

Development of High-Efficiency Water Pump Using CFD Simulation

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ABSTRACT

Water pumps are often used for many continuous hours, and as a result, they account for a large part of the CO₂ emissions of general-purpose products. Therefore, it is desirable that the fuel consumption of such pumps be improved.

In order to make such an improvement, computational fluid dynamics was used to develop water pump specifications that would adjust the working performance and enhance the efficiency of such pumps.

The water pump developed herein was targeted at users of three-inch pumps doing irrigation work with low head (lifting height) in Southeast Asia. The researchers forecast that the new pump could improve fuel consumption by more than 20% compared to a current model within the operating range of the market, thanks to adjustment of the pump performance in line with the needs of the target market, enhancement of pump efficiency, use of a low-displacement engine, and adjustment of air-fuel ratio. The effect was then confirmed by testing.

1. Introduction

1.1. Issues Concerning Water Pumps

Ensuring adequate water resources on the global scale has become a major issue in light of population growth and global warming in recent years. Projections indicate that food production will continue to increase in the future (Fig. 1)⁽¹⁾, a trend which is likely to increase water demand. Water pumps are used around the world as machines for helping irrigators use water resources, and as food production and water demand rise, the demand for water pumps is expected to increase as well.

These pumps perform a number of jobs, including irrigation of paddies and dry farm fields, draining and adjusting the water levels of ponds and pools, and filling water tanks.

Pumps are often used for four to eight hours continuously, so they tend to have higher CO₂ emissions than other equipment. Based on an analysis of the various general-purpose products sold by Honda, it is forecast that water pumps will account for 85% of the CO₂ emissions of this product category (Fig. 2).

Thus, as demand for water pumps rises in the future, CO₂ emissions are expected to increase all the more. As a manufacturer of water pumps, Honda therefore wishes to improve water pump fuel consumption and lower the CO₂ emissions of these products.

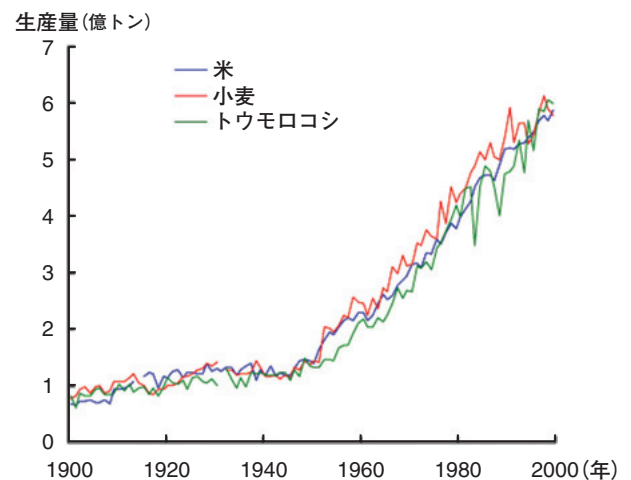


Fig. 1 Quantity of crops production

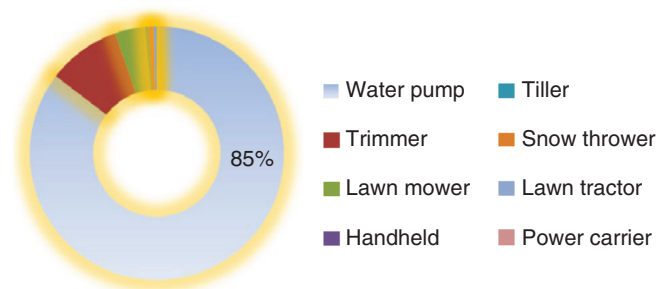


Fig. 2 CO₂ emission ratio of Honda power products

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1.2. Analysis of Honda Water Pump Sales Patterns

This section discusses sales patterns for water pumps at Honda. Honda began selling water pumps in 1967. Its product lineup is categorized in inches according to the diameter of the pump's inlet and outlet. Sales results from FY2011 indicate that the three-inch class had the most sales, accounting for 52% of all pumps sold (Fig. 3).

By region, the results indicate that about 44% of Honda pumps were sold in China, Southeast Asia, or Oceania (Fig. 4).

1.3. Market Characteristics

Figure 5 shows a work point map for water pumps in various regional markets as indicators of discharge capacity and head. The operating range of water pumps in each region is determined by such factors as application, installation environment, and awareness of oil fuel. Southeast Asia clearly differs from other parts of the world,

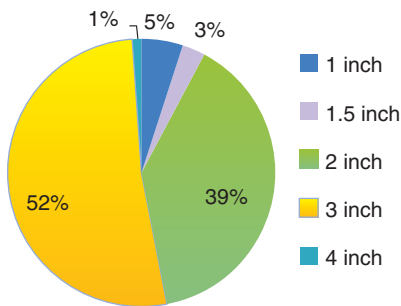


Fig. 3 Inch categorized sales result of Honda pumps

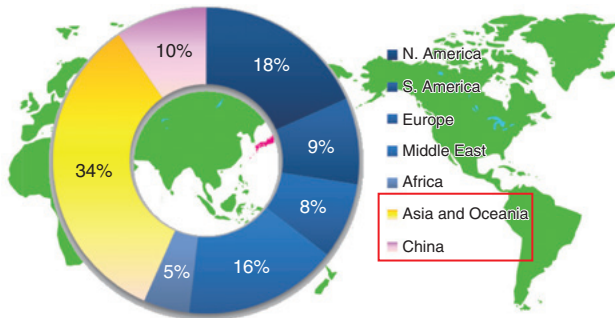


Fig. 4 Area categorized sales result of Honda pumps

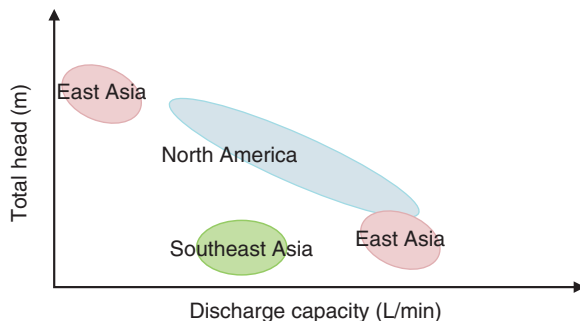


Fig. 5 Work point map of water pump

where water pumps are frequently used to irrigate paddy fields. The work point here is characterized by low rotation, meaning limited discharge capacity, and low head.

2. Characteristics and Performance Targets for the Newly Developed Pump

2.1. Characteristics of the Newly Developed Pump

Water pumps sold by Honda are mostly self-priming. Pumps need to have appropriate pump performance (the transport performance of water) as well as be self-priming, meaning that upon starting up, the pump can lift water from the source all the way up to the pump itself. Self-priming is the process in which a pump expels inlet-side air once only the inside of the pump is filled with water (Fig. 6). During self-priming, air and water mix inside the pump, after which only the air that is close to the outlet becomes separated and expelled (Fig. 7).

There are several ways to get good self-priming performance, such as increasing the turbulence at the air-water interface to encourage mixing, and encouraging separation by drawing the mixed fluid with a centrifugal flow. However, during ordinary work after self-priming has already occurred, the structure of a pump that enhances these self-priming properties tends to lower pump efficiency. Thus pump performance and self-priming performance often conflict with each other.

2.2. Component Configuration

As Fig. 8 shows, the major components of a water pump are the impeller, volute, casing, inlet, and outlet.

While the form of each component has to be decided based on a balance of pump performance and self-priming performance, the newly developed pump favors pump performance.

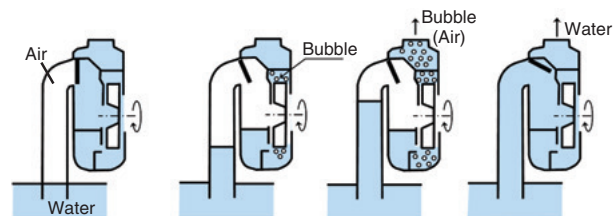


Fig. 6 Self-priming image

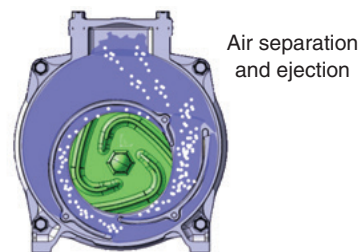


Fig. 7 Water circulation image of self-priming process

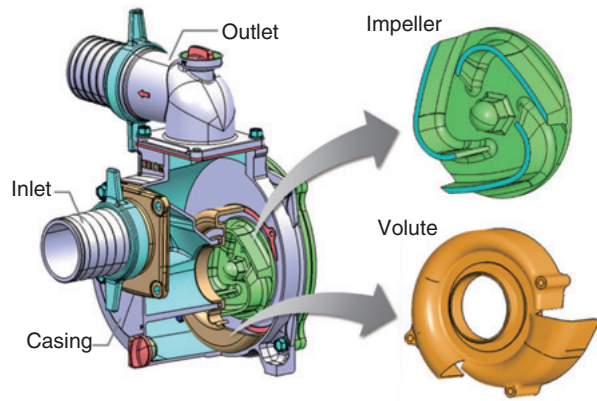


Fig. 8 Main parts of water pump

2.3. Development Target Market and Performance Targets

The newly developed water pump was targeted at users of three-inch pumps doing low-head irrigation in Southeast Asia. It was intended to improve fuel consumption in actual use.

The performance target was to improve fuel consumption in actual use by at least 20%, in part by optimizing impeller form to enhance pumping efficiency and by making adjustments like switching engines.

3. Examination of Specs

3.1. Pump Performance Adjustment Concept

The researchers examined pump performance suitable for low-head, low-rotation operation. As an example, two pumps (A and B) with the same maximum discharge capacity and efficiency were compared. B has a lower maximum head than A. Figure 9 illustrates operation of the two pumps at a low-head, low-rotation work point. The figure shows how the efficiency of pumps A and B differs at the work point under these conditions. B can operate at higher efficiency.

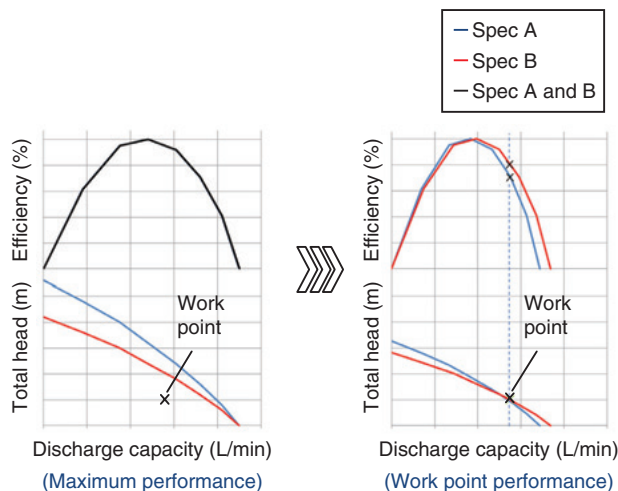


Fig. 9 Concept image of pump performance tuning

Table 1 CFD setting

Solver	Pressure-based
Viscous model	k- ω Standard
Motion	Mesh motion
Scheme	SIMPLE
Fluid materials	Water

Therefore, the pump performance was adjusted in the newly developed pump to prioritize efficiency at the work point and lower the maximum head.

3.2. Specs Examination Technique

To develop the new pump, the researchers used computational fluid dynamics (CFD) software to forecast pump performance and consider pump form. Table 1 lists the CFD settings, while Fig. 10 gives a CFD image and Fig. 11 shows results of confirming the forecasting precision on

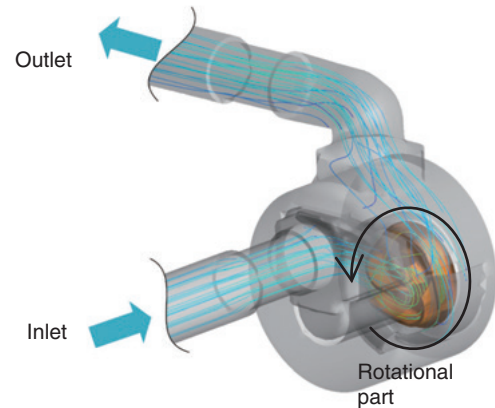


Fig. 10 CFD image

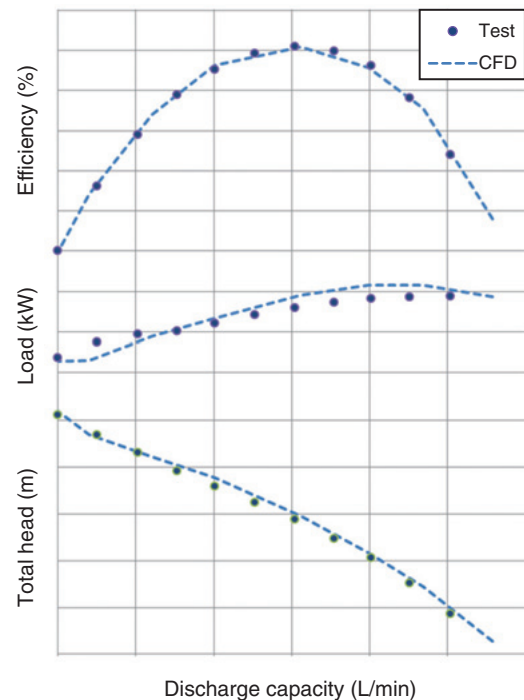


Fig. 11 Correlation result compared with test and CFD

a current model. Pump performance forecasting precision was within 5%, required load properties forecasting precision within 7%, and water pump efficiency forecasting precision within 3%. Cavitation is prone to occur close to the shutoff head, and enhancing precision in this range is an issue for the future, but the technique is sufficiently practical for a basic examination of pump performance. Analysis of self-priming performance involves the two phases of water and air, and it was determined that forecasting precision is insufficient as the technique currently stands, so testing was done to confirm trends in self-priming performance in respect to form.

3.3. Examination of Impeller Form

The researchers examined the form of the impeller for the newly developed pump by adjusting the various parameters shown in Fig. 12. Figure 13 gives a correlation

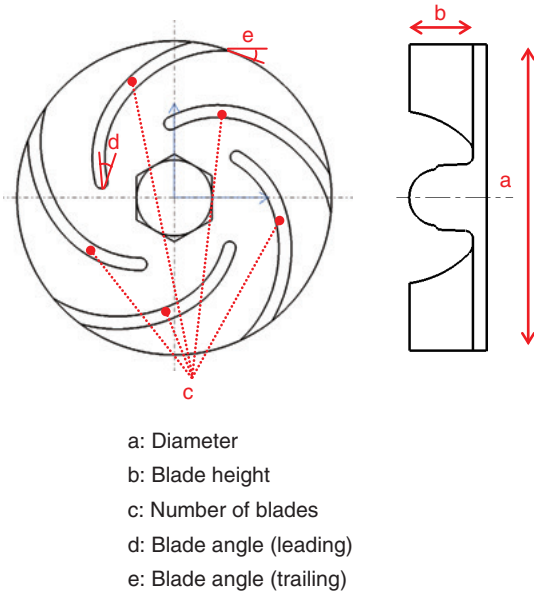


Fig. 12 Impeller parameters

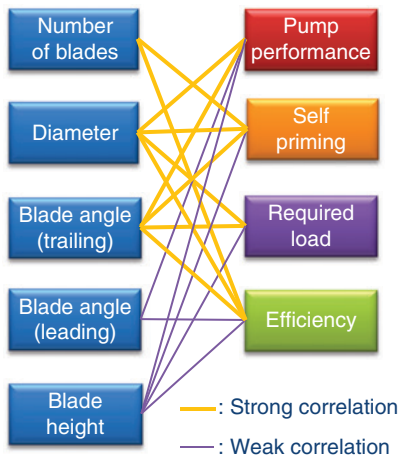


Fig. 13 Correlation map of parameter and pump performance

map between the parameters adjusted during this development and pump performance.

The first parameter selected for the development was the number of blades. A check of the correlation between number of blades and pump efficiency as based on the impeller from the current model resulted in the trend shown in Fig. 14. In general, a large number of blades tends to inhibit mixing of water and air in the impeller perimeter and lower self-priming performance, but for this development, the number of blades was chosen by prioritizing efficiency.

Next, the researchers examined diameter, which has a great impact on required load and head. Achieving the pump performance adjustment concept requires lowering the maximum head, but when the diameter was made smaller on the current model, pump efficiency tended to decrease, so for the new development, the same diameter was chosen as in the current model.

Finally, adjustments were made to the other impeller parameters. Larger blade angles on the outflow side tend to increase self-priming performance, but for this development, a smaller angle than the one used in the current model was chosen, since pump efficiency was the priority. Moreover, depending on the nature of the user's water source, foreign matter such as pebbles and plants could get sucked into the water pump. To help prevent such matter from getting stuck in the impeller, there has to be at least a certain blade height and a certain distance between blades.

3.4. Pump Performance Forecast

The impeller form, which the study results show has a major effect on pump performance, is shown in Fig. 15.

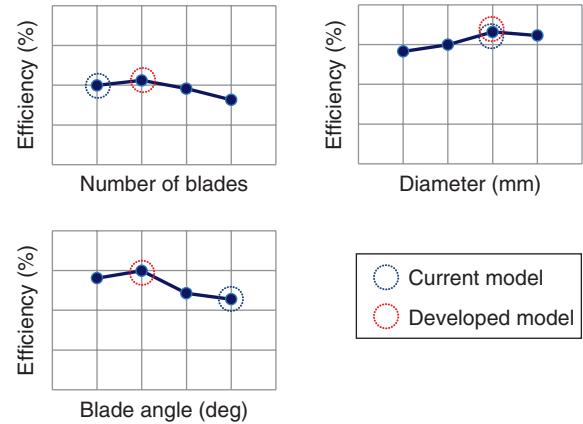


Fig. 14 Correlation of impeller parameters and efficiency

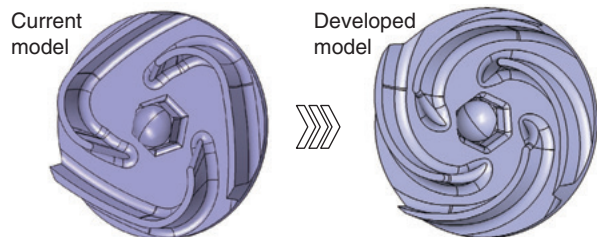


Fig. 15 Comparison of impeller

According to CFD, the current model exhibited areas on the backs of the blades where total pressure dropped (areas inside the red dashed lines in Fig. 16). However, the blade form of the newly developed irrigation model was designed to increase efficiency by eliminating these drops in total pressure, as shown in Fig. 17.

The researchers checked the head balance by considering the percentage of total head, as well as head loss in each part of the channel inside the pump, to theoretical head⁽²⁾ (Fig. 18). While the head loss in the

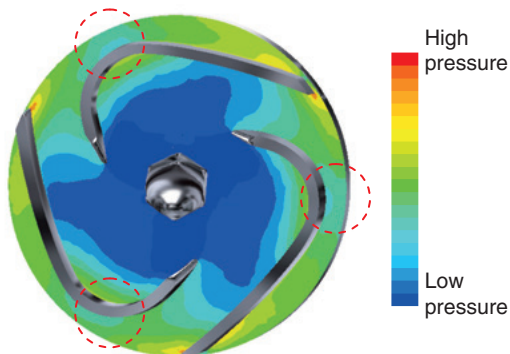


Fig. 16 CFD analysis result (Current model)

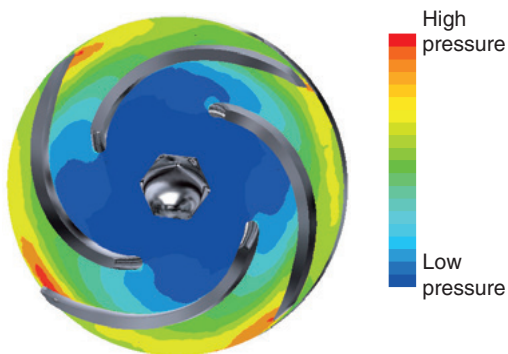


Fig. 17 CFD analysis result (Developed model)

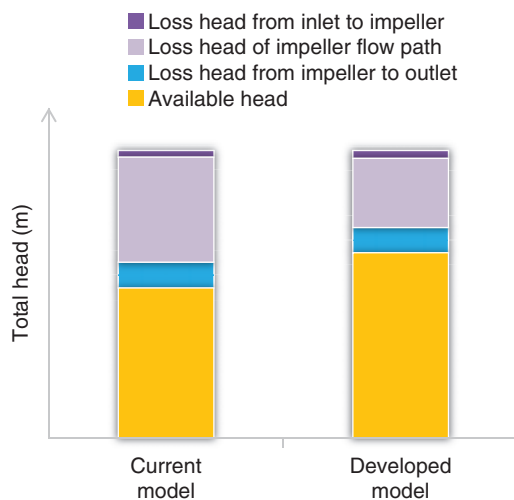


Fig. 18 Head balance

flow before and after the impeller was largely the same in the current model and irrigation model, the head loss in the impeller itself was smaller in the irrigation model. This was the result of enhancing the impeller form. As a result, the irrigation model, which has less head loss in total, has a higher percentage of head that is available as pump output.

Results of analysis of different aspects of pump performance are shown in Fig. 19. The forecast indicates that adjusting impeller form will yield pump performance as envisioned in the concept. It also indicates that the maximum required load declined, yielding an increase of about eight points in pump efficiency.

3.5. Fuel Consumption Forecast

Following is the forecast of fuel consumption improvement. (1) Fuel consumption was improved by about 7% as a result of enhanced pump efficiency and a lower required load. (2) In addition, if the GX160 engine is replaced with the GX120, fuel consumption is improved by about 8% as a result of differences in the fuel consumption properties of the two engines. (3) Furthermore, at the matching point with the pump, if the air-fuel ratio of the GX120 is optimized, fuel consumption is improved by about 7%.

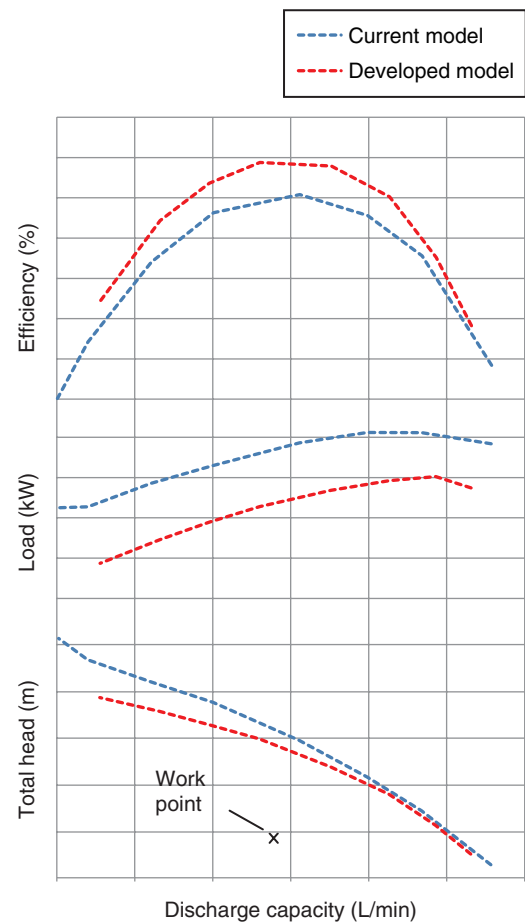


Fig. 19 CFD analysis result of pump performance

The forecast indicates that (1) - (3) above could lead to fuel consumption improvement of about 22% in total (Fig. 20).

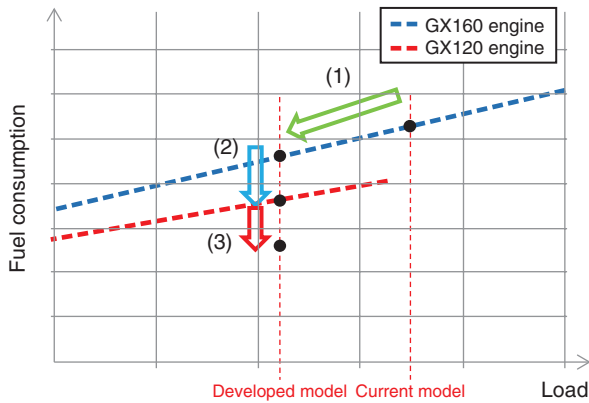


Fig. 20 Calculation of fuel consumption enhancement

4. Test Results

4.1. Results of Performance Testing

Measurements of the performance of the newly developed irrigation pump are shown in Fig. 21. The results indicate that the maximum efficiency rose by about eight points, just as forecast by CFD. Additionally, efficiency at a

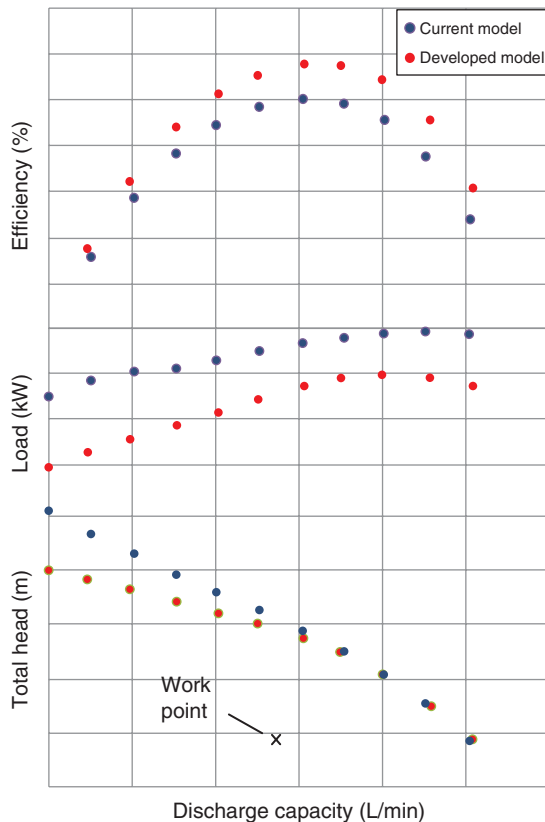


Fig. 21 Test result of pump performance

low-head, low-rotation work point rose by about 10 points, confirming the effectiveness of adjusting pump performance (Fig. 22).

The researchers also checked fuel consumption when the GX120 engine was used and the air-fuel ratio adjusted (Fig. 23). The results confirm that fuel consumption at the work point in Southeast Asia was improved by about 24% as compared to the current model, so that the newly developed model exhibited the fuel consumption effect that was forecast.

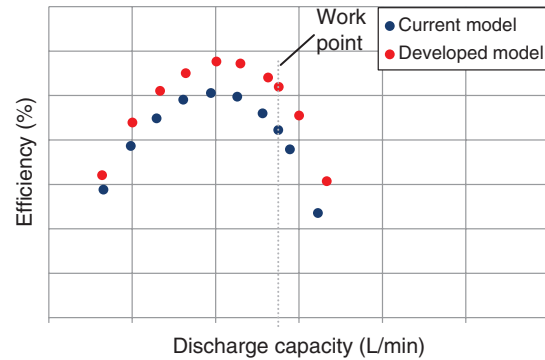


Fig. 22 Test result of pump efficiency at work point

	Engine	Work point CO (%)
Current model	GX160	4.7
Developed model	GX120	5.5

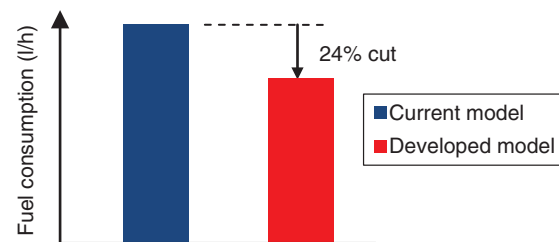


Fig. 23 Test result of fuel consumption at work point

5. Conclusion

The researchers attempted to use forecasting technology with CFD analysis to adjust various water pump performance requirements in line with low-head irrigation and thereby develop a pump with improved fuel consumption. They were able to increase pumping efficiency by eight points, which, when combined with the use of a low-displacement engine and adjustment of the air-fuel ratio, led to the development of a water pump with an improvement of greater than 20% in fuel consumption in actual irrigation use in Southeast Asia.

The issue of forecasting self-priming performance and cavitation will have to be addressed in the future. The researchers hope that developing these technologies will lead to CFD development of greater precision.

References

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