Product Introduction

Hydraulic Pump and Track Motor for Hydrostatic Transmission

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1 Introduction

There is a wide variety of hydraulically driven vehicles including construction equipment and agricultural machinery. These vehicles use hydro static transmissions (hereinafter "HST") as a driving transmission compatible with hydraulic pumps and motors because of their benefits of easy speed control and forward/backward travel without gear shifting. KYB has manufactured such compatible pumps and motors. Transmission systems integrated with pumps and motors in a single housing are called integrated HST. Transmission systems with separate pumps and separate motors connected by hydraulic piping constituting closed circuits are called separate HST. To meet the demand of the separate HST market for carriers (Photo 1), loaders and other base machines movable with crawlers, KYB has developed a hydraulic pump with modified swash plate control and a track motor with higher output and higher speed (compared to the level of the KYB's existing counterpart). This new separate HST has just been added to the KYB product lineup. This report introduces the overview of the development.

Photo 1 Crawler Carrier C30R-3 (Source: Yanmar Construction Equipment Co., Ltd. Website)

2 Hydraulic Pumps

This hydraulic pump is a compact design basically consisting of two swash plate type axial piston pumps assembled together back to back (tandem pump). The KYB conventional counterpart (PSVH2-28 Series) used a pump control system operated by a manual lever for use in mowers or other vehicle applications. However, KYB needed to meet the then-recent market demand for introducing a hydraulic-pilot or electronic control system into the swash plate control for higher usability and easier installation of additional functions. In response to demand, KYB has developed this hydraulic pilot controlled pump based on conventional technology. Table 1 compares the specifications between the conventional product and this new product. Photo 2 shows the appearance of the new product. As shown in Fig. 1, the pump consists of a swash plate piston pump section, swash plate control section, power regulating valve section and gear pump.

Table 1 Comparison of specifications between conventional and new products

Model		Conventional product	New product
		PSVH2-28CGH	PSVH2-28C-R35-SP
Displacement setting [cm^3/rev]		2×28.1	2×22.0 to 28.1
Specified pressure [MPa]		Maximum effective pressure: 25.0	Maximum effective pressure: 34.3
		Maximum discharge pressure: 25.9	Maximum discharge pressure: 37.3
Rated input speed [rpm]		2800	3000
Maximum theoretical discharge [L/min]		78.7	84.3
Auxiliary	Control system	Manual lever	Hydraulic direct
	Power regulation	N/A	Speed sensing
Product mass [kg] (including gear pump)		40.0	55.0

2.1 Mechanical Features

2.1.1 Hydraulic Pilot Control System

While the conventional product uses the swash plate control system with a manual lever, this new product uses a hydraulic direct control system with a pilot pressure. There are two types of hydraulic pilot control systems: swash plate inclination feedback control and hydraulic direct control. In the feedback control, the control

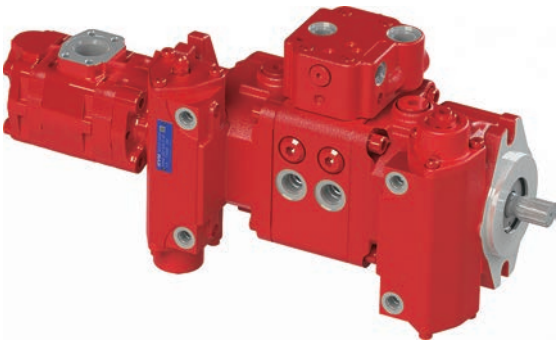

Photo 2 Appearance of new product (PSVH2-28C-R35-SP)

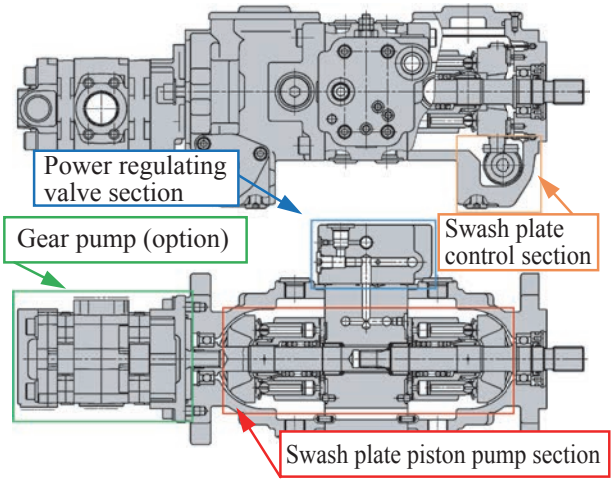

Fig. 1 Pump internal construction

pressure introduced into the swash plate control pistons is automatically regulated to achieve the target swashplate inclination according to the pilot pressure. In the hydraulic direct control, the pilot pressure is directly used as the control pressure, so the swash plate inclination is decided by the balance between the angular moment of the swash plate and the thrust of the swash plate control pistons.

2.1.2 Angular Moment of Swash Plate

The swash plate of a pump receives a hydraulic reaction force from a set of pistons. Each piston is exposed to large pressure variations while it turns one revolution including intake and discharge strokes. The swash plate is applied with moment forces with which the swash plate would be vibrated and/or inclined depending on the number of pistons and the internal pressure variation patterns decided by the valve plate settings.

The direction of inclination or the vibrating force can be tuned by modifying the valve plate settings.

2.1.3 Self Power Regulation

This new product is designed to increase the swash plate inclining moment under a higher load. When the motor drive load is high during slope climbing for example, the inclining moment overcomes the thrust of the swash plate control pistons to automatically reduce the inclination of the swash plate. These characteristics are shown in Fig. 2.

The theoretical torque consumption of the hydraulic pump is expressed in Equation (1):

$$T = \frac{V \cdot P}{2\pi} \quad \ldots(1)$$

T: Theoretical torque consumption of hydraulic pump, V: Displacement volume of hydraulic pump, P: Effective discharge pressure of hydraulic pump

According to Equation (1), a higher load will reduce the inclination of the swash plate, resulting in a lower displacement volume. This will automatically reduce the torque consumption of the pump. These characteristics can help suppress engine stalls due to an unexpected increase in load.

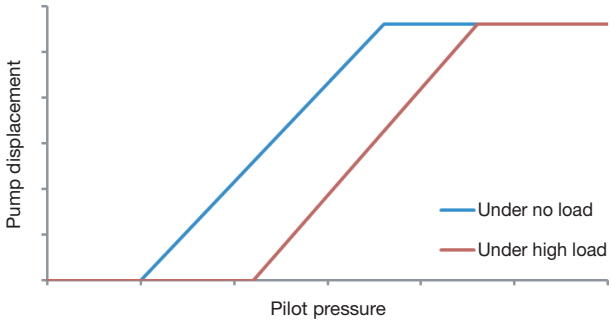

Fig. 2 Hydraulic pilot control characteristics

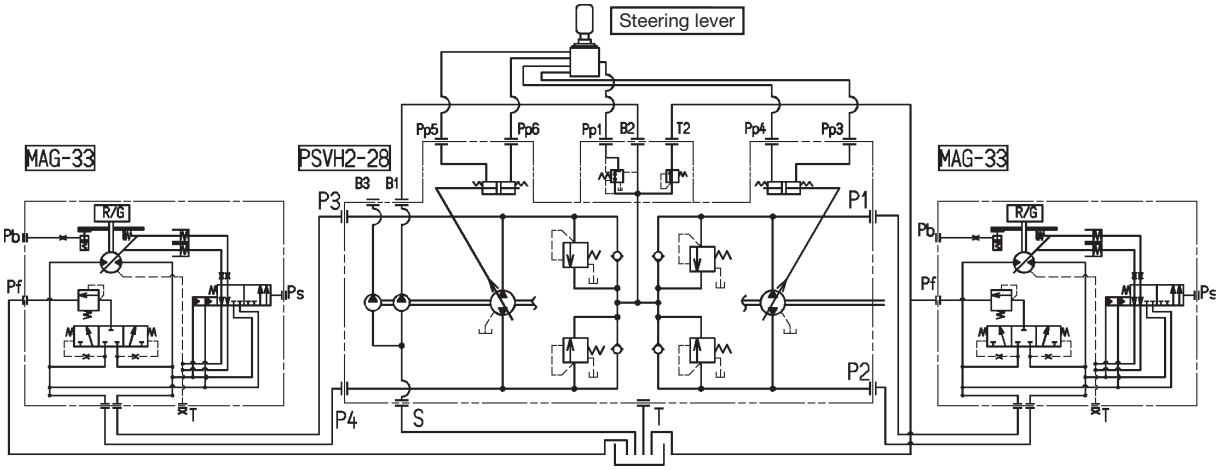

Fig. 3 HST circuit diagram

2.1.4 Non-Straight Travelling Correction

Fig. 3 gives a hydraulic circuit diagram of the new product (HST). This 2-pump, 2-motor crawler travelling system has right and left crawlers, each driven by their own motor. When the vehicle of this system is trying to go straight ahead, the difference in discharge flow rate between both pumps may cause the vehicle to move in non-straight direction. The tandem pumps are usually shipped after their maximum discharge flow rate is adjusted on the assembly line during delivery inspection so that there will be no difference in discharge flow rate between the two pumps. However, the mid-range discharge flow rate will be regulated by the pilot pressure, engine speed and motor load as stated above. This means that it will not be easy for the right and left pumps to have the exact same flow rate. Against the problem, the "setting to decrease the swash plate inclination under a higher load" described in section 2.1.3 will work to correct the non-straight motion, contributing to improved driving straightness of the vehicle.

For example, when a vehicle slightly curves to the left in spite of the driver's straight steering, the left wheels are turning at a lower speed than the right crawler. The motor for these slower crawler has a lower load as the left side of the vehicle is pulled toward the front by the right side of the vehicle that is moving ahead faster with the other motor, which has to bear a higher load. In this case, increasing the discharge of the pump on the side with lower load and decreasing the discharge of the pump on the opposite side will eventually diminish the difference in speed between the left and right motors, contributing to improved straightness of the vehicle.

2.2 Power Regulation (Speed Sensing)

As a power regulation option, a speed sensing valve has been added to the new product. This valve controls the pressure supplied to the steering lever manipulated by the operator (Fig. 3, Pp1). The control characteristics are shown in Figs. 4 and 5. The upper limit of control pressure is regulated to the varying engine speed of the base machine. If the allowable engine load is exceeded, the pilot pressure to the pump is automatically reduced according to the engine speed drop, which reduces the swash plate inclination, thereby reducing power consumption. This process can prevent a complete engine stall. The maximum engine stall level is decided by the self-power regulation characteristics stated above, speed sensing characteristics and engine power. Thus the engine speed is no longer dropped to a predetermined level or lower. Operator is now able to operate the vehicle without paying attention to engine power. In this way the speed sensing valve can help reduce the work load of the operator.

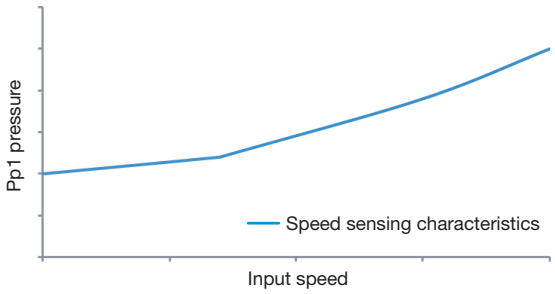

Fig. 4 Speed sensing valve characteristics

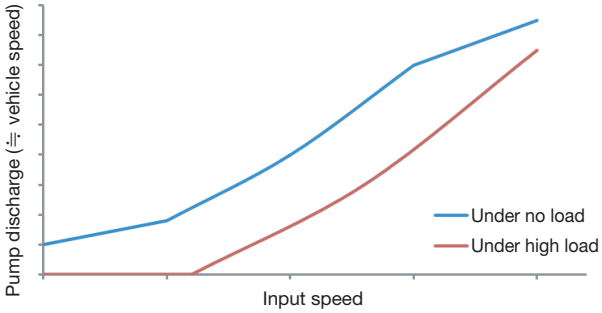

Fig. 5 Power regulation characteristics

2.3 Challenges in achieving compatibility between noise reduction and stopping on slopes

As the pressure requirement becomes higher, the amplitude of the vibration applied to the swash plate increases. Particularly, it had been known for long that the pump issued higher noise when it was applied with a higher load. Noise reduction was one of the challenges to be overcome in developing this product. Various approaches were available to reduce the noise. The development team reviewed the valve plate specifications to optimize the variation patterns of the internal piston pressure.

Another issue to be considered when using HST for vehicle applications is stopping on a slope. Being able to move the vehicle ahead, back, or stop it with a single lever, and to use the hydraulic dynamic brake during stoppage is an advantage of HST. When the vehicle is stopped on slope for instance, the pump is in neutral position and the motor has to bear a continual load. In this condition, the motor would turn as long as the closed circuit leaks internally, which cannot prevent the vehicle from slipping down the slope at a very low speed. The valve plate is one of the components that are most likely to leak internally. The development team needed to optimize the design by taking this issue into account.

Optimization with these points in consideration achieved a valve plate design that satisfied the requirements for noise reduction and stopping on slope, as well as all of the swash plate control characteristics stated in section 2.1.3. The optimized valve plate was also recognized by customers to have been effectively improved through actual machine testing. Table 2 shows the result of optimization:

Table 2 Valve plate optimization

Internal leakage	Lower by 50.7%
Swash plate vibrating force	Lower by 11.6%
Swash plate inclining moment amplitude	Lower by 15.2%
Discharge pressure pulsation amplitude	Lower by 17.6%
Noise under high load	Lower by 3.1 dB

3 Track Motors for Closed Circuit

This product is a hydraulic motor with a case-rotating transmission for crawlers. KYB has manufactured the conventional counterpart without changing the original specifications since its release. The track motor for a closed circuit that can be typified by crawler carriers is required to be run more frequently and last longer than the excavator motor. In addition, the market has demands for higher-speed motors with a higher output torque. To meet the demands, KYB has developed this product that can provide a longer life, higher torque and higher speed, based on the conventional counterpart.

Table 3 Comparison of specifications between conventional product and market demands

Model		Conventional product	Market demands
		MAG-33VP-550	——
Maximum output torque (N・m)		3649	Not less than 4000 (higher by 10% or more)
Maximum output speed (rpm)		130	Not less than 140 (higher by 8% or more)
Outer dimensions (height x max outer diameter)		313×φ286	←
Mounting dimensions (vehicle side)		Fit diameter: φ200, Fastening holes: 10 x M14 x 2.0	←
Mounting dimensions (output side)		Fit diameter: φ230, Fastening holes: 9 x M14 x 2.0	←
Life ratio		100%	Not less than 170% (higher by 70% or more)
Auxiliary	Transmission	Manual transmission	Manual or automatic transmission
	Parking brake	Equipped as standard	Equipped as standard
	Flushing valve	Mountable	Equipped

Photo 3 Product appearance (MAG-33VP-650)

Photo 3 shows the appearance of the product. The hydraulic track motor consists of a control valve section, swash plate piston motor section and reduction gear section as shown in Fig. 6.

KYB's hydraulic track motor has the following major features:

① Specially-designed case-rotating type motor that is most suitable for driving crawlers and so small that can be accommodated within the crawler width

② High continuous running performance (= high output torque) achieved by use of a case-rotating planetary reduction gear and hydraulic pistons

③ Shifting system supports Run and Traction modes. It is possible to select an automatic shifting system that monitors loads during Run mode and switches into Traction mode upon detection of a high load. The speed ratio between Run and Traction modes is up to two times for the same flow rate.

④ Workability and stopping performance on a slope are generally required depending on the work environment. The product allows the operator to work or stop on a slope with the parking brake function. Equipping of a parking brake function is required by laws in some European regions.

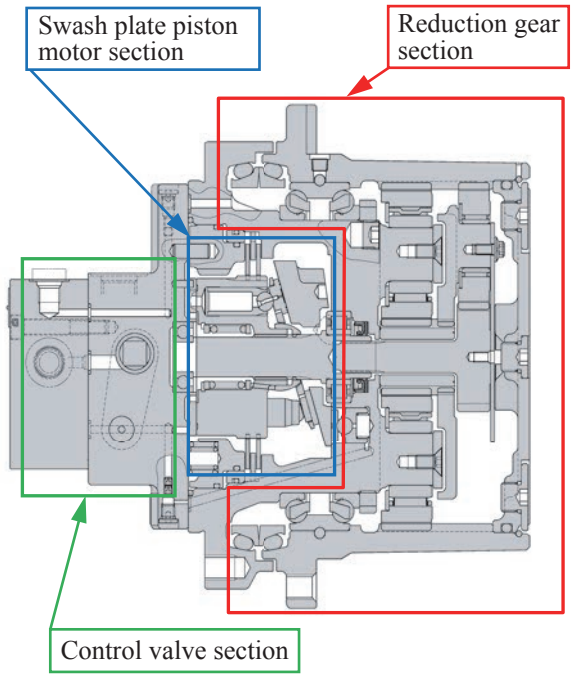

Fig. 6 Cross section of hydraulic track motor

3.1 Challenges to be overcome for longer life and higher output

For higher service life of hydraulic track motors, various approaches are available, including enhancing the strength of the tribological rotary parts to improve durability and increasing the gear module or face width to enhance reduction gear strength and durability. The output torque of the motors could be raised by expanding the motor volume, by elevating the motor pressure or by increasing the speed reduction ratio. These conventional approaches may compensate for the drawbacks of the motors, but will inevitably upsize them.

Construction machinery manufacturers always demand to maintain the compatibility with conventional products

during installation. (Any remodeled motors must be able to be mounted on conventional machinery). Therefore, it is a must to achieve "longer life and higher output" without changing the fit diameters on the vehicle side, as well as on the output side as shown in Fig. 7.

In this product development, a longer-life, higher-output motor with existing outer dimensions that can deliver the existing vehicle speed as construction machinery must be developed. To do so, it is indispensable to increase the rotary parts pressure for higher output, to improve the tribological characteristics for longer life, and to improve gear strength and durability without changing the gear size of the transmission.

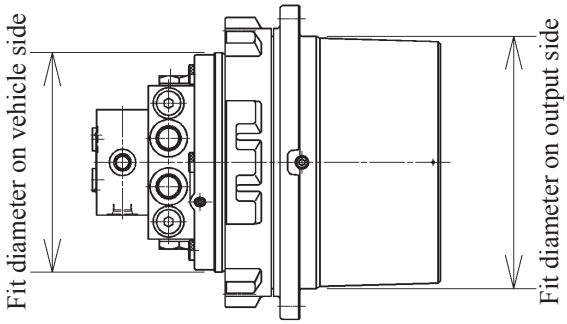

Fig. 7 Vehicle fitting diameter

3.2 Development Technologies for Longer Life, Higher Output and Higher Speed

3.2.1 Piston Motor Section

The piston motor outputs the hydraulic energy in the form of rotation or torque as the rotary parts slide with each other.

Fig. 8 shows the rotary parts of the piston motor. The surface treatment of the cylinder block and swash plate has been optimized. The piston shoes have been changed from conventional single pads to multipad to suppress shoe deformation occurring with high pressure and to enhance the tribological characteristics. These improvements have resulted in longer life and higher pressure, thereby enabling the motor to satisfy demands for higher output and higher speed.

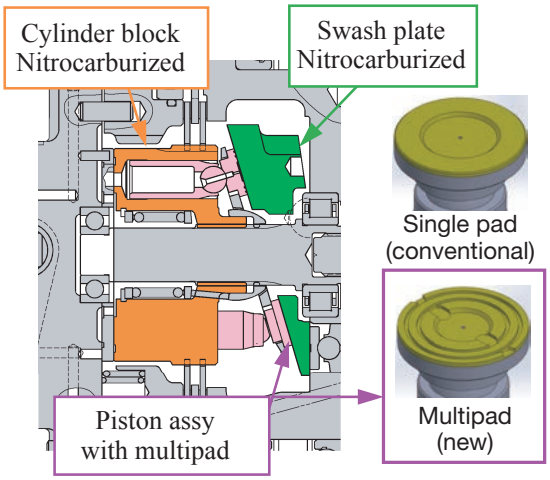

Fig. 8 Cross section of piston motor

3.2.2 Reduction Gear Section

The reduction gear section has been improved to achieve a longer life, higher output and higher speed with the conventional outer dimensions unchanged. Part of the improvement is described below.

(1) Gear strength and gear shaft rigidity

Gears with a larger module have higher flexural strength and, those with a larger face width have higher durability because of a lower contact surface pressure. However, changing the module or face width will inevitably upsize the transmission in the radial or axial direction, making it difficult to design a construction with the same fit diameter and same total length as the conventional ones.

It should also be noted that, even if a gear has higher strength itself, the tooth surface may have pitching or other faults unless proper engagement is ensured. In this case durability cannot be enhanced. To ensure proper engagement, shaft rigidity is one of the important factors.

Here, the total rigidity balance of the reduction gear assembly was reviewed to suppress the shaft deflection, ensuring e shaft rigidity. The tooth profile was also reviewed to correct the gear engagement, resulting in a longer life and higher output.

(2) Floating seal

It is indispensable for achieving a higher speed to take measures against heat generation in the sliding interfaces of the floating seals. Changing of the floating seal material and ring profile resulted in a lower seal load. The development team eventually developed a seal compatible with high-speed revolution without degrading the resistance to sediment invasion, and introduced the seal into the new product.

3.3 Product Features

Table 4 provides the major specifications of the product.

Table 4 Comparison of specifications between conventional and new products

Model		Conventional product	New product
		MAG-33VP-550	MAG-33VP-650
Maximum equivalent volume [cm^3/rev]		863	←
Maximum pressure (inlet) [MPa]		30.9	37.3 (20%UP)
Charge pressure [MPa]		3.0	←
Maximum motor speed [rpm]		3600	4000 (11%UP)
Reduction rate		25.526	←
Maximum output torque [N・m]		3649	4050 (11%UP)
Maximum output speed [rpm]		130	150 (15%UP)
Life ratio		100%	177% (77%UP)
Outer dimensions (height x max outer diameter)		313×φ286	←
Mounting dimensions (vehicle side)		Fit diameter: φ200, Fastening holes: 10 x M14 x 2.0	←
Mounting dimensions (output side)		Fit diameter: φ230, Fastening holes: 9 x M14 x 2.0	← Fastening holes: 12 x M14 x 2.0
Auxiliary	Shifting system	Manual shifting	Manual shifting Automatic shifting (option)
	Parking brake	Equipped as standard	←
	Flushing valve	Mountable	Equipped
Product mass [kg]		55.0	←

The new product achieves a longer life by 77%, a higher torque by about 11% than that of the conventional counterpart with the outer dimensions unchanged from the conventional ones, and a faster output speed than that of the conventional one by about 15%.

In addition to the conventional manual shifting, an automatic shifting system has been successfully added to the product lineup.

4 In Closing

The development team has achieved the hydraulic pilot control, longer life, higher output and higher output speed that are demanded by the market, and has successfully expanded the separate HST product lineup. The new product introduced in this report has already been ordered for mass production by customers and delivery started in spring 2017.

The development team efficiently promoted the product development by making full use of simulation approaches against various challenges. The demands of the construction equipment and agricultural machinery markets are increasingly becoming even more sophisticated in a wide range of aspects including computerization, efficiency enhancement and cost reduction. The team is committed to continue making efforts to catch up with these demands. Finally, we would like to extend deep gratitude to those concerned who have extended their great support and cooperation to us.

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