

Vibration Reduction Technology with Mount Rubber for Outboard Motors BF4/5/6

Yasukata KOHASHI*

Takeshi OKADA*

Yoshihiro HARADA*

ABSTRACT

When the BF5 outboard motor underwent a model change recently, a model was added with 20% more output, with faster engine speed and a higher compression ratio, even as it kept the same balancer-less engine and the same basic frame structure. The development discussed in this paper enhanced the customer appeal of the outboard motor by reducing handle vibration and yawing while idling. The mount rubber is a critical component for reducing vibration, as it transmits the thrust of the outboard motor and absorbs vibration. The specs of the mount rubber can also be changed. As such, the mount rubber became the focus of this study. Changing the characteristics of the mount rubber resulted in maintaining about the same level of handle vibration at the maximum speed, with only half as much yawing while idling, even though the new outboard motor had greater output.

1. Introduction

The five-horsepower BF5 outboard motor recently got its first model change in 30 years. Upon making this model change, Honda expanded the lineup into a series. Instead of a single model with five horsepower, there are now three models, offering four, five, and six horsepower. As a result, the BF6, which offers the most horsepower of the three models, offers 20% more output than the previous model, even as it keeps the same single-cylinder 127 cm³ engine and the same basic frame structure. Basic specifications of the engine are given in Table 1.

Major uses of outboard motors of this class include power for small fishing boats and tenders (small boats that move people and cargo between larger boats and shore), and kicker engines for large boats. Outboard motors are attached to the stern of the boat. The user controls the boat with a hand on the tiller handle, which is used to steer and adjust engine speed. Therefore, lowering handle vibration is desirable to make the outboard motor more appealing to customers. The previous model, BF5, was the only model in its output class, at Honda or any other manufacturer, to use mount rubber, and as a result offered the lowest handle vibration in its class, as noted in Fig. 1. The mount rubber, however, caused more visible swinging (below, yawing) of

Table 1 Engine specifications

	BF5 (previous)	BF6 (new)	BF4/5 (new)
Engine type	Single cylinder, 4-stroke		
Displacement (cm ³)	127		
Bore × Stroke (mm)	60 × 45		
Compression ratio	8.7:1	9.8:1	
Mass of reciprocating parts (g)	209.5	215.8	
Inertia force – 1st order (N)	646	958	805
Full throttle speed (r/min)	5000	6000	5500

the outboard motor while idling.

The recent model change included a newly designed mount rubber, the emblematic feature of the previous model. The new shape of the mount rubber changed its mounting characteristics and reduced handle vibration and yawing.

This paper introduces how the vibration was reduced and how the mount rubber can simultaneously provide its other function: supporting the outboard motor as it sustains thrust.

* Power Products R&D Center

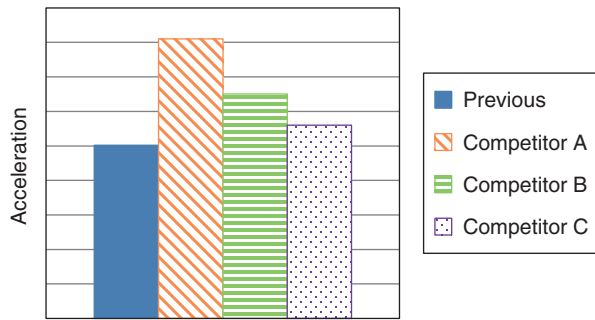


Fig. 1 Tiller handle grip vibration

2. Development Goals and Targets

The overall frame structure is shown in Fig. 2. The main frame connects the single-cylinder balancer-less longitudinal engine with the gear case, which moves the propeller. The mount rubber is positioned between the main frame and the outboard motor support parts (shown in blue in Fig. 2), which connect the main frame to the boat transom, in such a manner that no pressure is applied, and from there the mount rubber supports the main frame. The tiller handle is attached to the outboard motor support parts.

This research enhanced the characteristics of the five-part mount rubber, resulting in reduced handle vibration, reduced yawing, and more durable mount rubber.

When establishing the six-horsepower model as the top-of-the-line in terms of horsepower, Honda modified the compression ratio and changed the upper limit of engine speed (Table 1). Honda made other changes to counter the increase in cylinder pressure from the changed compression ratio, such as increasing the thickness of the main motor system components. As a result, the mass of the reciprocating parts of the main motor system increased. In addition, the upper limit of engine speed was increased by 1000 r/min over the previous model. This results in an increase of about 50% in exciting force by inertia. Vibration increases correspondingly, making it necessary to lower handle vibration.

The next issue to address was the fact that using mount rubber increases yawing while idling, as noted previously and as shown in Fig. 2. This results from fluctuation in the crank shaft driving torque. When the customer appeal of the motor is considered, it is desirable to have less yawing. Tests with actual equipment showed that cutting the amplitude of yawing in half compared to the previous model enhanced customer appeal, so one development target was to lower yawing.

Furthermore, greater output increased the amount of thrust generated by the propeller, raising maximum thrust 25%, from 560 N to 700 N. This thrust reaches the boat transom through the aforementioned mount rubber, becoming propulsive power for the boat. In other words,

there is more load on the mount rubber, which means that there is more displacement. Therefore, it is necessary to check for any decrease in mount rubber durability and verify the contact with structural members of the frame supported by the mount rubber.

In response to the above-mentioned exciting force increase, yawing while idling, and durability of mount rubber, the following were chosen as development targets for the new six-horsepower model.

- Keep handle vibration at 6000 r/min at the same level as 5000 r/min in the previous model.
- Reduce amplitude of yawing while idling by half compared to the previous model.
- In terms of mount durability, there should be no loss of function owing to damage or deformation even at 25% greater input load than that experienced by the previous model.

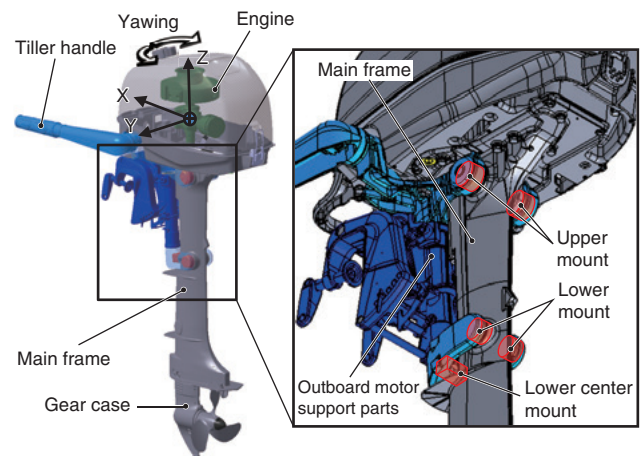


Fig. 2 Frame structure and mount rubber

3. Study of Mount Rubber

Since this development follows the basic structure of the previous model, the size and installation position of the mount rubber would remain the same. The study, therefore, would focus mainly on changing the shape of the mount rubber.

Figure 3 outlines the effects of changing the mount rubber spring rate. Low-rigidity rubber is preferable in respect to vibration, but high-rigidity rubber is preferable in respect to maximum displacement and durability. The new model would need to offer both these aspects. In the past, Honda's BF9.9 outboard motor achieved a more non-linear spring rate and lower vibration by adapting the shape of the mount rubber⁽¹⁾. This development sought likewise to achieve its vibration and durability targets with mount rubber having a non-linear spring rate. Figure 4 illustrates non-linear spring characteristics such as that rubber has low

rigidity under low load and high rigidity under high load. This paper describes the results of using CAE to forecast the effect of using such non-linear spring characteristics, and discusses the mount rubber shape that was finally chosen.

3.1. Requirements of Mount Rubber

To begin, the authors analyzed factors of handle vibration at high engine speeds. Figure 5 shows the results of vibration measurements at the tiller handle and close to the upper mount of the main frame. When the engine speed rose from 5000 r/min to 6000 r/min, the lateral acceleration of the main frame rose rapidly, leading longitudinal vibration of the tiller handle to increase. That is, lateral vibration of the main frame causes handle vibration to increase at high engine speeds. For that reason, lowering handle vibration requires damping lateral vibration.

Thus, the authors used CAE analysis to study the relationship between mount rubber spring rate and handle vibration⁽²⁾. Figure 6 is a conceptual diagram of the CAE analysis model. The outboard motor frame and tiller handle were modeled with 1D elements, with the upper and lower mount rubber expressed as spring elements. The various kinds of exciting force occurring at the engine's crank shaft were applied and the response of the tiller handle was evaluated.

To lower the lateral vibration with this model, the lateral spring rate was set lower than that of the mount rubber of

the previous model for the purposes of this study. The CAE analysis results are shown in Fig. 7. The results show that if the lateral spring rate is lowered 50% compared to the previous model, the new model operating at 6000 r/min will have even less handle vibration than the previous model had at 5000 r/min. This would meet the development target.

The authors next studied yawing while idling. The target was to cut such yawing in half compared to the previous model. Using the aforementioned CAE model, we confirmed the effect of changing the mount rubber's spring rate. The results are shown in Fig. 8. The previous model showed greater yawing at idling speed because of the mount rubber's resonance. First, based on the results of the study of handle vibration, the authors lowered the longitudinal and lateral spring rate by 50% compared to the previous

	Increase spring rate (increase resonance)	Decrease spring rate (decrease resonance)
Transfer function	Response Common use revolution Frequency	Response Common use revolution Frequency
Yawing	Good	Good
Tiller handle vibration	Poor	Good
Maximum displacement	Good	Poor
Durability	Good	Poor

Fig. 3 Effect of rubber from spring rate

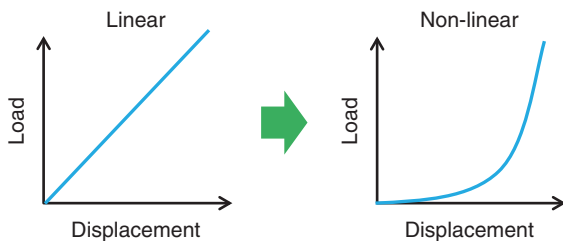


Fig. 4 Spring rate of mount rubber

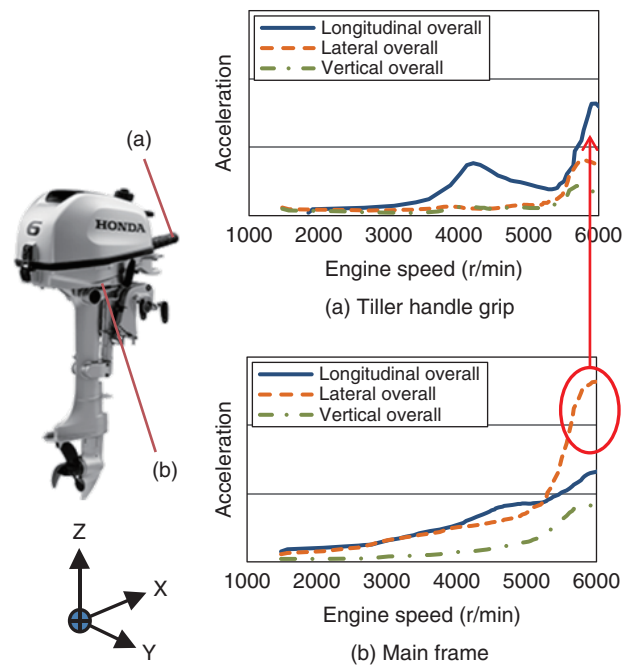


Fig. 5 Tiller handle and main frame vibrations

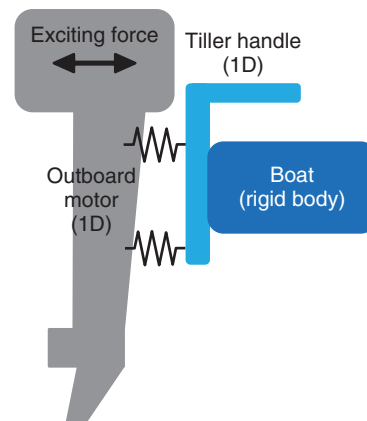


Fig. 6 CAE model

model and found that the results for yawing did not meet the target at engine speeds under 1500 r/min. When we further lowered the spring rate, to 33% that of the previous model, yawing declined by half across the entire idling speed zone, which meets the target.

Therefore, lowering the spring rate to just 33% or less that of the previous model became the requirement to achieving the handle vibration and yawing targets.

Next, this paper discusses permissible maximum displacement. Thrust from the propeller causes the mount rubber to deform. It is necessary to limit the amount of deformation in the mount rubber. This way, there will be no contact when there is narrow clearance with the main frame and outboard motor support parts, as illustrated in Fig. 9. The permissible maximum displacement for the mount rubber was determined based on the amount of clearance needed to help avoid contact between parts. Results of the

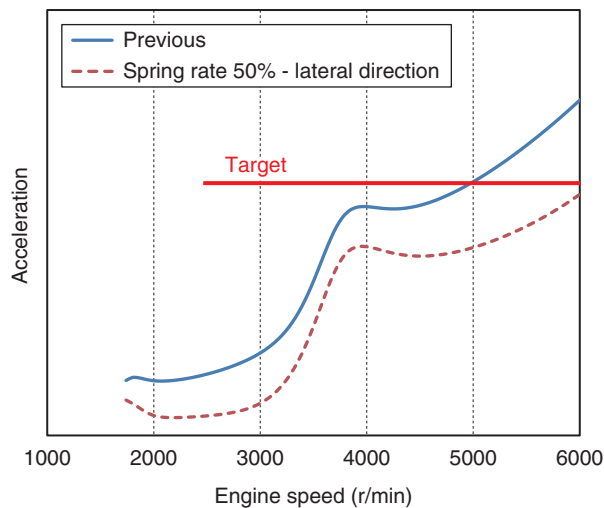


Fig. 7 Tiller handle vibration, by CAE

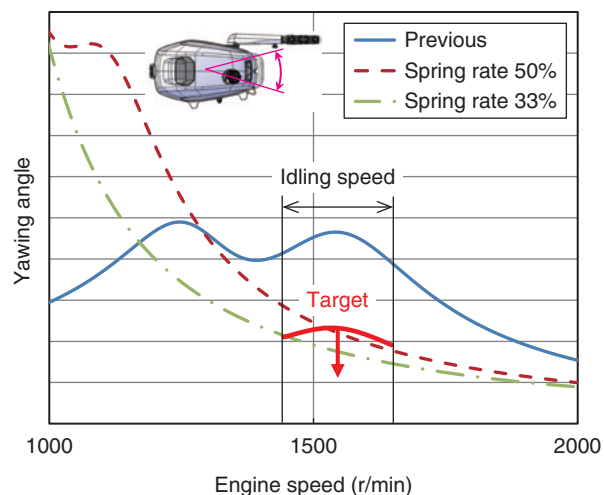


Fig. 8 Yawing while idling, by CAE

Table 2 Design targets for new mount rubber

Items	Direction	Upper	Lower
Spring rate at low load (comparison to previous)	Longitudinal	33% or under	
	Lateral		
Maximum displacement (mm)	Longitudinal	11.5 or under	4.5 or under
	Lateral	3.5 or under	2.0 or under
Strain	Longitudinal	Previous value or under	
	Lateral		

study are shown in Fig. 10. Making the displacement as great as possible is desirable for the purpose of lowering the mount rubber's spring rate, but the results show it is necessary to set longitudinal displacement no greater than 50% higher than that of the previous model at both the upper and lower mounts. Therefore, it is not possible to greatly increase longitudinal displacement.

Finally, the authors used CAE analysis to check the maximum strain value, which affects mount durability. A requirement was set to keep the maximum strain value within that experienced by the previous model.

Table 2 summarizes the requirements guiding design of the mount rubber so far.

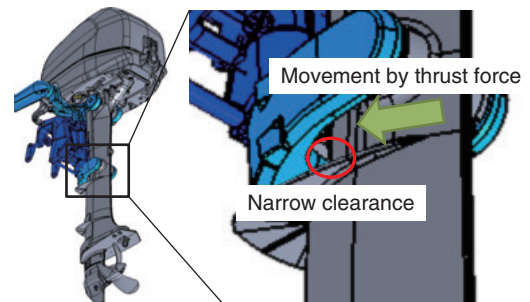


Fig. 9 Clearance between main frame and support parts

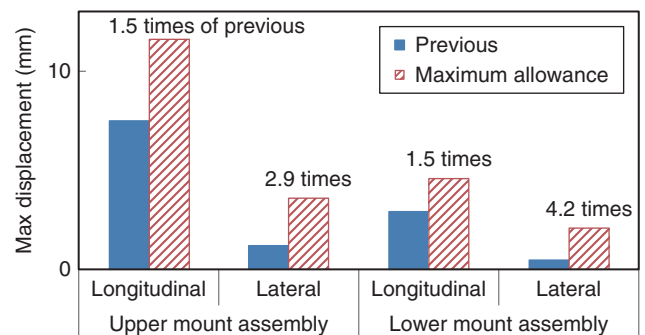


Fig. 10 Maximum displacement allowance to keep clearance

3.2. New-Shape Mount Rubber

Figure 11 compares the shape of the mount rubber in the previous and new models as studied here, taking the aforementioned requirements as preconditions.

Adding the protuberances shown as red circles greatly reduced rigidity in the longitudinal and lateral directions under low loads. In addition, the upper and lower mount rubbers were shaped to have plains along the circumference to give directionality in the longitudinal and vertical directions; this regulates rotation.

The spring characteristics of the mount rubber were confirmed by CAE. Figure 12 shows the upper mount assembly's spring characteristics in the longitudinal direction, while Fig. 13 shows the same in the lateral direction. The mount rubber's protuberances, shown within circles in the figure, are designed to make contact under low load. As the load increases, the protuberances are flattened so that the entire mount rubber bears the load. This structure helps enable the non-linear spring characteristics that the

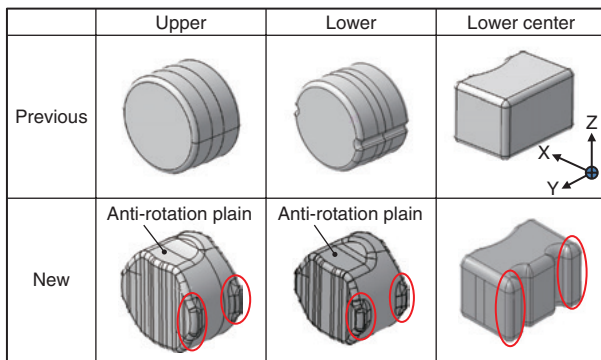


Fig. 11 Mount rubber shape

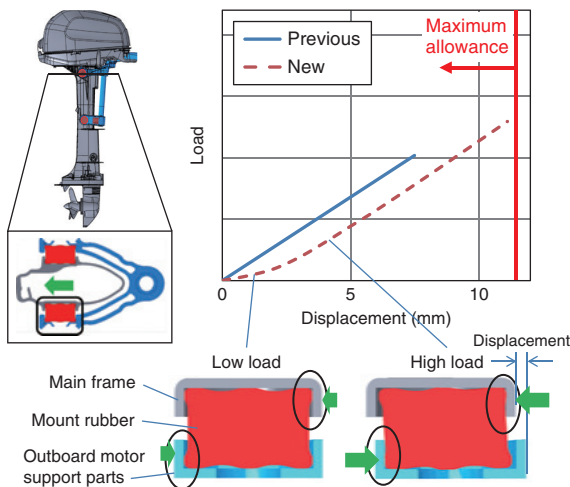


Fig. 12 Non-linear characteristic and deformation of new mount rubber (upper mount assembly, longitudinal)

research was targeting. In addition, permissible maximum displacement was within requirements even under the increased load of high output.

The spring characteristics of the lower mount assembly are shown in Figs. 14 and 15. Like the upper mount assembly, the rubber showed low rigidity under low load, while maximum displacement under high load also met requirements.

Additionally, CAE analysis was conducted on the mount rubber strain value in each direction of load to help the new mount rubber meet the durability target. The results are shown in Fig. 16. The strain value of the new-shape mount rubber remained as low as that of the previous model regardless of the higher maximum displacement.

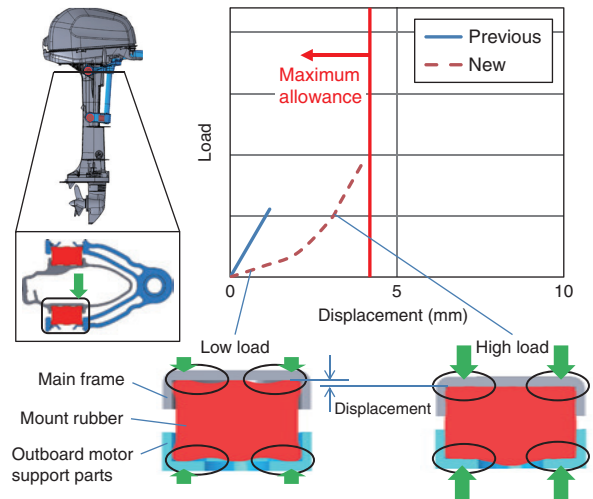


Fig. 13 Non-linear characteristic and deformation of new mount rubber (upper mount assembly, lateral)

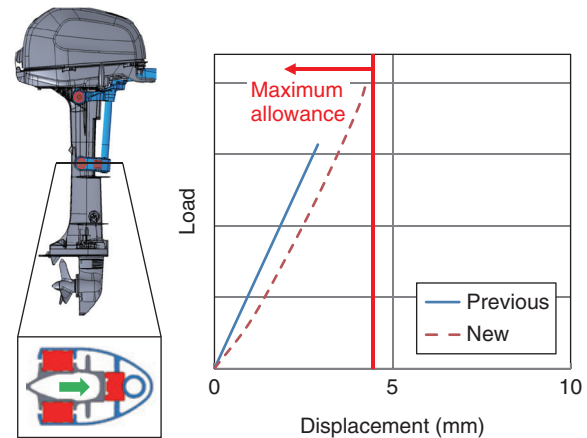


Fig. 14 Non-linear characteristic of new mount rubber (lower mount assembly, longitudinal)

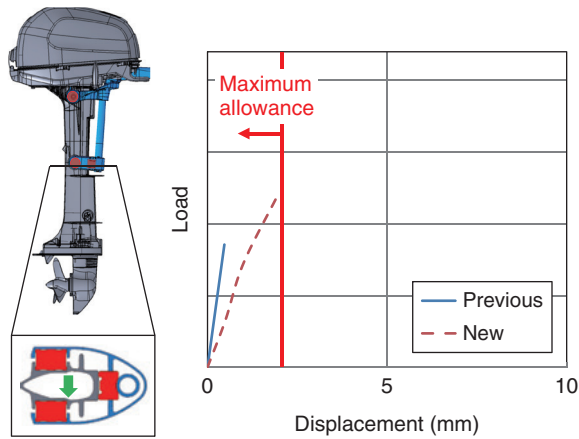


Fig. 15 Non-linear characteristic of new mount rubber (lower mount assembly, lateral)

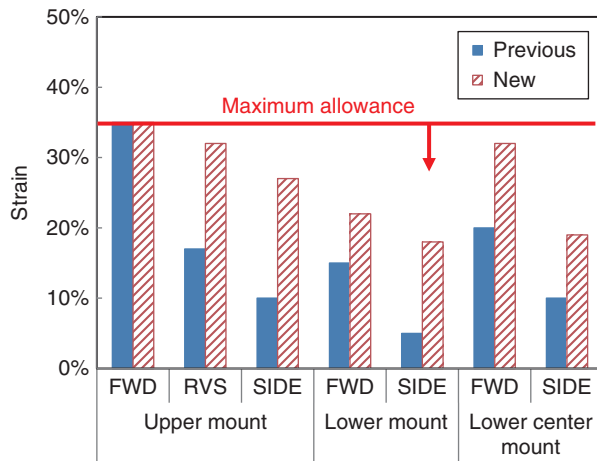


Fig. 16 Strain value, by CAE (each part and load direction)

4. Test Results

Vibration tests were conducted on actual equipment incorporating the new-shape mount rubber illustrated in Fig. 11.

Handle vibration test results are given in Fig. 17. Acceleration at 6000 r/min in the new model was about the same as that at 5000 r/min in the previous model, which was one of the development targets. In addition, tiller handle vibration was greatly reduced over the entire range from low speeds to high. Acceleration decreased by up to 50% when the two models were compared at the same speed.

Next, test results for yawing during idling are given in Fig. 18. The new model caused up to 75% less yawing than the previous model, thus achieving the target.

Finally, the paper discusses the results of the durability check. The mount rubber did not suffer damage or cracking in the various durability and strength tests conducted

during development. Even with protuberances added to the mount rubber to lower rigidity, the mount rubber satisfied the durability target by keeping the maximum strain value within requirements.

The above results indicate the effect of giving the mount rubber non-linear properties so that it has low rigidity at low loads and high rigidity at high loads.

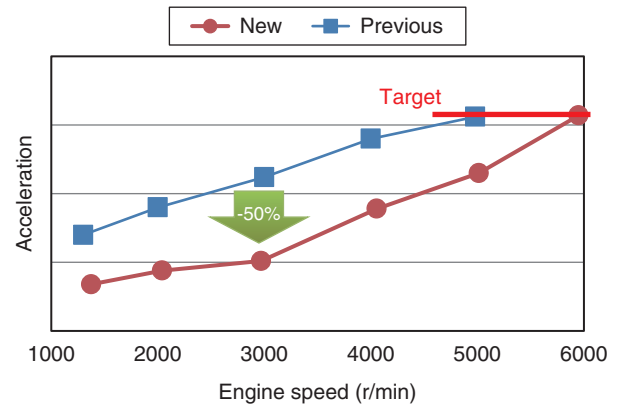


Fig. 17 Tiller handle vibration (experiment)

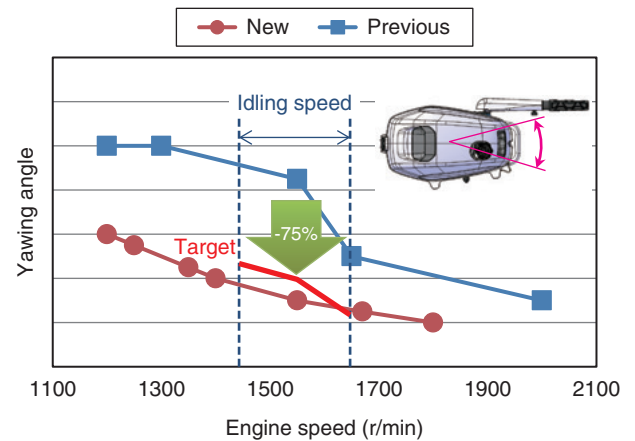


Fig. 18 Yawing (experiment)

5. Conclusion

Tests and CAE analysis were used to clarify the performance required of mount rubber in and of itself in order to satisfy the target vibration performance of an outboard motor. To embody such performance, the shape of the mount rubber was newly designed to make it highly non-linear. In other words, the mount rubber has two opposing characteristics: it has low rigidity in respect to vibration and high rigidity in respect to load.

The results indicate the target vibration performance was achieved even with the new model's high output and speed.

Specifically, handle vibration is reduced by up to 50% at the same speed, and even at its maximum speed, the new model has about as much handle vibration as the previous model at its own maximum speed. Additionally, the amplitude of yawing during idling is reduced by up to 75% compared to the previous model, greatly contributing to customer appeal.

References

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■ Author ■



Yasukata KOHASHI



Takeshi OKADA



Yoshihiro HARADA