Vibration Analysis of Grass Trimmer using FEM - A Review

[1]Mr. S. S, Jain, [2]Prof. D. A. Warke,
[1]P. G. Student, [2]Asso.Prof.MechEnggDeptt, J. T. M. COE,Faizpur, India
ssjain87@gmail.com

Abstract—The Indian Farmer while Working on Field he has to put all effort into field. The farmer always needed to reduce effort, while cutting grass on field there is Vibration. The important thing is that the vibration which is available in grass Trimmer/Cutter affects the Hand of operator who is operating trimmer, Prolonged use of electric grass trimmer exposes the user to the risk of hand-arm vibration syndrome. A simple approach for the suppression of hand-arm vibration in electric grass trimmer is presented.

The proposed system is a Modal analysis and operating deflection shape analysis of the electric grass trimmer were carried out and It is designed and fabricated for testing. The results in some previous experiment indicated that minimum vibration level was related to the position of the System on the shaft and reducing Hand Arm Vibration on electric grass trimmer. The results has to take from modal analysis and operating deflection shape which has to reveal that the presence of Vibrations has successfully reducing or not. The Vibration has to take in all Axis i.e. X,Y,Z. There are other way that reduce vibration by Isolating System from operator by means of Glovesor Providing Damping or Shock absorber to the system.

Keywords- Hand arm vibrations,accelerometer, calibrator, FFT analyzer and post-processing software.

I. INTRODUCTION

HAV is classified as an industrial disease and has been affecting innumerable workers. It affects on Work as well as work on Field. Grass trimming is usually carried out with the use of petrol engine or electric motor powered trimmer which uses a rotating nylon string that cut the grass. The use of petrol engine is subjected to emission regulation which limits their application. The US Environmental Protection Agency (2010) has adopted new regulations for small engines (operate at or below 19 kW) that are widely used in lawn and garden area. Electric models produce no emissions at the point of use. This factor favours the application of electric grass trimmer for maintenance of grass compound in places where emission is regulated. The electric grass trimmer usually employs an AC electric motor of 400 W with the plastic rotating head coupled directly to the motor. A single nylon string is attached to the rotating head. The single string construction of the electric grass trimmer made it a rotationally unbalanced which resulted in high level of vibration. Under this condition the user is exposed to hand-arm vibration (HAV). Extensive exposure of HAV can lead to a series of vibration induced disorder in the vascular and nonvascular structures in human hand-arm.

II. LITERATURE SURVEY

Ko Ying Haoetal ; The design and development of suspended handles for reducing hand-arm vibration in petrol driven grass trimmer in International journal of Ergonomics, 41 (2011) pages 459-470 ;The operator identified that portable petrol driven grass trimmer is as that machine which can be subjecte
d to large magnitude of hand-arm vibration. These vibrations can cause complex vascular, neurological and musculoskeletal disorder, collectively named as hand-arm vibration syndrome. The vibration total level on the handle of grass trimmer of 11.30 m/s^2 was measured, and it has reached the exposure limit value of 5.0 m/s^2 for daily vibration exposure.[1]

K.N. Dewanganetal : Tuned vibration absorber for suppression of hand-arm vibration in electric grass trimmer, International Journal of Industrial Ergonomics 41 (2011) pages 494-508; workers are employed to perform grass trimming job in many developing countries. This paper presents the effect of handle types (commercial and prototype) on the commonly used grass trimmer.Hand tractor is extensively used as a mechanical source of farm power for small and medium size farm. Vibration transmitted from the handles of the hand tractor to the operator causes discomfort, pain and early fatigue. This paper presents the results of hand-transmitted vibration in actual field conditions during transportation on tarmacadam road, rota-tilling in untilled field and rota-puddling in submerged field.Relevance to industry: This study emphasizes the need to provide intervention to reduce hand-transmitted vibration of the hand tractor for increasing comfort and safety of the operators and to reduce early fatigue, which may ultimately increase the adoption of hand tractor by more farmers.[2]

Lee XinMeietal : Prolonged use of electric grass trimmer exposes the user to the risk of hand-arm vibration syndrome. A simple approach for the suppression of hand-arm vibration in electric grass trimmer is presented. The proposed system is a tuned vibration absorber (TVA). Modal analysis and operating deflection shape analysis of the electric grass trimmer were carried out and a TVA was designed and fabricated for testing. The results indicated that minimum vibration level was related to the position of the TVA on the shaft of electric grass trimmer. The TVA was found to have best performance with 95% reduction on the acceleration level at position 0.025L.[3]

S. Loutridisetal ; A study on the effect of electronic engine speed regulator on agricultural tractor ride vibration behavior . In this study, the effect of electronic speed adjustment on tractor ride vibration levels is examined. With normal pedal operation the engine rotational speed drops with an increasing load. The electronic regulator provides a constant speed mode of operation independent of the load. Vibration levels were measured under different perating conditions and surfaces. As a first series of tests, the tractor was driven on a conglomerate bituminous track at speeds of 20, 25 and 28 km/h. Vibration was measured upon the surface of the operator seat simultaneously in the x, y and z directions.[4]

ZulquernainMallicketal ; Optimization of operating parameters for a back-pack type grass trimmer. International

Journal of Industrial Ergonomics 38 (2008) 101–110 ; Optimization of operating parameters for a back-pack type grass trimmer . Hand–arm vibration syndrome (HAVS) is very common among workers operating power tools and performing similar work for extended period of time. Grass trimming involves the use of motorized cutter spinning at high speed, resulting in high levels of hand–arm vibration (HAV) among the machine operators. In this study the influence of handle–hand interaction of a grass trimming machine (GTM) is evaluated based on different hand positions of operator during operation.[5]

III. THEORY

3.1 Theoretical Background

3.1.1 Practices on HAV

The disorders are referred to hand-arm vibration syndrome (HAVS). Loriga in 1911 is the first to document the relationship between the exposure of HAV and HAVS. Great efforts have been made by researchers in order to reduce vibration of hand tools and its effect. These included isolation of the hand from the vibrating handle with the use of anti-vibration gloves. The effect of anti-vibration gloves to the human tools interface has been extensively studied, such as the investigation of the vibration isolation characteristic for a gloved hand using a laser based vibration sensor, The developments is always done for a more reliable method of effectiveness of anti vibration glove; evaluation of the effect of wearing anti-vibration gloves on the grip strength applied to cylindrical handles. However, different hand tools will have different influence on the isolation performance of the anti-vibration glove as it is tool or excitation spectrum specific. In certain cases where the machines have clear handle modules, vibration attenuation can be achieved by the isolation of the tool handle from the vibrating source using vibration isolators. Another feasible technique is to channel the vibration energy to a secondary system by adding a secondary mass-spring damper to a primary system which is known as tuned vibration absorber (TVA). This will reduce the vibration of the vibrating system thus reducing the handle vibration.

3.1.2 Vibration isolation concept

One of the most useful techniques for reducing handle vibration is to insert isolator or rubber mount between the handle and the source of excitation. The function of an isolator is to reduce the magnitude of motion transmitted to the handle. The concept of vibration isolation is well established and illustrated by considering single degree of freedom system as showninFig.1. This system consists of a mass supported by spring and damper connected to a moving plate which represents a vibrating machine by an isolator having resilience and energy-dissipating means.

The performance of the isolator can be evaluated by the characteristic of the response of the combined isolator system x(t) to steady-state sinusoidal vibration $y(t) = Y \sin \omega t$. This characteristic is referred asthe steady-state displacement transmissibility, X/Y given as:

$$\frac{X}{Y} = \left\{ \frac{1 + (2\tau r)^2}{(1-r^2)^2 + (2\tau r)^2} \right\}^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where X is the amplitude of the mass, τ is the relative damping, r isthe frequency ratio$\left(\frac{\omega}{\omega_n}\right)$, ω is the forcing frequency and ω_n is the natural frequency. In general isolation become effective when the frequency ratio exceeds 2. If the ratio is less than 2, the vibration may easily be amplified. It is widely understood that reducing the stiffness of isolators/mounts and increasing the mass of the part to be isolated are two ways to increase the efficiency of isolator.

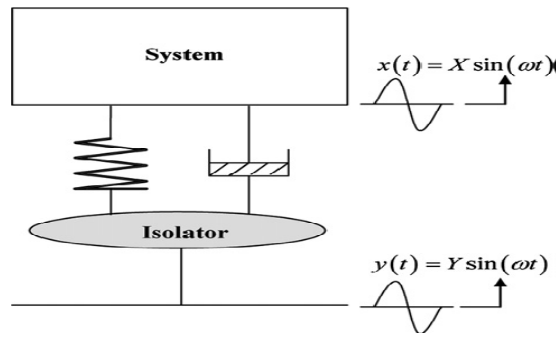

Fig.1 Schematic diagrams of vibration isolation systems.

3.1.3 Dynamic characteristic of rubber mount

Dynamic stiffness and loss factor play vital role in the performance of a rubber mount. the dynamic transfer stiffness (k) as frequency dependent ratio of the blocked force on output of a vibration isolator (F) to the displacement in the input (u) given as below:

$$k = \frac{F}{u} \ldots\ldots\ldots\ldots\ldots (2)$$

Fig. 2 illustrates the concept of dynamic transfer stiffness where a rubber element is placed under a preload mass. The excitation force is on the top of the preload mass. The input response of rubber mount is defined as u(t) while the blocked force transmitted from the bottom of rubber mount is expressed as F(t). If the element mass is negligible, the equation of motion for the rubber mount is given as:

$$c\frac{du(t)}{dt} + ku(t) = F(t) \ldots\ldots\ldots\ldots\ldots (3)$$

where c is damping coefficient. Assuming F(t) is simple harmonic such that $F(t) = F_e^{i\omega t}$,the input response of rubber mount is expressed as $u(t) = H(i\omega)F_e^{i\omega t}$
where the receptance function is given by:

$$H(i\omega) = \frac{1}{c(i\omega)+k} \ldots\ldots\ldots\ldots (4)$$

$$\text{Since } \tan\theta = {(c\omega)}/{k}, \quad \text{where} \theta = \omega t.$$

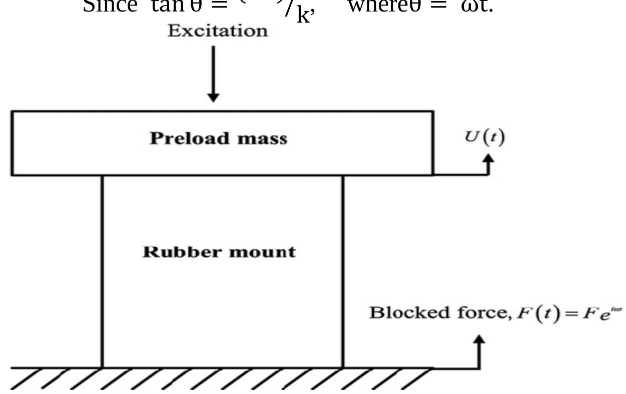

Fig. 2 The Concept of Dynamic transfer stiffness for rubber mount

The receptance function H(iω) can be rewritten as

$$H(i\omega) = \frac{1}{k(1 + i\tan\theta)} \ldots\ldots\ldots\ldots (5)$$

The rubber mount dynamic loss factor (η)is defined by

$$\eta = \tan\theta = \frac{\mathrm{Im}\{H(i\omega)\}}{\mathrm{Re}\{H(i\omega)\}} \quad \ldots\ldots\ldots (6)$$

Where Im{H(iω)}&Re{H(iω)} are the the imaginary and real part of the receptance function{H(iω)}. The inverse of the reception function is the dynamic transfer stiffness of an element, where

$$k = \frac{1}{H(i\omega)} \quad \ldots\ldots\ldots (7)$$

3.1.4 Measurement of hand-arm vibration

Provides the general requirement for measuring and reporting hand-transmitted vibration exposure. It also defines a frequency weighting filter, W_h which is the combination of band limiting and weighting filter, to allow uniform comparison of vibration measurement. The magnitude of vibration is measured by means of the frequency-weighted root-mean-square (rms) acceleration, expressed in m/s^2 in (Eq. (8))

$$a_{hw} = \sqrt{\sum_j (W_{hj} a_{hj})^2} \quad \ldots\ldots (8)$$

Where $a_{hw}$is the value of the frequency-weighted rmsacceleration,W_{hj} is the weighting factor for the one-third octave band j and $a_{hj}$is the rms acceleration for the one-third octave band j.The vibration total value a_{hv} is established by root-sum-of squares of frequency-weighted rms acceleration measured in three orthogonal axes, written as:

$$a_{hw} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2} \quad \ldots\ldots (9)$$

Where a_{hwx}, a_{hwy}, a_{hwz} are the value of a_{hw}(frequency-weighted rms acceleration in single axis) in meters per second squared, m/s2,for the X_h_, Y_h_ and Z_h_axes respectively.

3.1.5 Grass trimmer description

The electric grass trimmer with a weight of 2.74 kg was used in this study. The basic element of the electric grass trimmer consists of the cutting head, connected by a tubular hollow aluminium square structure on which is fitted the upper plastic casing which houses the handle and the switch controlled by the operator. The tubular hollow aluminium structure has an adjustable collar which allows the operators to adjust the overall length of the trimmer to suit their height.

3.1.6 Vibration analysis of electric grass trimmer

Vibration analysis is carried out in order to determine the operating frequency of the electric grass trimmer, the vibration level and the dominant axis. Vibration analysis shall be carrying out by instruments which include the miniature tri-axial accelerometer, calibrator, FFT analyzer and post-processing software. The electric grass trimmer was tested under free-running condition. Since the length of nylon string for grass trimmer has some influence on the engine speed, a constant length of nylon string was used throughout the study. The accelerometer is mounted on the front handle near the hand grip location. The data from the accelerometer are stored and analyzed. Vibration total values a_{hv} are calculated from the frequency-weighted rms acceleration measured in three orthogonal axes (X_h ,Y_h and Z_h) of the handle. The Z_h axis is defined as the longitudinal axis from third metacarpal bone towards the distal end of the finger. The X_h axis is perpendicular with Z_h axis. The Y_h axis is perpendicular to X_h and Z_h axes and is the direction towards the thumb .

3.1.7 Experimental modal analysis

The inherent dynamics characteristics of a structure can be determined from experimental modal analysis. Frequency response functions (FRFs) of a structure are determined through experimental modal analysis which establishes the relationship between measured output and input as a function of frequency. From these FRFs, the natural frequencies, damping, and mode shapes of a structure can be obtained and can be used to predict the effect of SM. It is an important tool in evaluating and controlling the effect of resonance. Impact testing has become a popular method to perform experimental modal analysis since it is fast, convenient and cost effective.

3.1.8 Acceleration transmissibility measurement

Acceleration transmissibility test was carried out to determine the characteristic of handles. Acceleration transmissibility of handles was measured on a shaker (Tira GmbH, vibration test system TV 50101) using a sine swept signal, frequency range of 0-1280 Hz . Accelerometers were attached to handle and the base plate of shaker.

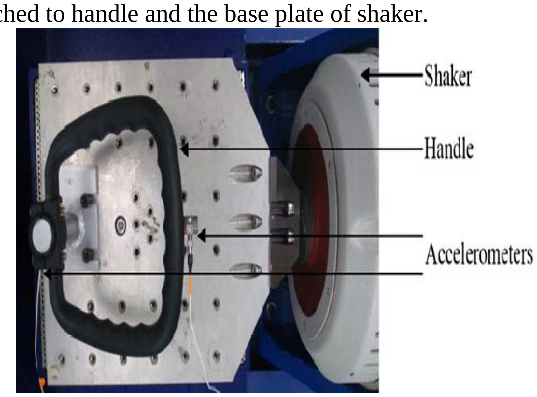

Fig. 3 Acceleration transmissibility measurement setup in Xh_axis

The acceleration transmissibility of the handle was determined by measuring the ratio of acceleration on the handle to the base plate using LMS spectral testing software. Handle acceleration transmissibility measurement was performed without hand grip on handles to avoid hand-arm interaction.

IV. OPERATION

Fifteen representative male operators were chosen for this study, with attributes summarized in Table 2. All operators were technicians who volunteered for this study. They were all in good physical condition and had some experience in using grass trimmer. Eye and ear protective equipments were provided to all operators during each task for safety purpose.

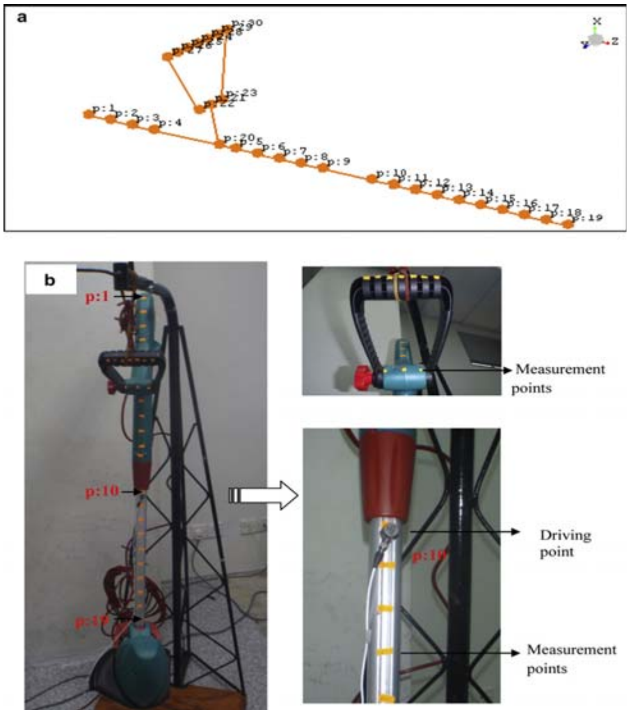

Fig.4 Points approximately to be taken

These points are taken from reference copy of Hand arm Vibration. In this article the HAV is means that Hand Arm Vibration.

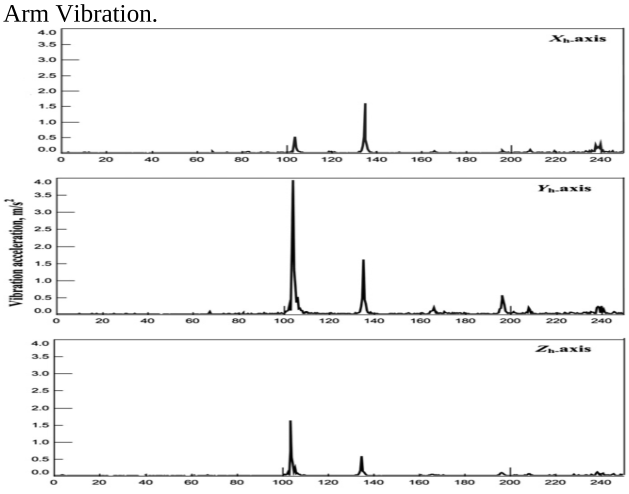

Fig. 5 Frequency spectra for the handle of the grass trimmer in the Xh_ Yh_ and Zh_axes.

TABLE 1
Dimensions of the redesigned handle.

Handle	B	C	D
Length of Handle grip, mm	129.38	152.00	152.00
Dia. Of Handle grip, mm	33.58	33.14	33.14
Length of Handle	178.00	94.01	94.01
Thickness of Handle, mm	6.02	6.24	6.24
Width of length, mm	32.03	33.02	33.02
Length of base plate, mm	98.35	133.21	133.21
Width of plate, mm	32.03	32.62	32.62
Thickness of base plate ,mm	6.08	3.O8	3.08

TABLE 2
Distribution of operator attributes.

Attribute	Mean	Standard deviation	Range
Age(Years)	33.1	7.2	24-44
Height (cm)	170.1	7.7	160-184
Weight(kg)	71.9	13.1	52-91

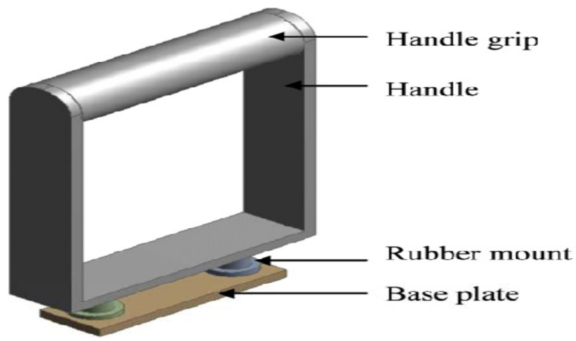

Fig.6The redesigned handle.

4.1 Accessories

The different accessories employed during the study were handle adapter, light weight tri-axial accelerometer (Dytran, 3023M20 SN: 4011), calibrator exciter (B&K, 4294) and data acquisition system (LMS Scadas Mobile, SCM05). A tri-axial accelerometer having a mass of 2.4 g was used to measure vibration at the handle of the grass trimmer. The adapter was rigidly fixed on the handle grip so that there were no relative motion between the handle grip and adapter (Fig. 7).

4.2 Measurement, data collection and analysis

Before the actual experiment was conducted, all the operators were briefed about the objective of the experiments. A training session was organized for the operators in order to familiarize them with the task. For measuring vibration at the handle grip of grass trimmer, the accelerometer was mounted on the handle adapter with the use of petrol-wax (Fig. 7)

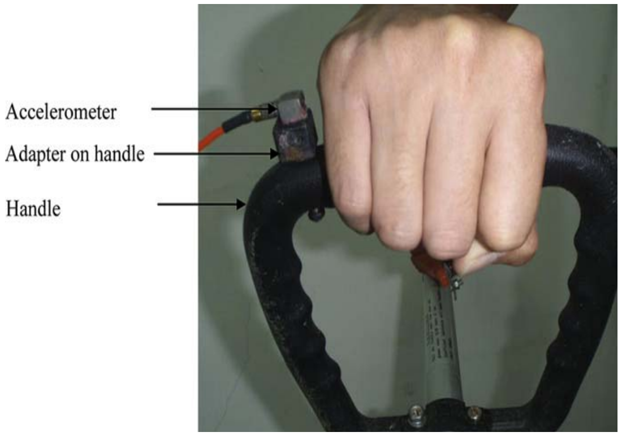

Fig. 7 Mounting of an accelerometer on the handleadapter of the grass trimmer.

and connected to LMS Scadas Mobile and the data analyzed using LMS spectral testing software. Before and after each measurement, the accelerometer was calibrated to ensure accuracy. The recommendation of was followed for orientation of the measurement axes: Z_h_ axis is defined as the longitudinal axis from the third metacarpal bone towards the distal end of finger; X_h_ axis is perpendicular with Z_h_ axis; Y_h_ axis is perpendicular to X_h_ and Z_h_- axes, and is in the direction towards the thumb. The four grass trimmers were allowed to run under no cutting condition for 5 min until stable conditions were reached before the experiment is commenced.The operators then operate the grass trimmers with the different handle design. For each measurement, the operator was asked to hold the grass trimmer at full engine speed of 6200 rpm for 60 s while maintaining grip and push force. Immediately after 1 min of data sampling, they started to carry out grass trimming task for the duration of 15 min. Stored data were analyzed for vibration acceleration in rms (a_{hj}) at 1/3rd octave bands centered from 8 to 1000 Hz for each measurement and each axis. For each axis, the overall weighted rms acceleration (a_{hwx}, a_{hwy} ,a_{hwz}) was calculated. From the overall weighted rms acceleration of three axes, vibration total value (a_{hv}) was calculated for each subject. Average of vibration acceleration of the 15 operators was calculated which represented vibration exposure of grass trimmer. The reduction of vibration was calculated by subtracting the averaged vibration total value (a_{hv}) of prototype handles (B, C, and D) from the commercial handle A. After the field test, the operators rest until their physiological responses were normal before the test on the next handle started.

During the rest period, the operators were asked to rate the handle in following categories: perception of grip force required (rate of difficulty) and perception of vibration. The subjective ratings were made using the Borg CR-10 scale. The CR-10 scale consists of numerical scale from 0 (too little grip force required/no vibration) to 10 (too high grip force required/high vibration). The operators were asked to report honestly based on what they feel and experienced. One-way analysis of variance (ANOVA) was performed to test the different level of frequency-weighted rms acceleration of different axes among the handles. A t-test was then conducted to calculate the vibration reduction level of the prototypes handles from the commercial handle. Finally, the Pearson correlation coefficient calculation was carried out to evaluate the correlation between the subjective rating and vibration total value (a_{hv}).

4.3 Subjective rating

Operator's rating of perception of grip force and vibration are shown in Table 3. The perception of grip force is taken into account because more grip force on the handle is required when exposed to the higher vibration. The increased grip force increases the stiffness of the hand thus causes higher vibration transmissibility. From Table 3, it was observed that the perception of grip force was highest for handle D (4.13 in Borg scale). This is followed by handle A and C which have the same value of 4.00. The rating of grip force required for handle B is lowest (3.87 in Borg scale). The perception of grip force is in agreement with the level of measured vibration.On the other side, rate of vibration perception was the highest for handle B with the value of 4.53. The values of 4.27, 4.13 and 3.73 were observed for handle A, D and C respectively (Table 3). Pearson correlation was carried out to evaluate the relation between measured vibration total value (ahv) and subjective rating of vibration perception.A positive value reflects a direct association between measured vibration total value (ahv) and subjective rating of vibration perception while a negative value reflects inverse relationship. The strength of the correlation is indicated by the correlation values: zero is the weakest correlation, and 1 or -1 is the strongest; correlations between 0 and 0.30 are weak; those between 0.31 and 0.60 are moderate; and those greater than 0.60 are strong. For handle A, correlation between vibration total value (ahv) and vibration perceptions is 0.522 and is considered moderate. This revealed that higher vibration total value (ahv) tends to have a higher rate of vibration perception. The perception of operators is correct. The correlations among pairs of variables for handle C, D are all positive but considered weak. The correlation coefficients for handle B were negative and consider weak.

TABLE 3
Correlation of vibration total value (ahv) and vibration perception.

Correlation (Pearson correlation)	
Vibration total value (ahv) of handle	Vibration perception
A	0.522[a]
B	-0.288
C	0.061
D	0.313

This indicated even with lower vibration total value (ahv); higher rate of vibration perception was reported. This result reveals that perception of vibration by the operators did not reflect the measured vibration level. Handle B which has the lowest vibration total value (ahv) of 2.69 m/s^2 was perceived to have the highest perception of vibration.the works on hand-transmitted vibration in power tools showed workers were not aware of the level of vibration transmitted to the hand. Operator's rating of discomfort was also found to differ from the vibration level in the study that evaluate the effect of gender, handle size and vibration levels on the ability to perform a precision task. The unawareness of vibration level among operators represents an additional risk. They should be at least being informed about the effects these vibrations can have.

V.CONCLUSION

Characteristics of HAV with different handle types on a grass trimmer were presented in this study. The following major conclusions can be drawn from the present study:-

1. Not all the handles with rubber mounts were effective in reducing hand-arm vibration. The reduction of vibration depended on the handle dynamics which influences the vibration transmissibility of handle-isolation system. The suspended handle design approach is to minimize vibration transmissibility within the operating frequency range of the machine based on the machine vibration spectra.
2. The existing commercial handle (handle A) has the highest vibration total value (11.30 m/s^2) and had reached the exposure limit value (ELV) of 5.0 m/s2 for daily vibration exposure. Immediate actions should be taken. The prototype handle B is the most effective handle with the lowest vibration transmissibility value at dominant frequency in all axes. It has the lowest vibration total value of 2.69 m/s2 and shows 76% of reduction compared with commercial handle A.
3. The subjective rating showed that operators are not fully aware of the level of vibration

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