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Reduction of High Frequency Vibration of Brush Cutter by Structure Optimization

J. Yoshida, M. Uemura, S. Miyakawa, T. Oono, and D. Ishikawa

***Abstract*— Balancing trimmer was developed to be used safety and easy handling. But vibration of the trimmer was evaluated to be bad. In this study, we investigated which frequency band affects the bad vibration feeling and tried to reduce the vibration. Through vibration measurement analysis to the handle vibrations of several trimmers, high frequency vibration from 100 to 250 Hz was very large. Also, handle pipe vibration characteristic was found to have high influence to the vibration. Then, we tried to decrease the resonance frequency and response level at the high frequency to improve vibration characteristic of the handle pipe considering not to increase the total weight. Thin handle pipe, concentrated mass, and modification of rubber bush were applied to realize it. As a result, the high frequency vibration of the handle of balancing trimmer was reduced so much without any additional total weight.**

***Index Terms*— light weight, high frequency, transfer function, trimmer, vibration**

I. Introduction

SMALL engine trimmer is a kind of agricultural machine for cutting weeds, and a lot of people use the machine all over the world by the low price and easy to handling. However, many accidents are reported by the opened rolling cutter[1]. Representative accident of the trimmer is "kick back" that occurs when rolling cutter attached on land and trimmer moves rapidly to the operator. In some cases, the rolling cutter comes to the operator directly and foot is seriously injured by kick back. Balancing trimmer was developed to be used safety and easy handling. When the operator leaves his/her hand from handle, the balancing trimmer could keep the rotation surface as horizontal axis by balancing moment of the body (Fig. 1).

Fig 1 Balancing trimmer.

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This balancing trimmer was developed focusing not only safety but also light weight considering the machine is used for various people including aged person. On the other side, vibration feeling at the operational condition is evaluated as worse than other type trimmer and improvement of the vibration is required to protect the operator from hand-arm hazard by the vibration[2] and to increase the operating property.

In this study, we try to reduce the vibration arising bad feeling of balancing trimmer considering to keep the light weight. In addition, this trimmer has various variations having different type engine, therefore, countermeasure for the vibration reduction is performed to the body of the machine such as handle pipe.

II. Vibration evaluation at handle

Firstly, we evaluated vibration characteristic of the balancing trimmer by measuring vibration acceleration at handle of several trimmers (balancing trimmer, type A and type B trimmers) at operational condition. For measuring them, trimmer was hung by rubber string and vibration at left side handle (front-back direction) was measured when the engine rotation speed was from 3000 to 7000 rpm. The overall acceleration level applying ISO5349-1[3], that was a frequency weighting factor made to evaluate hand-arm vibration and weighted low frequency as having high influence, was calculated in each trimmer and each rotation speed. Figure 2 shows the weighted overall level.

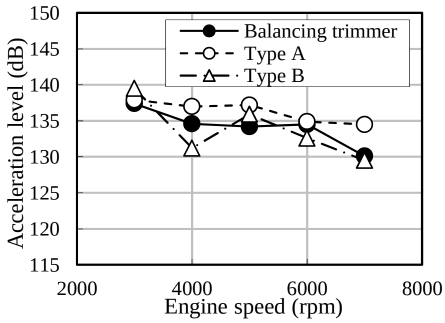

Fig 2 Overall of acceleration level at handle according to ISO5349-1 weighting.

Horizontal and vertical axes show engine rotation speed and weighted overall acceleration level, respectively. In this figure, the balancing trimmer is not observed to have high vibration by comparing with the other types of trimmer. This means low frequency vibration of the trimmer is similar with the other trimmers. Then, frequency analysis was performed

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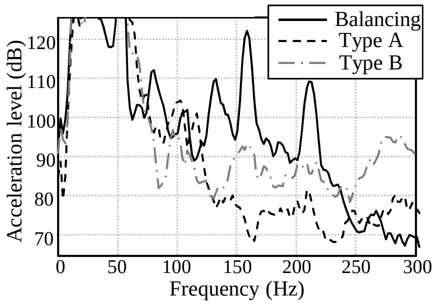
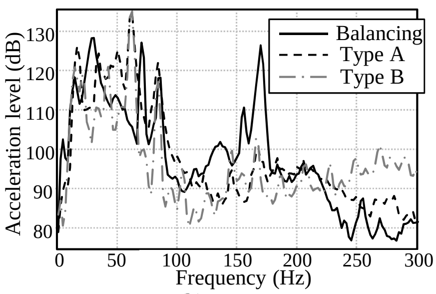
to evaluate the vibration in detail. Figure 3 shows the results at 3000 rpm (Fig. 3 (a)) and 5000 rpm (Fig. 3 (b)).



(a) 3000 rpm.



(b) 5000 rpm.

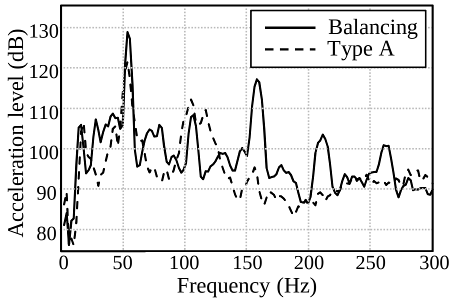
Fig 3 Spectrum of handle acceleration level.

Horizontal and vertical axes show frequency and acceleration level (any frequency weighting factors are not applied). The results indicate the balancing trimmer had very large vibration from 100 to 250 Hz in comparison with the other trimmers. This high frequency vibration is considered to be main factor of bad vibration feeling. Consequently, we try to reduce handle vibration at the high frequency band to improve bad vibration feeling in this study.

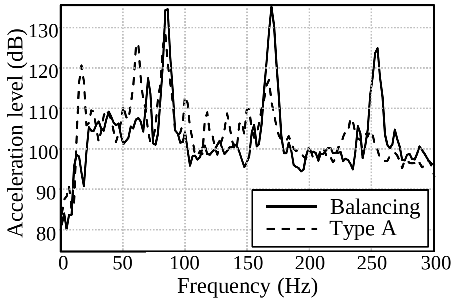
III. Factor Analysis

A. Engine vibration

Engine vibration, that is main vibration source, was evaluated here. The experimental condition was identical with the previous test and acceleration vibration at the engine side of coupling point between engine and main pipe was measured from 3000 to 7000 rpm. Frequency analysis results at 3000 and 5000 rpm were shown in Fig. 4 (a), (b), respectively. In these figures, the engine vibration was compared with type A trimmer, that is lowest vibration at the high frequency band.



(a) 3000 rpm.



(b) 5000 rpm.

Fig 4 Spectrum of engine acceleration level.

The result shows the engine vibration of the balancing trimmer was very larger than that of type A trimmer (Fig. 4) where the handle vibration was high (Fig. 3). This indicates the high engine vibration is a main factor to increase the handle vibration of the balancing trimmer.

B. Vibration transfer characteristic

Transfer characteristic of body of the balancing trimmer, that is the target for vibration reduction, was evaluated through impact hammering test. Two kinds of transfer function from engine to handle were measured. Transfer function 1 represents a transfer path through shaft and transfer function 2 represents a path through main pipe. In the measurement of path 1(shaft path transfer function), the input point was set at engine side shaft end (impact direction: vertical axis) and response point was left handle (front-back direction). In the measurement of path 2 (pipe path transfer function), the input point was main pipe end near engine (impact direction: vertical axis) and response point was left handle (front-back direction). In addition, to evaluate handle vibration characteristic of itself, point inertance at left handle was measured (impact and response directions: frond-back). To measure these transfer functions, body of the trimmer was hang by rubber string without engine to impact the shaft. Figure 5 (a), (b), and (c) show the shaft path transfer function, pipe path transfer function, and handle point inertance, respectively.

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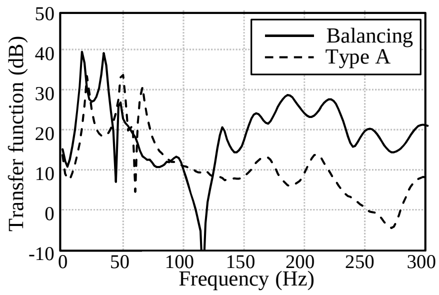
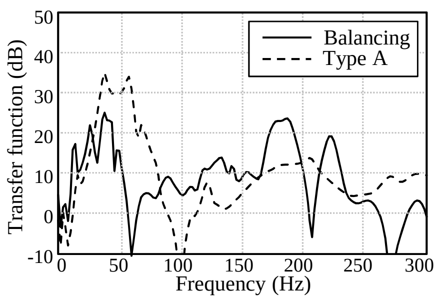
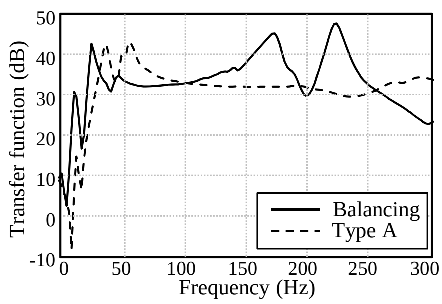


(a) Transfer function from shaft to handle.



(b) Transfer function from pipe to handle.



(c) Point inertance at handle.

Fig 5 Comparison of transfer functions between balancing trimmer and type A trimmer.

From these transfer functions, the balancing trimmer has much higher vibration response than type A trimmer between 100 to 250 frequency band, where the vibration was large at operational condition. This means vibration transfer characteristics of the body are another factor of the high frequency vibration at the handle. Especially, shaft and pipe paths transfer function had high response peak at 170 and 220 Hz, where the handle point inertance had high response peak. Hence, the high sensitivity of the handle at the frequency band is the main factor of the high response of the transfer function of the body. We try to reduce the handle vibration characteristic (point inertance) from 100 to 250 Hz by modifications of the body.

IV. Countermeasure by Body Modification

In this section, body of the balancing trimmer is modified to reduce the handle vibration characteristic that is one of the main factors of large vibration at high frequency band.

A. *Vibration reduction flow considering light weight*

In this study, we improve vibration of the balancing trimmer considering the light weight. Stiffness increase, dynamic damper or mass addition is performed to reduce a vibration of a body in general[4-7]. However, not only adding mass, but also increasing stiffness or adding dynamic damper increases total weight as the result of the countermeasure. This disturbs one of appeal points of the balancing trimmer (light weight). Then, to improve vibration characteristic of the handle from 100 to 250 Hz, we try to decrease stiffness of handle pipe and to reduce the total weight at once. Subsequently, the reduced weight is used for a concentrated mass, which is attached to the high amplitude position, to reduce resonance frequency and vibration response at the high frequency band.

B. *Low stiffness of handle pipe*

To decrease stiffness and weight of handle pipe, thickness of handle pipe was reduced from 2.5 mm (left side) and 2.0 mm (right side) to 1.1 mm (both sides). As a result, the weight was decreased about 200 g and the resonance frequency of the handle pipe and vibration response from 100 to 250 Hz was decreased as shown in Fig. 6.

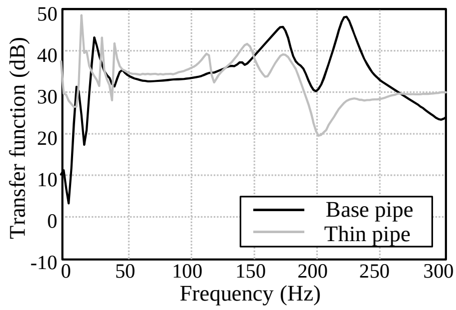


Fig 6 Point inertance comparison between base handle pipe and thin handle pipe.

C. *Attachment of concentrated mass*

Attachment Position (Vibration Mode)

Next, resonance frequency and vibration response from 100 to 250 Hz band are tried to be reduced more by attaching concentrate mass which weight is the same as reduced weight by the low stiffness (80 g). To obtain suitable attachment position of the mass, we performed modal analysis to the low stiffness body and investigated vibration mode at 147 Hz where peak amplitude was observed (resonance frequency). The vibration mode is shown in Fig. 7.

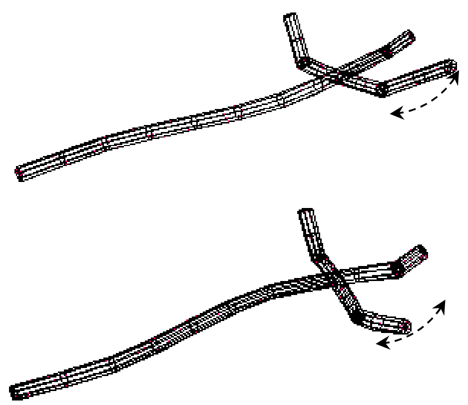


Fig 7 Vibration mode of balancing trimmer at 147 Hz.

The result shows the vibration mode at 147 Hz has highest amplitude near holding point of left handle. This point was also highest in the vibration mode at 164 Hz. Accordingly, the concentrated mass (80 g) was attached to the point.

Effect of Concentrated Mass Attachment

Impact hammering test was performed again to investigate the effect of the concentrated mass attachment. Figure 8 shows the point inertance of left handle before and after attachment of the mass.

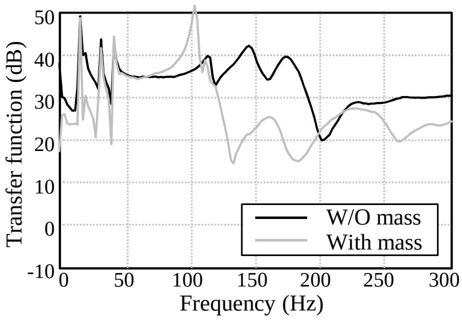


Fig 8 Point intertance comparison between with and without additional mass.

As shown in the figure, the resonance frequency was observed to be decreased to 100 Hz and the vibration response over 100 Hz was reduced very much about 20 dB at maximum by attached the mass. But the response at 100 Hz was increased by the mass attachment and the vibration at the frequency band is supposed to be bad at the operational condition.

D. High damping of rubber bush

Next, we tried to decrease the large vibration response at 100 Hz, which amplitude was increased by modifications. Then, we considered high damping is suitable to reduce the vibration response because the peak at the frequency was very steep as shown in Fig. 8. To add more damping, we focused on a rubber bush that is set between shaft (covered by resinous liner) and main pipe. The material and hardness of the rubber bush was modified to increase the damping efficiency. The effect of the modification was shown in Fig. 9.

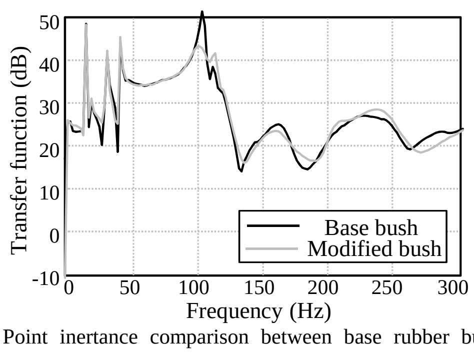
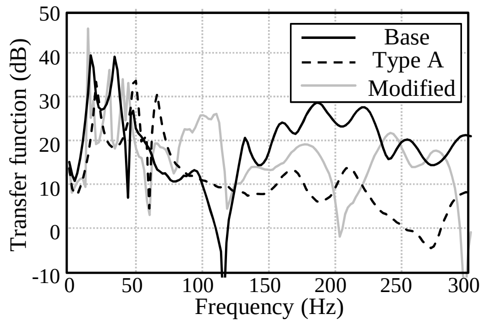


Fig 9 Point inertance comparison between base rubber bush and modified rubber bush.

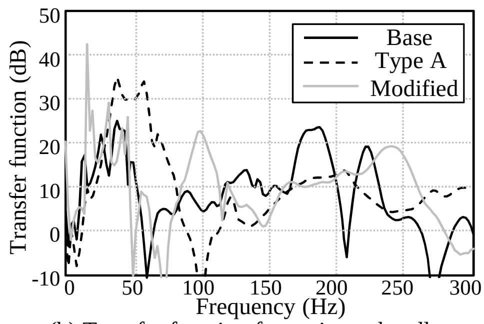
By the modification, the steep vibration response peak at 100 Hz was found to be reduced about 8 dB.

E. Total effect of body modifications

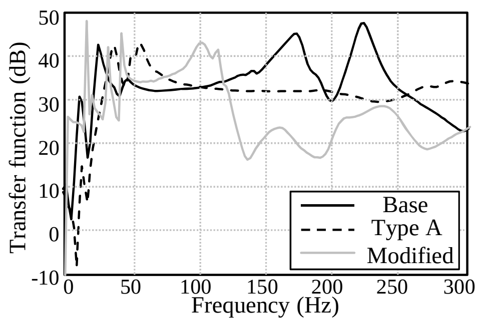
To evaluate total effect of all modifications (low stiffness of handle pipe, attachment of concentrated mass, high damping rubber bush) without any additional total weight, each transfer function was measured again. Figure 10 shows the comparison of original transfer function and transfer function after applying all modifications and transfer function of type A trimmer that had lowest transfer function. Fig. 10 (a), (b), and (c) show the shaft path transfer function, pipe path transfer function, and handle point inertance, respectively.



(a) Transfer function from shaft to handle.



(b) Transfer function from pipe to handle.



(c) Point inertance at handle.

Fig 10 Comparison of transfer functions between base and modified balancing trimmer.

As shown in above figures, the handle point inertance of balancing trimmer body is observed to be reduced very much from 100 to 250 Hz by the modifications (Fig. 10 (c)). The level was lower than that of type A trimmer. Also, in the other transfer functions (shaft path and pipe path transfer functions in Fig. 10 (a), (b)), the response was decreased much by the modifications and the level was close to the type A trimmer.

V. Vibration improvement at operational condition

To investigate how degree the high frequency vibration was improved by the modifications at the operational condition, we measured vibration at left side handle holding position again after applying all countermeasures when the engine rotational speed was from 3000 to 7000 rpm. Figure 11 shows the frequency spectrum comparison before and after modifications at 3000 and 5000 rpm.

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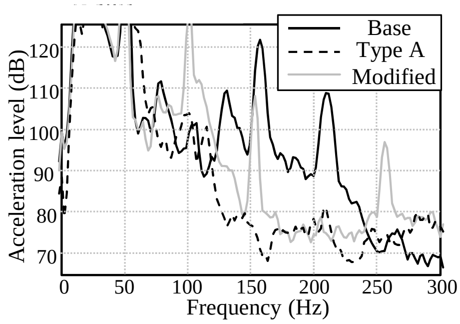
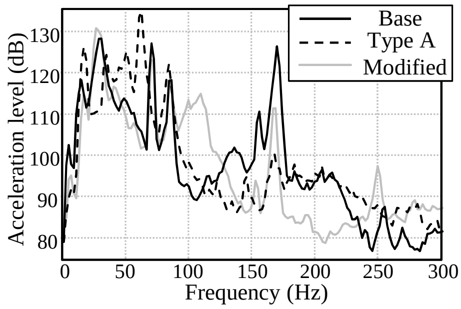


(a) 3000 rpm.



(b) 5000 rpm.

Fig 11 Point inertance comparison between base rubber bush and modified rubber bush.

In the above figures, the vibration at the high frequency band was reduced very much at both operational conditions and the level was close to the type A trimmer which was lowest vibration at the high frequency band. On the other hand, we did not apply any countermeasure to engine side to reduce vibration source level in this study, therefore, the vibration generated by engine rotation (i.e., 167 Hz vibration peak at 5000 rpm) is still higher than that of type A trimmer. Also, the resonance frequency was reduced by the modification to decrease the vibration at the high frequency band. Hence, low frequency vibration may increase by the modification. To evaluate the influence, we calculated overall acceleration level applying ISO5349-1, that was low frequency weighting function, in original and modified balancing trimmers. Figure 12 shows the weighted overall level.

As shown in this figure, the weighted overall level was almost same between original and modified balancing trimmer. This indicates low frequency vibration was not increased by the modification for the high frequency.

From the result, we finally could improve the high frequency vibration by body modification without increase of low frequency vibration and without any additional total weight. In addition, the reason why the low frequency vibration was not increased is considered as follows. The resonance frequency was moved from 170, 220 Hz to 100 Hz by the modification, but the frequency band was not major frequency band which affects the low vibration.

VI. Summary

In this study, we improved vibration of a balancing trimmer that was developed to cut bush safety and easily. Then, we tried the vibration reduction not to increase total weight because the light weight is one of important appeal points of the balancing trimmer. To realize it, firstly we selected which frequency band should be reduced to improve the vibration feeling through frequency analysis to measured acceleration vibration at handle. As the result of the analysis, the vibration at the frequency band from 100 to 250 Hz was very high and the frequency was found to be reduced to improve it. Then, to reduce vibration response of the body of balancing trimmer at the high frequency without additional total weight, we tried to resonance frequency down by low stiffness of a part. Decrease of the thickness of handle pipe, and attachment of concentrated mass, and modification of rubber bush were performed. Then, the total weight was not changed any before and after all modifications. As a result, the vibration response of handle at the high frequency was reduced 20 dB at maximum. In the operational condition (engine running condition), the vibration at the high frequency band was found to be reduced much by the countermeasures. In addition the low frequency vibration was not increased by the modification.

From these results, we could improve the vibration of the new developed balancing trimmer without additional any weight and increasing low frequency vibration.

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