Vibration Suppression of Grass Trimmer Handle using Tunable Vibration Absorber

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Abstract: The electrical grass trimmers are widely used for cutting grass along the highways, roadside & general agricultural work. Grass trimming involves the use of motorized cutter spinning at high speed, resulting in hand-arm vibration syndrome among the machine operators. The purpose of this work is to reduce the handle vibration of grass trimmer using tuned vibration absorber (TVA). The variable stiffness dual mass vibration absorber is designed using Dunkerleys Equation and fabricated for testing. The experimental modal analysis of absorber is conducted to find resonance frequencies of the absorber and to validate the results obtained from equations. The experimental tests are carried on grass trimmer with absorber attached at different location for two cutter head positions to find the absorber attachment location to reduce handle vibrations to minimum level. The results indicated that the vibration attenuation is affected by the location of absorber and cutter head position of grass trimmer.

Keywords: Grass Trimmer, Handle Vibration, Modal Analysis, Vibration Absorber, Vibration Control

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1 INTRODUCTION

The grass trimmers are generally used in maintenance of parks and areas with bushes. The electric grass trimmer usually employs an AC electric motor of 500 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. The operator of trimmer may be subjected to large magnitude of hand arm vibration and may cause complex vascular and neurological and musculoskeletal disorder, collectively named as hand-arm vibration syndrome.

Various techniques are used for controlling the vibration at the handle. These includes mounting of a dynamic vibration absorber on the grass trimmer, isolate the hand from the vibrating handle with the use of anti-vibration gloves [1-2] and isolate the tool handle form the vibrating source by using isolators [3-4]. The use of vibration isolators, however results in handle with a high mass and low stiffness. The isolation performance of the anti-vibration gloves for different hand tools is influenced by the excitation spectrum or tool type [5]. Alternatively, the excessive vibrations are suppressed by attaching a tunable vibration absorber to the grass trimmer. Fasana and Giorcelli [6] studied the application of the concept of TVA to motorcycle handle. The TVA was tuned to the frequency of maximum discomfort of biker. The attenuation of vibration is possible with the presence of TVA even if not perfectly tuned. Golysheva and Babitskyhowed [7] proposed that vibration attenuation of hand-held percussion machine could be very effective with combination of isolation and absorption principles. By introduce two TVAs (one tuned to fundamental frequency and the other tuned to second harmonic frequency) attached to the isolated handle resulted reduction of the amplitude at fundamental frequency and second harmonic frequency by a factor of 62 and 70 respectively. Kadam [8] attached a vibration absorber at the handle of pneumatic impact hammer and showed the vibration level of handle response is reduced. Recently Mallick [9] developed approach to minimize the vibration of grass trimmer was by carefully selecting the optimum parameters of grass trimmer, such as hand-handle position, engine operating speed, sway angle, length of nylon string and the material of handle. However, it could be difficult for the workers to adopt the suggested optimum parameter in the grass trimming operation. Hao et al. [10] suppressed the hand-arm vibration in electric grass trimmer by installing tunable vibration absorber. The dynamic behavior of the grass trimmer with absorber is analyzed by structural modification procedure. The optimum absorber attachment location was identified both analytically and experimentally. Hao and Ripin [11] applied imposing node technique to achieve vibration reduction at handle location of the petrol engine grass trimmer using two tunable vibration absorbers. Sheth [12] attained the vibration reductions of the centrifugal pump by modifying the fan cover and using it as a TVA. It is revealed that attaching the TVA to fan cover of a pump, results in reduction of sound and vibration considerably. Recently Patil [13] applied imposing node method for vibration reduction of petrol engine grass trimmer using vibration absorber. One of the well-known design concept is the beam like vibration absorber or dual cantilevered mass vibration absorber designed by Hill and Snyder [14]. This type of absorber consists of a beam with a mass attached on its end. The span of the beam can be varied to adjust the natural frequency of the absorber.

In previous research [10] the effect of grass trimmer head angle (position) on vibration performance is not studies. In addition, the absorber utilized for vibration suppression has limited resonance frequency range. The purpose of the present research is to reduce the handle vibration of electric grass trimmer and to find the absorber attachment location for two head position using variable stiffness vibration absorber which can be tuned to desired resonance frequency effectively. The plot of resonance frequencies of the absorber with mass position is developed, which is useful in selecting the desired resonance frequency of absorber as per the requirements.

2 ELECTRIC GRASS TRIMMER

The electric grass trimmer of Bosch ART COMBITRIM make with a weight of 3.4 kg was used in this study. The power of machine is 500 W with rotation 10500 rpm. The basic element of the electric grass trimmer consists of the cutting head, connected by a tubular hollow aluminium circular 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. The head of the grass trimmer has two angular positions depending on cutting operation.

2.1. Experimental Modal Analysis of Grass Trimmer

The experimental modal analysis of the grass trimmer system with all attachment was carried out to determine the natural frequencies of the system. For modal analysis the grass trimmer suspended in a “free-free” orientation as shown in “Fig. 1”. An impact hammer (Kistler 9722A2000) was used to excite the trimmer pipe while light-weight ICP accelerometer (CTC 100) fixed to handle was used to measure the frequency response read from a FFT vibration analyzer (Adash 4300).

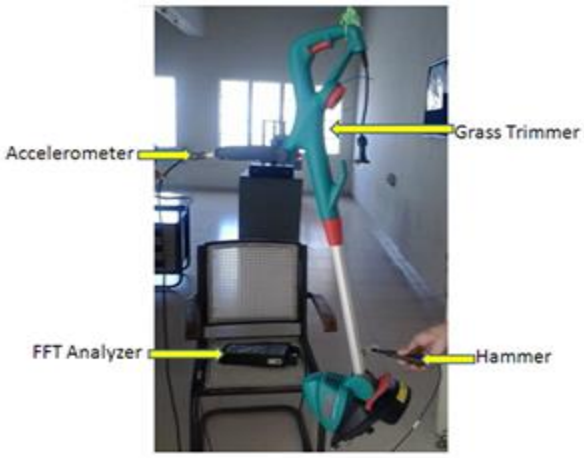

Fig. 1 Experimental modal analysis of grass trimmer.

Response spectrum of trimmer as given in "Fig. 2". shows that the first three modes get excited by impact hammer. First three natural frequencies of trimmer are 24 Hz, 124 Hz and 187 Hz respectively. It is observed that the operating speed of the grass trimmer (1050 i.e. 175 Hz) is near to the third natural frequency of the grass trimmer system (187 Hz).

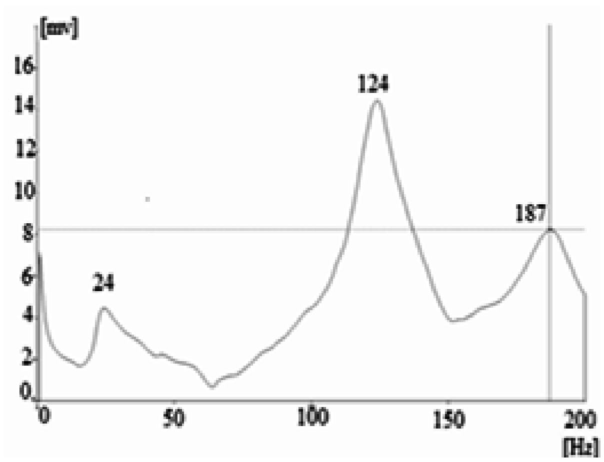

Fig. 2 Frequency spectrum of grass trimmer.

3 DESIGN AND EXPERIMENTAL MODAL ANALYSIS OF ABSORBER

Figure 3 illustrates the absorber, which comprises two cantilevered absorber masses mounted on beam fixed at the centre. The fixed centre is attached directly to the vibrating structure. The resonance frequency of device is adjusted by moving the masses towards or away from the base support along the cantilever beam, which alters the effective stiffness in the system and alters its resonance frequency.

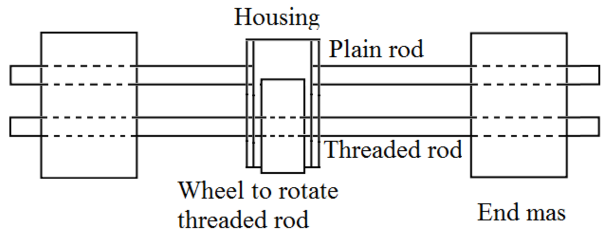

Fig. 3 Dual mass variable stiffness vibration absorber.

The absorber is modelled as dual cantilevered mass, which is represented as two discrete systems. The rod itself is assumed to be one vibration system and the absorber mass at the end of the rod is another system. Figure 4 shows the half part of the cantilevered masses which are symmetric at the fixed centre. The dimensions and material properties of the absorbers are listed in "Table 1".

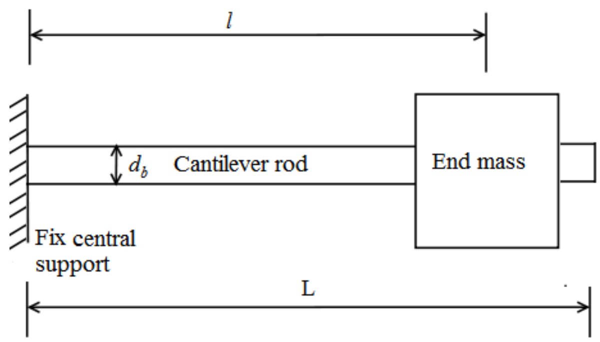

Fig. 4 Parameters of absorber used in design.

Table 1 Dimensions and material properties of absorber used in design

Density of rod and end mass	P_m	7800 Kg/m^3
Modulus of elasticity	E	2.1 x 10^{11} N/m^2
Total length of each rods	L	0.09 m
Position of absorber mass from support	l	0.09 m to 0.05m
Diameter of each rods	d_b	0.006 m
Mass of each end mass	m_a	0.1 kg

If the damping of the system is neglected, the natural frequency of absorber ω_1 can be determined using Dunkerleys Equation [15].

$$\frac{1}{\omega_1^2} = \frac{1}{\omega_b^2} + \frac{1}{\omega_a^2} \quad (1)$$

For two rod absorber, where rods are parallel the stiffness is doubled and the natural frequency of the cantilever rod, ω_b is given by:

$$\omega_b = 3.52\sqrt{2EI/m_b l^4} \quad (2)$$

The natural frequency of cantilever rod with secondary mass m_a attached at the end ω_a is given by:

$$\omega_a = \sqrt{3EI/m_a l^4} \quad (3)$$

The natural frequency of the absorber with the change in mass position l form base support is obtained from equation 1. Figure 5 shows the plot of natural frequencies of absorber with change in mass position along the rod length.

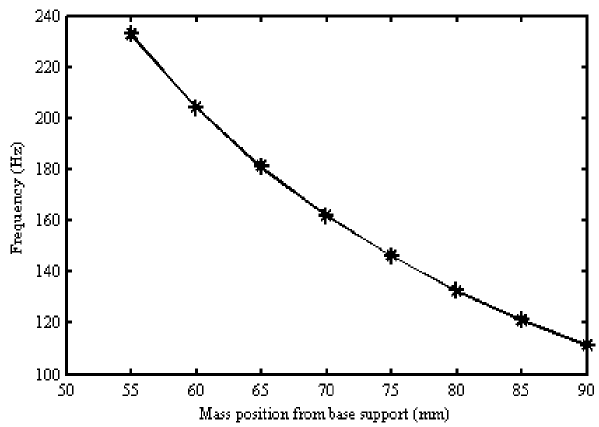

Fig. 5 Variation of frequencies of absorber with change in mass position along the rod length obtained by Dunkerleys Equation.

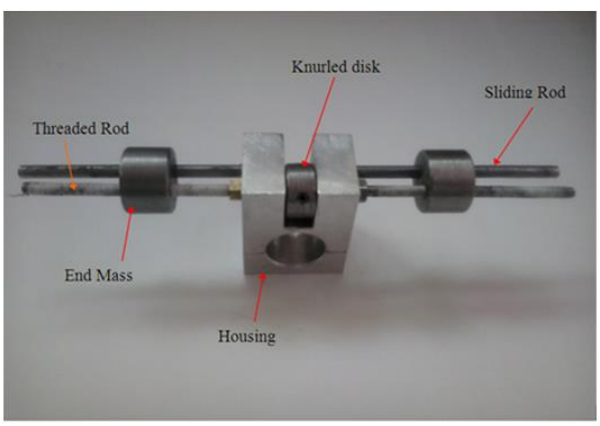

Fig. 6 Dual mass vibration absorber.

The designed resonance frequencies of the absorbers kept less than the required resonance frequencies, because at the time of experimentations the required resonance frequencies are obtained by moving end mass towards the base support. Figure 6 illustrates the absorber developed using parameters listed in “Table 1”.

The experimental modal analysis of the absorber was carried out to determine the resonance frequencies of absorber for different mass positions on the rods. Response spectrum of absorber is depicted in “Fig. 7”. It shows that the first two modes get excited by impact hammer. This is the experimental validation of the discussion from Hill and Snyder [14] that the first two modes of absorber are characterized by vertical displacement of masses, with the masses in phase for first mode and out of phase for second mode and frequencies are in close proximity for these modes.

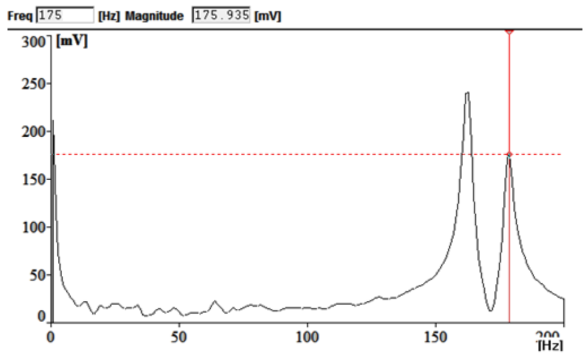

Fig. 7 Frequency spectrum of absorber.

Figure 8 describe the relationship between the mass position and the resonance frequencies of the absorber. It is observed that the resonance frequency of the absorber increases linearly as mass moves towards the base support. Comparison of “Fig. 5 and Fig. 8” shows that the frequencies obtained from Dunkerleys Equation are slightly higher than experimental results.

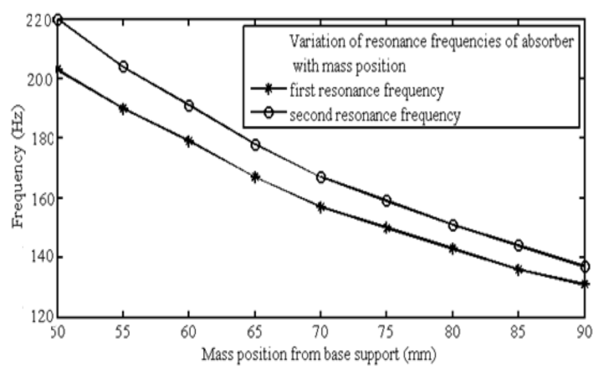

Fig. 8 Variation of frequencies of absorber with change in mass position along the rod length obtained by experimental modal analysis.

4 EXPERIMENTAL TESTING

The testing is carried on electric grass trimmer with and without absorber to find the effectiveness of the absorber in reduction of the handle vibration for two angular positions of the cutting head. In addition, the absorber is attached at five different points i.e. at 0 mm, 20 mm, 40 mm, 60 mm and 80 mm from plastic casing, along aluminium circular structure to find absorber location to gives the maximum vibration suppression. Figure 9 shows the testing setup in which the grass trimmer is supported on table at both ends.

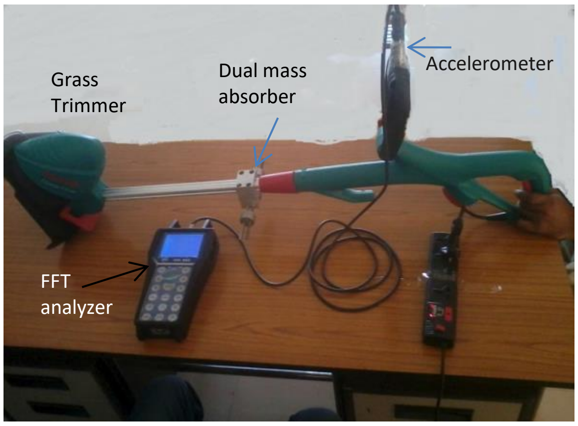

Fig. 9 Vibration measurements of grass trimmer with and without vibration absorber.

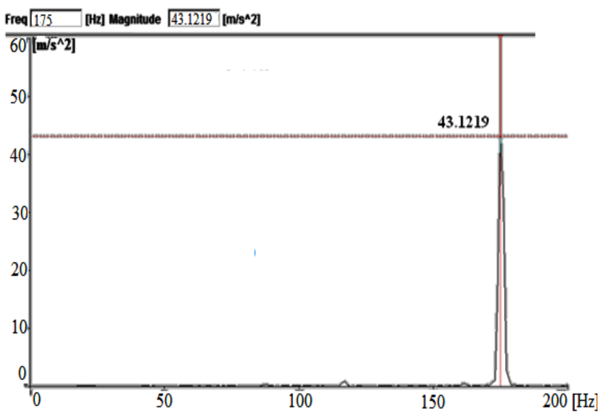

Fig. 10 Frequency spectrum of grass trimmer without absorber.

The vibrations of grass trimmer are measured using FFT vibration analyser and accelerometer mounted on the handle of grass trimmer. The vibration acceleration of grass trimmer without TVA is around 44 m/s^2 at handle location with operating frequency of 175 Hz and spectrum is as shown in “Fig. 10”. The procedure to tune the absorber to reduce handle vibrations for different attachment location is as follows:

1- First absorber is attached near to plastic casing i.e. at 0 mm
2- Then absorber is tuned by moving end masses in or out such that the acceleration at grass trimmer handle location is minimum and recorded.
3- The tuned absorber mass position from fixed support also recoded
4- Next absorber is attached at next location and same procedure is followed for other attachment locations.

“Table 1 and Table 2” list the grass trimmer handle acceleration for different absorber attachment location for first and second head positions respectively. Tables also give the tuned absorber mass position from fixed support for different attachment locations.

Table 2 Acceleration at grass trimmer handle for various absorber attachment locations for first head position

Sr. No	Absorber attachment location (mm)	Absorber end mass position (mm)	Acceleration at trimmer handle (m/s^2)
1	0	71	9.895
2	20	70	10.1909
3	40	67	10.4279
4	60	64	9.0537
5	80	68	9.3357

Table 3 Acceleration at grass trimmer handle for various absorber attachment locations for second head position

Sr. No	Absorber attachment location (mm)	Absorber end mass position (mm)	Acceleration at trimmer handle (m/s^2)
1	0	70	11.357
2	20	73	12.919
3	40	68	10.521
4	60	66	9.512
5	80	69	9.981

It is observed that the acceleration is minimum when absorber is at 60 mm for both head positions. Thus the vibrations of grass trimmer are reduced from 43.1219 m/s^2 to 9.0537 m/s^2 with the use of TVA attached at 60 mm from plastic cover for first head position. For second head position vibrations are reduced 9.512 m/s^2. Figure 11 shows the acceleration spectrum of grass trimmer handle. In addition, it is revelled from Tables and Fig 8 that the absorber mass position 64 mm for first head position and 66 mm for second position gives the resonance frequency of absorber near to 175 Hz.

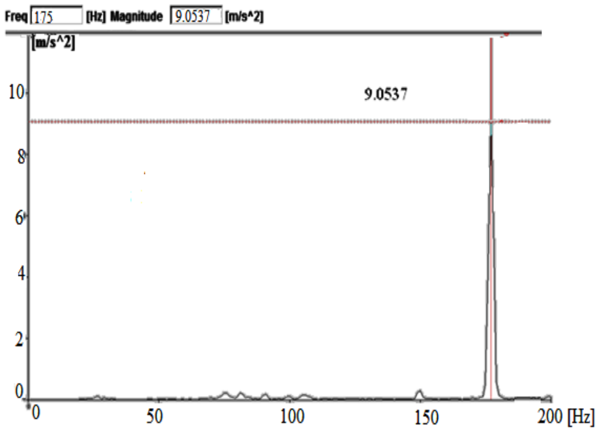

Fig. 11 Frequency spectrum of grass trimmer with absorber.

5 CONCLUSION

The present investigation is carried out to reduce to handle vibration of electric grass trimmer using variable stiffness vibration absorber. The experimental modal analysis result of absorber reveals that the absorber has resonance frequency from 90 Hz to 220Hz. The TVA required to tuned near to the operating frequency (175 Hz) of electric grass trimmer to attenuate handle vibration. The electric grass trimmer with the TVA installed at the particular location is effective in reducing acceleration level of vibration. The experimental result shows that the presence of TVA has successfully reduce the vibrations of the handle by 80%. for both cutter head position.

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