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Effectiveness of Commercially Available Vibration Dampeners in Reducing Hand-Arm Vibrations on Diesel-Powered and Gasoline-Powered Hand Tractor

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Hand tractors are among the major agricultural machines used by Filipino farmers. They aid farmers in the laborious process of preparing the land prior to planting. Though hand tractors enhance efficiency and productivity of farming, they still pose some threat to the user, specifically with the vibration they generate during operation. Prolonged exposure to vibration from hand tractors may lead to the health risk called hand-arm vibration syndrome (HAVS). This study compared the effectiveness of vibration dampeners available in the market when operating a diesel- and a gasoline-powered hand tractor. The experiment was done in a stationary position based on the standards set by IS/ISO 5349: 2001. Baseline measurements of vibration at 2100, 2700, and 3300 rpm were as follows: 6.60, 7.12 and 10.50 m s^{-2} for diesel-powered hand tractor, and 6.81, 4.65 and 11.04 m s^{-2} for gasoline-powered hand tractor, respectively. Combinations of handle grips and engine mounts were tested to determine the optimal reduction of transmitted hand-arm vibration. The combination of BMX handle grip with mount model F5A had the highest reduction in vibration by 35.23% when a diesel-powered hand tractor was used. Mountain bike handle grip with mount model F5A yielded the highest reduction by 52.29% when a gasoline-powered hand tractor was used.

Key Words: commercially available hand grips, hand-arm vibration syndrome, vibration dampeners

Abbreviations: AMMDA – Agricultural Machinery Manufacturers and Distributors Association, BMI – body mass index, EAV – exposure action value, ELV – exposure limit value, FFT – Fast Fourier Transform, HAVS – hand-arm vibration syndrome, IRRI – International Rice Research Institute, ISO – International Organization for Standardization, PAES – Philippine Agricultural Engineering Standards

INTRODUCTION

The Philippine economy still maintains a large agricultural sector despite its emerging industrialization. Of the Philippines' total land area of 30 million ha, 9.671 million ha or 32% make up agricultural land (CountrySTAT 2013). In 2013, 11.84 million out of 38.12 million people of the total Filipino work force were engaged in agriculture.

Advancement in science and technology has re-engineered the field of agriculture. The shift from the use of farming animals and crude tools to agricultural machines has changed the farming practices in the country and mechanization has since played a critical role in modernizing the agricultural sector. Adoption of farming machinery has significantly reduced the discomfort of users, and has improved efficiency and productivity, greatly increasing their economic gains and elevating their social status (Maranan 1985).

The hand tractor is one of the major agricultural machines used for lowland farming and land preparation. When the International Rice Research Institute (IRRI) released its initial low-cost designs of a two-wheel hand tractor in the early 1970s, rapid growth of domestic production took place (Trabajo 1994). Because of this development, the use of large imported machines has shifted to the use of small low-cost and locally manufactured machines. The acquisition of hand tractors has steadily increased since the 1960s. As of 2002, the number of hand tractors acquired in the Philippines reached 1.5

million units (Table 1), indicating that its use became widespread among farmers. In addition to the steadfast utilization of hand tractors, the Department of Agriculture organized rice mechanization programs to further promote farm mechanization and 32,000 more units of hand tractors were expected to be deployed from 2011 to 2016 (PhilMech 2012).

A two-wheel hand tractor is a hand tractor with one axle, self-powered and self-propelled, which can pull and power various farm implements such as a trailer, a cultivator or harrow, a plough, or various seeders and harvesters (Singh 2014). The operator usually walks behind it or rides the implement being towed. In 2011, Collado (2010) modified a two-wheel hand tractor using the anthropometric profile of farmers in the provinces of Cavite, Laguna, Batangas, Rizal and Quezon (CALABARZON), resulting in less drudgery by minimizing strains and pains of operators. The modified hand tractor has components based on the Philippine Agricultural Engineering Standard (PAES) 109: 2000 (Fig. 1).

In a study conducted by Sigmund et al. (2012), three vibration sources produced by internal combustion engines were identified, namely: combustion, mechanical piston slap, and mechanical gear rattle. In combustion for diesel engine, air is compressed and diesel fuel is injected. The injected fuel then mixes with the air in the cylinder during the delay period and then begins to combust. In combustion for gasoline engine, the air-fuel mixture is ignited by a spark from a spark plug. Compression ignition produces higher vibration compared with spark ignition because of higher compression ratio. The piston slap is a more prominent source of noise and vibration in the compression ignition engine than in the spark ignition gasoline engine. The gear rattle occurs when torsional inputs cause the teeth of meshing gears to span operating clearances and impact their neighboring teeth.

Prolonged exposure to high levels of vibration produced by diesel-powered or gasoline-powered hand tractor during farm operations can cause both short- and long-term hazardous effects on the farmer's health. Revilla et al. (2015) measured vibration from a plowing hand tractor to as high as 21.74 m s^{-2}. From the Health and Safety Executive (2005), for an 8-h continuous working day, the maximum exposure limit value is 5 m s^{-2} and the exposure action value is 2.5 m s^{-2}. These data indicate that if vibration is above 2.5 m s^{-2}, then immediate

Table 1. Census of major farm machinery in the Philippines.

Farm Machinery	No. of Units Acquired
Plow	2,723,850
Harrow	1,643,325
Sprayers	1,941,050
Hand tractor	1,526,557

Source: National Statistics Office (NSO), 2010

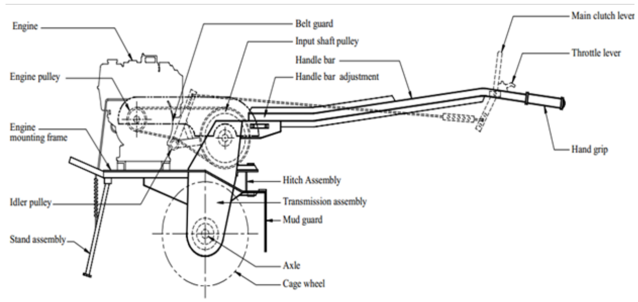


Fig. 1. Walking-type two-wheel hand tractor (Source: PAES 109:2000).

actions on the vibrating tool or object must be done before proceeding with the task.

One of the implications of exposure to high levels of vibration from hand tractors is hand-arm vibration syndrome (HAVS), which exhibits symptoms caused by vibration damages that may lead to neurological, vascular, and musculoskeletal disorders in the fingers, hands, and arms when working with vibrating tools or machinery. Farmers employing hand tractors are susceptible to the risks of HAVS. The main factor contributing to high level of generated vibration is the engine that energizes the hand tractor which may be powered by gasoline or diesel.

There was a decline in sales of gasoline-powered hand tractor until 1989, based on data from the Agricultural Machinery Manufacturers and Distributors Association (AMMDA) (Fig. 2). Diesel-powered hand tractors surpassed the sales of gasoline-powered hand tractors from 1986 to 1989, possibly due to cheaper cost of diesel fuel (Singh 2014). Layaoen et al. (2015) reduced vibration of gasoline-powered hand tractors by 36.54% using a combination of commercially available handle grips and engine mounts. There is a similar need to reduce vibrations in diesel-powered hand tractors.

This study compared the effectiveness of a combination of commercially available handle grips and engine mounts in reducing transmitted hand-arm vibrations to operators of diesel- and gasoline-powered hand tractors using the standards set by the International Organization for Standardization (ISO)

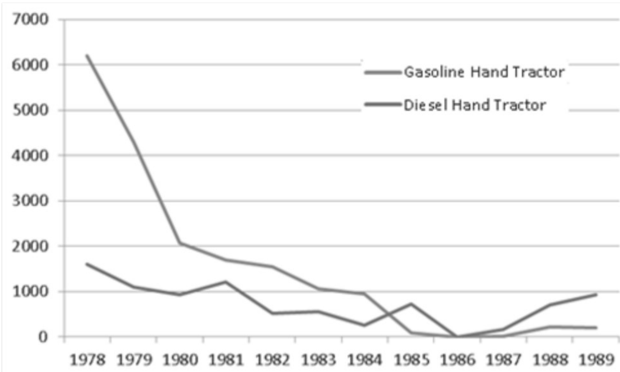


Fig. 2. Decline in sales of gasoline hand tractor [Source: Agricultural Machinery Manufacturers and Distributors Association (AMMDA), as cited by Trabajo (1994)].

5349: 2001.

Specifically, this study aimed to achieve the following: (1) to establish the baseline of hand-transmitted vibrations from a stationary diesel-powered hand tractor, (2) to compare the extent of reduction in transmitted hand-arm vibrations using a combination of handle grips and engine mounts on diesel and gasoline tractors, and (3) to optimize the combination of handle grips and engine mounts to reduce vibration level below the exposure limit value (ELV) of 5.0 m s^{-2}.

MATERIALS AND METHODS

Location of the Study and Field Test

Data gathering was conducted in a laboratory set-up at the grounds of the Agricultural Machinery Division, University of the Philippines Los Baños, Laguna from February 2014 to May 2014. Additional data gathering was conducted in October 2014 to adequately provide the needed data for the study. Initial data analyses and evaluation were conducted from August 2014 to September 2014, and from May 2015 to July 2015.

Materials

Hand Tractor

The two-wheel hand tractor used in this study was designed by Collado (2011) based on the anthropometric measurement of CALABARZON farmers. Its specifications are shown in Table 2.

Table 2. General specifications of hand tractor and engines used in the study.

Materials	Item	Specifications
Two-wheel hand tractor	Overall width (cm)	130.0
	Overall height (cm)	182.5
	Ground clearance (cm)	145.0
	Weight without engine (kg)	85.0
	Type of main clutch	Idler
	Type of power transmission system	
	● Engine to driver shaft	Pulley and V-belts
	● Driver shaft to axle	Chain and sprockets
Diesel-powered engine	Model	KAMA KM170F
	Displacement (mL)	211
	Rated power (kW rpm^{-1})	2.5/3000, 2.8/3600
	Overall dimension (L*W*H) (mm)	332 x 348 x 416
	Weight (kg)	26
Gasoline-powered engine	Model	KENBO KB5.5
	Displacement (mL)	163
	Rated power (kW rpm^{-1})	3.1/3000
	Overall dimension (L*W*H) (mm)	590 x 430 x 435
	Weight (kg)	19

Sources: Collado (2011); Focus Technology Co. Ltd. (2014)

Engine

The engine is the main source of vibration for hand tractors. Kama KM170F diesel engine and Kenbo KB5.5 gasoline engine were used in this study for basis of comparison. Table 2 shows the specifications of engines used.

Operator

An operator in good health with normal body mass index (BMI) was used in the study. The operator was 24 yr old, weighed 63.5 kg, and was 162.56 cm high. Proper knowledge on how to operate a hand tractor was not necessarily required since the experiment was done in a stationary position. Body posture of the operator while using the stationary hand tractor was controlled.

Handle Grips

Four types of handle grips commercially available in the Philippines are appropriate for the handle bar of a two-wheel hand tractor (Layaoen et al. 2015). These are BMX, motorbike, mountain bike and tennis rubber tape handle grips. The detailed specifications of each handle grip are shown in Table 3.

Engine Mount

Six kinds of engine mounts that are commonly available in the market (Layaoen et al. 2015) were used in the study (Table 4). The engine mounts considered were those used for lightweight engines. Engine mounts were composed of two steel plates with rubber in between that separated the plates.

Table 3. Commercially available handle grips used in the study.

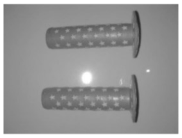
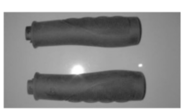
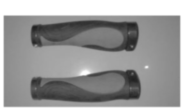
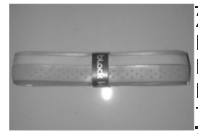
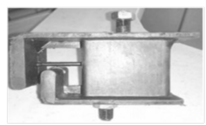
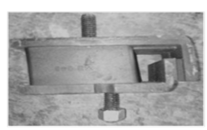
Handle Grip Model	Illustration	Specifications	
BMX		Name tag	Handle A
		Price (Php)	65.00
		Length (mm)	109.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	28.00
		Thickness (mm)	3.00
		Name tag	Handle B
		Price (Php)	50.00
		Length (mm)	121.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	31.00
		Thickness (mm)	4.5
		Name tag	Handle C
		Price (Php)	55.00
		Length (mm)	94.50
		Inside diameter (mm)	22.00
		Outside diameter (mm)	29.00
		Thickness (mm)	3.50
MOTOR-BIKE		Name tag	Handle D
		Price (Php)	299.75
		Length (mm)	134.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	35.00
		Thickness (mm)	6.50
		Name tag	Handle E
		Price (Php)	250.00
		Length (mm)	130.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	35.00
		Thickness (mm)	6.5
		Name tag	Handle F
		Price (Php)	239.75
		Length (mm)	131.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	.00
		Thickness (mm)	5.50
MOUN-TAIN BIKE		Name tag	Handle G
		Price (Php)	300.00
		Length (mm)	130.50
		Inside diameter (mm)	22.00
		Outside diameter (mm)	33.00
		Thickness (mm)	5.50
		Name tag	Handle H
		Price (Php)	500.00
		Length (mm)	130.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	34.00
		Thickness (mm)	6.00
		Name tag	Handle I
		Price (Php)	570.00
		Length (mm)	141.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	.33.00
		Thickness (mm)	7.00
		Name tag	Handle J
		Price (Php)	570.00
		Length (mm)	132.00
		Inside diameter (mm)	22.00
		Outside diameter (mm)	35.00
		Thickness (mm)	6.50

Table 3. Continued. . .

Handle Grip Model	Illustration	Specifications	
TENNIS RUBBER TAPE		1 Layer	
		Name tag	Handle K
		Price (Php)	149.00
		Length (mm)	145.00
		Thickness (mm)	3.00
		2 Layers	
		Name tag	Handle L
		Price (Php)	149.00
		Length (mm)	145.00
		Thickness (mm)	6.00
		3 Layers	
		Name tag	Handle M
		Price (Php)	298.00
		Length (mm)	145.00
		Thickness (mm)	9.00

Php – Philippine peso

Table 4. Engine mounts used and their specifications.

Engine Mount Model	Specifications	
	Model No.	F5A
	Name tag	Mount A
	Price (Php)	750.00
	No. used	4
	Model No.	11220-40N00
	Name tag	Mount B
	Price (Php)	2200.00
	No. used	4
	Model No.	4BA1LH
	Name tag	Mount C
	Price (Php)	2400
	No. used	2
	Model No.	C240
	Name tag	Mount D
	Price (Php)	700.00
	No. used	2
	Model No.	4D30
	Name tag	Mount E
	Price (Php)	750.00
	No. used	2
	Model No.	4DR5
	Name tag	Mount F
	Price (Php)	750.00
	No. used	2

Php – Philippine peso

Methods

Data Measurement and Calculation

Transmitted hand-arm vibration was measured by attaching a 3-axis accelerometer to the point of contact of the operator and the vibration source, which was between the hand of the operator and the handle bar. The orientation of each axis and the location of the accelerometer was based on the standards set by IS/ISO 5349-2:2001 (Fig. 3). The accelerometer measured acceleration along one line and produced a signal on one of the three outputs labeled X, Y, and Z. The x-axis was positioned perpendicular to the metacarpus bone pointing to the ground; the y-axis was slightly parallel along the handle bar; and the z-axis was situated parallel to the metacarpus bone pointing to the side of the hand tractor.

The signal outputs of the accelerometer were logged directly to a laptop computer through the use of LabQuest®2 and Logger Pro 3.8.6. These signals in time domain were converted to their equivalent in the frequency domain by applying the Fast Fourier Transform (FFT) function of Logger Pro 3.8.6. One-third octave band data were then derived from these frequency-domain data, as suggested by IS/ISO 5349:2001. However, the maximum capacity of the accelerometers and LabQuest®2 used in the study was 60,000 samples per minute – a sampling rate of 1,000 Hz. Thus, this only allowed one-third octave band analysis of up to 500 Hz. Frequency weighting factor was then applied to these one-third octave band data to obtain the frequency-weighted hand-transmitted vibration.

Baseline Establishment

Baseline for hand-transmitted vibration was established to obtain a point of comparison when dampeners were installed to the hand tractor. Based on the standards set by IS/ISO 5349: 2001, baseline was measured for the diesel and the gasoline engine set at three different speeds – 2100, 2700, and 3300 rpm.

Evaluation for Best Handle Grips

The handle grips were evaluated per category – BMX (subcategories: A, B, C), motor bike (subcategories: D, E, F), mountain bike (subcategories: G, H, I, J), and tennis grip (subcategories: K, L, M). The handle grip that provided the best reduction for hand-transmitted vibration for each category was chosen for the next set-up.

Combinations of Engine Mounts and Best Handle Grips

Six models for engine mounts considered for this study were tagged as Mounts A, B, C, D, E, and F (Table 4). Each mount was tested first with the diesel and gasoline engines to establish a point of comparison when handle grips were included. Then, the combination of each mount with the best handle grips per category were tested with the two engines.

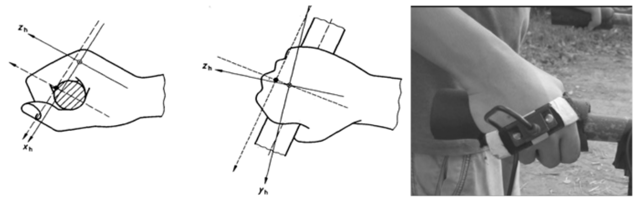


Fig. 3. Orientation of 3-axis accelerometer on the hand (Source: IS/ISO 5349-1:2001).

Installation of Dampeners

A pipe with 22 mm diameter was used as an adapter in installing the dampener because the diameter of the hand tractor's handle bar was 27 mm. The adapter was fastened rigidly to the handle bar using a metal screw. With the adapter, handle grips were then attached to the hand tractor. To ensure that handle grips were tightly fitted, masking tape was wrapped around the adapter to slightly increase the diameter of the pipe. For Handles F to J, clamps were included and served as a lock. Although Handles K to M already fit the handle bar of the hand tractor, they were still placed on the adapter so as not to deviate from other handle grips.

For the installation of engine mounts, a base mount made from steel plate was formed. The base mount allowed the installation of engine mounts since the hand tractor was not initially designed for these dampeners. Mounts A and B needed four pieces each to be installed for stability. Mounts C, D, E, and F required only two pieces each.

Data Analysis

Fast Fourier Transform (FFT). FFT works on the principle that any signal or waveform can be reconstructed by just adding sine waves with their respective frequency, amplitude and phase (Baker 2001). One-third octave band data can be derived from an FFT data with sufficient resolution (Audio Precision Inc. 2013). In this study, FFT data were derived from the time-domain signal by using Logger Pro 3.8.6.

One-third octave band analysis. Octave band analysis splits the frequency domain of a signal into groups called "bandwidth". Nominal mid-frequencies for one-third octave band are defined by

Eq. 1. The upper and lower limit frequencies are defined by Eq. 2 and 3, respectively.

$$f_{i-1} = f_i/2^{1/3} \quad \text{(Eq. 1)}$$

$$f_i^{high} = 2^{1/6} f_i \quad \text{(Eq. 2)}$$

$$f_i^{low} = f_i/2^{1/6} \quad \text{(Eq. 3)}$$

where f_i is the nominal mid-frequency on the i^{th} frequency band number, and i is the frequency band number.

Tri-axial frequency weighted vibration. Based on the standards set by ISO 5349:2001 (Mechanical Vibration – Measurement and Evaluation of Human Exposure to Hand Transmitted Vibration), the hand tractor's hand-transmitted vibration to the operator was determined. Vibration for each axis was computed from the one-third octave band data with frequency range from 6.3 to 500 Hz. Frequency weighting factor was then applied to obtain frequency-weighted vibration for each axis using Eq. 4.

$$a_{h,w} = \sqrt{\sum_{i=1}^{n}\left(W_{h,i}a_{h,i}\right)^2} \quad \text{(Eq. 4)}$$

where $a_{h,w}$ is the frequency-weighted vibration for an axis, W_{hi} is the weighting factor for the i^{th} one-third octave band, $a_{h,i}$ is the root mean square (rms) acceleration measured in the i^{th} one-third octave band, and i is the frequency band number.

Total vibration value. Evaluation of hand-transmitted vibration was based on a quantity that combined all frequency-weighted vibration of x, y, and z axes. It is defined by Eq. 5 as the root-sum-of-squares of the three components.

$$a_{h,v} = \sqrt{a_{h,w,x}^2 + a_{h,w,y}^2 + a_{h,w,z}^2} \quad \text{(Eq. 5)}$$

where $a_{h,v}$ is the vibration total value, and $a_{h,w,x}$, $a_{h,w,y}$, $a_{h,w,z}$ are the frequency-weighted vibrations for the x, y and z-axes, respectively.

Statistical Analysis. The data obtained in the present study were statistically analyzed using Design-Expert 9. For the baseline establishment, the significance of engine speeds, engine type and measuring location to the total vibration accelerations were evaluated. For the evaluation of handle grips and engine mount, engine speed was assessed to determine its influence in the total vibration acceleration and was used as block (if influence was found significant). The significant difference between alternatives for each category was tested to help decide the best alternative. For the combination of handle grips and engine mounts, the effects of engine speed and each material were tested for the total vibration acceleration and percent reduction.

RESULTS AND DISCUSSION

Baseline Establishment for Existing Hand Tractor

The time-based data gathered by LabQuest® 2 through the accelerometers were analyzed and transformed into frequency-based data by Logger Pro 3.8.6 using FFT function. The transformed frequency-based data and total acceleration measured per axis at the hand, elbow, and shoulder with their corresponding engine speed and engine type are presented in Table 5. These data show that the vibration accelerations were highest at the hand and lowest at the shoulder. In a previous study, Griffin (1996) observed that vibration decreases with increasing distance from the source. This observation supports the finding in the present study that among the three locations, the highest total vibration was measured at the hand and the least at the shoulder in both engine types. Moreover, only measurements at the hand exceeded the exposure limit value (ELV) of 5 m s^{-2} for all the engine speeds, except for the gasoline engine at 2700 rpm, which exceeded the exposure action value (EAV) of 2.5 m s^{-2}.

Figure 4 shows the relationship between the engine speed and vibrations measured at the hand, elbow, and shoulder. In the case of the diesel engine, there was a positive correlation between engine speed and vibration measured, while in the case of the gasoline engine, a nonlinear correlation was observed between engine speed and vibration. The effect of engine type on the transmitted vibration was not significant based on the analysis of variance at 99% confidence level wherein a p-value of 0.10806 was obtained.

Best Handle Grip per Category

In deciding the best handle grip, 3300 rpm engine speed was used because it was where the highest vibration was measured. The handle grip per

Table 5. Frequency-weighted vibration of x, y, z axes and total vibration.

Location	Engine Speed (rpm)	X-Axis (m s^{-2})	Y-Axis (m s^{-2})	Z-Axis (m s^{-2})	Total Vibration (m s^{-2})
				Diesel Engine	
	2100	5.90	1.89	2.26	6.60**
Hand	2700	5.51	3.55	2.80	7.12**
	3300	7.78	6.35	3.05	10.50**
	2100	1.26	0.99	0.95	1.87
Elbow	2700	1.41	0.94	0.88	1.91
	3300	1.93	0.96	0.87	2.33
	2100	0.62	0.77	0.59	1.15
Shoulder	2700	0.51	0.58	0.66	1.01
	3300	0.51	0.54	0.64	0.98
				Gasoline Engine	
	2100	4.84	1.71	4.47	6.81**
Hand	2700	2.81	1.79	3.25	4.65*
	3300	7.92	4.97	5.87	11.04**
	2100	2.69	0.58	0.81	2.86*
Elbow	2700	0.87	0.49	0.40	1.08
	3300	2.41	0.96	1.05	2.80*
	2100	0.69	0.46	0.84	1.18
Shoulder	2700	0.28	0.37	0.31	0.55
	3300	0.64	0.49	0.85	1.17

*Exceeds exposure action value (EAV) ** Exceeds exposure limit value (ELV)

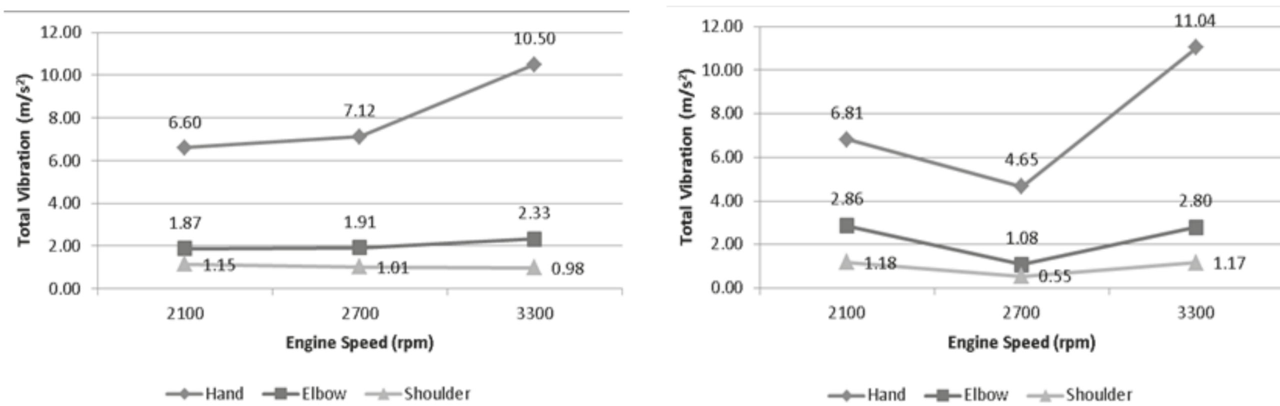


Fig. 4. Model graph of baseline vibration for hand tractor using diesel engine (right) and using gasoline engine (left).

category with the highest percent reduction on vibration was obtained and summarized in Table 6.

Best Combination of Handle Grips and Engine Mount

Best handle grip per category was used in combination with engine mounts to obtain the highest percentage reduction on vibration. Table 7 shows percent reduction of the total vibration for each combination of handle grip, engine mount, engine speed, and engine type. It can be observed that percent reduction does not have a direct additive property when handle grip and engine mount are combined. Table 7 also shows that not all handles were compatible with every engine mount. It is also evident that what worked in reducing vibration on diesel engine may not work with gasoline engine. The negative percent reduction in Table 7 also demonstrated that vibration dampeners were not applicable to all noise problems, as stated by Geiger (1950). One example was mount B which exhibited reduction for 3300 rpm diesel engine, but showed amplification for 3300 rpm gasoline engine. According to Geiger (1950), these vibration amplifications may be the results of resonance existing between the vibration generated by the engine and the natural frequency of the hand tractor.

Figure 5 shows the interaction graphs of total percent reduction in every combination for diesel and gasoline engines. It was evident that among all experimented combinations, those with mount A largely reduced the total vibration on both engines. Out of the four handles combined with mount A, handle A had the highest reduction on the total vibration of diesel engine. On the other hand, combination of mount A with handle J had the

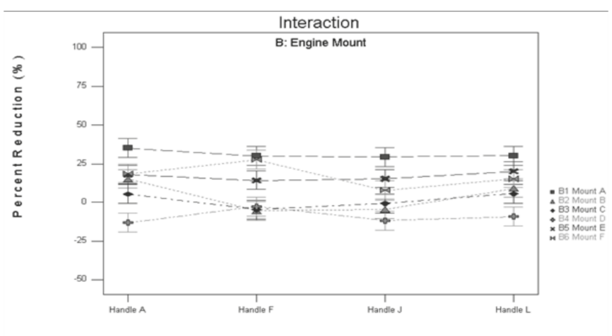
Table 6. Summary of best handle grips per category subjected to 3300 rpm engine speed. Baseline accelerated vibration used for diesel and gasoline engines are 10.50 and 11.04 m s^{-2}, respectively.

Category	Name Tag	Reduced Total Vibration (m s^{-2})	Percent Reduction (%)	Reduced Total Vibration (m s^{-2})	Percent Reduction (%)
		Diesel Engine		Gasoline Engine	
BMX	Handle A	7.74	26.24	8.62	21.94
Motorbike	Handle F	6.93	34.02	7.77	29.59
Mountain bike	Handle J	7.82	25.54	7.76	29.72
Tennis rubber tape	Handle L	8.12	22.68	9.85	10.81

Table 7. Percent reduction on vibration for each combination of handle grips and mounts at different engine speeds for diesel and gasoline engines. Values were computed from obtained difference of baseline measurement at hand and reduced total vibration upon application of each combination.

Engine Mount	Handle Grip	Reduction (%)					
		Diesel			Gasoline		
		2100	2700	3300	2100	2700	3300
Mount A	Handle A	23.65	35.32	47.89	52.29	35.04	53.68
	Handle F	-6.20*	54.98	46.52	53.86	27.08	39.36
	Handle J	10.47	23.97	57.14	56.88	59.05	43.20
	Handle L	-4.31*	50.73	46.65	55.78	56.22	38.54
Mount B	Handle A	2.21	-11.27	56.42	34.79	5.43	-20.31*
	Handle F	-29.25*	-16.62	30.04	49.02	1.11	-15.10*
	Handle J	17.90	-53.20	24.18	54.04	-0.32*	-10.44*
	Handle L	11.84	-17.91	35.38	53.69	1.00	-2.67*
Mount C	Handle A	-26.03*	1.12	43.05	31.65	-13.36*	35.83
	Handle F	-30.60*	-13.34	31.66	29.18	-17.67*	27.86
	Handle J	-15.95*	2.17	20.48	23.35	-1.58*	22.34
	Handle L	-2.62*	-3.23	24.31	23.84	-5.31*	25.68
Mount D	Handle A	1.16	8.43	-44.56*	30.54	-85.08*	62.33
	Handle F	-4.09*	18.72	-20.98*	29.25	-91.25*	55.65
	Handle J	5.82	-3.22*	-27.72*	30.87	-131.59*	48.75
	Handle L	-19.83*	36.56	-42.72*	29.62	-81.65*	55.01
Mount E	Handle A	8.76	31.54	16.59	45.74	6.48	-6.93*
	Handle F	17.63	12.60	15.62	43.57	18.32	-5.46*
	Handle J	8.88	25.38	17.98	44.11	19.20	-7.27*
	Handle L	11.58	36.20	17.70	42.13	8.04	-22.04*
Mount F	Handle A	12.93	35.41	11.06	41.62	22.73	10.53
	Handle F	12.67	34.79	42.71	48.50	12.56	19.98
	Handle J	-12.10*	27.82	15.50	44.66	16.61	1.97
	Handle L	10.28	25.69	15.91	47.01	4.76	8.00

*amplified vibration



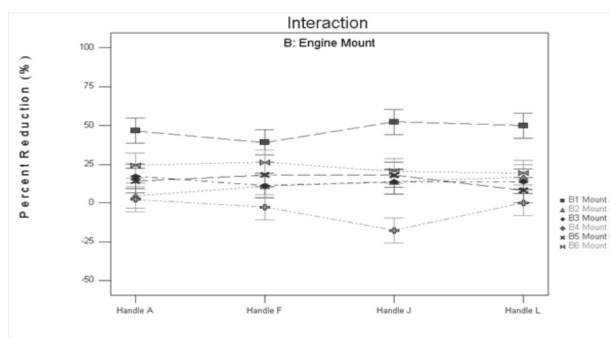


Fig. 5. Interaction graph of percent reduction on vibration of commercially available handle grips and engine mounts for diesel engine (top) and gasoline engine (bottom). Error bars exhibit the confidence interval of each set of data using 95% confidence level.

highest reduction on the total vibration using gasoline engine. Based on Layaoen et al. (2015), the optimal combination of dampeners on gasoline-powered hand tractor was engine mount B in combination with handle E. Even though the materials used in both studies were held constant, the outcomes were different due to variation in the deployed approach of data gathering and analysis.

Table 8 shows the percent reduction per combination with engine speed ignored as a contributing factor. As previously stated, for the diesel engine, mount A (model F5A) combined with handle A (BMX category) indeed provided the highest reduction at 35.23%, which reduced the vibration to 5.13 m s^{-2}. Similarly, for the gasoline engine, mount A (model F5A) combined with handle J (mountain bike category) provided the highest reduction at 52.29%, which reduced vibration to 3.24 m s^{-2}. The vibration from diesel engine transmitted to the hand was near the ELV of 5 m s^{-2} but still higher by 0.13 m s^{-2}, while vibration from gasoline engine transmitted was reduced below the ELV of 5 m s^{-2} but still exceeded the EAV of 2.5 m s^{-2}.

Comparing the diesel engine and the gasoline engine when the best combinations of dampeners were applied revealed that the engine type was significant (at α = 0.01) as shown in Table 9. Furthermore, it was evident that the diesel engine (5.13 m s^{-2}) had a higher reduced vibration compared with that of the gasoline engine (3.24 m s^{-2}).

CONCLUSION

Technological advances have improved agricultural practices of Filipino farmers through deploying farm machines such as hand tractors and the like. One of the trade-offs of utilizing the hand tractor was exposing its user to vibration. Commercially available dampeners were widely used due to their effectiveness in reducing transmitted vibration. Thus, the magnitude of the effectiveness of vibration dampeners and the optimal combinations for a specific type of engine were studied.

Baseline measurements were established on hand, elbow and shoulder. Total vibration was transmitted from hand to elbow, and then to shoulder in a decreasing manner. It was highest at the hand, which is the point of contact, and lowest at the shoulder, which is the farthest from the source of vibration. At the hand, transmitted vibration from a diesel-powered hand tractor reached up to 10.50 m s^{-2}, while that from a gasoline-powered hand tractor reached up to 11.04 m s^{-2}. Since both engines exceeded the exposure limit value (ELV) of 5 m s^{-2}, it was necessary that appropriate dampening materials be applied to the hand tractor.

Four commercially available handle grips, specifically BMX, motorbike, mountain bike, and tennis rubber tape, were used as handle grips in a hand tractor. Six engine mounts used for vehicles were also studied as vibration dampener. The combination of best handle grip and engine mount significantly reduced the total vibration transmitted to the hand. Percent reduction in transmitted vibration of diesel engine ranged from −13.22% (amplified) to as high as 35.23% and from −17.75% (amplified) to 52.29% for gasoline engine.

Moreover, the best combination of handle grip and engine mount for both engines was determined. In diesel engine at any engine speed, the combination of mount F5A (mount A) and BMX (handle A) had the highest percent reduction at 35.23% (5.13 m s^{-2}), while in gasoline engine at any engine speed, the combination of mount F5A (mount A) and mountain bike (handle J) resulted in the highest percent reduction at 52.29% (3.24 m s^{-2}). However, even if vibration produced by diesel engine was reduced by

Table 8. Summary of percent reduction per combination of best handle grip per category and engine mount when engine speed was ignored as contributing factor.

Engine Mount	Handle Grip (%)							
	Diesel				Gasoline			
	A	F	J	L	A	F	J	L
Mount A	35.23	30.08	29.47	30.38	46.67	39.26	52.29	49.94
Mount B	15.31	-5.55	-4.66	9.17	4.48	11.22	13.90	16.93
Mount C	5.31	-4.79	-0.89	5.45	17.37	11.42	13.78	14.06
Mount D	-13.22	-2.73	-11.86	-9.29	2.09	-2.85	-17.75	0.03
Mount E	18.17	14.34	15.47	20.22	14.44	18.28	18.15	8.38
Mount F	18.68	27.83	8.07	20.22	24.37	26.38	20.76	19.46

Table 9. ANOVA for diesel and gasoline engines after best dampeners were applied.

Source	Sum of Squares	DF	Mean Square	F Value	P-Value PROB>F
Model	20.66	1.00	20.66	21.31	0.00003*
A-Engine type	20.66	1.00	20.66	21.31	0.00003*
Residual	42.66	44.00	0.97		
Lack of fit	27.62	2.00	13.81	38.55	0.00000*
Pure error	15.04	42.00	0.36		
Cor Total	120.71	47.00			

*Significant at α = 0.01

35.23%, reduced vibration still did not meet the ELV of 5 m s^{-2}. The outcome was different for gasoline engine. Optimal combination of handle grip and engine mount resulted in reduced vibration of 3.24 m s^{-2} and was successfully driven down below ELV of 5 m s^{-2}.

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