Vibration reduction of brush cutter considering human response characteristic

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ABSTRACT

Balancing brush cutter was developed to be used safety and easy handling. In this study, we tried to improve the vibration through subjective evaluation tests and the vibration analyses. In the first subjective test, participants evaluated handle vibration feelings of some brush cutters and the frequency characteristic to the vibration feeling was clarified. Subsequently, the handle vibration from 100 to 200 Hz was found to be large and the handle pipe structure had high influence on the large vibration through measurements and analyses of the handle vibration at the operational condition. We then applied several countermeasures including modification of the handle pipe length to reduce the vibration. As a result, the handle vibration of the brush cutter was reduced much and the vibration feeling was improved.

Keywords: Brush cutter, Vibration, Transfer function
I-INCE Classification of Subjects Number(s): 13.6.1

1. INTRODUCTION

Small engine brush cutter 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 handling. However, many accidents by the opened rolling cutter have been reported. Representative accident is “kick back” that occurs when rolling cutter attaches on the ground and brush cutter runs rapidly to the operator. In some cases, the rolling cutter comes to the operator directly and his/her foot is seriously injured (1-3).

On the other side, operators are basically exposed the vibration by the rotating engine and the blade. This may cause impairment of hand nerve through long-term operation. Hence, vibration reduction of brush cutter is essential and has been attempted until now (4-8). In the vibration reduction procedure, total weight of the product is generally increased if the countermeasures are applied to reduce vibration at wide frequency range. The increase of the weight deteriorates usability in the operation. Therefore, focusing a frequency band which deteriorates the vibration feeling strongly and measuring the vibration intensively is important to be compatible the vibration with the light weight.

In this study, vibration improvement of a brush cutter was performed considering the operators’ response characteristics to the vibration through subjective vibration evaluation test and the actual vibration reduction of the brush cutter.

2. QUANTIFICATION OF THE VIBRATION FEELING

For the quantification of the vibration feeling of brush cutters, operators evaluated vibration feelings to several cutters and calculation method from the measured vibration acceleration to the vibration feeling was considered.

2.1 Subjective vibration evaluation test

Subjective vibration evaluations were carried out to obtain vibration feeling of each brush cutter. Eight people participated in the test. Each participant evaluated the handle vibration feeling of five brush cutters (Type A, B, C, D, and E) in case the engine rotated at 4000, 6000, or 8000 rpm using paired comparison

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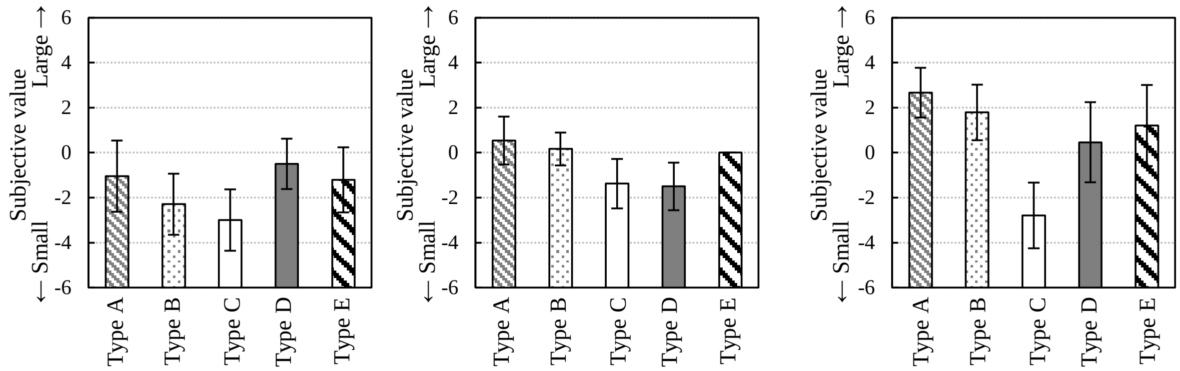
method. Firstly, a standard machine (Type E) was operated at 6000 rpm for about 15 s and then, the evaluation target machine (Type A, B, C, D or E) was used at a constant engine speed (4000, 6000 or 8000 rpm). After this procedure, the participants evaluated how they felt the vibration of the target machine by selecting a category from “very small,” “small,” “slightly smaller,” “unchanged,” “slightly large,” “large” and “very large.” There are 14 evaluation pairs except for the evaluation of the standard machine. Each participant iterated the evaluation three times. Therefore, each participant performed 42 evaluations and there were 336 evaluations in all participants (8 participants x 42 evaluations).

Figure 1 (a), (b) and (c) show the obtained vibration feeling in each target machine averaged for all participants when engine rotational speed is 4000, 6000 and 8000 rpm, respectively. Horizontal axis indicates target machine and engine rotational speed. Vertical axis indicates the obtained vibration feelings. Nothing that in case the value is small, the vibration was evaluated as small.



(a) 4000 rpm (b) 6000 rpm (c) 8000 rpm

Figure 1 – Subjective vibration of brush cutters in each engine speed

As shown in the above figure, vibration feeling of type C machine was observed to be felt the smallest vibration comparing to the other types. On the other hand, Type A machine was evaluated as large vibration. In the following section, we considered an index which can estimate the obtained vibration feeling accurately as shown in the above figure from the measured vibration at several points of the brush cutter.

2.2 Quantification of the vibration feeling

In order to quantify the vibration feeling from the measured vibration acceleration of the brush cutter, we firstly measured handle vibrations of the five brush cutters. For the measurement, brush cutters were hung by rubber strings and vibrations at left and right side handles (front-back and left-right directions) were measured when the engine rotation speeds were 4000, 6000 and 8000 rpm. Subsequently, overall levels were calculated from the measured vibration to investigate the relationship with the vibration feeling. Here, a frequency weighting function was considered to be the overall level able to express the vibration feeling accurately.

As the frequency weighting function, a function was proposed in ISO5341 (9), and the weighted overall level was calculated using the function. Table 1 shows the correlation coefficient between the calculated overall level using the weighting function in each position and the vibration feeling.

Table 1 – Correlation coefficient between vibration feeling and calculated overall using ISO5341 weighting

Measurement position and direction	Correlation coefficient
Left handle front-buck	0.17
Left handle left-right	0.23
Right handle front-buck	0.46
Right handle left-right	0.29

As shown in this table, all coefficients are very low and this result indicates the weighting function of ISO5341 has difficulty to express vibration feeling of brush cutter well. The weighting function was established to assess the influence of various machine (mainly chainsaw) vibrations on the neurological disorder of hand and arm. Therefore, this function is not considered to express the vibration feeling of brush cutter well. Then, we considered various frequency weighting functions and applied them for making the overall level able to express the vibration feeling. As the result, a function mainly weighted from 50 to 500 Hz as shown in Fig. 2 showed good correlation with the vibration feeling.

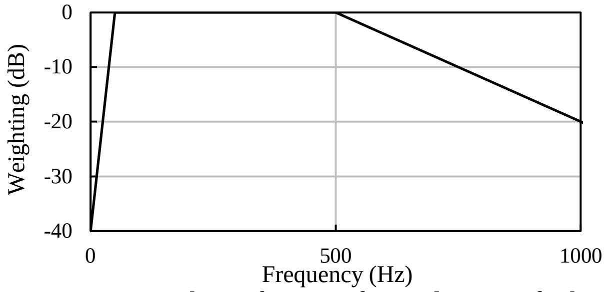


Figure 2 – Frequency weighting function for evaluation of vibration feeling

Table 2 shows the correlation coefficient between the calculated overall level using the function and vibration feeling.

Table 2 – Correlation coefficient between vibration feeling and calculated overall using 50-500 Hz weighting

Measurement position and direction	Correlation coefficient
Left handle front-buck	0.78
Left handle left-right	0.82
Right handle front-buck	0.83
Right handle left-right	0.75

The result shows correlation coefficients became much higher than those using ISO5341 weighting. In addition, the frequency function of 50-500 Hz was found to be able to express the vibration feeling very well. From these results, it was clarified that the vibration from 50 to 500 Hz deteriorate the vibration feeling of brush cutters strongly and it is important to reduce the vibration at the frequency range to improve the feeling.

Subsequently, operators of brush cutters are supposed to evaluate all vibrations totally what they are exposed. Hence, total vibration feeling level (Vib_{feel}) was calculated by adding all weighted overall levels (left handle overall levels at front-back: LV_x and left-right: LV_y directions and right handle levels at front-back: RV_x and left-right RV_y directions) as shown in Eq. (1). The two constant values in Eq. (1) were used to adjust the calculated amplitude and average value as equal to the subjective vibration feeling obtained in the previous subjective vibration evaluation test.

$$Vib_{feel} = 0.098\times(LV_{x\_weight} + LV_{y\_weight} + RV_{x\_weight} + RV_{y\_weight}) - 59.74 \quad (1)$$

To evaluate the accuracy of the calculated total vibration feeling level, we made a scatter diagram as shown in Fig. 3. Horizontal axis denotes the vibration feeling of the five brush cutters at each engine speed (4000, 6000 and 8000 rpm) obtained in the subjective evaluation test (subjective value) and vertical axis denotes the total vibration feeling level (objective value) calculated from the measured vibration accelerations. R value indicates the correlation coefficient between subjective and objective values.

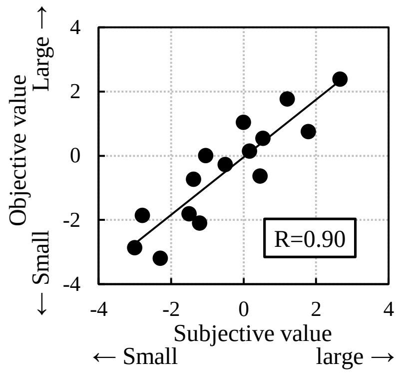


Figure 3 – Scatter diagram of subjective and objective vibration feeling

From this result, the correlation coefficient is observed to be very high at 0.90. Therefore, quantified value was found to be able to express the vibration feeling very accurately. In addition, we can estimate the vibration feeling using the above quantification procedure using only measurement vibration acceleration without subjective evaluation test. Furthermore, we can consider which frequency band and position of the brush cutter should be measured intensively to improve the vibration feeling using the quantification procedure.

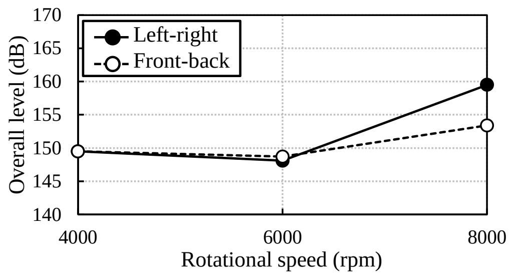
3. VIBRATON IMPROVEMENT

In this section, a vibration improvement was attempted considering the vibration feeling characteristic obtained in the previous section. A balancing brush cutter (10), that was developed to increase the operability, was the target machine and the machine was assessed the vibration as high at the high engine speed. Figure 4 shows the brush cutter.

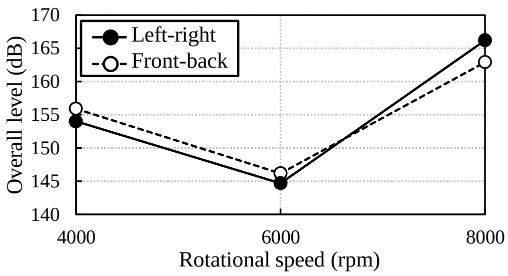
Figure 4 – Balancing type brush cutter

3.1 Vibration measurement

At first, vibration of the brush cutter was measured and analyzed the feeling using the quantification method. 50-500 Hz weighting overall levels were calculated using measured both side handles at each direction and each engine rotational speed (4000, 6000 and 8000 rpm). The obtained overall levels are shown in Fig. 5.



(a) Left handle weighted O.A. level



(b) Right handle weighted O.A. level

Figure 5 – Weighted overall level of each position and direction

Figure 5 (a) and (b) shows the left and right handle weighted overall levels, respectively. Solid line with filled circle and dotted line with opened circle denote the vibration directions of left-right and front-back. Also, the horizontal and vertical axes in both figures denote engine speed and the overall levels.

From these results, the vibration was found to increase largely when the engine speed was high at 8000 rpm. In addition, the right handle vibration along left-right direction was largest. Frequency analysis was performed to find which frequency band in the right handle vibration should be measured. The result of the analysis is shown in Fig. 6.

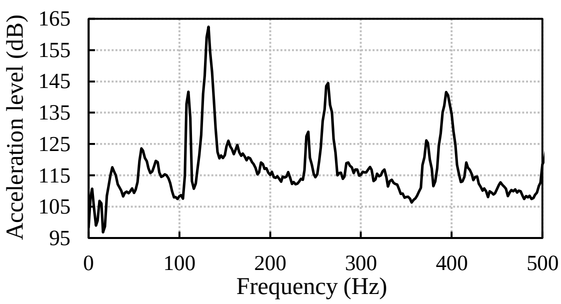
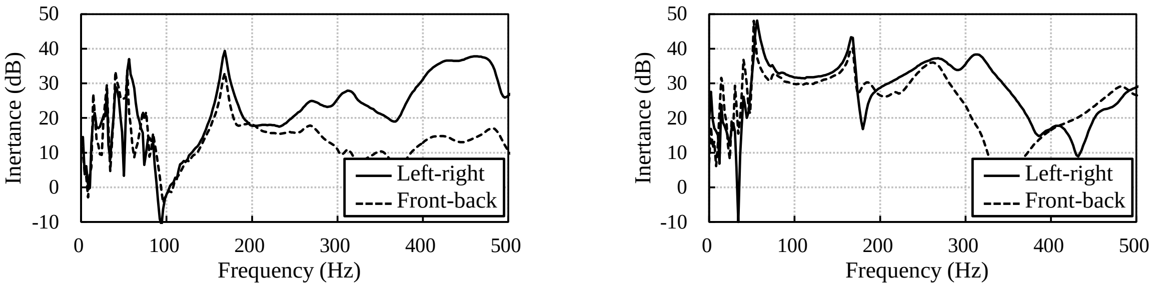


Figure 6 – Right handle acceleration level along left-right direction at 8000 rpm

As shown in the figure, the balancing type brush cutter is observed to have especially large vibration level from 100 to 200 Hz. The frequency band is in the range which deteriorates the vibration feeling strongly. Hence, the large vibration level from 100 to 200 Hz is considered to be a major factor to deteriorate the vibration feeling at the high engine speed.

3.2 Handle and main pipes vibration characteristics

The balancing brush cutter uses various engines and cutters depending on the operated situation, therefore, we tried to decrease the vibration sensitivity of the body (handle and main pipes) of the cutter for the reduction of the vibration. Then, we performed a hammering test to obtain vibration transfer function of the body. For obtaining the transfer function, the coupling point between the engine and the main pipe along vertical direction was used as the input point and the vibrations at right handle left-right and front-back directions were used as the response point. In addition, point inertance of right handle were measured to obtain the vibration characteristic of handle itself. Figure 7 (a) and (b) show the measured transfer function from engine to right handle and point inertance of the handle, respectively.



(a) Inertance from engine to right handle pipe (b) Point inertance at right handle pipe

Figure 7 – Transfer function of balancing type brush cutter

Solid and dotted lines in these figures indicate the inertance of left-right and front-back directions, respectively. From the results, large vibration resonance is observed at 170 Hz band in both transfer function from engine to handle and point inertance at handle. Therefore, the handle vibration characteristic is considered to affect the vibration of the brush cutter largely, and vibration reduction of the cutter at high engine speed is expected by the reduction of these transfer functions from 100 to 200 Hz.

4. VIBRATION REDUCTION

Countermeasures for the vibration reduction were considered through the modification of the body structure. In the reduction procedure, we took care not to increase the total weight by the countermeasure because light weight is one of the important appeal points of the machine.

4.1 Vibration reduction by the handle pipe modification

The handle pipe could be assumed a lateral vibration of a beam as following equation;

$$f_i = \frac{\alpha}{2\pi l^2}\sqrt{\frac{EJ}{\rho A}} \qquad (i = 1, 2\ldots) \tag{2}$$

Where,

f_i : Natural frequency,
α : Eigenmode,
l : Pipe length,
E : Young's modulus,
J : Second moment of area,
ρ : Density,
A : Cross-sectional area.

From the above equation, we can see the pipe length has highest influence on the natural frequency. Hence, in order to move the natural frequency higher, length of the right handle was shortened 80 mm. Figure 8 shows the comparison of the transfer function from engine to right handle before and after the change of the length.

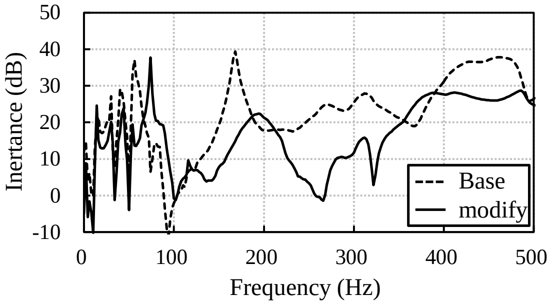


Figure 8 – Comparison of transfer function before and after the modification of handle pipe

As shown in the above figure, the transfer function could be reduced significantly from 100 to 200 Hz by shortening the right handle length. However, there is a slight vibration peak at 120 Hz and, the inertance at 190 Hz was increased by comparing to the inertance of the original handle. Then, we applied the other three countermeasures as follows.

1. Change of the handle pipe attachment point on the main pipe
   (Coupling position was advanced to engine side for 110 mm, where the vibration node of the main pipe.)
2. Change of the handle angle
   (Handle pipe angle was inclined 15 degrees to rotary cutter side.)
3. Inserting rubber mat
   (Rubber mat was inserted between joint point between handle and main pipe.)

Figure 9 shows the comparison between the original transfer function from engine to right handle (left-right direction) and the transfer function after applying these four countermeasures.

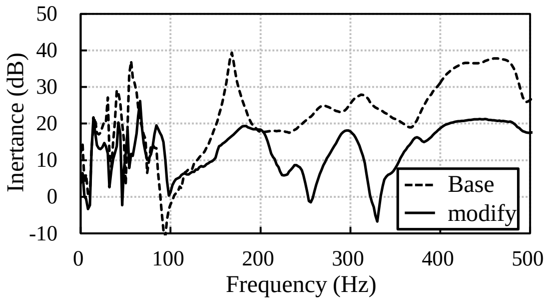


Figure 9 – Comparison of transfer functions before and after applying all countermeasures

From this result, the inertance peak at 120 Hz and the increase of inertance at 190 Hz are observed to be reduced, and the inertance from 100 to 200 Hz could be reduced very much by these countermeasures. Then, we measured the vibration at the operating condition again to verify the vibration reduction at the condition. The comparison of the right handle vibrations along left-right direction before and after modification when the engine speed was 8000 rpm is shown in Fig. 10.

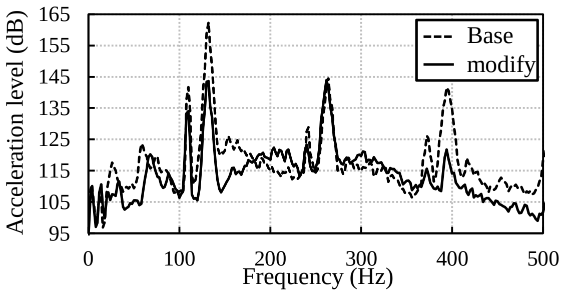


Figure 10 – Comparison of right handle vibration at 8000 rpm before and after applying all countermeasures

As shown in Fig. 10, the vibration level from 100 to 200 Hz could be reduced largely by the countermeasures. The vibration feeling is expected to be improved by the vibration reduction at this frequency band. On the other hand, there is a possibility of vibration increase at the other engine speeds (4000 and 6000 rpm). To assess them, we measured the right handle vibration at these engine speeds and calculated 50-500 Hz weighted overall level in each condition. The calculated overall levels are shown in Fig. 11.

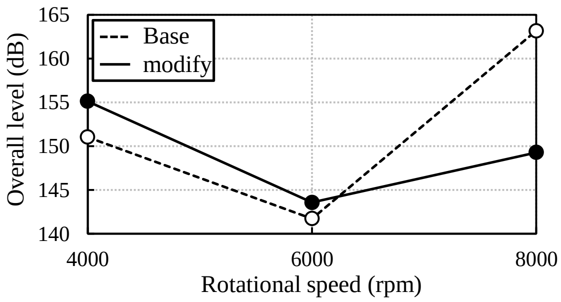


Figure 11 – Weighted O.A. before and after countermeasures

From the results, the overall level at 8000 rpm was found to be reduced significantly as expected and the levels at 4000 and 6000 rpm were not increased largely. Subsequently, we calculated the total vibration feeling level using the calculation procedure proposed in the second section to estimate the improvement of the vibration feeling. The result is shown in Fig. 12.

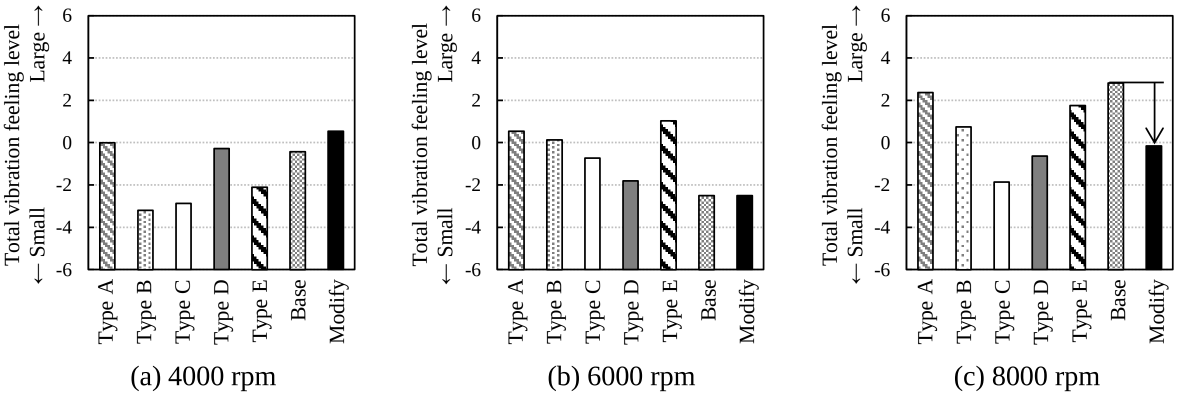
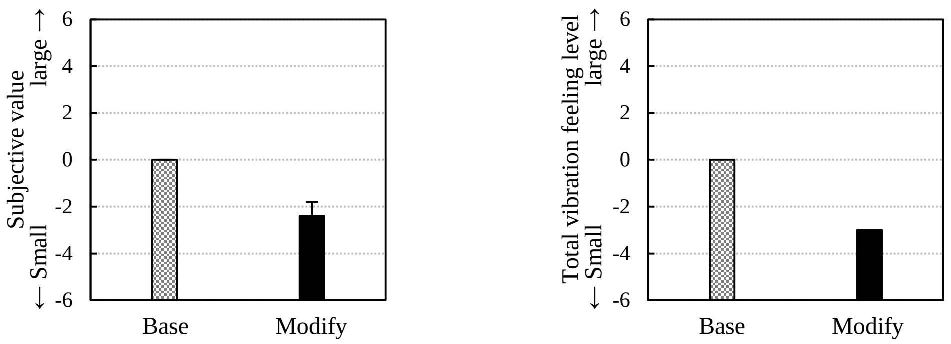


Figure 12 – Total vibration feeling levels before and after modification

For comparison, total vibration feeling levels of the other five brush cutters used in the subjective evaluation test were calculated and added in Fig. 12. From the result, the level of the balancing brush cutter at 8000 rpm was decreased largely by the modification and the level approached to the level of type C brush cutter that was evaluated lowest vibration. Also, the levels at 4000 and 6000 rpm were not increased so much. These results indicate operators will perceive the vibration improvement significantly by the modification.

4.2 Subjective evaluation to verify the vibration improvement

In the previous section, the handle vibration at 8000 rpm was reduced and the vibration feeling was expected to be improved. Consequently, subjective evaluation test was performed again to confirm whether operators can determine the vibration improvement or not, and to verify the accuracy of the quantified total vibration feeling levels. The experimental procedure was almost same conducted in the first subjective evaluation. In this test, only the comparison of vibration feeling between original and modified balancing brush cutters at 8000 rpm was performed. Six people participated in the test, and each participant iterated the comparison three times. Averaged score of the vibration feeling for the six participants is shown in Fig. 13 (a). Figure 13 (b) shows the difference of the calculated total vibration feeling levels between original and modified cutter for the comparison. Here, the level of original balancing brush cutter is set as zero in both figures to compare the relative difference.



(a) Subjective evaluation result (b) Estimated level

Figure 13 – Vibration feeling difference between original and modified brush cutter at 8000 rpm

From these results, the vibration feeling at 8000 rpm was actually improved by the modification, and the improved level was almost same as the expected level by the quantification procedure. This indicates the quantification method for the vibration feeling of brush cutters is very accurate.

5. SUMMARY

In this study, vibration improvement of a brush cutter was performed considering operators' response characteristics to the vibration feeling. We firstly carried out subjective vibration evaluation tests using several brush cutters to obtain the characteristics and quantify the vibration feeling. As a result, vibration feeling was found to be affected by the front-back and left-right directions of the both side handles' vibrations. Especially, vibration acceleration from 50 to 500 Hz was found to affect the vibration feeling largely.

Subsequently, we tried to improve the vibration feeling of a balancing brush cutter using the obtained vibration feeling characteristics. Through the vibration measurement at the operational condition and the frequency analysis, the handle vibration was large from 100 to 200 Hz, where the vibration feeling was deteriorated strongly. Accordingly, we tried to reduce the vibration taking into account the total weighting. As the countermeasures, the length of the right handle, attachment point of handle and main pipe, handle pipe angle were modified in addition to inserting a rubber mat at the attachment point. As the result, the handle vibration could be reduced very much and the vibration feeling was verified to be improved. From these procedures, we finally could improve the vibration of the new developed balancing brush cutter considering operators vibration feeling characteristics.

REFERENCES

1. Kashima J. et al. Analysis of accidents related to brush-cutter use. Journal of the Japan Forest Engineering Society. 2010;25(2):77-84. (In Japanese).
2. Futatsuka M. A study on the vibration hazards due to using bush cutters. Japanese Journal of Industrial Health. 1979;21(3):269-273 (In Japanese).
3. Toyoda N, Minakawa K. Tsukamoto S. A study on enhanced safety of the bush cutter -Development of cutting blade stop mechanism- :1st report. Annual Meeting of Japanese Agricultural Machinery and Food Engineers. 2014;73:126. (In Japanese).
4. Seto K. New method of vibration isolation utilizing vibration node: 1st report, on the theory of this method. Transactions of the Japan Society of Mechanical Engineers. 1983;49(439):341-350. (In Japanese).
5. Seto K. New method of vibration isolation utilizing vibration node: 2nd report, application to the handle device. Transactions of the Japan Society of Mechanical Engineers. 1983;49(447):2092-2099. (In Japanese).
6. Daikoku M. Hand-transmitted vibration reduction of the walking type and the portable type agricultural machinery. Technical Report of the Institute of Agricultural Machinery. 1991;27:1-74. (In Japanese).
7. Okada S. et al. Study on Low Vibration Bush Cutter. JSME Industrial, Chemical Machinery & Safety Division Conference 2009. 2009:23-24. (In Japanese).
8. Yoshida J. et al. Reduction of trimmer vibration while maintaining low weight -reduction of high-frequency vibration in engine powered trimmer without increasing its weight-. Journal of the Japanese Society of Agricultural Machinery and Food Engineers. 2014;76(1):99-106. (In Japanese).

9. ISO5349-1. Mechanical vibration - measurement and evaluation of human exposure to hand-transmitted vibration part:1 general requirements. 2001.
10. Ishikawa D, Miyakawa S, Oono T, Yamamoto T. Kawano T. Experimental verification on mitigation of mowing work burden of yajirobe type brush cutter. Ergonomics. 2013;49:236-237. (In Japanese)