Product Introduction

Development of Piston Pumps for Compact-Excavators

TAKEI Gen, SAKAI Yuki

1 Introduction

Excavators are generally classified by body mass. As Fig. 1 shows, those under 6t are called “mini excavators”, those between 6t and 9t are called “compact excavators”, and those 10t and over are called “medium/large excavators”.

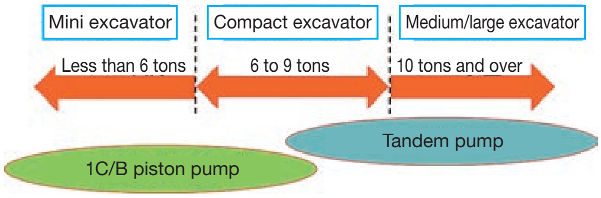


Fig. 1 Excavator classes and used pumps

The installed pump differs for each class, and “1C/B2 flow pump” (hereinafter referred to as “1C/B pump”), which is shown in the upper image of Fig. 2, is used for mini excavators. “C/B” in “1C/B pump” is short for “Cylinder Block”. In the rotary part which consists of a C/B, piston, etc., the C/B rotates to allow the piston to move in and out, changing the cylinder capacity and collecting/discharging oil. Although one pump is used in this type of pump, the C/B discharge ports are divided into the inner ones and outer ones (inner ones: blue, outer ones: red), as shown in the lower image of Fig. 2. This division allows 2 discharge types. This structure enables us to shorten the overall length and achieves a compact size and low cost, but we cannot control the discharge flow volume of the 2 ports separately.

Next, in medium/large excavators, we use a “tandem pump” as shown in the upper image of Fig. 3. This system consists of 2 pumps, so the overall length is increased. C/B discharge ports are not divided as shown in the lower image of Fig. 3, and the size is larger and the cost is higher compared to 1C/B pumps. However, they can control the discharge flow volume for each port and have many functions, including a number of added functions.

In compact excavators in between these types, the pump used differs for each mother machine manufacturer, and both types are used.

These developed products are 1C/B piston pumps for compact excavators, but we installed the added functions of tandem pumps on the 1C/B pumps and strived to develop low-cost and high-functioning 1C/B pumps with

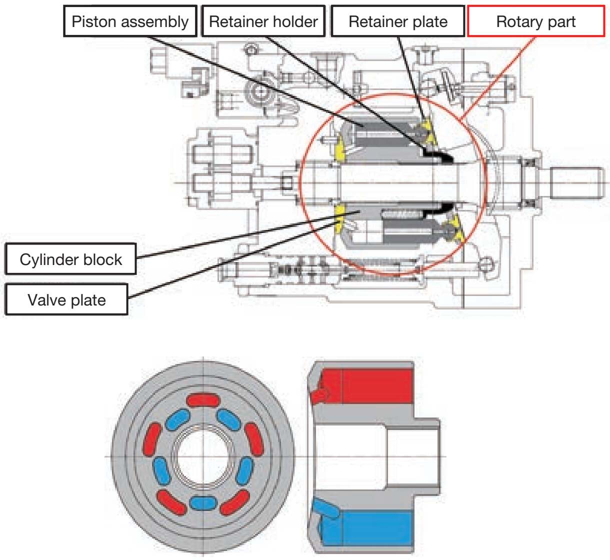


Fig. 2 (Upper image) 1C/B pump, (Lower image) C/B details

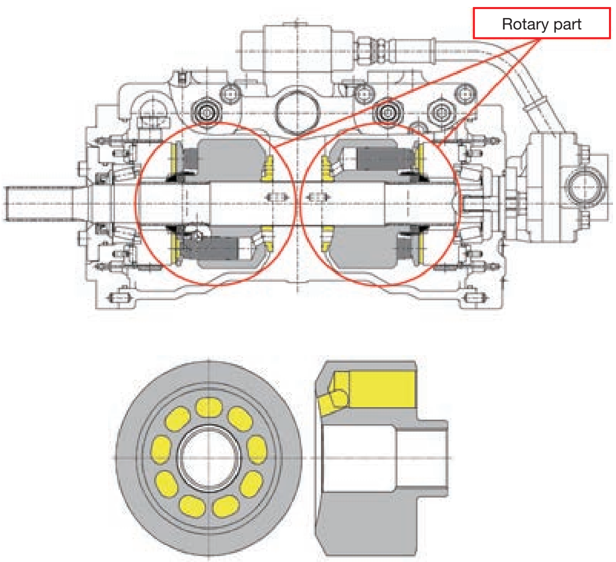


Fig. 3 (Upper image) Tandem pump, (Lower image) C/B details

the aims of expanding the application scope of 1C/B pumps and replacing the tandem pumps.

2 Product Summary

2.1 Lineup

The newly developed 1C/B pumps include PSVL-84, which is a single flow load sensing (hereinafter referred to as “L/S”) pump, and PSVD2-42, which is a split flow open pump, and PSVL2-42, which is a split flow L/S pump. Fig. 4 shows PSVL2-42.

In this development, we simultaneously promoted the development of the above 3 models. In order to improve the development efficiency and reduce the cost, standardization of the rotary part was one of the development requirements. By using the C/B with two discharge ports, which was mentioned in the previous chapter, the single flow integrates 2 flows within the pump to discharge from one location (there is no functional difference from a single pump), and the split flow discharges the 2 flows from 2 locations as P1 and P2.

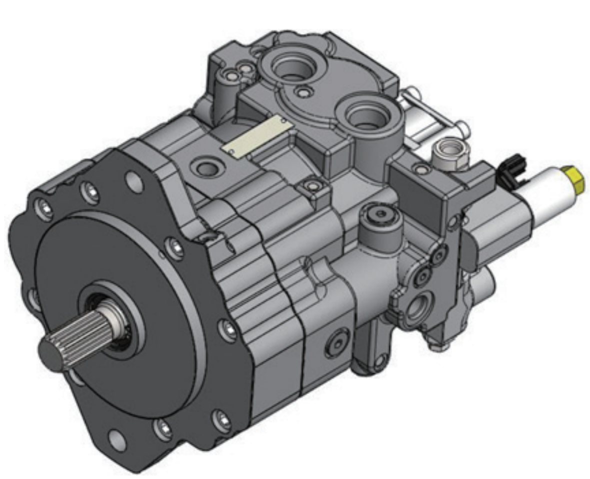


Fig. 4 PSVL2-42

Fig. 5 shows part of the product lineup for pumps used in KYB excavators. The yellow ones are the developed products, and the blue parts in the lower half of the image are the split flow open pump. The green parts in the upper half are the L/S pump (both split flow and single flow). We were able to add pumps for almost all excavators up to the 9t class to the product lineup.

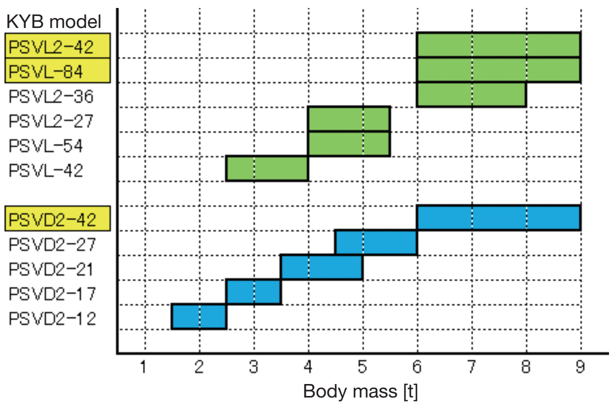


Fig. 5 Pump product lineup for excavators

As Table 1 shows, by mass producing these products, we were able to set up the product lineup for all of the hydraulic equipment installed on 6-9t excavators. By offering hydraulic equipment for excavators as systems, we can offer them as total solutions that include tuning and maintenance.

Table 1 List of hydraulic systems for excavators

	Open	Load sensing (LS)	
	Split	Split	Single
Pump	PSVD2-42	PSVL2-42	PSVL-84
Control valve	KVMM-80	KVSX-18	KVMX-18
Traveling motor	MAG-50		
Turning motor	MSG-44		

2.2 Product Specifications

Specifications of the developed products are shown in Table 2. The maximum pressure and the rotational speed were set to values that can respond to the demands of all customers. The maximum value for displacement volume is 42.3 + 42.3 cm3/rev so that the actuator’s operation speed can be maintained even if the engine rotational speed is reduced to conserve energy for excavators. In addition, the minimum value is 36.0 + 36.0 cm3/rev in order to respond to as wide a scope of classes as possible.

Table 2 Product specifications

Displacement volume [cm^3/rev]	• Split flow: 36.0+36.0～42.3+42.3 • Single flow: 72.0～84.6
Maximum pressure [MPa]	32.0
Maximum rotational speed [rpm]	2200

2.3 Added Functions

As mentioned in the beginning, a number of added functions were incorporated into the 1C/B pump in these developed products. Table 3 shows a list of these functions.

Table 3 List of added functions

1	Horsepower control
2	Hydraulic pilot type variable horsepower control
3	Electronic type variable horsepower control
4	★Stand-by control
5	★Variable gain L/S control
6	★L/S dual level gain change control

* ★ are added functions only available for L/S pumps

2.3.1 Horsepower Control

Horsepower control is a basic function for pumps for excavators that prevents the pump absorbing horsepower from exceeding the maximum engine horsepower to prevent engine failure. As shown in Fig. 6, the discharge flow volume (swash plate angle) is changed according to the load pressure to control the pump absorbing horsepower.

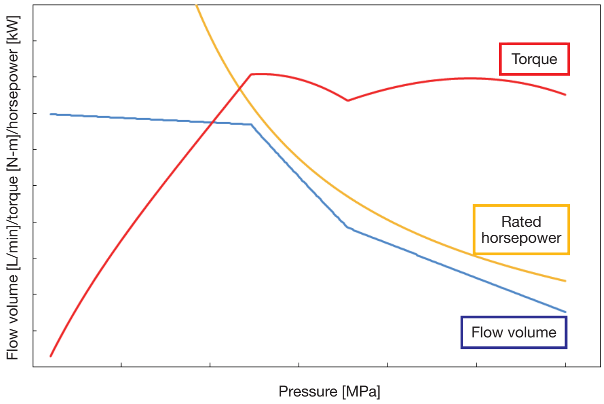


Fig. 6 Horsepower control characteristics diagram

2.3.2 Hydraulic Pilot Type Variable Horsepower Control

The hydraulic pilot type variable horsepower control is a function that can change the horsepower control absorbing horsepower with external pilot pressure.

Fig. 7 shows the characteristics of reduced horsepower control that reduces the absorbing horsepower with this function. The pump absorbing horsepower can be changed in 2 levels by switching the external signal pressure ON and OFF.

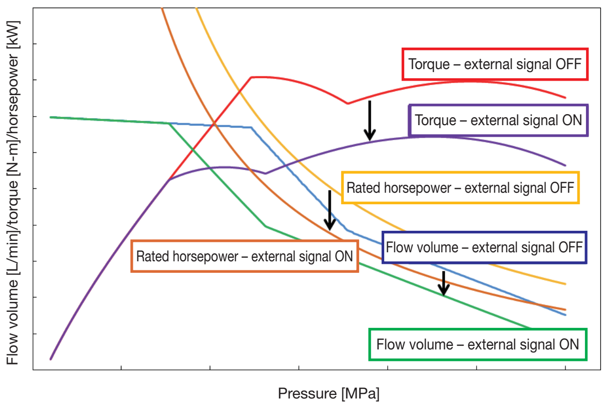


Fig. 7 Reduced horsepower control diagram

2.3.3 Electronic Type Variable Horsepower Control

Electronic type variable horsepower control uses electronic control for the above absorbing horsepower changes by using a proportional solenoid. While the external pilot type has 2 levels of ON and OFF, electronic control can change the pump absorbing horsepower without the restrictions of levels by changing the current value, improving the pump's versatility.

2.3.4 Stand-by Control

The stand-by control is a function that maintains the minimum pump absorbing horsepower by minimizing the pump discharge flow volume when the control valve is unloading (=when the excavator operator is not performing lever operations). This function controls unnecessary fuel consumption and contributes to energy conservation of excavators.

2.3.5 Variable Gain L/S Control

L/S control is an energy-conserving function that provides the operator's lever operation volume to the pump as feedback in a hydraulic manner to let the pump only discharge the necessary flow volume. In this L/S control, the function to change the gain between the "lever operation volume" and "discharge flow volume" is called the "gain changing function". The mainstream control nowadays is the gain change L/S control that reduces the gain when the engine rotational speed is reduced to prevent deteriorating operability.

Variable gain L/S control is a function to optimize the gain change volume according to the rotational speed. With regular gain change L/S control, for example, the discharge flow volume proportionally changes according to the rotational speed, as shown in the blue line in Fig. 8. When the engine rotational speed is reduced from A to B, it conserves energy, but the operation speed (discharge flow volume) at the same lever position also decreases. Variable gain L/S control changes this to the gain characteristics as indicated in red so that the same flow volume can be discharged with rotational speed B as A. In other words, this control can achieve the same actuator operation speed by changing the gain characteristics even if the rotational speed is reduced.

This function allows operators to reduce the engine rotational speed to as low as possible according to the work load, so this system enables fuel consumption reduction while working.

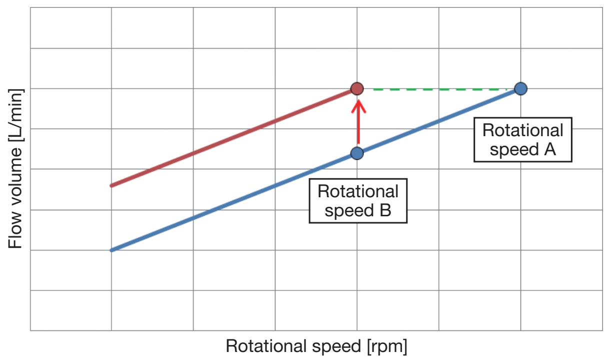


Fig. 8 Variable gain LS characteristics

2.3.6 L/S Dual Level Gain Change Control

In the aforementioned gain change L/S control, the basic control is linearly proportional control, such as that shown in the red line in Fig. 9. However, operators often operate with reduced engine rotational speed due to the recent energy-conservation preference. This has the issue that the operation speed is reduced.

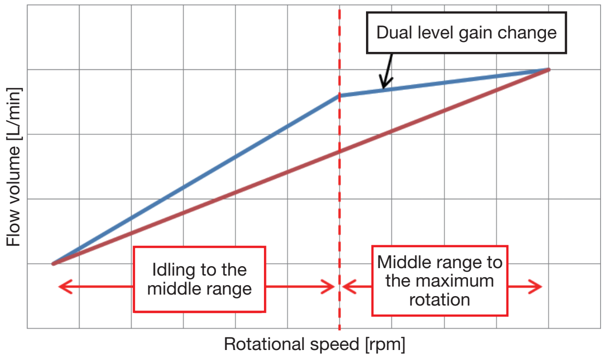


Fig. 9 Dual level gain change characteristics

In L/S dual level gain change control, the operator can set the gain change characteristics in two different levels, as shown in the blue line in Fig. 9. It controls the reduction of control flow volume between the maximum rotational speed and medium speed to secure the operation speed, and it increases the reduction of the control flow volume between the medium speed and idling to secure operability during low speed.

3 Rotary Part Design

These developed products use a spherical rotary part. This spherical rotary part is designed by making a valve plate (hereinafter referred to as "V/P") into a spherical shape as shown in Fig. 10 so that it makes spherical contact with the cylinder block. This spherical rotary part is generally said to be able to enhance the speed, increase the pressure, and stabilize the performance of pump specifications.

The rotary part is a core part of a piston pump, and its design determines the performance. Efficiency, quietness, and durability are the 3 most important aspects of pump performance, and design that balances these 3 aspects is required.

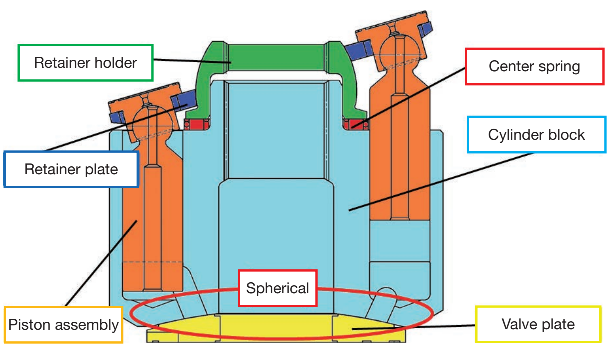


Fig. 10 Spherical rotary part cross-section

3.1 Spherical Clearance Design

We focused on the fact that the contact force on the outside of the V/P increases due to the distorted shaft caused by the hydraulic power when pressure load is applied. We differentiated the spherical radius (SR) of the V/P and that of the C/B (SR-V/P < SR-C/B) so that the distortion can be absorbed, as shown in Fig. 11. However, discharge must be divided into two in case of split flow. If the inner ones are P1 ports and the outer ones are P2 ports as shown in Fig. 12, the outer (P2) ports are prone to being affected by the clearance (CL). Leakage from the outer (P2) ports increases due to the clearance caused by the spherical radius difference.

Therefore, we performed a bench test in order to learn the correlation between the spherical radius difference and the outer (P2) port volume efficiency. We prepared 3 levels A, B, and C (CL-A < CL-B < CL-C) with different clearance and compared the port volume efficiency of each outer (P2) port. Refer to Fig. 13.

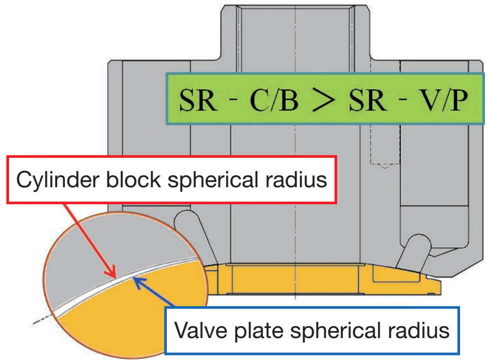


Fig. 11 Spherical radius difference

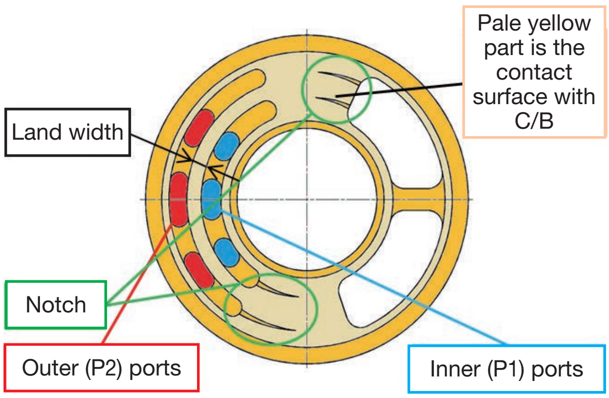


Fig. 12 Valve plate form

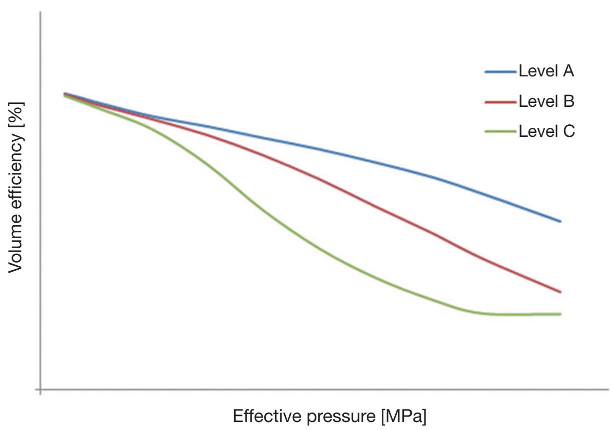


Fig. 13 Outer (P2) port volume efficiency test result

The test indicated that the greater the clearance is, the greater the volume efficiency reduction is. Level C has great reduction volume in the low pressure range (more leakage). Based on this result, we set the spherical clearance.

3.2 Optimization of the Hydraulic Balance

In order to satisfy performance, quietness, and durability, the optimal design of the hydraulic pressure balance that functions with the cylinder block is important. In order to streamline the design, we modeled the cylinder block, valve plate, piston assembly, and shaft as shown in Fig. 14 and established an analysis program that calculates the force on each part at arbitrary angles.

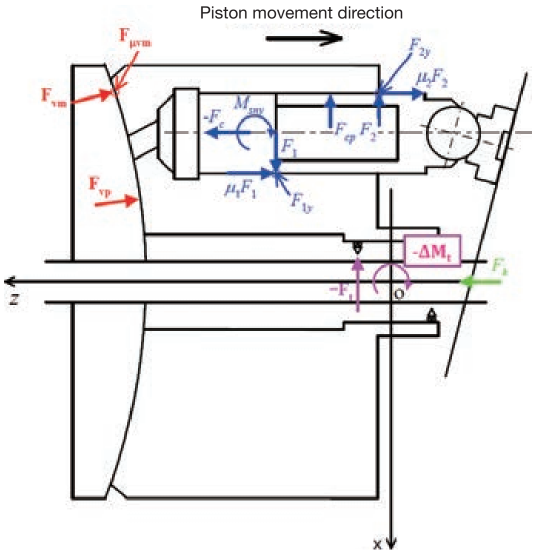


Fig. 14 Hydraulic balance calculation model

By entering the dimensions and pressure of each component, it calculates the pressure distribution, etc. between V/P and C/B as shown in Fig. 15. It outputs this data to calculate the pressing ratio (ratio of the entire load in the Z direction shown in Fig. 14) per pitch (angle obtained by dividing 360˚ by the number of pistons) and fluctuations of the moment balance (ΔMt) that indicates the C/B stability, as shown in Fig. 16.

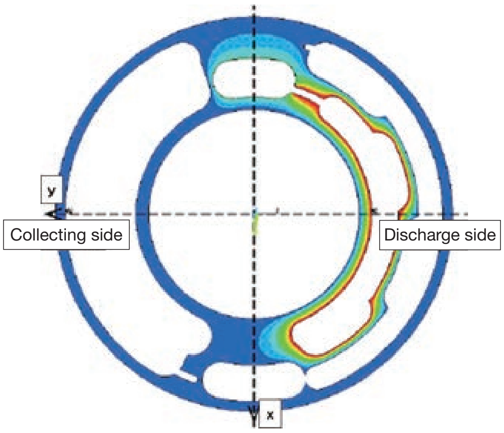
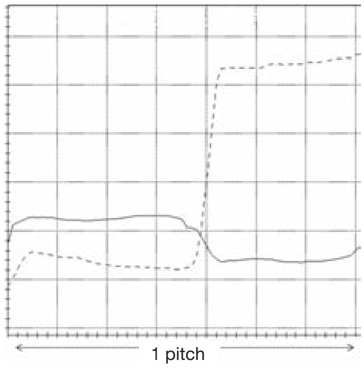
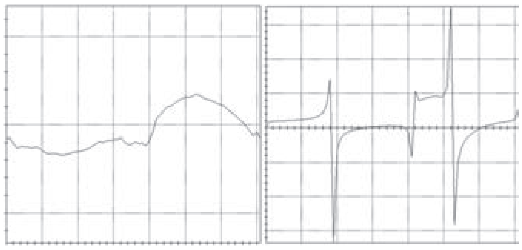


Fig. 15 Pressure distribution reference between V/P and C/B



(a) Pressing rati



Moment ratio

(b) Around the x shaft (c) Around the y shaft

Fig. 16 Output graph

By utilizing this analysis model, we performed performance and durability evaluations through bench tests by using the design values in which the pressing ratio and moment balance fluctuations are small and stable by changing the notch form in Fig. 12 to change the cylinder inner pressure patterns and changing the V/P land width to change the pressing ratio, etc., thus utilizing the design values that satisfy the performance, quietness, and durability.

4 Performance Result

Fig. 17 shows a graph that compares the overall efficiency of PSVL2-36, which is KYB's existing product,

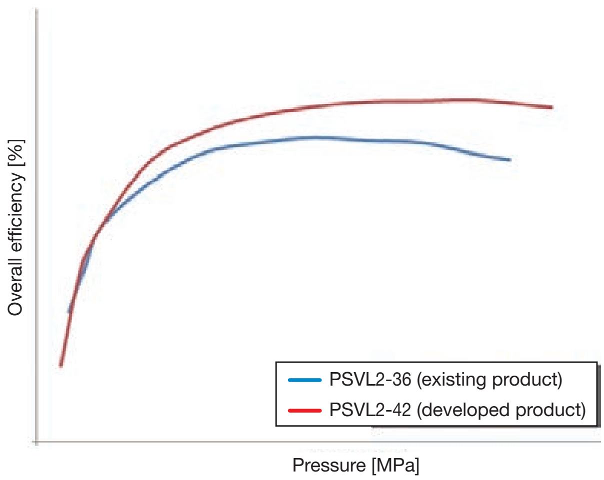


Fig. 17 Overall efficiency comparison

and PSVL2-42, which is this newly developed product. Based on the comparison according to KYB's evaluation points, the efficiency has been improved by approximately 4%, achieving the high efficiency goal through the optimization of the rotary part mentioned in Chapter 3.

As Fig. 18 shows, noise was also reduced by approximately 4 to 8 dB (A) compared to the existing product PSVL2-36, according to the measurement value taken 1m behind the pump. They have also passed all of the strict tests on durability conducted by KYB. We were able to develop products that satisfy all of the aspects of efficiency, quietness, and durability.

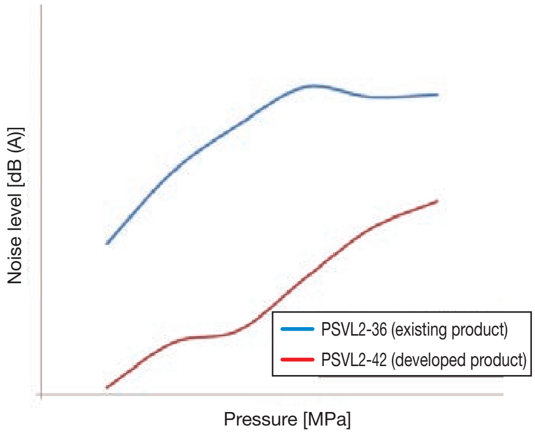


Fig. 18 Noise level comparison (1m behind the pump)

5 In Closing

We developed high-efficiency 1C/B piston pumps for compact excavators responding to energy conservation needs with added functions to expand the application scope. With the launch of these products, we were able to set up the product lineup of hydraulic systems for KYB's excavators up to the 9t class.

Finally, we would like to express our sincere gratitude for everyone involved in the development who has provided us with their great cooperation.

Author

TAKEI Gen

Joined the company in 2013.
Development Sect. No.1, New Products Development Dept., Engineering Headquarters, Hydraulic Components Operations.
Engaged in development of hydraulic pump products.

SAKAI Yuki

Joined the company in 2009.
Development Sect. No.1, New Products Development Dept., Engineering Headquarters, Hydraulic Components Operations.
Engaged in development of hydraulic pump/motor products.