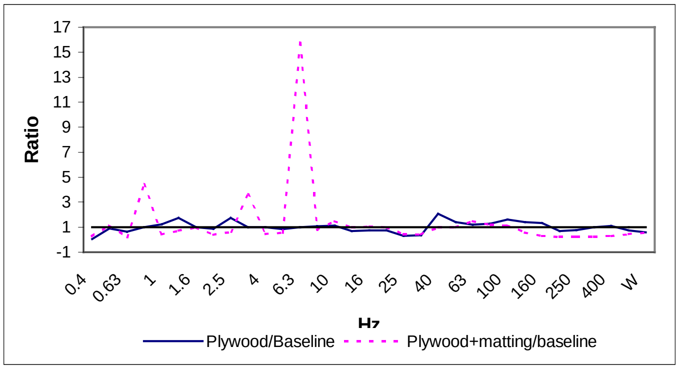


Figure 15 – Isolation Ratio for Interventions at the Edger Optimizer

- The baseline measure of .136 m/s^2 could cause operator discomfort.
- The Interventions, plywood (38.6%) and plywood + matting (42%), both reduced vibration.

Table 13 – Sawmill Stacker r.m.s. Values for Z-Axis

	Z-Axis		CHANGE (L)		**CHANGE (W)**	
Measurement	**L (rms)**	**W (rms)**	rms	%	**rms**	**%**
Sawmill Stacker						
Baseline	0.331	0.019				
Matting	0.115	0.023	-0.216	-65.1	0.004	20.9

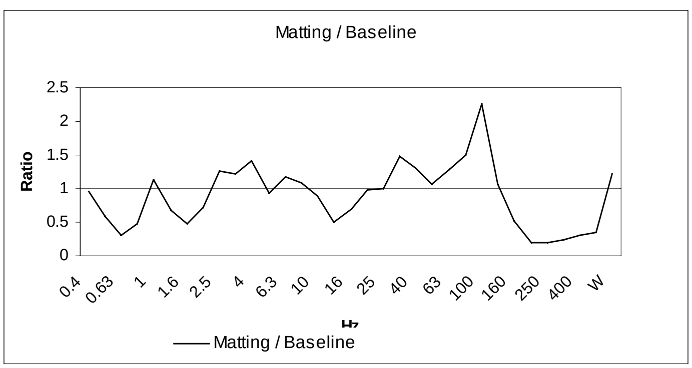


Figure 16 – Isolation Ratio for Interventions at Sawmill Stacker

- The weighted value shows that matting amplifies vibration by 21%, and the linear value attenuates vibration by 65%.

Table 14 – Kiln Forklift r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		**(W) CHANGE**	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Kilns **AR12 Patrick Forklift**						
Baseline	0.577	0.361				
Sorbothane C	1.027	0.621	0.450	78.0	0.259	71.8
T-Gel C	0.852	0.544	0.275	47.7	0.182	50.5

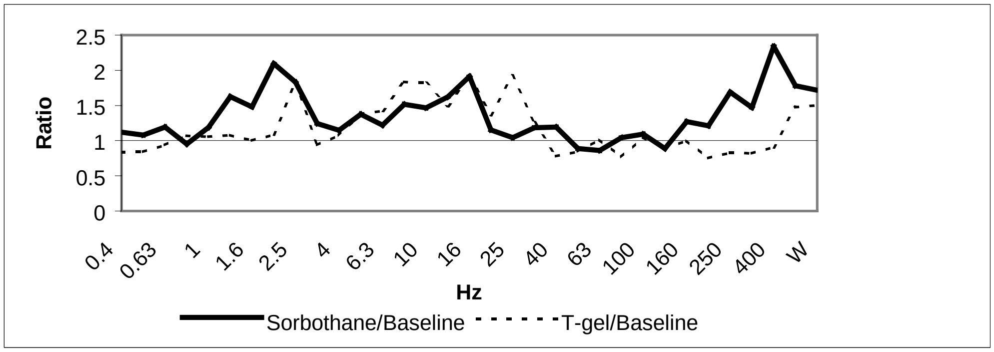


Figure 17 – Isolation Ratio for Interventions with Kiln Forklift

- Baseline measures of the Kiln forklift showed a value of .361m/s^2 that could have an effect on operator performance.
- Both the sorbothane cushion and t-gel cushion amplified the vibration by 71.8% and 50.5 % respectively, moving the levels into the absolute exposure limit.

Table 15 – Planer Feeder Forklift r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		**(W) CHANGE**	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Planer Feeder **AR12 Patrick Forklift**						
Baseline	0.429	0.285				
Sorbothane C	0.395	0.258	-0.034	-7.8	-0.027	-9.5
T-Gel C	0.336	0.218	-0.093	-21.7	-0.068	-23.7

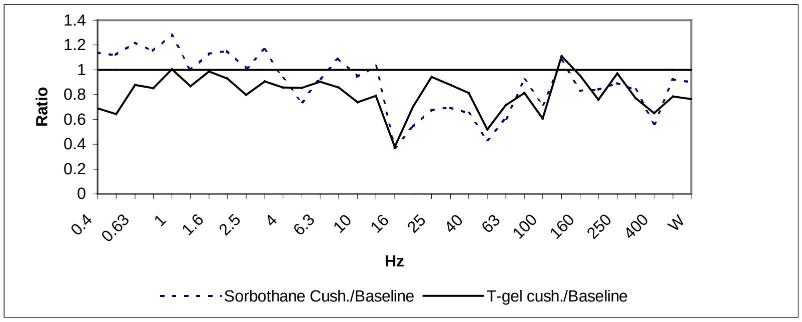


Figure 18 – Isolation Ratio for Interventions with Planer Feeder Forklift

- T-gel cushion and Sorbothane cushion attenuated vibration, by 23.7% and 9.5% respectively, from the baseline level of .285 m/s^2.

Table 16 – Sawmill Takeaway Forklift r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		(W) CHANGE	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Sawmill Takeaway WA250 Komatsu Forklift						
Baseline	0.463	0.328				
Sorbothane C	0.486	0.342	0.023	5.0	0.015	4.5
T-Gel C	0.410	0.288	-0.053	-11.5	-0.040	-12.2

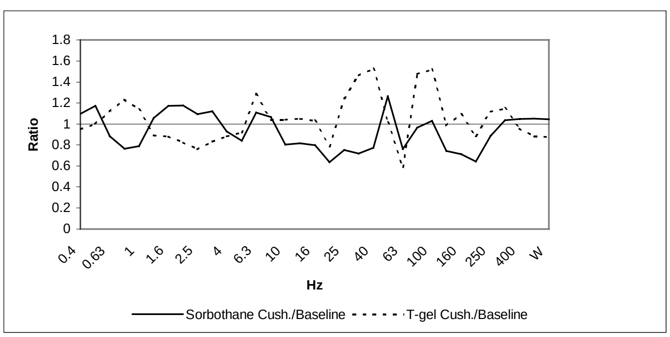


Figure 19 – Isolation Ratio for Interventions with Sawmill Takeaway Forklift

- A high baseline measure of .328 m/s^2 is attenuated by the t-gel cushion – 12%, and amplified by the sorbothane cushion – 4.5%.

Table 17 – Shipping Forklift r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		**(W) CHANGE**	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Shipping **WA180 Komatsu Forklift**						
Baseline - Wt-No	0.394	0.288				
Sorbothane C	0.558	0.392	0.164	41.7	0.104	36.1
T-gel C	0.383	0.277	-0.011	-2.7	-0.011	-3.7
Wt-Ok	0.489	0.352	0.095	24.2	0.065	22.5

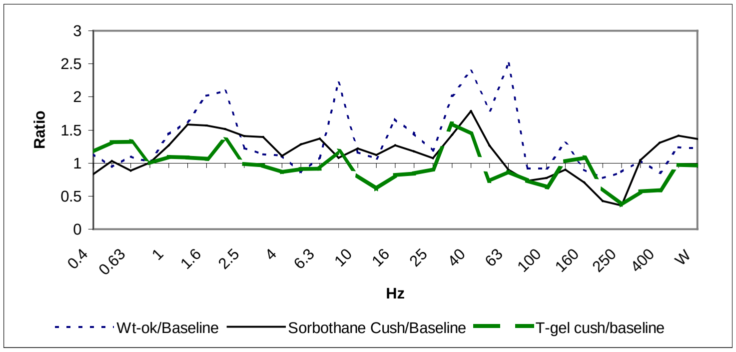


Figure 20 – Isolation Ratio for Interventions with Shipping Forklift

- The baseline measure with the seat adjusted incorrect is .288 m/s^2.
- The T-gel cushion attenuated the vibration minimally by 3.7%. Both the sorbothane cushion and proper seat adjustment amplified vibration by 36% and 22.5% respectively.

Table 18 – Planer Takeaway Forklift r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		**(W) CHANGE**	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Planer Takeaway **AR10 Patrick Forklift**						
Baseline	0.248	0.159				
Sorbothane C	0.411	0.262	0.163	65.8	0.102	64.2
T-Gel C	0.442	0.288	0.194	78.0	0.128	80.5

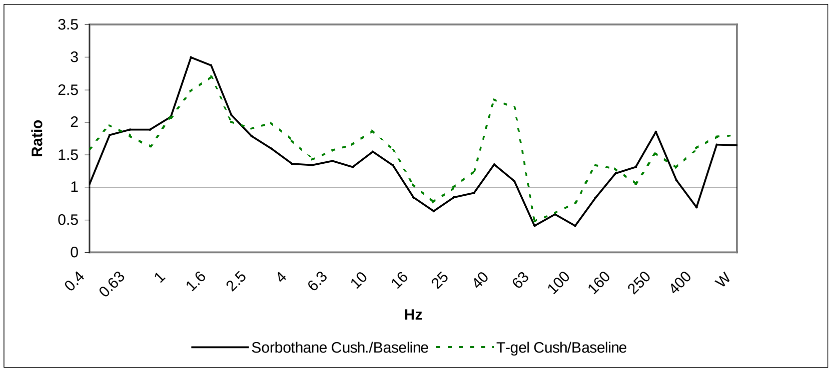


Figure 21 – Isolation Ratio for Interventions with the Planer Takeaway Forklift

- Both the sorbothane and t-gel interventions significantly amplified the baseline vibration of .159 m/s^2 by 64% and 80.5% respectively.

Table 19 – Towmotor r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		(W) CHANGE	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Towmotor Forklift FG40 Komatsu Forklift						
Baseline - Non-Susp. Seat	0.443	0.361				
Sorbothane C	0.407	0.324	-0.036	-8.1	-0.037	-10.4
T-gel C	0.446	0.366	0.004	0.8	0.005	1.3
Susp. Seat	0.385	0.309	-0.057	-12.9	-0.053	-14.6

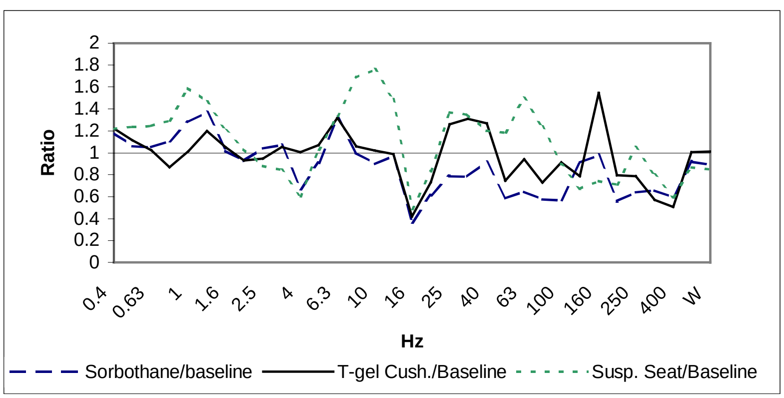


Figure 22 – Isolation Ratio for Interventions with the Towmotor Forklift

- The non-suspension seat showed a baseline value of .361 m/s^2.
- Both the sorbothane cushion and suspension seat attenuated the vibration by 10% and 14.6% respectively. The t-gel cushion amplified vibration by 1%

Table 20 – Loader r.m.s. Values for Z-Axis

	Z-Axis		(L) CHANGE		**(W) CHANGE**	
Measurement	L (rms)	W (rms)	rms	%	rms	%
Loader WA450 Komatsu Loader						
Baseline	0.459	0.316				
Sorbothane C	0.493	0.330	0.035	7.5	0.013	4.2
T-Gel C	0.509	0.346	0.051	11.0	0.030	9.4

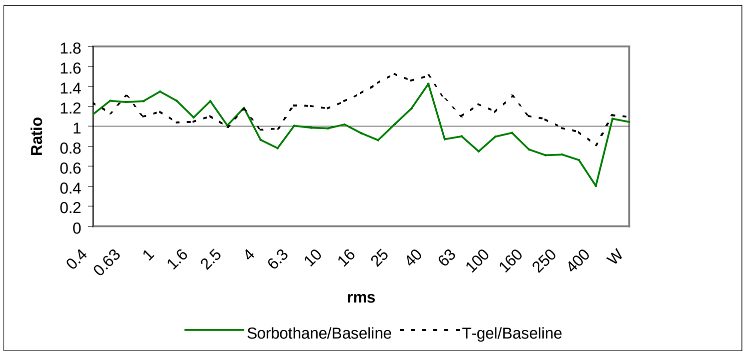


Figure 23 – Isolation Ratio for Interventions with the Loader

- Both the sorbothane cushion and t-gel cushion amplified the vibration by 4% and 9% from a baseline measure of .316 m/s^2.

Hand-Arm Vibration

The higlighted values in the following table represent the dominant axis of vibration for each hand tool. The change in Aeq4 and the percent chance of symptoms are based on these dominant axis values. The Aeq4 values are based on: 4 hrs use/day with chainsaw and 2 hrs use/day with the grinders.

Table 21 – r.m.s. Values for Hand-Arm Vibration

	X-Axis		Y-Axis		Z-Axis		CHANGE (Aeq4)		chance of symptoms
	Aeq (rms)	Aeq4 (rms)	Aeq (rms)	Aeq4 (rms)	Aeq (rms)	Aeq4 (rms)	rms	%	%
Chainsaw Bucker									10 years exposure
baseline	3.38	3.38	4.26	4.26	**7.94**	**7.94**			>50
gel	3.98	3.98	3.46	3.46	**4.78**	**4.78**	-3.16	-39.8	25
sorbothane	*	*	*	*	**5.55**	**5.55**	-2.39	-30.1	34
10" Walter Welder									15 years exposure
baseline	**4.31**	**3.05**	3.84	2.71	2.78	1.97			23
gel	**5.24**	**3.70**	4.26	3.01	3.31	2.34	0.66	21.6	34
sorbothane	**4.95**	**3.50**	3.67	2.59	3.5	2.47	0.45	14.8	31
7" Makita Welder									15 years exposure
baseline	6.09	4.31	5.18	3.66	**9.12**	**6.45**			>50
gel	6.38	4.51	5.43	3.84	**6.09**	**4.31**	-2.14	-33.2	46
sorbothane	5.88	4.16	5.68	4.02	**12.8**	**9.05**	2.60	40.4	>50
5" Makita Welder									15 years exposure
baseline	**2.21**	**1.56**	1.92	1.36	1.31	0.93			<10
gel	**9.01**	**6.37**	3.09	2.18	2.13	1.51	4.81	307.7	101
sorbothane	**4.62**	**3.27**	2.54	1.80	1.88	1.33	1.70	52.2	27

* no values available

- Levels associated with Bucking and using the 7” grinder pose a health risk in the long term.
- Both interventions attenuated vibration on the chainsaw. Neither showed any attenuation on the grinders except the gel foam with the 7” grinder.
- The 5” Makita grinder showed much lower levels of vibration than the 10” Walter grinder in the dominant x-axis.

3.2 RESULTS - VIBRATION QUESTIONNAIRE

The questionnaires that were used can be found in Appendix A. As noted earlier, responses are confidential and therefore all raw data is not reported since association of responses with a location would identify the response of that operator. A total of fourty-eight people answered the baseline vibration questionnaire; thirty-one of these employees also completed at least one more questionnaire after using various interventions.

Figures 24 to 29 show the results from the questionnaires that were given before and after interventions were put in place. For comparison purposes, the results of the baseline questionnaire, shown in this section, represent just the thirty-one employees who used interventions and completed another questionnaire. Some of the thirty-one people tried out more than one intervention for a total of fourty-nine interventions tried. Table one shows this breakdown. Refer to Appendix C for a more detailed breakdown of the questionnaire responses.

Table 22 *- Actual Response to Question 1 (value 1-7)*

Respondent	**Baseline** (total sawmill)	1st Intervention	2nd Intervention	3rd Intervention
1	4	3	2	
2	4	4	4	4
3	3	3	3	3
4	4	4	3	
5	6	2	2	
6	6	3	4	
7	7	3	2	
8	4	2	3	
9	6	2	2	2
10	5	2	2	2
11	5	2	3	
12	5	2	2	
13	5	2	2	
14	6	3		
15	4	2		
16	4	2		
17	6	3		
18	6	2		
19	7	7		
20	7	2		
21	4	4		
22	6	5		

23	7	4		
24	6	6		
25	3	3		
26	5	3		
27	3	4		
28	4	5		
29	4	3		
30	2	1		
31	5	5	5	
32	2			
33	5			
34	6			
35	4			
36	5			
37	5			
38	5			
39	2			
40	4			
41	3			
42	4			
43	5			
44	4			
45	7			
46	5			
47	3			
48	1			
n=	48	31	14	4
mean=	4.65	3.16	2.79	2.75
S.D.=	1.45			

73% of employees said that they are exposed to vibration for at least 8 hours at work. 85% of the employees surveyed are exposed to WBV while 15% are exposed to HAV. 71% of the people exposed to HAV are exposed for less than five hours each day. Employees were asked to rate the amount of vibration that they experience on the job on a scale of one to seven (1 - none, 4 - moderate, 7 - excessive). Figure 24 shows that after the various interventions were introduced, the 'high' amount of vibration that is experienced on the job decreased from 87% to 32%. 'High', is a rating from 4 to 7. 82% of the employees answered that they did notice a reduction in vibration after using the interventions. The interventions where people did not notice much reduction in vibration were with the tool wrap, the insoles, and the T-gel cushion.

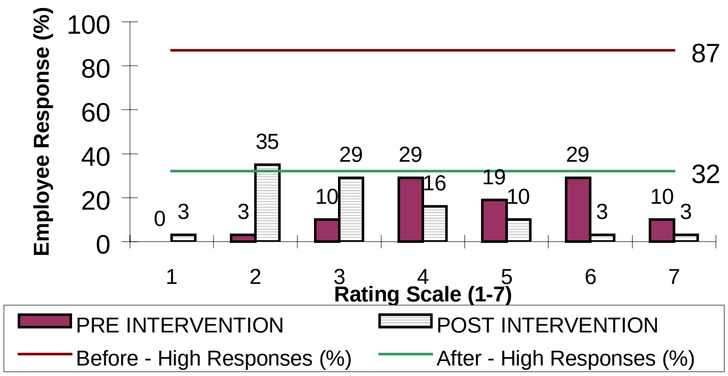


Figure 24 - *Rated Amount of Vibration Experienced on the Job Before and After the Use of Interventions*

Figure 25 shows areas of pain or discomfort experienced by employees in the six months prior to the use of any of the vibration interventions. 45% of employees were experiencing low back pain. The feet (29%), shoulders (26%), and legs (22%) were also noticeable areas of discomfort.

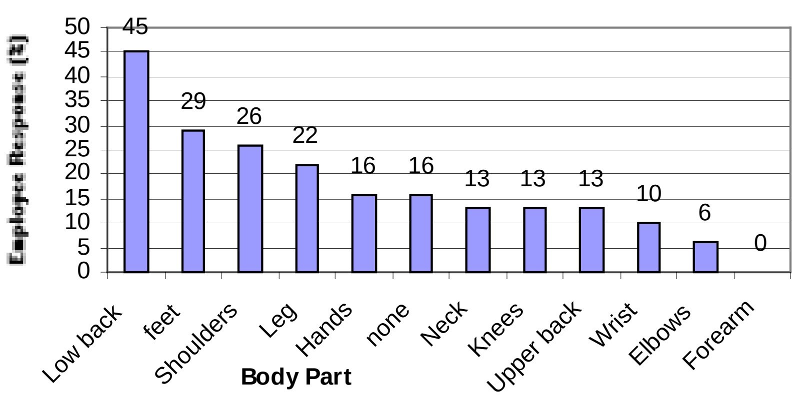


Figure 25 - *RSI Symptoms Experienced before Interventions in Place*

Only 31% of the employees understood the term 'Vibration Syndrome' or 'Raynaud's Disease'. After people had used the interventions and we had discussed some of the effects of vibration, the awareness increased to 48%. The training program was not implemented at this point.

When asked if their level of comfort when exposed to vibration had changed with the use of the interventions, 80% of employees said that comfort improved, 18% said there was no change, and 2% said that their level of comfort decreased.

Figure 26 shows the responses when the employees were asked if there had been any decrease in previous noted symptoms after the use of the interventions. Overall, 58% noticed a decrease in symptoms. Of the 42% who did not notice any changes, 7% had no symptoms to begin with. The highest improvement was seen in the low back and feet where 26% of the employees noticed a decrease of symptoms in both of these areas.

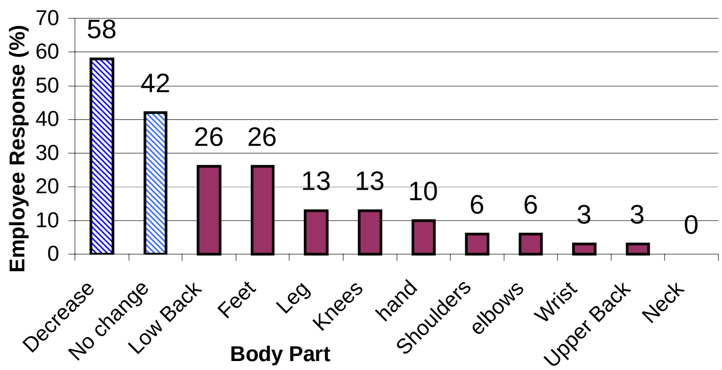


Figure 26 - Percentage of People Noticing a Decrease in RSI Symptoms with the Use of Interventions

Figure 27 illustrates which interventions had an affect in reducing discomfort in the low back and feet. The results showed that the insoles and plywood interventions had the greatest effect in decreasing discomfort in the feet. Use of insoles, matting, isolation and airbags all had similar results in helping to reduce low back discomfort, with matting being the most effective.

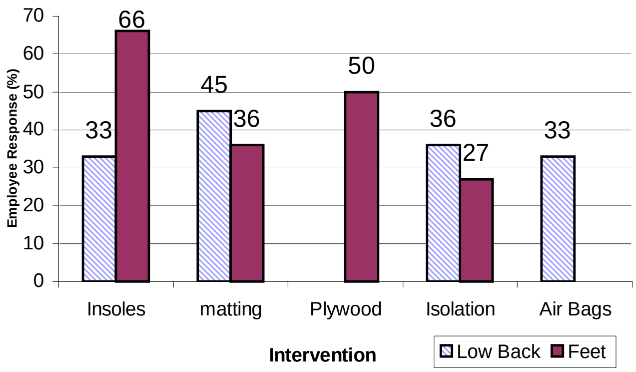


Figure 27 - Interventions that had an Affect in Reducing Discomfort in Low Back and Feet

Figure 28 illustrates the percentage of people who did not notice any change in symptoms while using the interventions. All of the people who used the T-Gel cushion and the suspension seat did not notice any decrease in symptoms.

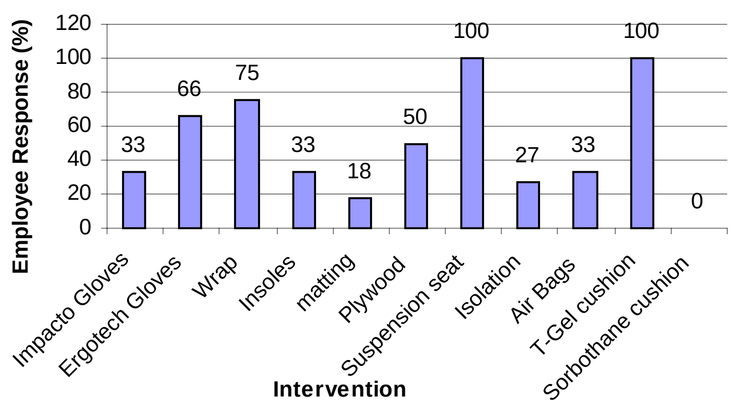


Figure 28 - Percent of People who did not notice any changes in symptoms while using the following Interventions

Employees were also asked to rate the 'user comfort' of the interventions that they tried, on a scale from one to seven (1 - very uncomfortable to use, 7 - very easy/comfortable to use while working). These results are shown in Figure 29. 60% of the employees rated the 'user comfort' of the interventions they tried, as high. High is defined as a rating of 5, 6, or 7.

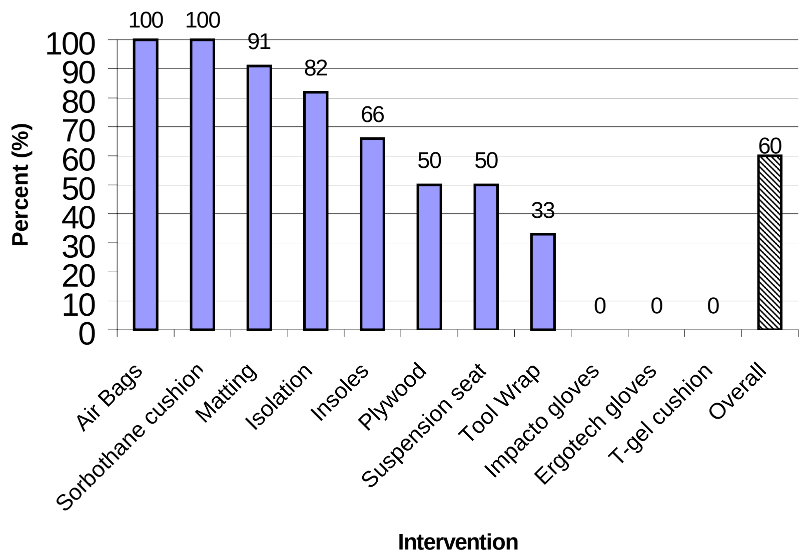


Figure 29 - Percentage of the Employees who rated the 'User Comfort' of the Interventions as High. ***Note*** *- 'High' is a rating of 5-7 on a scale of 1-7*

92% of employees said that they would continue to use the interventions especially if the results from vibration analysis showed that the level of vibration actually decreased. Employees said that they would use the tool wrap on the small handle of the chainsaw and grinder, but not the main handle. The welders would wear the gloves if it were beneficial, but only when grinding for a couple hours straight since it was not practical to take the gloves on and off.

3.3 RESULTS – PEARSON CORRELATION

Correlation between the subjective rating of vibration and the actual rms values are given in the table below.

Table 23 - Pearson Correlation of Questionnaire Rating with r.m.s. Vibration Levels

	WHOLE-BODY VIBRATION	**HAND-ARM VIBRATION**
WEIGHTED RMS	r = .475 n = 57	r = -.028 n = 9
LINEAR RMS	r = .324 n = 57	____

- Both weighted and linear whole-body r.m.s. values are significantly correlated with the questionnaire rating of perceived vibration levels. There is no significant correlation for hand-arm vibration.

The following table shows the correlation between the percent change in the questionnaire rating and the vibration levels.

Table 24 - Pearson Correlation of % Change in Questionnaire Rating and r.m.s. Vibration Levels

	WHOLE-BODY VIBRATION	**HAND-ARM VIBRATION**
WEIGHTED RMS	r = .159 n = 29	r = -.407 n = 5
LINEAR RMS	r = .433 n = 29	____

- There is a significant negative correlation between the percent change in questionnaire rating and the weighted hand-arm r.m.s. levels.
- There is a significant correlation between the percent change in questionnaire rating and the percent change in linear whole-body r.m.s. levels for the interventions. This significant relationship is not seen for the weighted values.

4.0 DISCUSSION AND CONCLUSION

4.1 DISCUSSION

Through out this report, assessment on human health and comfort has been compared to the old ISO 2631:1985 guidelines which consider the potential effects vibration levels have on comfort at .1 m/s^2, and fatigue decreased proficiency at .32 m/s^2. The new ISO 2631-1:1997 guidelines provide cautionary zones for levels where actual health risks are likely (.63-1.2 m/s^2 and greater). The new ISO standards also provide guidelines on comfort that say minimal comfort *may* be experienced in a range of .3 - .8m/s^2, above that discomfort is more likely. These guidelines have raised the standards on vibration exposure and do not consider the potential health effects that lower vibration levels (.1 m/s^2) may have on comfort and as outlined in ISO 2631:1985. Even though health risks have not been clearly documented below the zone outlined in ISO 2631:1997, a previous incident at Canfor – Fort St John division, supports the need to still refer to the old ISO guidelines when assessing human criteria. An employee complained that the vibration associated with working at the Tilthoist, before isolation was in place, aggravated his back so much that he had to leave his job. The adjacent floor levels were measured as .211 m/s^2 , which support his complaints of discomfort and decreased ability to perform this job.

The highest levels of vibration appear to be associated with the mobile equipment, with baseline measures ranging from .159 m/s^2 to .361m/s^2. These values are lower than those found by Boshuizen et al (1992) where the average z-axis reading was .59 m/s^2. The Towmotor and Kiln forklift measured the highest. The characteristics of the smaller Towmotor forklift may have more amplifying effects than some of the other equipment. Boshuizen et al (1992) did not find much difference between the large and small (towmotor) forklifts. None of the interventions made a significant difference towards reducing the vibration in any of the equipment. The t-gel cushion appeared to be more effective than the sorbothane cushion, but in some cases both amplified the vibration by more than 50%. Several additional factors may have an effect on vibration, including the different machine, seats, road surface, operators, and age of equipment.

The AR12 Patrick Forklift was used for both the Kiln and Planer Feeder routes. The levels for the Kiln route were 27% higher. This job involves repeatedly driving over kiln tracks and moving kiln carts and therefore different job functions and yard conditions may affect vibration. The weighted x and y-axis values, in addition to the z-axis, were also higher for the kiln route which is likely due to the forceful jarring that occurs as the forklift pushes up against the kiln carts.

The Patrick AR10 Planer Takeaway forklift had the lowest levels of vibration. It is difficult to say whether this machine is associated with lower levels of vibration compared to the other models of mobile equipment, or if other previously mentioned factors were involved. This machine is equipped with an air ride seat, opposed to a mechanical suspension seat like the other machines. Additionally, all of the mobile equipment were measured under normal working conditions which involved different driving routes in the yard. On this route there may be fewer potholes in the pavement, creating less vibration.

One area of interest, which was not tested in this study due to time restraints, is hand-arm vibration in the mobile equipment. The operators are exposed to vibration from the steering wheel and hand controls for the entire shift, and symptoms have been noted in this area. Further evaluation in this area would be beneficial.

All non-isolated measures of standing whole-body vibration (except Grader, Planer and Sawmill Stacker) showed levels that could be a concern for operator comfort, with values ranging from .136 m/s^2 to .244m/s^2. The measures that represented the actual *current* operating conditions, at Canfor – Fort St. John division, showed that the highest levels of vibration are at the Drop Sort and Trimmer.

Isolating the workstation is the most effective intervention, showing a significant reduction of vibration in all applicable areas. The Planer Stacker and Grader adjacent floor levels were not of concern, yet the isolation intervention showed the greatest amount of attenuation at these two locations. It is likely that pre-isolation measures at the 18” chip-n-saw and the McGehee would have been much higher, since the adjacent floor measures were higher than the reconnected floor measures in all other areas.

The adjacent floor measures were greater than the reconnected floor levels. The method in which the floor was reconnected did not return the r.m.s. value to a similar z-axis value as the adjacent floor, but it did return the x- and y-axis levels to similar ranges. The beams that support the isolated area give their support in the z-axis, and remain to do so even when the floor is reconnected. The method in which the floors have been isolated is very effective since the z-axis is the dominant axis of vibration.

When assessing the effectiveness of the insoles and matting interventions, there is a difference between the weighted and linear values. Overall, the insoles were more effective than the matting. The weighted values for insoles and matting showed that these interventions were only effective in some locations. In areas like the Drop Sort and Grader, the matting and insoles amplified the vibration at the lower frequencies (.4 – 400Hz) that are of interest for human vibration. In contrast, when evaluating the linear measures, the interventions always showed a large attenuation of vibration, usually greater than 40%.

This amplification at the lower frequencies, and attenuation in the higher frequencies may have some affect on perception of comfort. This is seen in this study where there was a significant correlation between the percent change in questionnaire rating and the percent change in linear whole-body r.m.s. values, compared to the weighted comparison where there was not a significant association. Employees may actually notice the attenuation in the higher frequency ranges because it may make the feet and toes feel better, especially if you consider the feet and/or toes as segments. Therefore, if there is only 15% amplification the intervention may be all right to use, especially if employee response is positive. If the intervention amplifies at around 50% it likely would not be recommended to use. It would be interesting to see what effect the higher frequencies have on foot segments and if there is any similarity to hand-arm segmental vibration.

The weighted values show that matting coupled with plywood is more effective than matting alone. It would be beneficial to assess plywood and matting both separate and coupled together under the same conditions.

Of the five operators booths that were assessed, the Debarker, with a baseline level of .118m/s^2, was the only area of interest when using the old ISO standards as a guideline. Proper weight adjustment of the seat made a greater than 50% improvement. The Debarker seat was the only area that the seat adjustment was effective in attenuating vibration. At all other areas, including the Shipping forklift, the vibration was higher when the seat was adjusted to the proper weight of the operator. The Debarker chair was only 2 months old; where as all the other seats were at least 2 years old. It is possible that the age and condition of a seat play a big factor, and that seats should regularly be replaced. Further research in this area would provide better guidelines on the life span of different seats.

The airbags on the Cut-off-saw shacks were of minimal benefit in attenuating the actual r.m.s. values. This differs from the response by the operators who feel the airbags significantly helped to reduce vibration. The t-gel cushions were not effective and actually amplified the vibration a small amount.

The tools that were measured for hand-arm vibration did not produce dominant values in the same axis. In the case of the grinders, this may be due to the different mounting location on the 7" Makita grinder. It would have been beneficial to measure both the side and main handle on all the grinders. The 5" Makita grinder produced the lowest baseline levels of vibration out of the three grinders and the risk of developing symptoms is less than 10% with this tool, opposed to greater than 50% with the 7" grinder and the chainsaw. The 10" Walter grinder had less vibration than the 7" grinder. The 10" Walter grinder is not a standard tool supplied in the mill but shows that a different brand may be better to use. This tool may have been newer and in better condition as well. Several factors may have an effect on the vibration produced by each tool such as: age and upkeep of tool, location and how tightly the accelerometer was mounted.

Welders would be better off to use the 5" Makita due to lower vibrations. Based on ISO 5349:1986 figure 2, there is a less than 10% chance of developing symptoms after 15 years use with the 5" Makita grinder, and there is still a 46% chance after only 10 years use with the 7" Makita grinder. For bigger jobs requiring heavy grinding, the larger grinders will get the job done quicker. Therefore, there is a trade off depending on which tool is used. If the small grinder is used – there is less vibration but it is used for longer periods to finish the job.

The gel foam appeared to be more effective overall. Both the gel foam and sorbothane attenuated vibration on the chainsaw, but amplified vibration on all the grinders except the gel foam on the 7” Makita grinder, which was mounted in a different location than the other grinders.

In reference to the sorbothane on the grinders, it is unclear whether amplification was due to the ineffectiveness of the intervention and/or the method of mounting the accelerometer. An article by EAR Specialty Composites, which reviews a study performed on the ability of their viscoelas material to reduce vibration levels, supports this reports findings for all three grinders. They state that there will always be amplification of vibration at low frequencies, but that this material is very effective at higher frequencies above 1500 Hz which is not concerned with hand arm vibration.

Because there is no frequency analysis available for hand-arm vibration it is difficult to understand why the materials attenuated with the chainsaw but not with the grinders. It is possible that the chainsaw has a much broader band frequency than the grinder and so the benefits provided by the gel foam and sorbothane are more noticeable. See figure 30 for a better understanding of this statement.

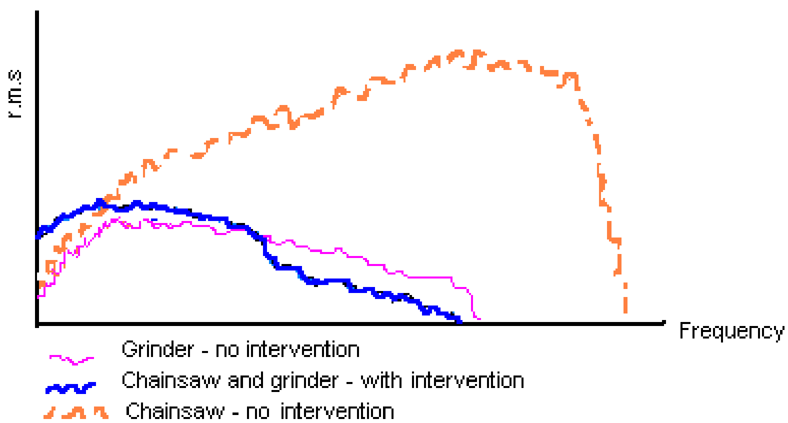


Figure 30 - Possible Frequency Spectra for the Chainsaw and Grinders with and without interventions

Vibration Questionnaire

The most frequent symptom reported was low back pain at 45%. This correlates with a survey performed by West Coast Industrial Ergonomics in which low back pain was also the highest (58%) symptom reported in Canfor mobile equipment operators. The results also support some studies which suggest exposure to vibration is associated with musculoskeletal disorders (Bovenzi et al., 1987; Boshuizen et al., 1992; Seidel, 1993).

Only 31% of the employees understood the term 'Vibration Syndrome' or 'Raynaud's Disease'. This demonstrates that there is a need to increase awareness in the workplace on the effects of vibration and related disorders.

Most of the interventions were only used for a period of one week, which may not have been long enough for changes in symptoms to be noticed. The T-Gel cushion, gloves and wrap were all rated as very low for user comfort as seen in Figure 29; the employees may not have used them for an entire week due to the inconvenience they created while working.

The t-gel cushion and the interventions for the hand tools appeared to be the most uncomfortable to work with. Both types of gloves were inconvenient to wear because they must be worn under the regular pair of welding gloves. This causes the glove to become very bulky and difficult to grasp objects. Because the gloves are bulky when worn, the welders only wore them when using the grinder, which would be for a couple minutes at a time throughout the day. This meant that the welders were constantly taking the gloves on and off. If welder's gloves were manufactured with these materials directly into the gloves, the user comfort may be improved.

Employees responded that the tool wrap was more comfortable to use than the gloves because it stays on the tool. The wrap was very comfortable to use on the small side handle, but it made the main handle slightly larger making it difficult to grip. The small side handles on the grinders were machined down to a smaller size so that the circumference around the handle was not affected with the addition of the tool wrap. The grip on the main handle of both the chainsaw and the grinder became larger when the wrap was put on. This caused the employee to exert a greater grip force just to hold onto the tool, which in turn created more discomfort. So in the case of the tool wrap, it may have been comfortable to use with the small handle, but uncomfortable on the main handle.

The results of the survey also showed that the insoles helped to increase comfort while working, and decrease symptoms that were present in the feet and low back, even though employees did not seem to notice any reduction in actual vibration.

4.2 CONCLUSION

The main purpose of this study was to quantify the levels of vibration employees are exposed to in the Canfor – Fort St John mill, and to determine if there were any areas that are of concern. Additionally, this study attempted to determine which vibration interventions were most effective in attenuating human vibration.

It is important to note that this study was performed under regular working conditions, which presented several limitations to the project. In spite of these limitations, this study is able to provide preliminary information about vibration levels in different areas of the sawmill, and how certain interventions respond under these conditions.

Mobile equipment operation is of most concern in the sawmill with many baseline values greater than .2 m/s^2. Based on the results from this study, use of sorbothane or t-gel cushions are not recommended as they did not show a significant reduction, and in some areas, such as the kiln, the sorbothane cushion amplified levels to within the health risk caution zones. The following recommendations should be considered to help reduce the risks associated with operation of mobile equipment:

- maintain yard conditions free of pot holes,
- use air ride seats where possible,
- replace seats when the suspension system is no longer effective,
- take frequent mini breaks to get out of equipment and walk around,
- job rotate operators onto a job with less vibration,
- enlarge job with other duties to allow operator to get out of equipment.

Several factors, such as the life span of the seats, different style seats, age and make of equipment, were not considered in this study and are worthy of further study.

All other areas in the sawmill setting do not present levels of whole-body vibration that pose health risks when using the ISO 2631-1:1997 as a guideline. If the old ISO standards are considered, there is a possibility that many mill areas may have an affect on employee comfort and fatigue decreased proficiency. This study showed the planer infeed areas to be of most concern. Isolating the workstations completely from the surrounding area has proven to be the most effective method of reducing vibration. More cost-effective interventions like plywood, matting, and insoles are marginally effective in some areas. These interventions, as well as isolation, appear to play a large role in improving the overall comfort employees perceive while working.

There are potential long-term health risks for employees using chainsaws and the 7" Makita grinder for more than 10-years. Use of the 5" grinder poses much less health risk for operators and should be used, instead of the larger grinders, for day to day functions Use of the vibration gloves or tool wrap would be beneficial for the chainsaw but appear to be ineffective with the grinders. Unfortunately these interventions are uncomfortable and can compromise the ability to grip the tool, resulting in more grip force to handle the tool, which in turn can increase risk of developing musculoskeletal disorder symptoms.

Looking at the weighted r.m.s. value alone for hand-arm and whole-body vibration does not consider the beneficial effects that some of the interventions, matting and tool wrap for example, had on the higher frequencies, which are not concerned with human vibration weightings. It is possible that the comfort perceived by people is related more to these higher frequencies, even though the interventions are not as effective at the lower frequencies. This study showed a significant association between the percent change in the questionnaire rating and the percent change in linear vibration levels; further study in this area would be worthwhile.

The results presented in this study demonstrated that some interventions proved very effective while others were questionable. As previously mentioned, this study tested the interventions under regular working conditions and therefore provided less control for testing. Interventions that worked well in some locations and not in others may have been a result of the different environment and work processes. In areas where the intervention was not very effective, it is important to consider that the baseline r.m.s. may have been low to begin with. At the sawmill stacker for example, the addition of matting does not amplify the vibration to levels of concern, so if the operator feels it is more comfortable for his feet and legs with the matting, then it is worthwhile to use. Further research is necessary to find interventions effective at the lower frequencies concerned with human vibration, especially hand-arm vibration.

5.0 APPENDICES

Confidential

Vibration Questionnaire #1

Current Position:________________________________ Time in Position: ___________

1. Rate the amount of vibration you experience on your job.

1	2	3	4	5	6	7
none			moderate			Excessive

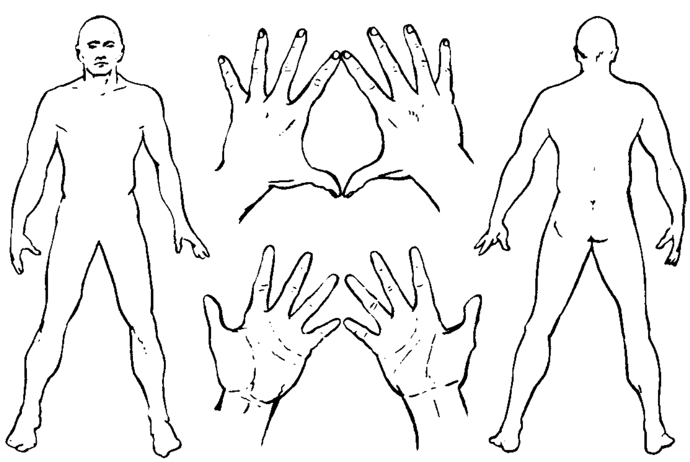
2. How many hours each day are you exposed to vibration? _______________

3. Is the vibration you are exposed to primarily
   - ☐ hand-arm (holding tools, controls) or
   - ☐ whole-body (sitting in vibrating shack, standing on vibrating floor)

4. Do you currently use any interventions for the vibration?

☐ None	☐ anti-fatigue matting	☐ Suspension Seat
☐ Vibration wrap for tools	☐ Plywood platform	☐ Vibration gloves
☐ insoles	☐ Other_________________________	

5. Shade on the diagram any areas in the last 6 months have you experienced pain or discomfort.



Rate that discomfort as:
1 - always present
2 - occurs same time each day with certain activities
3 - occurs occasionnaly

1. Are you aware of the term "Vibration Syndrome" or "Raynauds Disease" ? ☐Yes ☐ No

Confidential

Vibration Questionnaire #2

Current Position:________________________________ Time in Position: ___________

1. Rate the amount of vibration you experience on your job.

1	2	3	4	5	6	7
none			moderate			Excessive

2. How many hours each day are you exposed to vibration? _______________

3. Is the vibration you are exposed to primarily
   - ☐ hand-arm (holding tools, controls) or
   - ☐ whole-body (sitting in vibrating shack, standing on vibrating floor)

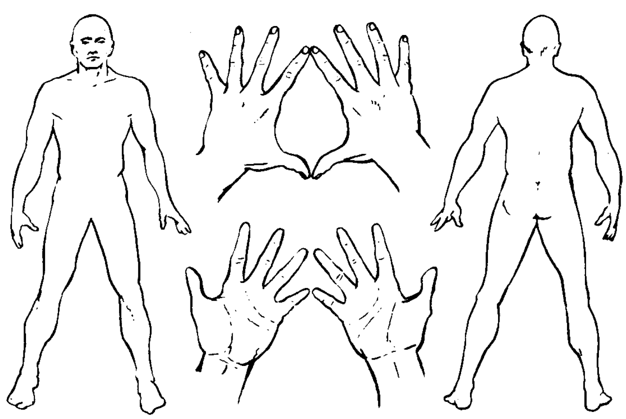
4. What new interventions have been implemented for the vibration?
   - ☐ vibration gloves
   - ☐ anti-fatigue matting
   - ☐ Suspension Seat
   - ☐ Vibration wrap for tools
   - ☐ plywood platform
   - ☐ insoles
   - ☐ Other ___________________________

5. Since the vibration intervention was implemented have you noticed a reduction in the amount of vibration experienced at you workstation/job? ☐Yes ☐No

6. Has your level of comfort while working
   - ☐improved
   - ☐no change
   - ☐decreased

7.
8. Shade on the diagram any areas you notice a decrease in discomfort felt since vibration interventions were implemented.

9. How comfortable is/are the interventions to use while working?



1	2	3	4	5	6	7
Very uncomfortable to work with						Very comfortable to use/minimal adjustment

1. Will you continue to use the vibration interventions implemented in your job? ☐Yes ☐No

10. Are you aware of the term "Vibration Syndrome" or "Raynauds Disease"? ☐Yes ☐No

5.2 APPENDIX B - DETAILED RESULTS OF WHOLE-BODY AND HAND-ARM VIBRATION

The followng tables provide a breakdown of the frequency spectra in the range .4 – 400 Hz, in the x-, y-, and z-axes, for all whole-body vibration data. Only the z-axis is available for the Drop Sort, Edger Optimizer, and Sawmill Stacker. A table with the Aeq and Aeq4 values collected for the chainsaw is also provided. All of the collected data for the grinders is provided in the results section.

Table 25 – Frequency Spectra Data for the Cut-off-saw #1

x-axis	**Hz**	**0.4**	**0.5**	**0.63**	**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**	**8**
Baseline - No AB,Wt not Ok	**rms (m/s^2)**	0.0132	0.0122	0.0107	0.0113	0.0098	0.0105	0.0087	0.0092	0.0082	0.0081	0.0088	0.0088	0.0091	0.0066
AB,Wt-OK	**rms (m/s^2)**	0.0206	0.0193	0.0166	0.0128	0.0114	0.0092	0.0081	0.0089	0.0082	0.0069	0.0083	0.0092	0.0082	0.0067
AB,Wt not Ok	**rms (m/s^2)**	0.0064	0.0095	0.0067	0.0061	0.0067	0.0059	0.0062	0.0064	0.0061	0.0062	0.0064	0.0082	0.0073	0.0057
y-axis															
Baseline - No AB,Wt not Ok	**rms (m/s^2)**	0.0251	0.0237	0.0200	0.0138	0.0109	0.0074	0.0055	0.0052	0.0081	0.0105	0.0094	0.0067	0.0062	0.0077
AB,Wt-OK	**rms (m/s^2)**	0.0324	0.0293	0.0241	0.0207	0.0120	0.0107	0.0086	0.0100	0.0095	0.0104	0.0112	0.0109	0.0075	0.0082
AB,Wt not Ok	**rms (m/s^2)**	0.0034	0.0026	0.0017	0.0024	0.0023	0.0019	0.0023	0.0035	0.0056	0.0079	0.0076	0.0055	0.0046	0.0062
z-axis															
Baseline - No AB,Wt not Ok	**rms (m/s^2)**	0.0084	0.0087	0.0103	0.0078	0.0078	0.0064	0.0074	0.0089	0.0094	0.0119	0.0135	0.0146	0.0161	0.0158
AB,Wt-OK	**rms (m/s^2)**	0.0140	0.0171	0.0169	0.0159	0.0155	0.0148	0.0167	0.0209	0.0216	0.0163	0.0209	0.0224	0.0227	0.0210
AB,Wt not Ok	**rms (m/s^2)**	0.0029	0.0025	0.0020	0.0020	0.0021	0.0020	0.0022	0.0024	0.0031	0.0057	0.0104	0.0127	0.0125	0.0139

10	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**L**	**W**
0.0054	0.0043	0.0066	0.0220	0.0185	0.0094	0.0070	0.0110	0.0113	0.0074	0.0051	0.0023	0.0021	0.0018	0.0012	0.0010	0.0008	0.0674	0.0299
0.0062	0.0051	0.0060	0.0210	0.0201	0.0116	0.0087	0.0116	0.0109	0.0082	0.0072	0.0030	0.0026	0.0021	0.0016	0.0014	0.0013	0.2195	0.0369
0.0046	0.0033	0.0049	0.0211	0.0178	0.0086	0.0059	0.0094	0.0103	0.0075	0.0060	0.0013	0.0012	0.0014	0.0010	0.0008	0.0006	0.0494	0.0197
0.0087	0.0065	0.0145	0.0092	0.0047	0.0054	0.0110	0.0218	0.0290	0.0209	0.0064	0.0056	0.0027	0.0024	0.0022	0.0018	0.0017	0.1009	0.0404
0.0087	0.0061	0.0113	0.0092	0.0055	0.0074	0.0143	0.0216	0.0280	0.0167	0.0080	0.0071	0.0035	0.0027	0.0022	0.0017	0.0016	0.1459	0.0518
0.0078	0.0059	0.0135	0.0095	0.0034	0.0044	0.0103	0.0228	0.0328	0.0176	0.0051	0.0053	0.0016	0.0015	0.0012	0.0007	0.0006	0.0560	0.0110
0.0123	0.0102	0.0282	0.0207	0.0087	0.0055	0.0050	0.0077	0.0116	0.0098	0.0054	0.0043	0.0023	0.0023	0.0016	0.0010	0.0007	0.0708	0.0460
0.0184	0.0178	0.0287	0.0234	0.0129	0.0067	0.0048	0.0078	0.0105	0.0072	0.0037	0.0029	0.0020	0.0018	0.0013	0.0009	0.0007	0.0977	0.0649
0.0113	0.0096	0.0248	0.0214	0.0087	0.0053	0.0043	0.0085	0.0139	0.0089	0.0050	0.0035	0.0021	0.0022	0.0017	0.0010	0.0005	0.0510	0.0385

Table 26 – Frequency Spectra Data for the Cut-off-saw #2

X-Axis	**Hz**	**0.4**	**0.5**	**0.63**	**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**	**8**
***Baseline* - No AB,Wt not Ok**	**rms (m/s^2)**	0.0059	0.0050	0.0044	0.0044	0.0042	0.0045	0.0042	0.0041	0.0044	0.0051	0.0117	0.0079	0.0085	0.0123
AB,Wt-OK	**rms (m/s^2)**	0.0060	0.0071	0.0097	0.0121	0.0061	0.0049	0.0050	0.0057	0.0122	0.0226	0.0123	0.0111	0.0201	0.0129
AB,Wt not Ok	**rms (m/s^2)**	0.0036	0.0031	0.0029	0.0032	0.0027	0.0028	0.0027	0.0031	0.0034	0.0061	0.0121	0.0062	0.0096	0.0112
Y-Axis															
***Baseline* - No AB,Wt not Ok**	**rms (m/s^2)**	0.0041	0.0032	0.0027	0.0024	0.0022	0.0018	0.0014	0.0016	0.0021	0.0029	0.0050	0.0094	0.0053	0.0102
AB,Wt-OK	**rms (m/s^2)**	0.0026	0.0029	0.0026	0.0025	0.0028	0.0030	0.0027	0.0030	0.0056	0.0100	0.0068	0.0156	0.0125	0.0080
AB,Wt not Ok	**rms (m/s^2)**	0.0065	0.0046	0.0032	0.0151	0.0098	0.0083	0.0075	0.0051	0.0033	0.0038	0.0063	0.0161	0.0116	0.0087
Z-axis															
***Baseline* - No AB,Wt not Ok**	**rms (m/s^2)**	0.0014	0.0013	0.0012	0.0013	0.0016	0.0018	0.0021	0.0036	0.0038	0.0049	0.0062	0.0068	0.0069	0.0126
AB,Wt-OK	**rms (m/s^2)**	0.0035	0.0033	0.0055	0.0056	0.0072	0.0092	0.0099	0.0085	0.0107	0.0129	0.0140	0.0126	0.0127	0.0131
AB,Wt not Ok	**rms (m/s^2)**	0.0007	0.0006	0.0005	0.0005	0.0006	0.0008	0.0010	0.0014	0.0016	0.0023	0.0035	0.0066	0.0059	0.0090

Axis	Hz	**10**	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**L**	**W**
***Baseline* - No AB,Wt not Ok**	**rms (m/s^2)**	0.0088	0.0084	0.0165	0.0312	0.0763	0.0425	0.0112	0.0074	0.0059	0.0065	0.0031	0.0016	0.0015	0.0016	0.0025	0.0016	0.0010	0.1006	0.0170
AB,Wt-OK	**rms (m/s^2)**	0.0068	0.0101	0.0152	0.0496	0.0626	0.0263	0.0082	0.0071	0.0052	0.0052	0.0032	0.0018	0.0017	0.0018	0.0015	0.0011	0.0009	0.0993	0.0295
AB,Wt not Ok	**rms (m/s^2)**	0.0049	0.0085	0.0100	0.0399	0.0562	0.0259	0.0067	0.0055	0.0053	0.0038	0.0017	0.0014	0.0010	0.0011	0.0008	0.0009	0.0008	0.0799	0.0138
Y-Axis																				
***Baseline* - No AB,Wt not Ok**	**rms (m/s^2)**	0.0186	0.0203	0.0347	0.0197	0.0174	0.0123	0.0146	0.0172	0.0205	0.0182	0.0116	0.0086	0.0025	0.0026	0.0024	0.0034	0.0016	0.0710	0.0114
AB,Wt-OK	**rms (m/s^2)**	0.0070	0.0250	0.0264	0.0155	0.0184	0.0170	0.0082	0.0143	0.0200	0.0176	0.0118	0.0088	0.0026	0.0022	0.0021	0.0026	0.0016	0.0651	0.0149
AB,Wt not Ok	**rms (m/s^2)**	0.0084	0.0260	0.0273	0.0188	0.0205	0.0172	0.0106	0.0121	0.0152	0.0128	0.0105	0.0105	0.0044	0.0037	0.0024	0.0019	0.0016	0.1477	0.0252
Z-axis																				
***Baseline* - No AB,Wt not Ok**	**rms (m/s^2)**	0.0148	0.0258	0.0468	0.0287	0.0186	0.0153	0.0174	0.0229	0.0087	0.0057	0.0040	0.0023	0.0010	0.0025	0.0019	0.0038	0.0031	0.0766	0.0540
AB,Wt-OK	**rms (m/s^2)**	0.0128	0.0372	0.0498	0.0226	0.0187	0.0162	0.0152	0.0175	0.0094	0.0067	0.0042	0.0027	0.0015	0.0026	0.0017	0.0024	0.0024	0.0858	0.0640
AB,Wt not Ok	**rms (m/s^2)**	0.0101	0.0309	0.0386	0.0238	0.0188	0.0230	0.0182	0.0209	0.0083	0.0053	0.0047	0.0027	0.0009	0.0017	0.0013	0.0018	0.0028	0.0714	0.0492

Table 27 – Frequency Spectra Data for the Chip-n-saw 30”

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline **- Wt not Ok**	**rms (m/s^2)**	0.0095	0.0099	0.0099	0.0092	0.0083	0.0087	0.0079	0.0088	0.0077	0.0074	0.0071	0.0096	0.0192	0.0349
Wt no Ok + T-gel C	**rms (m/s^2)**	0.0356	0.0302	0.0197	0.0134	0.0167	0.0157	0.0167	0.0173	0.0156	0.0141	0.0102	0.0121	0.0238	0.0449
Wt-Ok	**rms (m/s^2)**	1.0108	1.0096	1.0083	1.0083	1.0081	1.0084	1.0086	1.0096	1.0104	1.0082	1.0069	1.0083	1.0189	1.0421
Y-Axis															
Baseline **- Wt not Ok**	**rms (m/s^2)**	0.0061	0.0031	0.0032	0.0028	0.0025	0.0021	0.0030	0.0044	0.0071	0.0089	0.0099	0.0134	0.0185	0.0199
Wt no Ok + T-gel C	**rms (m/s^2)**	0.0094	0.0085	0.0080	0.0092	0.0081	0.0086	0.0107	0.0140	0.0195	0.0175	0.0139	0.0120	0.0150	0.0231
Wt-Ok	**rms (m/s^2)**	1.0163	1.0159	1.0142	1.0093	1.0135	1.0192	1.0185	1.0226	1.0133	1.0132	1.0142	1.0132	1.0171	1.0240
Z-axis															
Baseline **- Wt not Ok**	**rms (m/s^2)**	0.0038	0.0042	0.0033	0.0028	0.0027	0.0027	0.0031	0.0037	0.0039	0.0051	0.0103	0.0197	0.0309	0.0372
Wt no Ok + T-gel C	rms (m/s2)	0.0029	0.0031	0.0030	0.0025	0.0031	0.0032	0.0036	0.0047	0.0068	0.0076	0.0109	0.0177	0.0292	0.0470
Wt-Ok	**rms (m/s^2)**	1.0025	1.0030	1.0032	1.0029	1.0042	1.0050	1.0050	1.0062	1.0046	1.0055	1.0094	1.0168	1.0259	1.0399

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0346	0.0213	0.0306	0.0613	0.0853	0.0925	0.0835	0.0506	0.0225	0.0115	0.0150	0.0051	0.0058	0.0040	0.0030	0.0030	0.0019	0.1963	0.0312
0.0417	0.0192	0.0389	0.0714	0.1057	0.0598	0.0568	0.0360	0.0113	0.0069	0.0097	0.0050	0.0039	0.0030	0.0027	0.0019	0.0013	0.2317	0.0598
1.0392	1.0180	1.0348	1.0656	1.0884	1.0755	1.0804	1.0511	1.0224	1.0135	1.0198	1.0084	1.0063	1.0049	1.0047	1.0037	1.0029	1.1928	1.0321
0.0251	0.0413	0.0579	0.0661	0.0522	0.0293	0.0322	0.0741	0.0642	0.0214	0.0095	0.0110	0.0088	0.0036	0.0040	0.0025	0.0017	0.1639	0.0214
0.0317	0.0565	0.0830	0.1040	0.0828	0.0351	0.0263	0.0346	0.0321	0.0086	0.0052	0.0047	0.0050	0.0022	0.0021	0.0014	0.0012	0.1939	0.0391
1.0299	1.0562	1.0698	1.0808	1.0676	1.0306	1.0273	1.0612	1.0618	1.0220	1.0109	1.0101	1.0104	1.0051	1.0073	1.0033	1.0020	1.1860	1.0501
0.0457	0.0437	0.0317	0.0318	0.0245	0.0134	0.0104	0.0132	0.0125	0.0056	0.0049	0.0040	0.0023	0.0020	0.0018	0.0016	0.0010	0.1032	0.0891
0.0562	0.0515	0.0337	0.0277	0.0195	0.0136	0.0089	0.0131	0.0179	0.0084	0.0072	0.0036	0.0038	0.0026	0.0021	0.0012	0.0011	0.1127	0.1012
1.0492	1.0549	1.0277	1.0262	1.0291	1.0213	1.0130	1.0126	1.0087	1.0051	1.0044	1.0040	1.0026	1.0028	1.0029	1.0017	1.0012	1.1072	1.0935

Table 28 – Frequency Spectra Data for the Chip-n-saw 18"

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
***Baseline* - Reconnected**	**rms (m/s^2)**	0.0195	0.0286	0.0153	0.0184	0.0189	0.0171	0.0144	0.0148	0.0145	0.0101	0.0117	0.0355	0.0429	0.0289	0.0163	0.0261	0.0256	0.0288	0.0261	0.0207	0.0245	0.0186	0.0141	0.0114	0.0086	0.0058	0.0052	0.0042	0.0034	0.0022	0.0017	0.1716	0.0555
Isolation	**rms (m/s^2)**	0.0120	0.0110	0.0096	0.0097	0.0094	0.0094	0.0066	0.0051	0.0043	0.0039	0.0050	0.0060	0.0080	0.0061	0.0070	0.0117	0.0212	0.0220	0.0219	0.0235	0.0231	0.0197	0.0189	0.0078	0.0059	0.0035	0.0025	0.0024	0.0018	0.0013	0.0008	0.0789	0.0253
Y-Axis																																		
***Baseline* - Reconnected**	**rms (m/s^2)**	0.0114	0.0087	0.0101	0.0134	0.0238	0.0234	0.0249	0.0187	0.0248	0.0271	0.0268	0.0323	0.0530	0.0375	0.0394	0.0484	0.0423	0.0329	0.0344	0.0289	0.0275	0.0223	0.0210	0.0192	0.0131	0.0107	0.0084	0.0055	0.0050	0.0042	0.0037	0.1522	0.0632
Isolation	**rms (m/s^2)**	0.0167	0.0104	0.0082	0.0059	0.0053	0.0070	0.0060	0.0074	0.0095	0.0100	0.0088	0.0114	0.0190	0.0111	0.0107	0.0134	0.0186	0.0229	0.0187	0.0207	0.0168	0.0155	0.0153	0.0058	0.0038	0.0034	0.0032	0.0025	0.0022	0.0016	0.0011	0.1740	0.0261
Z-Axis																																		
***Baseline* - Reconnected**	**rms (m/s^2)**	0.0053	0.0040	0.0048	0.0069	0.0096	0.0086	0.0097	0.0117	0.0142	0.0150	0.0203	0.0300	0.0462	0.0298	0.0234	0.0226	0.0339	0.0465	0.0363	0.0213	0.0135	0.0075	0.0075	0.0054	0.0053	0.0053	0.0039	0.0029	0.0029	0.0029	0.0035	0.1118	0.0893
Isolation	**rms (m/s^2)**	0.0138	0.0070	0.0055	0.0032	0.0037	0.0039	0.0037	0.0042	0.0056	0.0053	0.0074	0.0138	0.0191	0.0149	0.0132	0.0122	0.0363	0.0581	0.0424	0.0262	0.0113	0.0058	0.0044	0.0040	0.0049	0.0039	0.0028	0.0016	0.0016	0.0012	0.0014	0.0935	0.0635

Table 29 – Frequency Spectra Data for the Debarker

x-axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
***Baseline* - Wt not Ok**	**rms (m/s^2)**	0.0441	0.0331	0.0351	0.0399	0.0280	0.0216	0.0212	0.0204	0.0251	0.0229	0.0213	0.0240	0.0239	0.0220	0.0372	0.0998	0.1180	0.0238	0.0240	0.0388	0.0366	0.0315	0.0410	0.0252	0.0183	0.0127	0.0113	0.0122	0.0093	0.0085	0.0099	0.2901	0.0891
Wt-OK	**rms (m/s^2)**	0.0041	0.0042	0.0046	0.0074	0.0091	0.0079	0.0077	0.0095	0.0129	0.0100	0.0082	0.0062	0.0066	0.0138	0.0425	0.1371	0.1683	0.0424	0.0360	0.0378	0.0342	0.0356	0.0442	0.0221	0.0144	0.0046	0.0041	0.0042	0.0048	0.0046	0.0069	0.2418	0.0399
Wt-OK+ T-gel Cushion	**rms (m/s^2)**	0.0067	0.0080	0.0082	0.0075	0.0079	0.0077	0.0092	0.0100	0.0119	0.0136	0.0132	0.0102	0.0096	0.0132	0.0367	0.1219	0.1886	0.0573	0.0380	0.0383	0.0291	0.0207	0.0231	0.0125	0.0053	0.0021	0.0018	0.0012	0.0009	0.0013	0.0017	0.2446	0.0421
y-axis																																		
***Baseline* - Wt not Ok**	**rms (m/s^2)**	0.0223	0.0351	0.0285	0.0279	0.0213	0.0334	0.0261	0.0391	0.0346	0.0444	0.0367	0.0344	0.0342	0.0276	0.0178	0.0274	0.0292	0.0241	0.0298	0.0400	0.0400	0.0416	0.0422	0.0379	0.0338	0.0216	0.0162	0.0167	0.0121	0.0110	0.0110	0.2062	0.0918
Wt-OK	**rms (m/s^2)**	0.0033	0.0035	0.0031	0.0039	0.0051	0.0042	0.0061	0.0079	0.0116	0.0161	0.0124	0.0100	0.0099	0.0150	0.0133	0.0275	0.0389	0.0238	0.0231	0.0207	0.0201	0.0346	0.0338	0.0324	0.0139	0.0095	0.0057	0.0060	0.0078	0.0050	0.0056	0.0971	0.0224
Wt-OK+ T-gel Cushion	**rms (m/s^2)**	0.0052	0.0041	0.0057	0.0052	0.0044	0.0043	0.0065	0.0101	0.0213	0.0218	0.0148	0.0104	0.0127	0.0174	0.0154	0.0230	0.0378	0.0330	0.0277	0.0252	0.0183	0.0214	0.0175	0.0150	0.0062	0.0035	0.0018	0.0016	0.0014	0.0010	0.0019	0.0903	0.0298
z-axis																																		
***Baseline* - Wt not Ok**	**rms (m/s^2)**	0.0229	0.0206	0.0216	0.0196	0.0226	0.0278	0.0294	0.0256	0.0225	0.0404	0.0437	0.0361	0.0295	0.0268	0.0274	0.0468	0.0774	0.0321	0.0192	0.0121	0.0120	0.0189	0.0185	0.0095	0.0079	0.0057	0.0047	0.0040	0.0033	0.0033	0.0041	0.1875	0.1178
Wt-OK	**rms (m/s^2)**	0.0019	0.0019	0.0019	0.0022	0.0031	0.0028	0.0045	0.0056	0.0078	0.0112	0.0159	0.0172	0.0186	0.0126	0.0132	0.0201	0.0332	0.0328	0.0203	0.0111	0.0060	0.0076	0.0082	0.0051	0.0023	0.0030	0.0018	0.0020	0.0013	0.0020	0.0036	0.0714	0.0545
Wt-OK+ T-gel Cushion	**rms (m/s^2)**	0.0024	0.0022	0.0023	0.0021	0.0020	0.0024	0.0026	0.0042	0.0098	0.0081	0.0126	0.0175	0.0226	0.0183	0.0177	0.0244	0.0416	0.0389	0.0235	0.0126	0.0095	0.0046	0.0029	0.0027	0.0020	0.0026	0.0019	0.0014	0.0013	0.0015	0.0026	0.0783	0.0640

Table 30 – Frequency Spectra Data at the McGehee

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
***Baseline* - Reconnected Floor**	**rms (m/s^2)**	0.0047	0.0041	0.0039	0.0040	0.0038	0.0037	0.0039	0.0051	0.0073	0.0093	0.0094	0.0078	0.0083	0.0213	0.0214	0.0204	0.0455	0.0606	0.0592	0.0571	0.0747	0.0562	0.0570	0.0483	0.0340	0.0430	0.0387	0.0404	0.0628	0.0605	0.0706	0.4572	0.0203
Reconnected Floor + Matting	**rms (m/s^2)**	0.0024	0.0019	0.0018	0.0017	0.0014	0.0014	0.0012	0.0012	0.0008	0.0007	0.0012	0.0024	0.0043	0.0214	0.0225	0.0229	0.0555	0.0865	0.1031	0.0964	0.0901	0.0918	0.1106	0.0458	0.0231	0.0229	0.0228	0.0304	0.0694	0.0325	0.0300	0.2956	0.0189
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0008	0.0006	0.0006	0.0007	0.0006	0.0003	0.0003	0.0006	0.0003	0.0005	0.0000	0.0027	0.0040	0.0209	0.0254	0.0222	0.0530	0.0763	0.0795	0.0940	0.1190	0.0804	0.1094	0.0538	0.0213	0.0324	0.0282	0.0275	0.1226	0.0463	0.0286	0.3013	0.0175
Isolated Floor	**rms (m/s^2)**	0.0007	0.0008	0.0005	0.0004	0.0009	0.0011	0.0014	0.0018	0.0022	0.0037	0.0067	0.0290	0.0291	0.0173	0.0151	0.0188	0.0054	0.0053	0.0042	0.0046	0.0034	0.0039	0.0082	0.0122	0.0059	0.0220	0.0138	0.0124	0.0120	0.0095	0.0133	0.0971	0.0172
Y-Axis																																		
***Baseline* - Reconnected Floor**	**rms (m/s^2)**	0.0031	0.0033	0.0036	0.0040	0.0045	0.0048	0.0049	0.0044	0.0036	0.0013	0.0024	0.0032	0.0036	0.0082	0.0107	0.0145	0.0384	0.0590	0.0971	0.0665	0.0610	0.0747	0.0698	0.0496	0.0407	0.0373	0.0431	0.0460	0.1181	0.0611	0.0851	0.6919	0.0176
Reconnected Floor + Matting	**rms (m/s^2)**	0.0019	0.0017	0.0015	0.0013	0.0014	0.0011	0.0008	0.0008	0.0006	0.0009	0.0013	0.0020	0.0036	0.0092	0.0130	0.0228	0.0577	0.0979	0.1744	0.1112	0.1001	0.0982	0.1045	0.0564	0.0276	0.0250	0.0213	0.0236	0.0706	0.0264	0.0225	0.3232	0.0220
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0009	0.0013	0.0007	0.0006	0.0005	0.0006	0.0004	0.0006	0.0006	0.0008	0.0013	0.0017	0.0034	0.0088	0.0116	0.0168	0.0513	0.0848	0.1450	0.1086	0.0638	0.0652	0.0770	0.0628	0.0290	0.0245	0.0169	0.0115	0.0590	0.0258	0.0201	0.2940	0.0186
Isolated Floor	**rms (m/s^2)**	0.0018	0.0015	0.0016	0.0015	0.0012	0.0012	0.0016	0.0020	0.0022	0.0032	0.0078	0.0354	0.0168	0.0088	0.0212	0.0138	0.0109	0.0061	0.0046	0.0094	0.0069	0.0029	0.0034	0.0053	0.0037	0.0086	0.0127	0.0106	0.0166	0.0108	0.0175	0.0905	0.0175
Z-Axis																																		
***Baseline* - Reconnected Floor**	**rms (m/s^2)**	0.0082	0.0084	0.0088	0.0105	0.0104	0.0099	0.0090	0.0079	0.0086	0.0111	0.0102	0.0079	0.0116	0.0154	0.0253	0.0271	0.0276	0.0479	0.0842	0.1886	0.2018	0.2040	0.2330	0.1158	0.1270	0.1458	0.1334	0.1758	0.3268	0.2561	0.3691	2.0660	**0.1415**
Reconnected Floor + Matting	**rms (m/s^2)**	0.0024	0.0041	0.0023	0.0016	0.0022	0.0017	0.0010	0.0017	0.0013	0.0009	0.0022	0.0028	0.0022	0.0105	0.0223	0.0258	0.0184	0.0461	0.0865	0.2029	0.2136	0.1486	0.1535	0.1206	0.0858	0.0719	0.0404	0.0332	0.1260	0.0528	0.0768	0.7879	**0.1341**
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0102	0.0087	0.0084	0.0068	0.0064	0.0055	0.0049	0.0046	0.0038	0.0020	0.0022	0.0022	0.0023	0.0118	0.0226	0.0252	0.0156	0.0354	0.0729	0.1446	0.1697	0.1625	0.1450	0.0725	0.0616	0.0573	0.0435	0.0458	0.0985	0.0490	0.1165	0.5833	**0.1097**
Isolated Floor	**rms (m/s^2)**	0.0012	0.0011	0.0013	0.0012	0.0009	0.0008	0.0007	0.0008	0.0008	0.0008	0.0014	0.0053	0.0027	0.0033	0.0148	0.0187	0.0087	0.0276	0.0308	0.0487	0.0731	0.0810	0.0708	0.0525	0.0388	0.0468	0.0329	0.0240	0.0349	0.0615	0.0872	0.3021	**0.0521**

Table 31 – Frequency Spectra Data at the Trimmer

X-Axis	**Hz**	**0.4**	**0.5**	**0.63**	**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**	**8**
***Baseline 1* - Adjacent Floor**	**rms (m/s^2)**	0.0373	0.0334	0.0254	0.0160	0.0124	0.0093	0.0062	0.0034	0.0027	0.0035	0.0030	0.0040	0.0077	0.0168
Isolated Floor	**rms (m/s^2)**	0.0326	0.0234	0.0230	0.0243	0.0275	0.0289	0.0348	0.0250	0.0237	0.0223	0.0168	0.0206	0.0217	0.0261
***Baseline 2* - Reconnected floor**	**rms (m/s^2)**	0.0026	0.0023	0.0017	0.0013	0.0012	0.0012	0.0011	0.0010	0.0009	0.0008	0.0015	0.0024	0.0055	0.0132
Reconnected floor + Matting	**rms (m/s^2)**	0.0054	0.0048	0.0042	0.0036	0.0036	0.0031	0.0024	0.0021	0.0018	0.0009	0.0000	0.0033	0.0075	0.0170
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0064	0.0058	0.0050	0.0045	0.0041	0.0036	0.0022	0.0015	0.0008	0.0009	0.0016	0.0030	0.0065	0.0161
Y-Axis															
***Baseline 1* - Adjacent Floor**	**rms (m/s^2)**	0.0166	0.0110	0.0091	0.0099	0.0119	0.0066	0.0050	0.0039	0.0033	0.0036	0.0052	0.0127	0.0144	0.0192
Isolated Floor	**rms (m/s^2)**	0.0443	0.0264	0.0259	0.0274	0.0288	0.0327	0.0369	0.0234	0.0226	0.0216	0.0158	0.0209	0.0208	0.0222
***Baseline 2* - Reconnected floor**	**rms (m/s^2)**	0.0037	0.0029	0.0017	0.0009	0.0007	0.0013	0.0014	0.0009	0.0015	0.0014	0.0027	0.0089	0.0103	0.0141
Reconnected floor + Matting	**rms (m/s^2)**	0.0109	0.0093	0.0079	0.0073	0.0069	0.0058	0.0047	0.0040	0.0035	0.0015	0.0031	0.0109	0.0151	0.0199
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0052	0.0050	0.0040	0.0037	0.0033	0.0029	0.0026	0.0025	0.0020	0.0016	0.0028	0.0095	0.0114	0.0153
Z-axis															
***Baseline 1* - Adjacent Floor**	**rms (m/s^2)**	0.0450	0.0412	0.0331	0.0238	0.0157	0.0079	0.0047	0.0045	0.0054	0.0058	0.0049	0.0043	0.0034	0.0039
Isolated Floor	**rms (m/s^2)**	0.0323	0.0246	0.0223	0.0247	0.0280	0.0311	0.0351	0.0249	0.0228	0.0214	0.0162	0.0201	0.0212	0.0190
***Baseline 2* - Reconnected floor**	**rms (m/s^2)**	0.0020	0.0023	0.0022	0.0014	0.0015	0.0019	0.0009	0.0022	0.0015	0.0014	0.0025	0.0027	0.0032	0.0038
Reconnected floor + Matting	**rms (m/s^2)**	0.0032	0.0028	0.0032	0.0027	0.0026	0.0029	0.0025	0.0029	0.0029	0.0025	0.0044	0.0065	0.0080	0.0116
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0054	0.0052	0.0040	0.0035	0.0033	0.0030	0.0024	0.0026	0.0026	0.0011	0.0019	0.0020	0.0022	0.0035

X-Axis	**10**	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**L**	**W**
***Baseline 1* - Adjacent Floor**	0.0220	0.0252	0.0307	0.0533	0.0391	0.0392	0.0453	0.0595	0.0708	0.0533	0.0625	0.0858	0.0810	0.0869	0.0780	0.0953	0.0853	0.6518	0.0528
Isolated Floor	0.0589	0.0422	0.0222	0.0180	0.0144	0.0118	0.0115	0.0102	0.0134	0.0089	0.0127	0.0089	0.0092	0.0123	0.0120	0.0108	0.0120	0.1876	0.0789
***Baseline 2* - Reconnected floor**	0.0212	0.0247	0.0291	0.0469	0.0332	0.0368	0.0464	0.0606	0.0795	0.0993	0.0715	0.1400	0.1782	0.1097	0.0708	0.0368	0.0229	0.4102	0.0118
Reconnected floor + Matting	0.0242	0.0307	0.0455	0.0925	0.0685	0.0573	0.0933	0.0797	0.0500	0.0244	0.0168	0.0166	0.0239	0.0327	0.0206	0.0174	0.0124	0.2085	0.0190
Reconnected Floor + Insoles	0.0224	0.0271	0.0387	0.0696	0.0615	0.0568	0.0480	0.0743	0.0608	0.0385	0.0302	0.0474	0.0344	0.0290	0.0230	0.0267	0.0184	0.1927	0.0177
Y-Axis																			
***Baseline 1* - Adjacent Floor**	0.0494	0.0352	0.0275	0.0590	0.0757	0.0757	0.0632	0.0689	0.0687	0.0593	0.0810	0.0851	0.0862	0.1091	0.1246	0.1171	0.1470	0.6752	0.0312
Isolated Floor	0.0412	0.0625	0.0393	0.0592	0.0246	0.0155	0.0120	0.0116	0.0137	0.0084	0.0099	0.0161	0.0130	0.0114	0.0176	0.0152	0.0200	0.2213	0.0862
***Baseline 2* - Reconnected floor**	0.0318	0.0250	0.0237	0.0541	0.0719	0.0806	0.0821	0.1474	0.2046	0.1274	0.1039	0.0815	0.1748	0.0901	0.0324	0.0252	0.0286	0.4723	0.0177
Reconnected floor + Matting	0.0459	0.0372	0.0428	0.1143	0.0888	0.0737	0.1544	0.1912	0.1165	0.0327	0.0385	0.0349	0.0211	0.0283	0.0156	0.0157	0.0198	0.3413	0.0301
Reconnected Floor + Insoles	0.0365	0.0326	0.0382	0.0915	0.1074	0.0768	0.0910	0.1594	0.1544	0.0712	0.0451	0.0495	0.0459	0.0252	0.0171	0.0175	0.0188	0.3233	0.0226
Z-axis																			

0.0098	0.0150	0.0299	0.0661	0.0935	0.1427	0.1523	0.2493	0.3241	0.2286	0.4426	0.4004	0.1801	0.1378	0.1023	0.1725	0.2439	1.2862	0.1482
0.0228	0.0258	0.0234	0.0269	0.0810	0.1370	0.0689	0.0423	0.0369	0.0247	0.0244	0.0245	0.0441	0.0525	0.0652	0.0644	0.1065	0.3824	0.1026
0.0050	0.0068	0.0113	0.0245	0.1026	0.1665	0.0759	0.0482	0.0546	0.0784	0.0867	0.0590	0.1121	0.1274	0.1037	0.1115	0.1573	0.6881	0.0933
0.0176	0.0274	0.0527	0.1427	0.2079	0.1301	0.0535	0.0632	0.0743	0.0694	0.1393	0.0948	0.0665	0.0492	0.0270	0.0268	0.0606	0.4036	0.1616
0.0041	0.0069	0.0118	0.0296	0.1034	0.1223	0.0376	0.0367	0.0388	0.0797	0.1184	0.0802	0.0713	0.0389	0.0299	0.0448	0.0753	0.3181	0.0793

Table – 32 Frequency Spectra Data at the Tilthoist

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3
Adjacent Floor	**rms (m/s^2)**	0.0009	0.0007	0.0007	0.0004	0.0006	0.0003	0.0000	0.0004	0.0005	0.0002	0.0006	0.0006	0.0011
Isolated Floor	**rms (m/s^2)**	0.0010	0.0009	0.0008	0.0007	0.0006	0.0008	0.0009	0.0011	0.0013	0.0015	0.0024	0.0030	0.0046
Reconnected Floor	**rms (m/s^2)**	0.0005	0.0005	0.0007	0.0007	0.0005	0.0006	0.0006	0.0007	0.0006	0.0005	0.0009	0.0013	0.0017
Reconnected Floor + Plywood	**rms (m/s^2)**	0.0025	0.0019	0.0015	0.0013	0.0012	0.0006	0.0005	0.0011	0.0006	0.0006	0.0000	0.0013	0.0018
Reconnected Floor + Plywood + Matting	**rms (m/s^2)**	0.0028	0.0014	0.0009	0.0008	0.0007	0.0003	0.0000	0.0003	0.0002	0.0002	0.0006	0.0011	0.0018
Y-Axis														
Adjacent Floor	**rms (m/s^2)**	0.0016	0.0013	0.0009	0.0008	0.0010	0.0005	0.0006	0.0007	0.0004	0.0005	0.0007	0.0018	0.0038
Isolated Floor	**rms (m/s^2)**	0.0029	0.0023	0.0018	0.0011	0.0011	0.0010	0.0011	0.0012	0.0012	0.0013	0.0016	0.0024	0.0042
Reconnected Floor	**rms (m/s^2)**	0.0015	0.0014	0.0013	0.0009	0.0008	0.0009	0.0005	0.0006	0.0007	0.0005	0.0007	0.0018	0.0042
Reconnected Floor + Plywood	**rms (m/s^2)**	0.0097	0.0087	0.0077	0.0071	0.0062	0.0056	0.0036	0.0026	0.0016	0.0007	0.0008	0.0023	0.0051
Reconnected Floor + Plywood + Matting	**rms (m/s^2)**	0.0051	0.0033	0.0019	0.0013	0.0007	0.0005	0.0004	0.0007	0.0004	0.0005	0.0007	0.0020	0.0046
Z-Axis														
Adjacent Floor	**rms (m/s^2)**	0.0001	0.0015	0.0013	0.0001	0.0007	0.0010	0.0001	0.0015	0.0009	0.0006	0.0020	0.0013	0.0020
Isolated Floor	**rms (m/s^2)**	0.0033	0.0040	0.0038	0.0019	0.0019	0.0014	0.0016	0.0018	0.0009	0.0008	0.0012	0.0011	0.0005
Reconnected Floor	**rms (m/s^2)**	0.0001	0.0008	0.0011	0.0005	0.0017	0.0013	0.0010	0.0017	0.0014	0.0016	0.0022	0.0017	0.0019
Reconnected Floor + Plywood	**rms (m/s^2)**	0.0107	0.0058	0.0037	0.0021	0.0023	0.0008	0.0002	0.0017	0.0010	0.0006	0.0015	0.0011	0.0007
Reconnected Floor + Plywood + Matting	**rms (m/s^2)**	0.0059	0.0057	0.0056	0.0046	0.0045	0.0037	0.0019	0.0018	0.0015	0.0005	0.0018	0.0014	0.0013

8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0022	0.0072	0.0156	0.0245	0.0256	0.0388	0.0581	0.0658	0.0562	0.0698	0.0367	0.0261	0.0380	0.0524	0.0691	0.0888	0.0553	0.0953	0.4697	0.0084
0.0087	0.0189	0.0343	0.0454	0.0348	0.0250	0.0256	0.0210	0.0131	0.0122	0.0110	0.0079	0.0086	0.0058	0.0094	0.0092	0.0104	0.0149	0.1348	0.0107
0.0033	0.0126	0.0251	0.0367	0.0412	0.0633	0.0886	0.0874	0.0982	0.1348	0.1088	0.1381	0.1490	0.1454	0.0951	0.0698	0.0332	0.0278	0.4058	0.0135
0.0036	0.0117	0.0262	0.0362	0.0401	0.0638	0.0874	0.0851	0.0821	0.1341	0.1065	0.1274	0.1431	0.1510	0.1213	0.0672	0.0395	0.0362	0.4307	0.0136
0.0034	0.0138	0.0211	0.0332	0.0408	0.0628	0.0998	0.0824	0.0918	0.1470	0.0799	0.0835	0.0782	0.0956	0.0933	0.0605	0.0335	0.0347	0.3215	0.0134
0.0044	0.0080	0.0188	0.0436	0.0387	0.0618	0.1051	0.1039	0.0371	0.0768	0.0525	0.0405	0.0458	0.0593	0.1124	0.0679	0.1103	0.2831	0.6208	0.0131
0.0163	0.0499	0.0127	0.0082	0.0078	0.0050	0.0061	0.0051	0.0091	0.0130	0.0192	0.0117	0.0086	0.0088	0.0095	0.0105	0.0101	0.0157	0.1171	0.0121
0.0035	0.0130	0.0185	0.0625	0.0582	0.0802	0.1442	0.1419	0.0848	0.1020	0.0824	0.0669	0.0717	0.1301	0.1498	0.0821	0.0373	0.0402	0.4091	0.0179
0.0044	0.0128	0.0194	0.0660	0.0635	0.0817	0.1466	0.1337	0.0537	0.1088	0.0901	0.0681	0.0995	0.1821	0.2292	0.0869	0.0681	0.0974	0.5263	0.0249
0.0042	0.0125	0.0209	0.0567	0.0592	0.0832	0.1312	0.1100	0.0658	0.1210	0.0923	0.0562	0.0413	0.0733	0.1031	0.0618	0.0353	0.0528	0.3376	0.0174
0.0032	0.0088	0.0325	0.0719	0.1226	0.2932	0.1616	0.1385	0.1363	0.3506	0.1168	0.0751	0.0520	0.0454	0.0817	0.1535	0.1702	0.3732	1.2828	0.2113
0.0018	0.0018	0.0032	0.0064	0.0126	0.0463	0.1435	0.0642	0.0735	0.0712	0.0590	0.0415	0.0260	0.0266	0.0425	0.0817	0.0772	0.1193	0.4559	0.0708
0.0032	0.0039	0.0059	0.0163	0.0534	0.1267	0.2924	0.1233	0.1486	0.1656	0.0925	0.0761	0.0637	0.1109	0.1720	0.1643	0.1519	0.2267	0.8756	0.1535
0.0021	0.0025	0.0053	0.0172	0.0507	0.1634	0.1938	0.0951	0.0923	0.2785	0.0806	0.0537	0.0670	0.0606	0.0663	0.0368	0.0546	0.0990	0.5026	0.1366
0.0023	0.0029	0.0059	0.0164	0.0546	0.1210	0.1341	0.0637	0.0759	0.1986	0.0571	0.0400	0.0387	0.0280	0.0312	0.0322	0.0394	0.0723	0.3440	0.1020

Table 33 – Frequency Spectra Data at the Planer Feeder

X-Axis	**Hz**	**0.4**	**0.5**	**0.63**	**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**
Baseline 1 **- Adjacent Floor**	**rms (m/s^2)**	0.0014	0.0013	0.0015	0.0011	0.0012	0.0010	0.0008	0.0011	0.0008	0.0006	0.0000	0.0014	0.0026
Isolated Foor + Plywood	**rms (m/s^2)**	0.0018	0.0016	0.0015	0.0012	0.0011	0.0011	0.0009	0.0011	0.0010	0.0010	0.0010	0.0013	0.0031
Baseline 2 **- Reconnected Floor + Plywood**	**rms (m/s^2)**	0.0006	0.0005	0.0006	0.0001	0.0003	0.0002	0.0002	0.0007	0.0003	0.0005	0.0011	0.0018	0.0029
Reconnected Floor + Plywood + Matting	**rms (m/s^2)**	0.0126	0.0106	0.0088	0.0033	0.0018	0.0012	0.0004	0.0006	0.0005	0.0005	0.0011	0.0018	0.0030
Y-Axis														
Baseline 1 **- Adjacent Floor**	**rms (m/s^2)**	0.0033	0.0019	0.0029	0.0018	0.0014	0.0015	0.0011	0.0012	0.0013	0.0010	0.0016	0.0026	0.0041
Isolated Foor + Plywood	**rms (m/s^2)**	0.0022	0.0021	0.0019	0.0015	0.0014	0.0014	0.0011	0.0012	0.0009	0.0007	0.0009	0.0014	0.0018
Baseline 2 **- Reconnected Floor + Plywood**	**rms (m/s^2)**	0.0012	0.0008	0.0009	0.0005	0.0007	0.0004	0.0005	0.0007	0.0006	0.0008	0.0014	0.0024	0.0048
Reconnected Floor + Plywood + Matting	**rms (m/s^2)**	0.0033	0.0024	0.0016	0.0009	0.0005	0.0007	0.0002	0.0006	0.0005	0.0007	0.0014	0.0025	0.0056
Z-Axis														
Baseline 1 **- Adjacent Floor**	**rms (m/s^2)**	0.0042	0.0038	0.0055	0.0024	0.0046	0.0024	0.0014	0.0027	0.0018	0.0004	0.0033	0.0021	0.0019
Isolated Foor + Plywood	**rms (m/s^2)**	0.0048	0.0032	0.0019	0.0004	0.0019	0.0001	0.0001	0.0016	0.0008	0.0003	0.0017	0.0012	0.0006
Baseline 2 **- Reconnected Floor + Plywood**	**rms (m/s^2)**	0.0016	0.0020	0.0015	0.0012	0.0024	0.0008	0.0001	0.0020	0.0005	0.0001	0.0014	0.0011	0.0006
Reconnected Floor + Plywood + Matting	**rms (m/s^2)**	0.0115	0.0049	0.0032	0.0012	0.0015	0.0013	0.0012	0.0013	0.0010	0.0001	0.0018	0.0013	0.0010

8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0058	0.0189	0.0411	0.1220	0.1146	0.1213	0.1599	0.1748	0.1121	0.1670	0.1498	0.1702	0.1871	0.2846	0.1647	0.1250	0.0948	0.1389	0.8780	0.0278
0.0074	0.0110	0.0602	0.0390	0.0337	0.0853	0.0516	0.0370	0.0125	0.0112	0.0263	0.0524	0.0370	0.0104	0.0148	0.0217	0.0277	0.0725	0.2159	0.0146
0.0064	0.0187	0.0411	0.1057	0.1184	0.1270	0.1964	0.2631	0.2940	0.3233	0.1552	0.0694	0.1131	0.1565	0.1725	0.0993	0.1051	0.1643	0.7403	0.0324
0.0072	0.0212	0.0546	0.1629	0.2243	0.1679	0.1552	0.3224	0.2846	0.1582	0.0513	0.0330	0.0358	0.0355	0.0365	0.0308	0.0331	0.0513	0.6010	0.0442
0.0131	0.0309	0.0490	0.0886	0.0702	0.0855	0.1683	0.1294	0.0956	0.1312	0.0908	0.1184	0.1502	0.2018	0.1959	0.2486	0.2808	0.3440	0.9811	0.0236
0.0068	0.0107	0.0228	0.0780	0.0940	0.1009	0.0881	0.0640	0.0215	0.0274	0.0290	0.0626	0.0573	0.0118	0.0142	0.0217	0.0381	0.0544	0.2718	0.0183
0.0145	0.0331	0.0488	0.0782	0.0731	0.1143	0.1846	0.1599	0.1256	0.1876	0.2336	0.0774	0.1980	0.2972	0.1831	0.1337	0.1539	0.1330	0.6956	0.0254
0.0152	0.0325	0.0538	0.1137	0.1223	0.0683	0.1634	0.2085	0.1846	0.1323	0.0855	0.0191	0.0269	0.0294	0.0238	0.0311	0.0561	0.0546	0.4402	0.0286
0.0046	0.0113	0.0269	0.0704	0.1378	0.1519	0.1758	0.2280	0.5929	0.4659	0.3564	0.2711	0.2846	0.2452	0.2610	0.4354	0.7524	0.9679	3.0594	0.2439
0.0024	0.0023	0.0053	0.0150	0.0277	0.0504	0.1045	0.1621	0.1927	0.0817	0.0443	0.0448	0.0286	0.0144	0.0135	0.0262	0.0435	0.1121	0.5220	0.0901
0.0026	0.0028	0.0055	0.0164	0.0326	0.0487	0.0893	0.1490	0.1846	0.1515	0.1466	0.0733	0.0451	0.0450	0.0404	0.0527	0.0731	0.1478	0.6059	0.0896
0.0031	0.0031	0.0057	0.0213	0.0418	0.0855	0.1080	0.1106	0.1127	0.0743	0.0503	0.0281	0.0248	0.0214	0.0184	0.0412	0.0753	0.1233	0.3544	0.0842

Table 34 – Frequency Spectra Data at the Grader

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline 1 - Adjacent Floor	**rms (m/s^2)**	0.0009	0.0007	0.0007	0.0007	0.0005	0.0005	0.0003	0.0007	0.0008	0.0011	0.0000	0.0014	0.0021	0.0089
Isolated Floor	**rms (m/s^2)**	0.0006	0.0008	0.0005	0.0004	0.0006	0.0004	0.0005	0.0007	0.0007	0.0004	0.0007	0.0005	0.0007	0.0020
Baseline 2 - Reconnected Floor	**rms (m/s^2)**	0.0014	0.0012	0.0017	0.0018	0.0018	0.0018	0.0018	0.0018	0.0022	0.0024	0.0020	0.0017	0.0022	0.0087
Reconnected Floor + Matting	**rms (m/s^2)**	0.0001	0.0007	0.0005	0.0005	0.0007	0.0004	0.0003	0.0007	0.0006	0.0011	0.0007	0.0015	0.0021	0.0092
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0021	0.0019	0.0017	0.0015	0.0014	0.0011	0.0010	0.0010	0.0010	0.0015	0.0007	0.0015	0.0024	0.0096
Y-Axis															
Baseline 1 - Adjacent Floor	**rms (m/s^2)**	0.0005	0.0006	0.0006	0.0007	0.0007	0.0006	0.0007	0.0008	0.0007	0.0050	0.0023	0.0024	0.0017	0.0039
Isolated Floor	**rms (m/s^2)**	0.0005	0.0009	0.0005	0.0007	0.0009	0.0009	0.0008	0.0008	0.0005	0.0004	0.0007	0.0008	0.0007	0.0015
Baseline 2 - Reconnected Floor	**rms (m/s^2)**	0.0013	0.0011	0.0010	0.0011	0.0013	0.0011	0.0014	0.0015	0.0017	0.0043	0.0024	0.0022	0.0020	0.0039
Reconnected Floor + Matting	**rms (m/s^2)**	0.0008	0.0008	0.0006	0.0006	0.0007	0.0006	0.0004	0.0005	0.0004	0.0043	0.0020	0.0021	0.0015	0.0040
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0032	0.0025	0.0023	0.0018	0.0015	0.0012	0.0009	0.0010	0.0008	0.0044	0.0020	0.0023	0.0016	0.0044
Z-Axis															
Baseline 1 - Adjacent Floor	**rms (m/s^2)**	0.0001	0.0021	0.0008	0.0001	0.0018	0.0012	0.0003	0.0021	0.0014	0.0008	0.0018	0.0014	0.0019	0.0054
Isolated Floor	**rms (m/s^2)**	0.0024	0.0030	0.0026	0.0034	0.0029	0.0032	0.0033	0.0039	0.0041	0.0040	0.0037	0.0029	0.0026	0.0052
Baseline 2 - Reconnected Floor	**rms (m/s^2)**	0.0059	0.0064	0.0068	0.0074	0.0074	0.0069	0.0062	0.0049	0.0044	0.0059	0.0066	0.0047	0.0044	0.0052
Reconnected Floor + Matting	**rms (m/s^2)**	0.0010	0.0023	0.0011	0.0015	0.0021	0.0001	0.0001	0.0015	0.0007	0.0001	0.0011	0.0007	0.0006	0.0036
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0065	0.0054	0.0048	0.0011	0.0007	0.0008	0.0006	0.0018	0.0009	0.0001	0.0020	0.0010	0.0012	0.0038

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0062	0.0091	0.0283	0.0138	0.0302	0.0256	0.0268	0.0246	0.0227	0.0214	0.0187	0.0248	0.0261	0.0212	0.0271	0.0451	0.0496	0.2225	0.0063
0.0016	0.0039	0.0142	0.0177	0.0108	0.0072	0.0031	0.0045	0.0042	0.0130	0.0055	0.0031	0.0032	0.0189	0.0372	0.0166	0.0097	0.0753	0.0033
0.0075	0.0110	0.0326	0.0148	0.0319	0.0283	0.0311	0.0331	0.0348	0.0459	0.0344	0.1112	0.0774	0.0375	0.0417	0.0556	0.0445	0.2154	0.0086
0.0078	0.0142	0.0444	0.0312	0.0824	0.0516	0.0507	0.0524	0.0212	0.0123	0.0058	0.0087	0.0214	0.0253	0.0250	0.0210	0.0125	0.1458	0.0111
0.0088	0.0174	0.0606	0.0431	0.0423	0.0464	0.0416	0.0249	0.0132	0.0115	0.0067	0.0072	0.0183	0.0204	0.0186	0.0190	0.0146	0.1216	0.0117
0.0062	0.0119	0.0181	0.0154	0.0269	0.0212	0.0176	0.0194	0.0254	0.0234	0.0224	0.0286	0.0380	0.0346	0.0590	0.0439	0.0443	0.2932	0.0062
0.0036	0.0098	0.0359	0.0054	0.0136	0.0370	0.0135	0.0059	0.0180	0.0141	0.0067	0.0106	0.0121	0.0193	0.0562	0.0122	0.0087	0.1009	0.0060
0.0065	0.0109	0.0206	0.0164	0.0254	0.0268	0.0465	0.0656	0.0325	0.0414	0.0403	0.0421	0.0645	0.0933	0.0454	0.0637	0.0521	0.2119	0.0077
0.0065	0.0137	0.0317	0.0418	0.0320	0.0254	0.0935	0.1573	0.0433	0.0201	0.0093	0.0087	0.0134	0.0175	0.0141	0.0146	0.0098	0.2035	0.0111
0.0076	0.0175	0.0425	0.0166	0.0349	0.0593	0.0879	0.0879	0.0268	0.0107	0.0049	0.0071	0.0098	0.0139	0.0091	0.0086	0.0118	0.1599	0.0114
0.0058	0.0120	0.0218	0.0230	0.0570	0.0610	0.0933	0.2381	0.1634	0.1039	0.0755	0.0755	0.0568	0.0759	0.1162	0.2171	0.2342	1.0329	0.0872
0.0031	0.0039	0.0107	0.0079	0.0122	0.0218	0.0109	0.0066	0.0079	0.0118	0.0160	0.0280	0.0470	0.0582	0.1836	0.1131	0.0774	0.3295	0.0188
0.0032	0.0036	0.0110	0.0099	0.0165	0.0261	0.0181	0.0154	0.0099	0.0207	0.0350	0.0806	0.1359	0.1539	0.2113	0.3855	0.4307	0.7403	0.0254
0.0021	0.0037	0.0138	0.0092	0.0267	0.0567	0.0459	0.0295	0.0166	0.0115	0.0121	0.0143	0.0174	0.0148	0.0175	0.0375	0.0540	0.1515	0.0342
0.0025	0.0044	0.0166	0.0155	0.0581	0.0737	0.0214	0.0158	0.0086	0.0094	0.0089	0.0121	0.0158	0.0118	0.0176	0.0299	0.0400	0.1599	0.0464

Table 35 – Frequency Spectra Data at the Planer Stacker

X-Axis	**Hz**	**0.4**	**0.5**	**0.63**	**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**	**8**
Adjacent Floor	**rms (m/s^2)**	0.0003	0.0009	0.0004	0.0000	0.0006	0.0004	0.0000	0.0005	0.0005	0.0009	0.0056	0.0086	0.0048	0.0100
Isolated Floor	**rms (m/s^2)**	0.0014	0.0015	0.0011	0.0010	0.0012	0.0010	0.0009	0.0012	0.0012	0.0015	0.0028	0.0035	0.0079	0.0224
Reconnected Floor	**rms (m/s^2)**	0.0000	0.0008	0.0003	0.0002	0.0007	0.0004	0.0001	0.0005	0.0006	0.0010	0.0059	0.0099	0.0055	0.0103
Reconnected Floor + Matting	**rms (m/s^2)**	0.0040	0.0035	0.0029	0.0028	0.0024	0.0022	0.0017	0.0017	0.0019	0.0015	0.0000	0.0102	0.0059	0.0094
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0007	0.0010	0.0007	0.0007	0.0006	0.0002	0.0003	0.0005	0.0004	0.0009	0.0034	0.0086	0.0049	0.0094
Y-Axis															
Adjacent Floor	**rms (m/s^2)**	0.0021	0.0018	0.0015	0.0016	0.0014	0.0012	0.0011	0.0012	0.0011	0.0018	0.0029	0.0057	0.0038	0.0050
Isolated Floor	**rms (m/s^2)**	0.0002	0.0007	0.0007	0.0008	0.0009	0.0007	0.0006	0.0009	0.0012	0.0017	0.0018	0.0031	0.0042	0.0063
Reconnected Floor	**rms (m/s^2)**	0.0009	0.0008	0.0006	0.0006	0.0006	0.0008	0.0006	0.0008	0.0013	0.0023	0.0032	0.0066	0.0043	0.0051
Reconnected Floor + Matting	**rms (m/s^2)**	0.0042	0.0037	0.0032	0.0028	0.0025	0.0022	0.0021	0.0019	0.0024	0.0027	0.0035	0.0073	0.0076	0.0069
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0006	0.0008	0.0008	0.0003	0.0007	0.0006	0.0006	0.0008	0.0012	0.0013	0.0017	0.0050	0.0041	0.0053
Z-Axis															
Adjacent Floor	**rms (m/s^2)**	0.0095	0.0087	0.0077	0.0062	0.0056	0.0055	0.0045	0.0045	0.0035	0.0012	0.0018	0.0011	0.0008	0.0022
Isolated Floor	**rms (m/s^2)**	0.0008	0.0003	0.0003	0.0004	0.0016	0.0010	0.0003	0.0017	0.0011	0.0000	0.0016	0.0010	0.0010	0.0022

Reconnected Floor	**rms (m/s^2)**	0.0000	0.0014	0.0009	0.0000	0.0015	0.0000	0.0000	0.0017	0.0009	0.0007	0.0016	0.0012	0.0007	0.0021
Reconnected Floor + Matting	**rms (m/s^2)**	0.0206	0.0170	0.0165	0.0135	0.0123	0.0112	0.0094	0.0090	0.0081	0.0032	0.0024	0.0018	0.0012	0.0024
Reconnected Floor + Insoles	**rms (m/s^2)**	0.0000	0.0013	0.0009	0.0000	0.0013	0.0004	0.0000	0.0015	0.0008	0.0000	0.0016	0.0011	0.0001	0.0019

10	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**L**	**W**
0.0261	0.0135	0.0297	0.0365	0.0341	0.0197	0.0172	0.0223	0.0240	0.0202	0.0312	0.0323	0.0331	0.0243	0.0224	0.0185	0.0294	0.1294	0.0101
0.0370	0.0128	0.0106	0.0277	0.0176	0.0085	0.0061	0.0050	0.0059	0.0118	0.0050	0.0089	0.0116	0.0063	0.0060	0.0087	0.0103	0.0832	0.0112
0.0304	0.0148	0.0316	0.0371	0.0327	0.0212	0.0149	0.0197	0.0240	0.0181	0.0503	0.0543	0.0418	0.0208	0.0185	0.0112	0.0150	0.1337	0.0110
0.0303	0.0181	0.0404	0.0768	0.0858	0.0450	0.0269	0.0366	0.0192	0.0088	0.0104	0.0095	0.0124	0.0133	0.0190	0.0114	0.0202	0.1616	0.0167
0.0318	0.0207	0.0538	0.0966	0.0661	0.0173	0.0199	0.0145	0.0080	0.0064	0.0051	0.0036	0.0041	0.0092	0.0109	0.0165	0.0256	0.1458	0.0158
0.0047	0.0075	0.0085	0.0156	0.0184	0.0301	0.0261	0.0231	0.0294	0.0160	0.0161	0.0197	0.0261	0.0280	0.0354	0.0290	0.0288	0.1378	0.0066
0.0123	0.0291	0.0186	0.0240	0.0171	0.0092	0.0071	0.0062	0.0057	0.0053	0.0046	0.0109	0.0102	0.0077	0.0099	0.0076	0.0107	0.0778	0.0074
0.0052	0.0079	0.0083	0.0172	0.0199	0.0339	0.0287	0.0272	0.0317	0.0206	0.0277	0.0249	0.0357	0.0500	0.0364	0.0166	0.0157	0.1243	0.0062
0.0075	0.0084	0.0118	0.0324	0.0326	0.0333	0.0432	0.0605	0.0534	0.0128	0.0113	0.0114	0.0061	0.0082	0.0107	0.0144	0.0208	0.1502	0.0111
0.0049	0.0079	0.0137	0.0210	0.0214	0.0477	0.0463	0.0239	0.0302	0.0054	0.0047	0.0053	0.0037	0.0040	0.0044	0.0106	0.0187	0.0966	0.0065
0.0020	0.0026	0.0044	0.0058	0.0134	0.0491	0.1544	0.0865	0.0685	0.0378	0.0337	0.0313	0.0309	0.0324	0.0408	0.0540	0.1074	0.4438	0.0600
0.0018	0.0025	0.0040	0.0057	0.0089	0.0163	0.0405	0.0195	0.0283	0.0362	0.0289	0.0166	0.0135	0.0164	0.0277	0.0535	0.0721	0.2603	0.0188
0.0020	0.0018	0.0027	0.0046	0.0073	0.0181	0.0470	0.0301	0.0428	0.0433	0.0567	0.0298	0.0227	0.0172	0.0344	0.0565	0.0770	0.2917	0.0223
0.0032	0.0042	0.0053	0.0107	0.0210	0.0552	0.0338	0.0305	0.0384	0.0166	0.0307	0.0149	0.0116	0.0169	0.0163	0.0449	0.0717	0.2243	0.0359
0.0018	0.0015	0.0033	0.0088	0.0153	0.0378	0.0181	0.0200	0.0297	0.0114	0.0137	0.0087	0.0084	0.0064	0.0069	0.0250	0.0482	0.1607	0.0209

Table 36 – Frequency Spectra Data at the Drop Sort

Z-Axis	**Hz**	**0.4**	**0.5**	**0.63**	**0.8**	**1**	**1.25**	**1.6**	**2**	**2.5**	**3.15**	**4**	**5**	**6.3**	**8**
Baseline	**rms (m/s^2)**	0.0001	0.0030	0.0018	0.0001	0.0038	0.0022	0.0001	0.0040	0.0024	0.0011	0.0050	0.0039	0.0066	0.0223
Matting	**rms (m/s^2)**	0.0001	0.0023	0.0019	0.0001	0.0033	0.0025	0.0001	0.0044	0.0025	0.0001	0.0046	0.0040	0.0071	0.0220

10	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**L**	**W**
0.0261	0.0337	0.0375	0.0888	0.2101	0.0783	0.0540	0.0747	0.1466	0.1986	0.2226	0.2272	0.2861	0.3080	0.4227	0.5943	0.5408	2.1577	0.1471
0.0323	0.0390	0.0413	0.0945	0.2331	0.1522	0.1001	0.0961	0.1975	0.1062	0.0835	0.0527	0.0306	0.0268	0.0392	0.0808	0.0958	0.4672	0.1692

Table 37 – Frequency Spectra Data at the Edger Optimizer

Z-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
Baseline	**rms (m/s^2)**	0.0013	0.0020	0.0032	0.0001	0.0029	0.0012	0.0001	0.0041	0.0015	0.0001	0.0038	0.0025	0.0001	0.0039	0.0034	0.0095	0.0184	0.0474	0.1374	0.2597	0.0860	0.0697	0.0747	0.0667	0.0265	0.0350	0.0407	0.0483	0.2331	0.0925	0.0802	0.5206	0.1358
Plywood	**rms (m/s^2)**	0.0001	0.0018	0.0020	0.0001	0.0036	0.0021	0.0001	0.0036	0.0026	0.0001	0.0038	0.0021	0.0001	0.0042	0.0039	0.0069	0.0138	0.0354	0.0406	0.0977	0.1791	0.0993	0.0915	0.0858	0.0427	0.0494	0.0546	0.0344	0.1816	0.0923	0.0898	0.3864	0.0835
Plywood + Matting	**rms (m/s^2)**	0.0004	0.0023	0.0006	0.0004	0.0012	0.0009	0.0001	0.0017	0.0009	0.0004	0.0018	0.0014	0.0016	0.0032	0.0051	0.0097	0.0195	0.0478	0.0640	0.1178	0.0853	0.0710	0.1140	0.0799	0.0311	0.0216	0.0118	0.0119	0.0594	0.0239	0.0235	0.2427	0.0786

Table 38– Frequency Spectra Data at the Sawmill Stacker

Z-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
Baseline	**rms (m/s^2)**	0.0008	0.0007	0.0007	0.0006	0.0004	0.0005	0.0004	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0009	0.0015	0.0040	0.0064	0.0074	0.0097	0.0184	0.0350	0.0330	0.0324	0.0189	0.0112	0.0142	0.0207	0.0311	0.0613	0.0876	0.1213	0.3311	0.0194
Matting	**rms (m/s^2)**	0.0007	0.0004	0.0002	0.0003	0.0005	0.0003	0.0002	0.0002	0.0003	0.0005	0.0005	0.0004	0.0006	0.0010	0.0014	0.0020	0.0045	0.0073	0.0098	0.0274	0.0458	0.0352	0.0414	0.0284	0.0254	0.0150	0.0108	0.0063	0.0122	0.0204	0.0371	0.1155	0.0234

Table 39 – Frequency Spectra Data for the Kiln Forklift

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline	**rms (m/s^2)**	0.0479	0.0545	0.0556	0.0717	0.1051	0.1089	0.1003	0.1159	0.1107	0.0972	0.0935	0.0865	0.0778	0.0839
Sorbothane C	**rms (m/s^2)**	0.0619	0.0530	0.0560	0.0797	0.1083	0.1219	0.1190	0.1355	0.1240	0.1091	0.1017	0.0974	0.0751	0.0833
T-Gel C	**rms (m/s^2)**	0.0527	0.0474	0.0565	0.0735	0.1109	0.1250	0.1250	0.1291	0.1276	0.1107	0.1042	0.0917	0.0823	0.0948
Y-Axis															
Baseline	**rms (m/s^2)**	0.1116	0.0884	0.0906	0.0879	0.0780	0.0951	0.1226	0.0747	0.0577	0.0570	0.0624	0.0642	0.0573	0.0571
Sorbothane C	**rms (m/s^2)**	0.1377	0.1164	0.1006	0.0987	0.0903	0.1089	0.1146	0.1001	0.0828	0.0841	0.0815	0.0711	0.0590	0.0582
T-Gel C	**rms (m/s^2)**	0.1171	0.1023	0.1048	0.0953	0.0998	0.1178	0.1281	0.1040	0.0802	0.0783	0.0764	0.0640	0.0551	0.0573
Z-Axis															
Baseline	**rms (m/s^2)**	0.0117	0.0114	0.0111	0.0178	0.0250	0.0550	0.1152	0.2101	0.2673	0.1404	0.1159	0.0749	0.0622	0.0821
Sorbothane C	**rms (m/s^2)**	0.0132	0.0143	0.0138	0.0223	0.0337	0.0690	0.1256	0.2630	0.2698	0.1665	0.1003	0.0585	0.0624	0.0810
T-Gel C	**rms (m/s^2)**	0.0146	0.0129	0.0144	0.0195	0.0287	0.0571	0.1204	0.2317	0.2661	0.1642	0.1118	0.0731	0.0751	0.0990

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.1411	0.1180	0.0464	0.0469	0.0764	0.0844	0.0780	0.0817	0.2231	0.0858	0.0527	0.0256	0.0214	0.0234	0.0200	0.0121	0.0112	0.5451	0.2682
0.1466	0.1312	0.0525	0.0501	0.0813	0.0977	0.0821	0.0741	0.1871	0.0590	0.0366	0.0183	0.0173	0.0179	0.0139	0.0072	0.0048	0.5801	0.2982
0.1692	0.1543	0.0503	0.0435	0.0774	0.0826	0.0737	0.0530	0.1197	0.0474	0.0312	0.0146	0.0110	0.0100	0.0075	0.0051	0.0040	0.5395	0.2996
0.0755	0.0405	0.0448	0.0652	0.1411	0.1447	0.1080	0.0953	0.0808	0.0356	0.0229	0.0163	0.0198	0.0177	0.0175	0.0172	0.0156	0.5464	0.2588
0.0817	0.0494	0.0522	0.0774	0.1477	0.1447	0.1107	0.0881	0.0780	0.0285	0.0190	0.0184	0.0167	0.0123	0.0101	0.0081	0.0070	0.6245	0.2996
0.0797	0.0501	0.0521	0.0764	0.1439	0.1483	0.1125	0.0993	0.1080	0.0259	0.0145	0.0116	0.0099	0.0077	0.0070	0.0065	0.0060	0.6245	0.3020
0.0731	0.0550	0.0490	0.0525	0.0628	0.0584	0.0307	0.0289	0.0327	0.0122	0.0085	0.0066	0.0067	0.0058	0.0056	0.0047	0.0080	0.4587	0.3162
0.0717	0.0560	0.0457	0.0453	0.0642	0.0689	0.0437	0.0252	0.0294	0.0091	0.0076	0.0062	0.0051	0.0041	0.0040	0.0031	0.0032	0.4932	0.3296
0.0862	0.0689	0.0652	0.0753	0.0958	0.0851	0.0462	0.0367	0.0360	0.0149	0.0097	0.0086	0.0074	0.0062	0.0055	0.0044	0.0065	0.5093	0.3459

Table 40 – Frequency Spectra Data for the Planer Feeder Forklift

X-Axis	**Hz**	**0.4**	**0.5**	**0.6**	**0.8**	**1.0**	**1.3**	**1.6**	**2.0**	**2.5**	**3.2**	**4.0**	**5.0**	**6.3**	**8.0**
Baseline	**rms (m/s^2)**	0.0344	0.0321	0.0341	0.0492	0.0640	0.0565	0.0381	0.0410	0.0491	0.0381	0.0412	0.0465	0.0414	0.0369
Sorbothane Cushion	**rms (m/s^2)**	0.0402	0.0405	0.0339	0.0522	0.0674	0.0632	0.0465	0.0464	0.0647	0.0475	0.0510	0.0490	0.0487	0.0378
T-Gel Cushion	**rms (m/s^2)**	0.0301	0.0246	0.0372	0.0545	0.0642	0.0573	0.0444	0.0415	0.0507	0.0451	0.0436	0.0478	0.0440	0.0341
Y-Axis															
Baseline	**rms (m/s^2)**	0.0697	0.0558	0.0470	0.0450	0.0530	0.0953	0.0757	0.0577	0.0570	0.0487	0.0437	0.0353	0.0364	0.0602
Sorbothane Cushion	**rms (m/s^2)**	0.0717	0.0553	0.0451	0.0521	0.0547	0.0888	0.0851	0.0764	0.0624	0.0587	0.0384	0.0322	0.0351	0.0533
T-Gel Cushion	**rms (m/s^2)**	0.0690	0.0482	0.0398	0.0421	0.0505	0.0780	0.0791	0.0541	0.0511	0.0461	0.0351	0.0288	0.0326	0.0464
Z-Axis															
Baseline	**rms (m/s^2)**	0.0102	0.0100	0.0095	0.0137	0.0210	0.0462	0.0617	0.1396	0.2848	0.0938	0.0679	0.0570	0.0433	0.0381
Sorbothane Cushion	**rms (m/s^2)**	0.0117	0.0112	0.0116	0.0158	0.0269	0.0461	0.0698	0.1607	0.2877	0.1089	0.0632	0.0421	0.0402	0.0415
T-Gel Cushion	**rms (m/s^2)**	0.0071	0.0064	0.0084	0.0117	0.0211	0.0402	0.0610	0.1297	0.2272	0.0851	0.0582	0.0487	0.0391	0.0326

10.0	12.5	16.0	20.0	25.0	31.5	40.0	50.0	63.0	80.0	100.0	125.0	160.0	200.0	250.0	315.0	400.0	L	W
0.0247	0.0201	0.0249	0.0789	0.1074	0.0689	0.0674	0.0700	0.1607	0.0735	0.0710	0.0385	0.0249	0.0240	0.0183	0.0092	0.0091	0.4251	0.1352
0.0291	0.0238	0.0285	0.0884	0.1143	0.0764	0.0697	0.0468	0.0913	0.0587	0.0435	0.0321	0.0172	0.0114	0.0062	0.0031	0.0040	0.3877	0.1528
0.0293	0.0324	0.0347	0.0683	0.0853	0.0674	0.0560	0.0332	0.0622	0.0293	0.0212	0.0155	0.0096	0.0072	0.0051	0.0032	0.0028	0.3479	0.1396
0.0418	0.0263	0.0401	0.0510	0.0761	0.0731	0.0413	0.0783	0.1344	0.0753	0.0638	0.0342	0.0151	0.0101	0.0104	0.0086	0.0128	0.4060	0.1816
0.0433	0.0251	0.0387	0.0607	0.0731	0.0618	0.0374	0.0375	0.1134	0.0789	0.0517	0.0292	0.0092	0.0057	0.0041	0.0038	0.0064	0.4069	0.1916
0.0326	0.0214	0.0213	0.0391	0.0638	0.0667	0.0378	0.0325	0.0735	0.0389	0.0321	0.0183	0.0076	0.0051	0.0039	0.0030	0.0026	0.3711	0.1661
0.0428	0.0418	0.1675	0.1026	0.0538	0.0366	0.0315	0.0344	0.0503	0.0163	0.0145	0.0096	0.0062	0.0054	0.0035	0.0033	0.0042	0.4285	0.2854
0.0404	0.0430	0.0622	0.0551	0.0364	0.0256	0.0205	0.0149	0.0305	0.0150	0.0104	0.0103	0.0052	0.0045	0.0031	0.0027	0.0024	0.3949	0.2582
0.0316	0.0331	0.0635	0.0723	0.0507	0.0321	0.0256	0.0179	0.0361	0.0133	0.0088	0.0106	0.0059	0.0041	0.0034	0.0025	0.0027	0.3357	0.2178

Table 41 – Frequency Spectra Data for the Sawmill Takeaway Forklift

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline	**rms (m/s^2)**	0.0497	0.0513	0.0577	0.0622	0.0958	0.1347	0.1009	0.0979	0.0865	0.0698	0.0490	0.0560	0.0637	0.0910
Sorbothane Cushion	**rms (m/s^2)**	0.0581	0.0567	0.0521	0.0685	0.1034	0.1358	0.1017	0.0837	0.0697	0.0533	0.0412	0.0488	0.0547	0.0464
T-Gel Cushion	**rms (m/s^2)**	0.0356	0.0331	0.0407	0.0564	0.0941	0.1274	0.0888	0.0682	0.0589	0.0494	0.0378	0.0448	0.0564	0.0482
Y-Axis															
Baseline	**rms (m/s^2)**	0.0535	0.0528	0.0555	0.0565	0.0628	0.0663	0.1143	0.1116	0.0810	0.0564	0.0490	0.0437	0.0390	0.0546
Sorbothane Cushion	**rms (m/s^2)**	0.0517	0.0540	0.0466	0.0480	0.0549	0.0698	0.1330	0.1246	0.0915	0.0719	0.0635	0.0535	0.0494	0.0415
T-Gel Cushion	**rms (m/s^2)**	0.0433	0.0454	0.0451	0.0454	0.0507	0.0647	0.1001	0.0901	0.0833	0.0571	0.0458	0.0375	0.0361	0.0422
Z-Axis															
Baseline	**rms (m/s^2)**	0.0103	0.0111	0.0134	0.0181	0.0261	0.0454	0.0998	0.1462	0.3020	0.1943	0.0935	0.0693	0.0570	0.0735
Sorbothane Cushion	**rms (m/s^2)**	0.0113	0.0130	0.0118	0.0139	0.0205	0.0479	0.1168	0.1720	0.3296	0.2178	0.0869	0.0582	0.0630	0.0784
T-Gel Cushion	**rms (m/s^2)**	0.0098	0.0111	0.0149	0.0224	0.0298	0.0406	0.0881	0.1209	0.2291	0.1620	0.0828	0.0637	0.0731	0.0764

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0687	0.0453	0.0391	0.0443	0.0693	0.0830	0.0525	0.0392	0.0499	0.0431	0.0817	0.0286	0.0194	0.0283	0.0120	0.0075	0.0057	0.4451	0.2526
0.0378	0.0256	0.0240	0.0371	0.0575	0.0968	0.0527	0.0525	0.0377	0.0341	0.0603	0.0326	0.0132	0.0119	0.0046	0.0039	0.0025	0.4285	0.2486
0.0413	0.0329	0.0275	0.0366	0.0502	0.0624	0.0476	0.0312	0.0290	0.0232	0.0476	0.0183	0.0084	0.0070	0.0048	0.0038	0.0023	0.3440	0.2170
0.0521	0.0521	0.0575	0.0567	0.0363	0.0647	0.1263	0.1629	0.2267	0.0682	0.0605	0.0886	0.0184	0.0162	0.0085	0.0065	0.0061	0.4864	0.2170
0.0344	0.0337	0.0437	0.0441	0.0320	0.0549	0.0815	0.1547	0.2280	0.0687	0.0595	0.0668	0.0125	0.0115	0.0056	0.0042	0.0030	0.4803	0.2323
0.0468	0.0369	0.0356	0.0349	0.0282	0.0531	0.0693	0.0906	0.1565	0.0377	0.0308	0.0313	0.0082	0.0075	0.0044	0.0036	0.0029	0.3750	0.1890
0.0614	0.0704	0.0735	0.0848	0.0465	0.0367	0.0257	0.0209	0.0351	0.0098	0.0110	0.0136	0.0074	0.0083	0.0052	0.0040	0.0036	0.4634	0.3277
0.0494	0.0575	0.0587	0.0540	0.0351	0.0263	0.0198	0.0265	0.0268	0.0095	0.0113	0.0101	0.0053	0.0054	0.0046	0.0042	0.0038	0.4864	0.3424
0.0640	0.0739	0.0759	0.0665	0.0577	0.0537	0.0393	0.0213	0.0207	0.0145	0.0167	0.0134	0.0081	0.0074	0.0058	0.0046	0.0035	0.4102	0.2877

Table 42 – Frequency Spectra Data for the Shipping Forklift

X-Axis	Status	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
***Baseline* - Wt-Not Ok**	**rms (m/s^2)**	0.0378	0.0334	0.0349	0.0404	0.0564	0.0570	0.0637	0.0505	0.0587	0.0454	0.0332	0.0366	0.0484	0.0472
Wt-not Ok + Sorbothane Cush.	**rms (m/s^2)**	0.0487	0.0478	0.0505	0.0547	0.0659	0.0739	0.0749	0.0637	0.0708	0.0577	0.0381	0.0468	0.0594	0.0585
Wt-not Ok + T-gel Cush.	**rms (m/s^2)**	0.0404	0.0353	0.0357	0.0464	0.0559	0.0671	0.0743	0.0772	0.0828	0.0729	0.0304	0.0302	0.0369	0.0378
Wt-Ok	**rms (m/s^2)**	0.0312	0.0252	0.0322	0.0348	0.0482	0.0717	0.0766	0.0624	0.0515	0.0436	0.0346	0.0386	0.0440	0.0465
Y-Axis															
***Baseline* - Wt-Not Ok**	**rms (m/s^2)**	0.0457	0.0361	0.0363	0.0440	0.0408	0.0461	0.0573	0.0676	0.1085	0.1017	0.0459	0.0392	0.0331	0.0359
Wt-not Ok + Sorbothane Cush.	**rms (m/s^2)**	0.0613	0.0474	0.0501	0.0533	0.0600	0.0737	0.0789	0.0826	0.1155	0.1001	0.0473	0.0415	0.0385	0.0441
Wt-not Ok + T-gel Cush.	**rms (m/s^2)**	0.0430	0.0367	0.0420	0.0480	0.0558	0.0619	0.0717	0.0833	0.0791	0.0632	0.0290	0.0287	0.0369	0.0411
Wt-Ok	**rms (m/s^2)**	0.0311	0.0234	0.0251	0.0247	0.0311	0.0462	0.0598	0.1161	0.1057	0.0985	0.0437	0.0357	0.0276	0.0399
Z-Axis															
***Baseline* - Wt-Not Ok**	**rms (m/s^2)**	0.0136	0.0103	0.0104	0.0126	0.0146	0.0223	0.0345	0.0558	0.2413	0.2541	0.0753	0.0443	0.0391	0.0460
Wt-not Ok + Sorbothane Cush.	**rms (m/s^2)**	0.0114	0.0106	0.0093	0.0127	0.0185	0.0353	0.0541	0.0846	0.3404	0.3536	0.0835	0.0568	0.0535	0.0497
Wt-not Ok + T-gel Cush.	**rms (m/s^2)**	0.0158	0.0135	0.0138	0.0126	0.0160	0.0242	0.0369	0.0753	0.2374	0.2446	0.0651	0.0403	0.0360	0.0543
Wt-Ok	**rms (m/s^2)**	0.0155	0.0097	0.0115	0.0128	0.0208	0.0361	0.0697	0.1164	0.2972	0.2894	0.0839	0.0382	0.0425	0.1017

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0261	0.0163	0.0211	0.0530	0.0510	0.0441	0.0348	0.0461	0.1125	0.0289	0.0514	0.0281	0.0378	0.0375	0.0341	0.0092	0.0057	0.4524	0.1435
0.0309	0.0184	0.0236	0.0559	0.0607	0.0420	0.0279	0.0342	0.0685	0.0288	0.0442	0.0240	0.0213	0.0134	0.0066	0.0029	0.0021	0.5093	0.1801
0.0274	0.0214	0.0235	0.0366	0.0406	0.0474	0.0587	0.0402	0.1026	0.0158	0.0190	0.0128	0.0113	0.0096	0.0056	0.0026	0.0016	0.3602	0.1724
0.0271	0.0216	0.0242	0.0487	0.0398	0.0476	0.0505	0.0555	0.2399	0.0284	0.0421	0.0332	0.0244	0.0293	0.0234	0.0079	0.0061	0.3926	0.1510
0.0386	0.0390	0.0320	0.0369	0.0490	0.0590	0.0585	0.0571	0.1897	0.0325	0.0425	0.0323	0.0410	0.0530	0.0630	0.0218	0.0093	0.4295	0.1679
0.0470	0.0422	0.0369	0.0406	0.0576	0.0521	0.0538	0.0603	0.1411	0.0255	0.0296	0.0229	0.0204	0.0161	0.0070	0.0033	0.0024	0.4524	0.2063
0.0292	0.0266	0.0265	0.0394	0.0444	0.0437	0.0360	0.0332	0.0958	0.0123	0.0169	0.0097	0.0105	0.0120	0.0082	0.0029	0.0016	0.3614	0.1710
0.0324	0.0341	0.0329	0.0306	0.0349	0.0474	0.0690	0.0757	0.2588	0.0338	0.0268	0.0458	0.0311	0.0401	0.0478	0.0167	0.0087	0.4202	0.1762
0.0490	0.0479	0.0271	0.0272	0.0282	0.0144	0.0103	0.0123	0.0328	0.0186	0.0210	0.0152	0.0106	0.0109	0.0116	0.0051	0.0044	0.3940	0.2877
0.0596	0.0538	0.0344	0.0320	0.0303	0.0206	0.0184	0.0155	0.0295	0.0136	0.0164	0.0137	0.0075	0.0047	0.0042	0.0053	0.0058	0.5585	0.3917
0.0399	0.0293	0.0222	0.0228	0.0254	0.0231	0.0149	0.0089	0.0286	0.0138	0.0134	0.0156	0.0114	0.0068	0.0043	0.0029	0.0026	0.3833	0.2770
0.0571	0.0511	0.0451	0.0393	0.0335	0.0291	0.0247	0.0220	0.0821	0.0172	0.0193	0.0198	0.0096	0.0085	0.0101	0.0053	0.0038	0.4892	0.3524

Table 43 – Frequency Spectra Data for the Planer Takeaway Forklift

X-Axis	Status	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline	**rms (m/s^2)**	0.0226	0.0224	0.0270	0.0366	0.0689	0.0844	0.0492	0.0318	0.0210	0.0181	0.0196	0.0244	0.0274	0.0178
Sorbothane Cushion	**rms (m/s^2)**	0.0418	0.0395	0.0375	0.0547	0.0964	0.1100	0.0913	0.0514	0.0406	0.0364	0.0378	0.0410	0.0413	0.0300
T-Gel Cushion	**rms (m/s^2)**	0.0418	0.0324	0.0280	0.0351	0.0577	0.0901	0.0886	0.0472	0.0424	0.0347	0.0381	0.0460	0.0461	0.0330
Y-Axis															
Baseline	**rms (m/s^2)**	0.0745	0.0447	0.0475	0.0337	0.0360	0.0533	0.1057	0.0717	0.0633	0.0423	0.0326	0.0173	0.0144	0.0148
Sorbothane Cushion	**rms (m/s^2)**	0.0524	0.0582	0.0547	0.0461	0.0490	0.0776	0.1547	0.0647	0.0633	0.0605	0.0396	0.0238	0.0233	0.0286
T-Gel Cushion	**rms (m/s^2)**	0.0448	0.0410	0.0366	0.0385	0.0560	0.0783	0.2109	0.1094	0.0915	0.0725	0.0464	0.0293	0.0289	0.0318
Z-Axis															
Baseline	**rms (m/s^2)**	0.0098	0.0070	0.0083	0.0108	0.0161	0.0250	0.0708	0.0640	0.1404	0.0823	0.0348	0.0273	0.0366	0.0394
Sorbothane Cushion	**rms (m/s^2)**	0.0103	0.0126	0.0156	0.0204	0.0335	0.0749	0.2035	0.1355	0.2512	0.1312	0.0474	0.0366	0.0513	0.0518
T-Gel Cushion	**rms (m/s^2)**	0.0155	0.0137	0.0148	0.0176	0.0332	0.0618	0.1912	0.1287	0.2673	0.1639	0.0600	0.0390	0.0575	0.0652

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0151	0.0162	0.0199	0.0256	0.0207	0.0167	0.0188	0.0218	0.0328	0.0682	0.1094	0.0888	0.0672	0.0299	0.0157	0.0114	0.0091	0.2742	0.1363
0.0265	0.0256	0.0271	0.0223	0.0222	0.0259	0.0505	0.0449	0.0297	0.0656	0.0755	0.0729	0.0729	0.0501	0.0244	0.0112	0.0069	0.3690	0.2014
0.0263	0.0241	0.0263	0.0265	0.0251	0.0311	0.0558	0.0490	0.0240	0.0475	0.0622	0.0546	0.0459	0.0226	0.0088	0.0062	0.0044	0.3323	0.1642
0.0145	0.0164	0.0259	0.0384	0.0494	0.0473	0.0469	0.0445	0.0344	0.0280	0.0418	0.0923	0.0710	0.0410	0.0259	0.0151	0.0129	0.3277	0.1724
0.0290	0.0326	0.0354	0.0425	0.0619	0.0708	0.0888	0.1118	0.0384	0.0304	0.0410	0.0925	0.0823	0.0506	0.0249	0.0099	0.0066	0.3895	0.2183
0.0361	0.0358	0.0399	0.0468	0.0624	0.0751	0.1161	0.1213	0.0335	0.0247	0.0229	0.0335	0.0315	0.0202	0.0095	0.0062	0.0059	0.4355	0.2710
0.0281	0.0332	0.0455	0.0587	0.0520	0.0385	0.0269	0.0217	0.0231	0.0157	0.0160	0.0150	0.0143	0.0114	0.0055	0.0043	0.0063	0.2480	0.1594
0.0435	0.0444	0.0386	0.0372	0.0441	0.0353	0.0363	0.0238	0.0093	0.0092	0.0065	0.0126	0.0174	0.0150	0.0102	0.0048	0.0044	0.4111	0.2618
0.0527	0.0522	0.0474	0.0451	0.0518	0.0479	0.0632	0.0484	0.0109	0.0095	0.0122	0.0202	0.0184	0.0120	0.0084	0.0056	0.0100	0.4416	0.2877

Table 44 – Frequency Spectra Data for the Towmotor Forklift

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline **- Non-Susp. Seat**	**rms (m/s^2)**	0.0414	0.0351	0.0323	0.0320	0.0384	0.0547	0.0654	0.0535	0.0497	0.0367	0.0285	0.0245	0.0275	0.0298
Sorbothane Cushion	**rms (m/s^2)**	0.0497	0.0405	0.0414	0.0453	0.0462	0.0622	0.0595	0.0437	0.0420	0.0383	0.0314	0.0276	0.0328	0.0360
T-gel Cushion	**rms (m/s^2)**	0.0443	0.0383	0.0371	0.0378	0.0494	0.0729	0.0725	0.0555	0.0490	0.0377	0.0357	0.0284	0.0319	0.0340
Susp. Seat	**rms (m/s^2)**	0.0385	0.0363	0.0393	0.0392	0.0490	0.0668	0.0605	0.0461	0.0498	0.0410	0.0316	0.0280	0.0341	0.0366
Y-Axis															
Baseline **- Non-Susp. Seat**	**rms (m/s^2)**	0.0406	0.0385	0.0305	0.0285	0.0317	0.0344	0.0334	0.0372	0.0633	0.0408	0.0298	0.0225	0.0256	0.0344
Sorbothane Cushion	**rms (m/s^2)**	0.0510	0.0476	0.0396	0.0363	0.0371	0.0386	0.0398	0.0451	0.0693	0.0476	0.0321	0.0307	0.0375	0.0470
T-gel Cushion	**rms (m/s^2)**	0.0386	0.0403	0.0333	0.0344	0.0353	0.0366	0.0355	0.0447	0.1026	0.0649	0.0415	0.0281	0.0344	0.0442
Susp. Seat	**rms (m/s^2)**	0.0486	0.0490	0.0444	0.0388	0.0392	0.0425	0.0430	0.0474	0.0706	0.0506	0.0372	0.0349	0.0417	0.0530
Z-Axis															
Baseline **- Non-Susp. Seat**	**rms (m/s^2)**	0.0072	0.0077	0.0091	0.0110	0.0139	0.0202	0.0360	0.0727	0.1991	0.2472	0.2331	0.0735	0.0556	0.0515
Sorbothane Cushion	**rms (m/s^2)**	0.0086	0.0082	0.0096	0.0122	0.0177	0.0277	0.0366	0.0674	0.2068	0.2645	0.1560	0.0668	0.0735	0.0517
T-gel Cushion	**rms (m/s^2)**	0.0088	0.0086	0.0093	0.0096	0.0141	0.0242	0.0377	0.0676	0.1886	0.2603	0.2350	0.0789	0.0733	0.0545
Susp. Seat	**rms (m/s^2)**	0.0088	0.0095	0.0114	0.0142	0.0220	0.0296	0.0434	0.0749	0.1758	0.2084	0.1408	0.0755	0.0743	0.0869

10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	L	W
0.0346	0.0236	0.0219	0.0363	0.0689	0.0935	0.0783	0.0774	0.0772	0.0525	0.0387	0.0780	0.0450	0.0336	0.0244	0.0161	0.0114	0.3258	0.1309
0.0423	0.0248	0.0254	0.0459	0.0906	0.1026	0.1068	0.0747	0.0935	0.0513	0.0289	0.0474	0.0478	0.0331	0.0200	0.0094	0.0038	0.3652	0.1396
0.0421	0.0265	0.0265	0.0497	0.0951	0.0935	0.0888	0.0603	0.0595	0.0375	0.0211	0.0259	0.0163	0.0153	0.0076	0.0031	0.0016	0.3285	0.1515
0.0422	0.0278	0.0290	0.0413	0.0622	0.0723	0.1164	0.0917	0.1626	0.0764	0.0661	0.0590	0.0356	0.0254	0.0139	0.0064	0.0047	0.3703	0.1404
0.0366	0.0347	0.0340	0.0238	0.0420	0.0431	0.0383	0.0581	0.0879	0.0643	0.0571	0.0535	0.0322	0.0289	0.0260	0.0158	0.0125	0.2871	0.1076
0.0517	0.0437	0.0354	0.0232	0.0511	0.0410	0.0360	0.0460	0.0715	0.0545	0.0447	0.0612	0.0470	0.0168	0.0156	0.0076	0.0037	0.3044	0.1284
0.0416	0.0410	0.0390	0.0247	0.0541	0.0427	0.0309	0.0303	0.0461	0.0355	0.0306	0.0324	0.0136	0.0094	0.0061	0.0035	0.0020	0.2848	0.1363
0.0537	0.0444	0.0369	0.0299	0.0422	0.0378	0.0525	0.0661	0.1068	0.0733	0.0668	0.1118	0.0573	0.0378	0.0230	0.0102	0.0066	0.3495	0.1355
0.0474	0.0392	0.0941	0.0524	0.0473	0.0390	0.0310	0.0269	0.0241	0.0167	0.0132	0.0152	0.0145	0.0120	0.0077	0.0058	0.0049	0.4426	0.3614
0.0427	0.0382	0.0344	0.0322	0.0372	0.0305	0.0283	0.0157	0.0156	0.0097	0.0075	0.0139	0.0142	0.0067	0.0050	0.0038	0.0029	0.4069	0.3240
0.0483	0.0388	0.0394	0.0384	0.0595	0.0511	0.0392	0.0200	0.0228	0.0121	0.0121	0.0120	0.0224	0.0095	0.0061	0.0033	0.0025	0.4462	0.3660
0.0835	0.0582	0.0460	0.0436	0.0649	0.0525	0.0372	0.0318	0.0361	0.0207	0.0118	0.0102	0.0108	0.0085	0.0081	0.0047	0.0029	0.3855	0.3087

Table 45 – Frequency Spectra Data for the Loader

X-Axis	Hz	0.4	0.5	0.63	0.8	1	1.25	1.6	2	2.5	3.15	4	5	6.3	8
Baseline	**rms (m/s^2)**	0.0479	0.0545	0.0556	0.0717	0.1051	0.1089	0.1003	0.1159	0.1107	0.0972	0.0935	0.0865	0.0778	0.0839
Sorbothane Cushion	**rms (m/s^2)**	0.0619	0.0530	0.0560	0.0797	0.1083	0.1219	0.1190	0.1355	0.1240	0.1091	0.1017	0.0974	0.0751	0.0833
T-Gel Cushion	**rms (m/s^2)**	0.0527	0.0474	0.0565	0.0735	0.1109	0.1250	0.1250	0.1291	0.1276	0.1107	0.1042	0.0917	0.0823	0.0948
Y-Axis															
Baseline	**rms (m/s^2)**	0.1116	0.0884	0.0906	0.0879	0.0780	0.0951	0.1226	0.0747	0.0577	0.0570	0.0624	0.0642	0.0573	0.0571
Sorbothane Cushion	**rms (m/s^2)**	0.1377	0.1164	0.1006	0.0987	0.0903	0.1089	0.1146	0.1001	0.0828	0.0841	0.0815	0.0711	0.0590	0.0582
T-Gel Cushion	**rms (m/s^2)**	0.1171	0.1023	0.1048	0.0953	0.0998	0.1178	0.1281	0.1040	0.0802	0.0783	0.0764	0.0640	0.0551	0.0573
Z-Axis															
Baseline	**rms (m/s^2)**	0.0117	0.0114	0.0111	0.0178	0.0250	0.0550	0.1152	0.2101	0.2673	0.1404	0.1159	0.0749	0.0622	0.0821
Sorbothane Cushion	**rms (m/s^2)**	0.0132	0.0143	0.0138	0.0223	0.0337	0.0690	0.1256	0.2630	0.2698	0.1665	0.1003	0.0585	0.0624	0.0810
T-Gel Cushion	**rms (m/s^2)**	0.0146	0.0129	0.0144	0.0195	0.0287	0.0571	0.1204	0.2317	0.2661	0.1642	0.1118	0.0731	0.0751	0.0990

0.1411	0.1180	0.0464	0.0469	0.0764	0.0844	0.0780	0.0817	0.2231	0.0858	0.0527	0.0256	0.0214	0.0234	0.0200	0.0121	0.0112	0.5451	0.2682
0.1466	0.1312	0.0525	0.0501	0.0813	0.0977	0.0821	0.0741	0.1871	0.0590	0.0366	0.0183	0.0173	0.0179	0.0139	0.0072	0.0048	0.5801	0.2982
0.1692	0.1543	0.0503	0.0435	0.0774	0.0826	0.0737	0.0530	0.1197	0.0474	0.0312	0.0146	0.0110	0.0100	0.0075	0.0051	0.0040	0.5395	0.2996

0.0755	0.0405	0.0448	0.0652	0.1411	0.1447	0.1080	0.0953	0.0808	0.0356	0.0229	0.0163	0.0198	0.0177	0.0175	0.0172	0.0156	0.5464	0.2588
0.0817	0.0494	0.0522	0.0774	0.1477	0.1447	0.1107	0.0881	0.0780	0.0285	0.0190	0.0184	0.0167	0.0123	0.0101	0.0081	0.0070	0.6245	0.2996
0.0797	0.0501	0.0521	0.0764	0.1439	0.1483	0.1125	0.0993	0.1080	0.0259	0.0145	0.0116	0.0099	0.0077	0.0070	0.0065	0.0060	0.6245	0.3020
0.0731	0.0550	0.0490	0.0525	0.0628	0.0584	0.0307	0.0289	0.0327	0.0122	0.0085	0.0066	0.0067	0.0058	0.0056	0.0047	0.0080	0.4587	0.3162
0.0717	0.0560	0.0457	0.0453	0.0642	0.0689	0.0437	0.0252	0.0294	0.0091	0.0076	0.0062	0.0051	0.0041	0.0040	0.0031	0.0032	0.4932	0.3296
0.0862	0.0689	0.0652	0.0753	0.0958	0.0851	0.0462	0.0367	0.0360	0.0149	0.0097	0.0086	0.0074	0.0062	0.0055	0.0044	0.0065	0.5093	0.3459

Table 46 – Aeq and Aeq4 Values Collected for the Chainsaw

	X-Axis		**Y-Axis**		**Z-Axis**	
Chainsaw	**Aeq (rms)**	**Aeq4 (rms)**	**Aeq (rms)**	**Aeq4 (rms)**	**Aeq (rms)**	**Aeq4 (rms)**
baseline	2.95	0.19	4.21	0.272	7.67	0.495
	2.72	0.175	4.16	0.269	7.67	0.495
	2.88	0.186	4.26	0.275	7.67	0.495
	3.09	0.199	3.84	0.248	7.07	0.457
	2.78	0.179	4.07	0.263	7.85	0.506
	3.38	0.218	*	*	7.16	0.462
	*	*	*	*	7.16	0.462
	*	*	*	*	7.76	0.501
	*	*	*	*	7.94	0.512
	*	*	*	*	7.67	0.495
gel	3.27	0.211	3.19	0.206	3.89	0.251
	3.46	0.223	2.98	0.192	4.12	0.266
	3.19	0.206	3.27	0.211	4.41	0.285
	2.75	0.177	3.12	0.201	4.78	0.309
	3.98	0.257	3.46	0.223	*	*
sorbothane	*	*	*	*	5.07	0.327
	*	*	*	*	5.55	0.358
	*	*	*	*	5.55	0.358
	*	*	*	*	5.18	0.334
	*	*	*	*	5.12	0.331

* no measure taken

5.3 APPENDIX C - DETAILED RESULTS OF QUESTIONNAIRES

The following tables provide a detailed breakdown of the answers to both questionnaires. Overall results represent all employees who answered the baseline questionnaire. Pre/Post results represent only the thirty-one people who used interventions.

Table 47 - Time Worked in Current Position

Time in Current Position:	**Overall N=48**	**Pre/Post N=48**
1-2 years	50%	50%
3-5 years	25%	25%
6-7 years	8%	8%
8-10 years	13%	13%
>15 years	4%	4%

Table 48 – Hours of Exposure to Vibration Each Day

# of hours of Exposure	**Overall n=48**	**Pre/Post n=31**
	%	%
<1 hour	4	0
1-2 hours	8	13
3-5 hours	10	10
6-7 hours	4	0
8-9 hours	73	77

Table 49 - Primary Type of Vibration Exposure

Vibration	**% n=48**	**% n=31**
Whole body Vibration	85	87
Hand Arm vibration	15	13

Table 50 - Type of Interventions Currently in use for Vibration

Interventions	**% n=48**	**% n=31**
None	58	65
Vibration wrap for tools	0	0
Vibration gloves	0	0
Suspension seat	15	10
Plywood platform	10	6
Anti-fatigue matting	23	16
Insoles	4	3
other	4	1

Table 51 - Symptoms of Pain or Discomfort Experienced in the Last Six Months

Areas of Discomfort	% n=48	% n=31
Neck	17	13
Shoulders	38	26
Upper back	15	13
Low back	44	45
Knees	17	13
Leg	25	22
feet	23	29
Forearm	4	0
Elbows	4	6
Wrist	15	10
Hand & Fingers	23	16
none	17	16

Table 52 - Employees Who are Aware of the Term Raynaud's Disease

Aware of the term vibration Syndrome / Raynaud's Disease	**% #1**	**% #1 Pre**	**% #2 Post**
	N=48	N=31	N=31
Yes	31%	32%	48%
No	69%	68%	52%

Table 53 - Responses to Questions after the use of Different Interventions

	N=49	Impacto gloves	Ergotech gloves	Tool Wrap	Insoles	Matting	Plywood	Suspension seat	Isolated Workstation	Air Bags	T-gel cushion	Sorbothane cushion
	Total %	N=3	N=3	N=4	N=6	N=11	N=2	N=2	N=11	N=3	N=3	N=1
Have you noticed a reduction in amount of vibration experienced at your workstation since the vibration intervention was implemented?												
Yes	82%	3	2	2	3	10	2	2	11	3	1	1
No	18%		1	2	3	1					2	
Since the intervention was implemented, has your level of comfort while working:												
Improved	80%	3	2	2	4	11	1	1	10	3	1	1
No change	18%		1	2	2		1	1	1		1	
Decreased	2%										1	
What areas have you noticed a decrease in discomfort since the interventions were implemented at your workstation?												
Neck	0%											
Shoulders	6%				1				1	1		
Upper Back	3%								1	1		
Low Back	26%				2	5			4	1		1
Knees	13%				2	3			3	1		
Leg	13%					5			3			
Feet	26%				4	4	1		3			
elbows	6%	1		1								
Wrist	3%	1	1									
hand	10%	1	1							1		
No change	42%	1	2	3	2	2	1	2	3	1	3	
% decrease	58%	66%	33%	25%	66%	82%	0%	0%	73%	66%	0%	100%
% no change	42%	33%	66%	75%	33%	18%	50%	100%	27%	33%	100%	0%
How comfortable is the intervention to use while working? (1 - very uncomfortable 7 - very comfortable to use)												
1	0%											
2	8%	2			1						1	
3	20%	1	3	2		1	1		1		1	
4	10%			1	1			1	1		1	
5	24%			1	3	4			2	1		1
6	16%				1	3			3	1		
7	20%					3	1	1	4	1		
Will you continue to use the vibration interventions that were implemented?												
Yes	92%	2	2	4	6	11	2	2	11	3	1	1
No	8%	1	1								2	

5.4 APPENDIX D - EMPLOYEE EDUCATION INFORMATION

Awareness and Prevention of Human Vibration in the Sawmill Industry

2 Types of Vibration

Whole-Body Vibration is transmitted to the body through the buttocks and feet

Whole-body vibration is associated with

- Transportation - driving mobile equipment
- Sitting in operators booths
- Operation of production machinery in the mill

Associated Disorders

Physiological Effects

- Symptoms of back pain – especially among mobile equipment operators
- Symptoms of abdominal pain, tissue damage

Performance Effects

- Comfort may be compromised at lower levels of vibration
- Vibration is seen as a nuisance/annoyance – may have negative effects on performance
- High levels may cause a decrease in fine manipulative tasks and visual function

Hand-Arm Vibration is transmitted through the hands when they are supporting powered hand tools

Hand-arm vibration is associated with

- Operation of power tools – grinders, chainsaws, chipping hammers
- Operation of vibrating hand controls and steering wheels in mobile equipment

Vibration Syndrome **-** Referred to as *White Finger* or *Raynaud's disease*

This disorder is caused by forceful gripping and prolonged use of vibrating tools, and is characterized by recurrent episodes of finger blanching - due to damage to arteries in fingers.

Long term exposure to vibration and cold trigger the following symptoms:

- Intermittent numbness and tingling in fingers
- Skin turns ashen, pale and cold
- Eventual loss of sensation and control in fingers and hands
- Stiffness, pain, blanching of fingers, loss of strength

- May experience vascular spasms and pain when hands are exposed to cold environment

Effects of Performance:

- Loss of grip strength and endurance while performing sustained holding tasks
- Inability to do fine manipulative tasks in cold weather/environment

Based on this study, the % chance of developing symptoms of white finger disorder for welders and chainsaw operators is outlined in the following chart.

		% Chance of Developing Symptoms after # Years Use		
Tool	**Hrs of daily operation**	**5 Years**	**10 years**	**15 Years**
5” Makita Grinder	2	<10%	<10%	<10%
7” Makita Grinder	2	12%	46%	>50%
10” Walter Grinder	2	<10%	10%	23%
272XP Husquvarna Chainsaw	4	17%	>50%	>50%
• With gel foam	4	<10%	25%	>50%
• With sorbothane wrap	4	<10%	34%	>50%

Workplace Strategies for the Prevention of Vibration Related disorders

1. Reduce Vibration
2. Decrease Exposure Time
3. Isolate Employees From Vibration

Equipment and Workplace

- Mount equipment on springs or compression pads
- Maintain equipment in balance, and replace worn parts
- Use materials/parts that generate less vibration
- Modify equipment speed, feed, motion - to change vibration characteristics
- Rotating movements on equipment causes less vibration than reciprocating movements
- Hydraulic and pneumatic transmissions are superior to mechanical transmissions

Exposure Time

- Alternate employees between work tasks with and without vibration – especially in areas where vibration is high
- Chipping hammers should not exceed 4 hours use/person/shift

Isolation

- Isolate a section of the workstation area from rest of the vibrating structures
- Use plywood, rubber matting, or insoles for standing operations
- Counter weight tools to minimize gripping forces required to operate

- Seated tasks – suspension or air ride seats in mobile equipment

Tips for Individuals Exposed to Vibration at Work

Vibrating Hand Tools

Use the 5” Makita grinder over the 7” Makita grinder.

- The 5” grinder is lighter and requires less grip force
- There is less chance of developing a disorder with the 5” grinder – even when it is used for longer periods

For employees who regularly use a chainsaw (Buckers) it would be worthwhile to use vibration gloves or tool wrap to reduce the amount of vibration from this tool.

When working in cold temperatures wear adequate clothing to maintain body temperature.

Let the tool do the work and grip the tool as lightly as possible - providing this is safe and you have control of the tool.

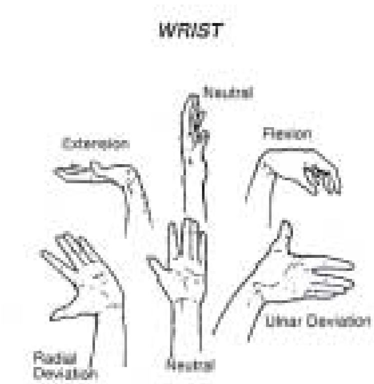
Avoid / minimize smoking while using vibrating equipment because nicotine reduces blood supply to the hands and fingers

Maintain tools in good working order - inform supervisor when abnormal vibration occurs

Tools should not give off cold gases or fluids over operators hands

Seek medical advice if you experience white/blue fingers, or if tingling and numbness occur for long periods

Bend the tool, not the wrist - Try to maintain wrists in a neutral position when using tool, to reduce additional stress on the hand-arm segments.



Whole-body Vibration

A person standing with their legs slightly bent and relaxed is at much less risk than a seated person is.

Inform supervisor when abnormal vibration of equipment occurs so that the maintenance department can fix problems.

Mobile Equipment:
Take the time to regularly get out of equipment to walk around and stretch. (At least 2-5 minutes every hour) Forklift operators should do quick stretches every time they get out of equipment to add/remove blocks. Suggested stretches are enclosed. Lunch and coffee breaks should be taken, and spent standing or walking around instead of sitting.

Ensure that the seat is adjusted properly with adequate lumbar support. If the back is in optimal posture it reacts more positively to the stresses of vibration.

Ensure that the suspension seats are working correctly. They should be replaced as soon as they wear out. Make sure to use the correct weight adjustment on new seats.

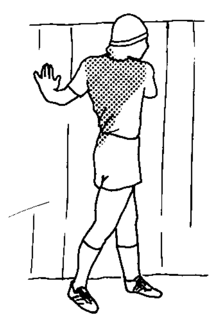
The road conditions are a factor in the amount of vibration experienced so try to minimize your exposure to potholes, kiln tracks etc, by;

- Reducing driving speed over rough surfaces
- Have major potholes regularly filled with gravel
- Try driving alternate routes to avoid/reduce exposure to rough conditions

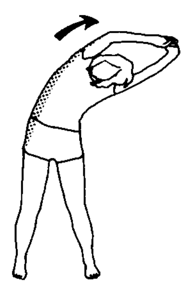
Try to minimize the shock of the forklift banging against bundles and kiln carts, as this creates very high levels of vibration.

STRETCHES
Never bounce when stretching, always just stretch to the first point of tension. Hold this stretch for 10 – 20 seconds.

Backward Bend



Trunk Rotation



Side Bends

5.5 APPENDIX E - SUPPLEMENTARY FINDINGS

This supplementary section has been included in the report as a follow up to the original hand-arm vibration measures that were taken. The method in which the accelerometer 4505 and hand tool adapter were mounted on the equipment, with duct tape, may not have been representative of a true handgrip. Therefore, measures for hand-arm vibration were reassessed with equipment used in the original study, as well as with a new transducer set that uses a hand adaptor which is more representative of a true handgrip. All materials used, methods and analysis are assumed to be the same as in the original project unless otherwise stated.

Two different hand-arm transducer/adapter sets were used.

1- The system that was used in the original project will be referred to as Type 2237 *T-adaptor*. The placement of this accelerometer is in the basicentric coordinate system.
2- A hand arm transducer set Type 4392 was used with Type 4374 accelerometer and Type UA0891 hand adaptor that fits over the head of the third metacarpal. This system was used with the Type 2237 Integrating sound level meter and hand-arm vibration meter that was originally used. This system will be referred to as *Type 4392 hand adapter*. The 4392 hand adapter set was used to better represent a true hand grip on tools. The placement of this accelerometer was in the biodynamic coordinate system with the origin of axis over the head of the third metacarpal. It was held in position by the natural grip of the operator. See figures 31 and 32.

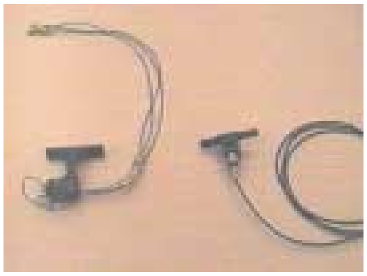


Figure 31 – Type 4392 hand adaptor (left) Type 2237 T – adaptor (right)

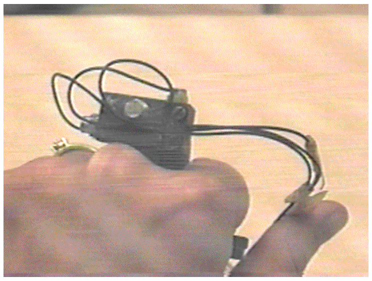


Figure 32 – Type 4392 hand adaptor position

verall weighted measures were collected under the same three conditions as in the original project – baseline, gel foam, and sorbothane. Only the 4392 hand adapter was used with the chainsaw. Two 30-second samples were taken in all three axis under all three conditions. Both the T-adapter and hand arm adapter were used to obtain measurements with all the grinders. Measures were taken on the side handle of all three grinders. Measures were also obtained on the main handle for the 7" grinder. One 30-second sample was obtained in each axis. Figure III shows the position of the Type 4392 hand adapter during measurements with the grinders.

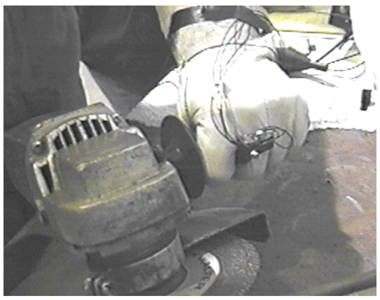


Figure 33 – Type 4392 accelerometer with Grinder

The Aeq values derived from the Type 4392 hand-adapter were multiplied by a factor of 3 because the 4374 accelerometer is three times less sensitive than the standard Type 4505 and 2237B, as predetermined through calibration. See Table 54 for a summary of Aeq and Aeq4 values.

In addition to the overall weighted measures, DAT recordings were measured with all grinders, but only in the x-axis. This allowed for complete analysis of the frequency spectra. Tables 55 - 62. All measurements were made in accordance with ISO:5439:1986

Analysis of the DAT recordings of the grinders in the x-axis was performed with Type 2143 single channel digital filter realtime analyzer. The analyzer was set up for 1/3 octave band analysis with the frequency range limited to 4 Hz to 2000 Hz for hand arm vibration. A ratio analysis of the interventions is provided where the x-axis was dominant, to demonstrate what parts of the frequency spectra had attenuation. Figures 34 – 39.

Table 54 – r.m.s. Values for hand-arm vibration (2237 T-adaptor and 4392 Hand adaptor)

		X-Axis		Y-Axis		Z-Axis		CHANGE (Aeq4)		chance of symptoms
Aeq4 based on:		Aeq (rms)	Aeq4 (rms)	Aeq (rms)	Aeq4 (rms)	Aeq (rms)	Aeq4 (rms)	rms	%	%
4hr use/day	**Chainsaw**									10 years exposure
	baseline	7.17	7.17	**7.71**	**7.71**	5.91	5.91			>50
	gel	7.53	7.53	**6.48**	**6.48**	3.09	3.09	-1.23	-16.0	47
	sorbothane	8.73	8.73	**3.63**	**3.63**	5.58	5.58	-4.08	-52.9	15
2 hr use/day	**10" Walter**									15 years exposure
2237 T-adaptor	baseline	**2.75**	**1.94**	1.69	1.19	2.29	1.62			9
	gel	**6.76**	**4.78**	1.84	1.30	2.88	2.04	2.84	145.8	57
	sorbothane	**9.22**	**6.52**	2.95	2.09	3.93	2.78	4.57	335.3	106
4392 Hand adaptor	baseline	5.13	3.63	3.81	2.69	**5.76**	**4.07**			41
	gel	7.44	5.26	6.18	4.37	**2.96**	**2.10**	-1.98	-48.5	11
	sorbothane	4.98	3.52	2.87	2.03	**3.84**	**2.71**	-1.36	-33.3	18
2hr use/day	**7" Makita**									
2237 T-adaptor	baseline	**10.2**	**7.21**	3.58	2.53	3.05	2.16			130
	gel	**9.55**	**6.75**	5.37	3.80	3.05	2.16	-0.46	-6.4	111
	sorbothane	**8.61**	**6.09**	3.93	2.78	5.01	3.54	-1.12	-15.6	92
4392 Hand adaptor	baseline	**8.43**	**5.96**	6.03	4.26	7.8	5.51			89
	gel	**7.8**	**5.51**	8.64	6.11	4.98	3.52	-0.45	-7.5	76
	sorbothane	**8.16**	**5.77**	7.8	5.51	7.62	5.39	-0.19	-3.2	83
2hr use/day	**7" Makita**									15 years exposure
2237 T-adaptor	baseline	5.55	3.92	3.75	2.65	**6.38**	**4.51**			51
	gel	6.53	4.62	4.57	3.23	**6.99**	**4.94**	0.43	9.6	61
	sorbothane	5.62	3.97	4.31	3.05	**6.45**	**4.56**	0.05	1.1	52
4392 Hand adaptor	baseline	**9.15**	**6.47**	6.54	4.62	5.19	3.67			104
	gel	**6.63**	**4.69**	6.54	4.62	3.63	2.57	-1.78	-27.5	55
	sorbothane	**8.94**	**6.32**	6.18	4.37	5.7	4.03	-0.15	-2.3	100
2hr use/day	**5" Makita**									15 years exposure
2237 T-adaptor	baseline	**3.84**	**2.71**	3.02	2.14	1.67	1.18			18
	gel	**5.95**	**4.21**	4.41	3.12	1.86	1.32	1.49	54.9	44
	sorbothane	**5.07**	**3.58**	2.78	1.97	1.69	1.19	0.87	32.0	32
4392 Hand adaptor	baseline	**6.33**	**4.48**	5.31	3.75	4.08	2.88			50
	gel	**7.62**	**5.39**	4.23	2.99	3.72	2.63	0.91	20.4	72
	sorbothane	**5.76**	**4.07**	3.36	2.38	4.08	2.88	-0.40	-9.0	41

Table 55 – Frequency Spectra Data for the 10" Walter Grinder with T- Adaptor

	Hz	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80
Baseline	**rms(m/s^2)**	0.2893	0.3732	0.1826	0.1435	0.1370	0.0915	0.1134	0.0865	0.1115	0.1539	0.2142	3.3004	4.0766	0.7343
Gel Foam	**rms(m/s^2)**	0.1177	0.1080	0.0136	0.0780	0.0623	0.0490	0.1051	0.0961	0.2073	0.3691	0.3172	10.1808	18.7234	1.6104
Sorbothane	**rms(m/s^2)**	0.1210	0.0719	0.0869	0.1071	0.0876	0.0958	0.0925	0.0998	0.1155	0.1556	0.3146	12.3390	29.1909	2.5175

100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	L	W
5.2582	4.9407	5.1735	4.9810	9.7756	6.7824	6.3729	17.1228	18.3718	12.2061	20.4735	25.7722	50.8543	69.0583	162.4920	2.2591
2.8131	3.8512	5.8439	6.8008	12.7121	7.2574	5.9076	12.1401	10.9235	11.8158	13.0964	8.4229	14.7935	14.4374	45.5105	5.9076
1.4888	3.1776	3.9037	5.1316	8.7484	7.9573	5.6878	6.5478	6.4948	6.1027	15.5325	15.5746	28.0290	23.4419	59.3417	8.3775

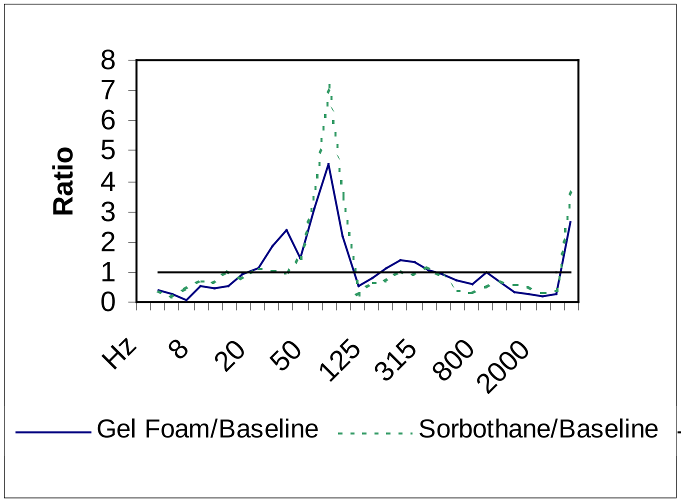


Figure 34 - Isolation Ratio for Interventions with 10" Walter Grinder with T- Adaptor

Table 56 – Frequency Spectra Data for the 10” Walter Grinder with Hand – Adaptor

	Hz	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	L	W
Baseline	**rms(m/s^2)**	0.0945	0.1236	0.1106	0.1112	0.1396	0.1246	0.1711	0.1458	0.1638	0.1355	0.1866	2.3400	16.7106	1.1956	1.4256	7.5583	3.5220	7.0064	11.5002	8.6307	7.9789	6.8008	6.7824	7.7448	21.3800	32.1798	64.5381	56.6719	106.7953	4.5676
Gel Foam	**rms(m/s^2)**	0.1298	0.1233	0.1152	0.1363	0.1515	0.1341	0.1539	0.1777	0.2493	0.3163	0.4685	6.5124	22.5088	1.3432	2.6576	9.9089	3.4747	4.4940	7.1987	4.0987	3.2210	3.4372	7.5175	7.7868	8.6776	12.6434	38.8959	39.0014	65.9514	6.2363
Sorbothane	**rms(m/s^2)**	0.4622	0.2107	0.1831	0.1519	0.1821	0.2439	0.3554	0.5961	0.8804	1.3038	1.0190	4.1546	47.7837	9.0618	5.9076	16.9384	7.0254	9.5403	8.9400	5.2298	2.5657	2.9060	4.0766	3.8097	9.4887	5.5059	14.0898	17.6884	60.3137	12.5411

Table 57 – Frequency Spectra Data for the 7” Makita Grinder with T– Adaptor Side Handle

	Hz	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	L	W
Baseline	**rms(m/s^2)**	0.0848	0.0527	0.0632	0.1439	0.1193	0.1263	0.2171	0.2189	0.2839	0.6208	0.6697	10.4887	31.6612	11.8800	5.0489	17.7363	11.0424	11.1929	13.6763	17.7363	17.7363	19.5524	12.4734	6.8192	13.4195	33.8788	24.4136	29.8302	86.9313	9.5145
Gel Foam	**rms(m/s^2)**	0.0998	0.0757	0.0136	0.0966	0.0692	0.0759	0.1057	0.1312	0.2298	0.3742	0.4597	8.4916	29.6691	6.7275	5.3734	18.6727	12.1731	16.8013	23.6971	30.0735	17.5453	6.8563	4.0546	4.0327	3.6581	6.0697	2.7084	1.5973	60.6412	8.9158
Sorbothane	**rms(m/s^2)**	0.0692	0.0652	0.0360	0.1168	0.1026	0.0379	0.1396	0.0933	0.1277	0.1831	0.5263	17.5453	17.4033	2.6720	7.9789	12.1073	11.5313	9.8553	13.1675	18.3718	11.5626	9.1110	9.1605	10.8351	13.6393	32.7956	15.7442	6.8563	59.6639	7.6406

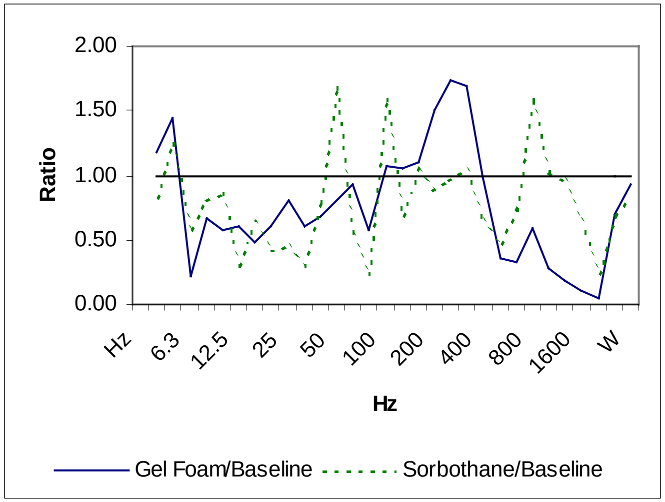


Figure 35 - Isolation Ratio for Interventions with 7" Makita Grinder with T – Adaptor   Side Handle

Table 58 – Frequency Spectra Data for the 7" Makita Grinder with T – Adaptor   Main Handle

	Hz	**4**	**5**	**6.3**	**8**	**10**	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**
Baseline	**rms(m/s^2)**	0.1319	0.2420	0.1439	0.1734	0.1670	0.1777	0.1896	0.2499	0.3259	0.4584	0.5881	4.2571	13.0257	5.4172
Gel Foam	**rms(m/s^2)**	0.1200	0.1103	0.1091	0.0886	0.0923	0.0793	0.0993	0.1045	0.1334	0.2639	0.4343	5.8439	9.7756	4.1434
Sorbothane	**rms(m/s^2)**	0.1348	0.1359	0.1341	0.1544	0.1569	0.1355	0.1629	0.2057	0.2696	0.3622	0.4826	2.1928	8.0877	4.8349

100	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**L**	**W**
8.6776	23.5054	14.2432	10.3476	6.8563	10.1808	18.5217	21.4380	23.8258	16.4859	8.3775	11.4071	10.8058	8.8197	60.4772	5.4172
10.1808	37.0455	15.9588	15.4068	11.5940	7.4971	10.5456	11.0424	10.7766	9.3611	4.1098	2.9858	2.2652	1.0413	52.1089	6.3042
10.0712	31.0668	16.0890	10.0168	12.3056	9.2603	8.6776	8.0658	11.0126	9.2603	3.9677	4.5552	3.4935	1.1511	46.0062	5.2868

Table 59 – Frequency Spectra Data for the 7" Makita Grinder with Hand – Adaptor Side Handle

	Hz	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80
Baseline	**rms(m/s^2)**	0.2917	0.1054	0.1094	0.2062	0.1772	0.1378	0.2770	0.3277	0.4284	0.7323	1.0584	14.9142	21.4380	3.9143
Gel Foam	**rms(m/s^2)**	0.1922	0.2948	0.2013	0.2374	0.2189	0.1197	0.3762	0.4474	0.8997	2.2287	1.5421	5.5358	24.1506	7.2969
Sorbothane	**rms(m/s^2)**	0.2980	0.1969	0.0430	0.4036	0.3721	0.2286	0.3146	0.3071	0.3321	0.5929	0.6276	6.2872	21.4380	7.1019

100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	L	W
12.2724	26.4080	13.3109	15.3651	19.1334	15.3236	9.1357	5.9557	6.1691	12.4060	17.4505	32.4423	26.7680	18.1247	76.7503	8.5609
7.1212	25.2199	9.7228	13.4559	9.0864	8.0006	7.7448	5.2868	5.6878	8.9885	23.1893	20.1982	19.8189	17.9781	63.3263	7.6613
11.4071	32.0928	13.3470	12.5411	7.1212	3.5411	3.2826	3.1605	3.1349	5.5209	13.9380	27.4284	11.3148	6.7275	57.1342	7.6406

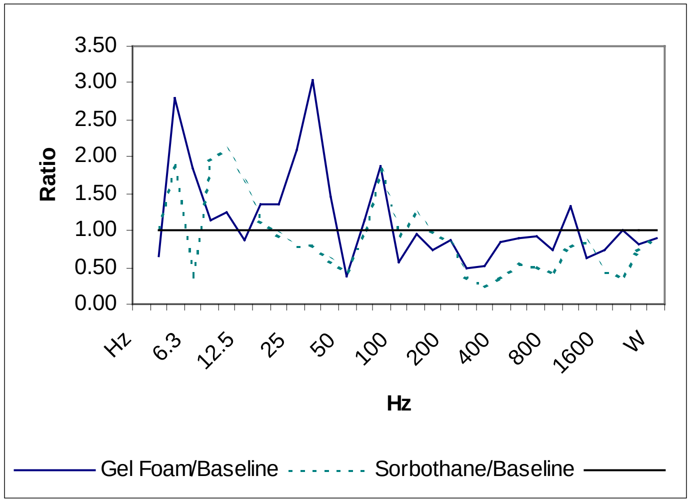


Figure 36 - Isolation Ratio for Interventions with 7" Makita Grinder with Hand – Adaptor Side Handle

Table 60 – Frequency Spectra Data for the 7" Makita Grinder with Hand – Adaptor Main Handle

	Hz	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80
Baseline	**rms(m/s^2)**	0.3844	0.2107	0.1359	0.3071	0.1359	0.1074	0.2355	0.2342	0.3612	0.5662	0.8709	4.2341	22.0264	17.1693
Gel Foam	**rms(m/s^2)**	0.3813	0.1216	0.1393	0.2682	0.2486	0.0745	0.2381	0.2243	0.2298	0.5364	0.5994	2.6648	14.3983	8.9400
Sorbothane	**rms(m/s^2)**	0.2755	0.1608	0.1423	0.3021	0.2171	0.1393	0.2778	0.1933	0.2870	0.5437	0.8852	4.8349	26.4796	20.5847

100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	L	W
14.6342	32.8846	18.0269	22.6310	16.5754	10.6894	12.2392	13.9003	16.9384	20.3079	12.2724	8.8437	5.1735	5.0353	69.0583	8.7247
10.9235	27.6521	16.0890	15.9588	15.1175	8.9400	3.7789	2.8747	2.3400	1.0273	0.7565	0.5013	0.3029	0.2540	44.8985	6.1524
12.7811	27.8023	10.8058	9.9357	5.0489	5.7342	8.2202	11.5002	7.7658	4.4697	2.8131	2.9696	1.6279	0.7900	51.5475	9.0618

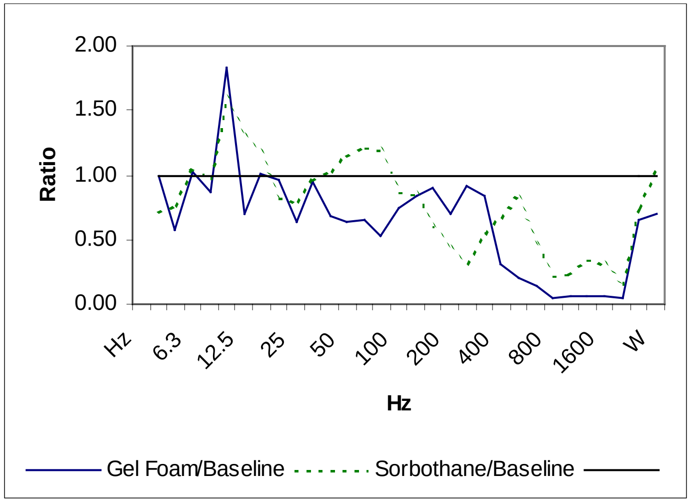


Figure 37 - Isolation Ratio for Interventions with 7" Makita Grinder with Hand – Adaptor Main Handle

Table 61– Frequency Spectra Data for the 5" Makita Grinder with T – Adaptor

	Hz	4	5	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80
Baseline	**rms(m/s^2)**	0.1772	0.1569	0.1263	0.1697	0.1527	0.1427	0.1490	0.1197	0.1152	0.1498	0.2057	0.2972	0.5335	4.1998
Gel Foam	**rms(m/s^2)**	0.2901	0.1341	0.1423	0.1643	0.1599	0.1341	0.1577	0.1412	0.1393	0.2342	0.3516	0.5081	0.9891	11.5626
Sorbothane	**rms(m/s^2)**	0.1435	0.1071	0.1348	0.1193	0.1439	0.1039	0.1229	0.1091	0.1348	0.2018	0.4307	0.6448	0.7565	2.1574

100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	L	W
13.8252	9.6703	6.7093	11.5313	9.5403	12.8853	9.3865	11.0724	10.8939	6.7275	9.1357	11.3148	12.3390	16.8013	50.4429	3.1011
25.7722	14.3594	6.5834	8.8676	7.4365	11.4381	19.0301	12.4060	5.3880	2.9376	3.6482	2.8825	2.0941	1.8945	43.4630	5.2725
24.5462	15.7869	3.4935	4.8875	8.6776	8.9642	12.2724	14.6738	10.3757	10.8351	12.9203	16.3525	11.8479	6.6912	47.6545	4.5676

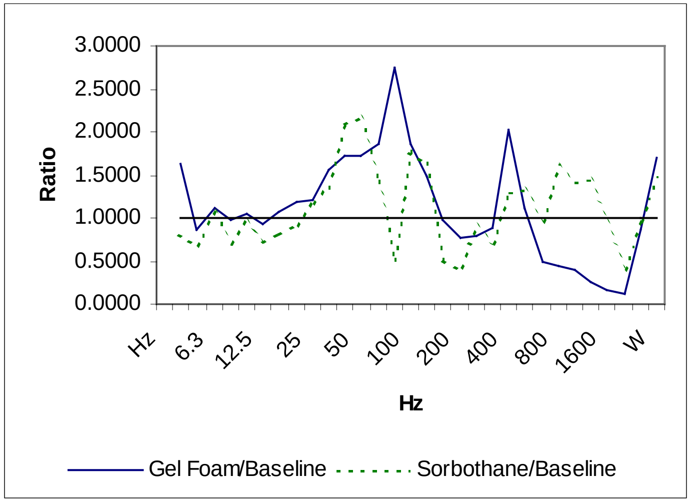


Figure 38 - Isolation Ratio for Interventions with 5" Makita Grinder with T- Adaptor

Table 62 – Frequency Spectra Data for the 5" Makita Grinder with Hand – Adaptor

	Hz	**4**	**5**	**6.3**	**8**	**10**	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**L**	**W**
Baseline	**rms(m/s^2)**	0.3772	0.3593	0.1054	0.3358	0.2610	0.2980	0.3772	0.3021	0.2433	0.5095	0.5136	0.5393	0.9021	6.7275	33.2427	19.1853	6.7824	12.7811	12.9553	11.7520	10.9828	9.6442	10.9828	14.0898	21.2070	34.3406	29.5888	24.4136	86.9313	6.2702
Gel Foam	**rms(m/s^2)**	0.1787	0.3181	0.5178	0.4879	0.3993	0.5109	0.4866	0.4723	0.5095	0.5437	0.7586	0.8709	1.7139	14.3983	39.6402	17.6405	10.4320	14.8336	7.2378	5.0353	7.2969	7.2378	7.7658	9.2103	8.7484	13.4559	16.4413	14.8336	62.4747	7.5788
Sorbothane	**rms(m/s^2)**	0.3189	0.2400	0.3459	0.3622	0.3146	0.3330	0.2980	0.2770	0.3385	0.3918	0.4025	0.9838	0.9269	11.6885	29.0333	17.4978	7.1405	9.3611	4.7957	3.0347	5.5358	6.6012	5.1456	4.7569	6.2363	7.2969	4.5184	2.2652	41.0605	5.7966

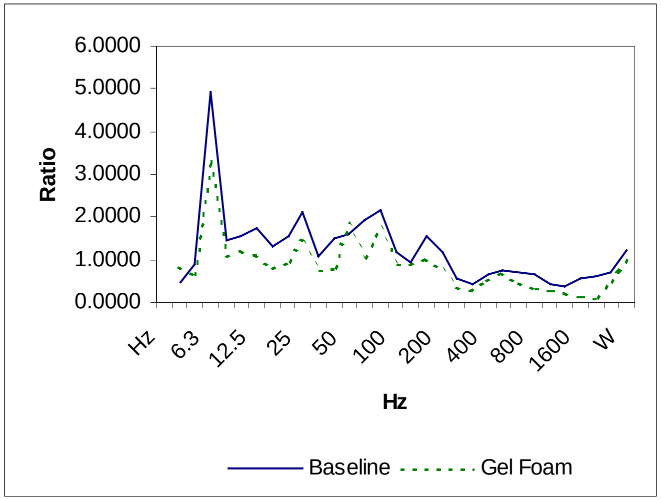


Figure 39 - Isolation Ratio for Interventions with 5" Makita Grinder with Hand – Adaptor

CONCLUSION

The purpose of the additional testing was to use the 4392 hand adaptor, which would provide measures using a more representative handgrip. Differences of approximately 3 to 6 dB were seen with the T- adaptor and hand adaptor, but in general, the results were similar in how effective the interventions were. Some of the difference in the results may also have been attributed to the differences in grinding forces exerted by the operator or the condition of the grinding discs.

The general observations indicate that both intervention methods, gel foam and sorbothane, had little positive effect and often made the "weighted value" higher. Mounting location, side or main handle, also made no difference in the performance of the interventions. Analysis of all the full frequency spectra data demonstrates that the interventions attenuate vibration at the high frequencies and amplify it at the lower frequencies where the hand-arm vibration weighting is most important.

These finding do support studies by the manufacturers where they state that there will always be amplification at the low frequencies, but attenuation at the high frequencies. There is a need for manufacturers to reassess their vibration reduction products and develop interventions that are effective in the low frequencies we are concerned with for human exposure, as outlined in the ISO standards. Human vibration exposure is an industry wide concern and this issue must be addressed as we focus on the prevention of vibration related disorders.

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