

Development of the KVSX-12C-PSL control valve for small hydraulic excavators

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1 Introduction

KYB offers a lineup of control valves: KVSX-12, KVSX-14, and KVSX-18. These valves use load sensing^{Note 1)} (LS) systems for two- to eight-ton hydraulic excavators (Table 1). There is increased demand in the excavator market for systems that use electric signals for automation and remote control. In contrast, the mini excavator market increasingly demands precise control for functions such as posture control and flow limiting. Furthermore, conventional hydraulically controlled spools require a pilot valve and hydraulic hoses to operate. Electrically controlling the spool operation enables the spools to operate with electric wiring alone. Currently, our product line includes control valves for agricultural and industrial applications that support electric control, but not for hydraulic excavators. To expand our product lineup, we have decided to develop a model with electrically controlled spools for two- to four-ton excavators. This model is the KVSX-12C-PSL^{Note 2)}. Fig. 1 shows the model's appearance.

Note 1) Load sensing = A system that controls the swashplate of a variable displacement pump by feeding back pressure to the pump in response to the operating load. This ensures a constant differential pressure across the spool orifice. This allows the pump to use only the necessary amount of oil.

Note 2) PSL = Proportional SoLenoid

Table 1 KVSX Series

Vehicle weight				Control valve product model
~2ton	~4ton	~6ton	~8ton	
	↔			KVSX-12
		↔		KVSX-14
			↔	KVSX-18

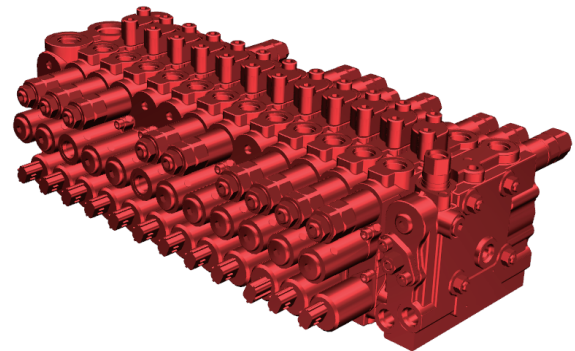


Fig. 1 Appearance of KVSX-12C-PSL

2 Development Challenges

Prior to the development project, we identified the following development challenges:

- 1) Supporting high pilot pressures
- 2) Ensuring tunability to match the machine controller
- 3) Improving assembly and maintenance.

Challenge 1) was based on the fact that our conventionally manufactured PSL products were designed for agricultural and industrial applications, which only require low pilot pressure. The goal of this project was to develop a model for construction machinery applications, which require higher pilot pressure. We then revised the structure of the pressure-reducing valve section.

Regarding Challenge 2), machinery-side controllers that use PSL products typically use PWM control^{Note 3)} to regulate voltage. However, this method presents challenges related to spool responsiveness and oscillation (vibration). While the dither setting (current frequency) and current amplitude can be adjusted by the controller, the adjustment is limited. Therefore, we modified the pressure-reducing valve section built into the valve to be tunable, enabling settings tailored to the controller.

Challenge 3) relates to the difficulty of assembling conventional PSL products, in which the spring

that is assembled in the pressure-reducing valve section is located at the end of the valve housing. During assembly or replacement, the spring was likely to fall off. We moved the spring to the front of the valve housing to make assembly easier.

Note 3) PWM = Pulse Width Modulation

PMW controls the output equivalently by varying the duty cycle within one cycle.

3 New Model Overview

3.1 Configuration

Fig. 2 compares the new model that we developed with the conventional model that does not have PSL. Although the new model uses the same hydraulic section as the conventional model, it has a proportional pressure-reducing valve for spool operation at the bottom. This valve operates according to the current value applied to the solenoid. It reduces the primary pilot pressure that is constantly supplied to the control valve to the secondary pressure necessary for spool operation, which actuates the spool. This configuration allows the PSL and hydraulic pilot operation sections to be merged within a single valve.

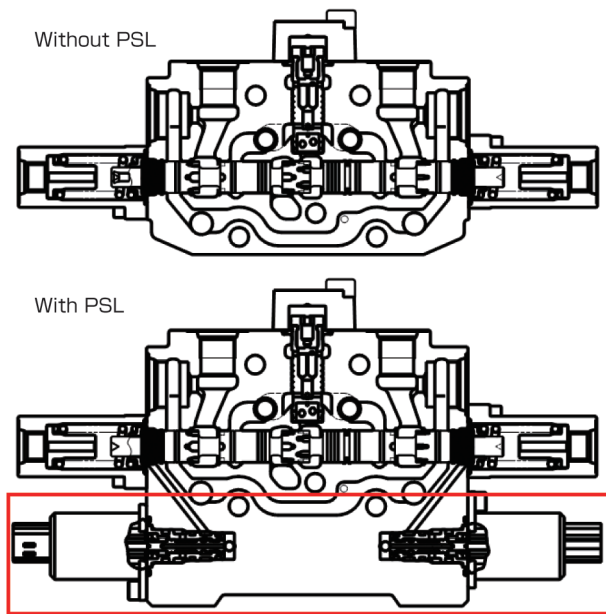


Fig. 2 Model comparison

The boom section may use an anti-drift valve. Both the PSL pressure-reducing valve and the anti-drift valve require external drain ports. Combining them into a single oil line allows for the use of only one port. This design reduced the number of pipes in the machinery. Fig. 3 shows the circuit diagram and cross-sectional view.

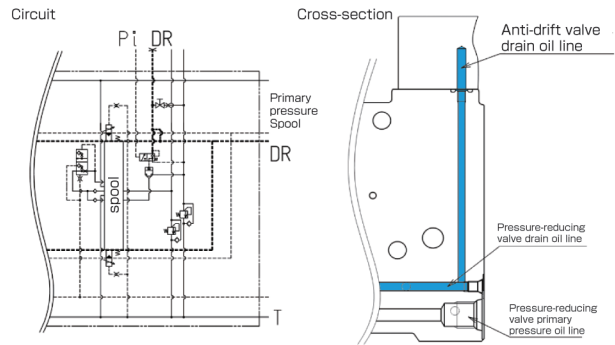


Fig. 3 Drain circuit

3.2 Supporting High Pilot Pressure

The pressure-reducing valve used in conventional PSL products has the same spool diameter in both the land between the primary and secondary pressure lines and the land between the primary pressure and drain oil lines (Fig. 6). This configuration provides a pilot pressure (secondary pressure) of up to approximately 2 MPa, as shown in Fig. 4. For agricultural and industrial applications, this pilot pressure was sufficient to operate conventional control valves. However, control valves for construction machinery require a pilot pressure of up to approximately 3 MPa. Therefore, we adopted a pressure-reducing valve spool structure with different pressure-receiving diameters. Furthermore, concerns were raised about hole distortion during assembly of the valve housing due to the sectional structure of this newly developed product. This issue was resolved by adding a sleeve that eliminated the effect of hole distortion (Fig. 7). This newly developed product's pressure-reducing valve, which has different pressure-reducing diameters, provides control pressure of up to approximately 3 MPa, as shown in Fig. 5.

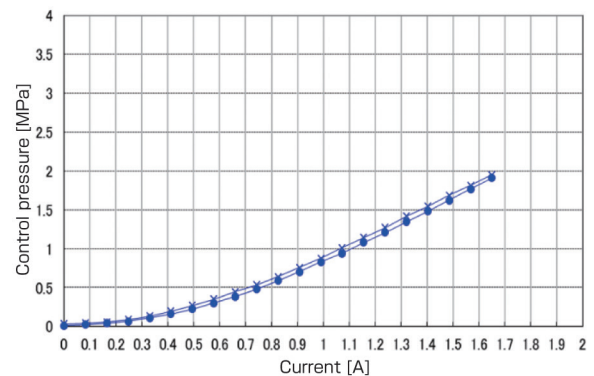


Fig. 4 Current-pressure characteristics of control valve with a uniform spool pressure-receiving diameter

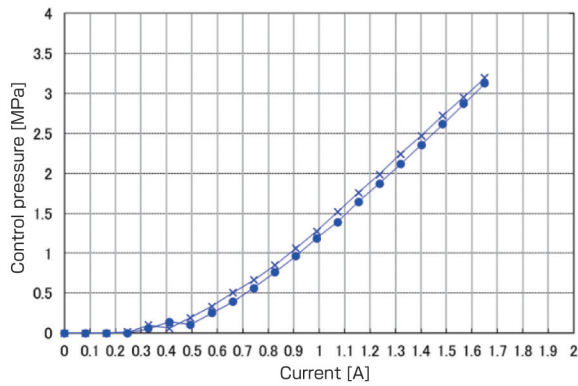


Fig. 5 Current-pressure characteristics of control valve with different spool pressure-receiving diameters

3.3 Ensuring Tunability

PSL products address performance issues, such as ensuring stability in spool response and operation (i.e., no oscillation), as well as reducing large variations in pilot operation.

If the machinery uses PWM control, these issues can be resolved by adjusting the dither setting (current frequency) and P-P setting (current amplitude). However, it is difficult to ensure matching only by adjusting these settings. Therefore, we adopted a structure in which the pressure-reducing valve on the control valve side can be optimized to match the controller on the machinery side. One option is a structure in which the pressure-reducing valve in conventional valves has different spool pressure-receiving diameters (Fig. 8). With this structure, the pressure-reducing valve can only adjust the opening area from the primary pressure to the secondary pressure and from the primary pressure to the drain as well as the timing of these adjustments. Increasing or decreasing the opening area, or opening these oil lines earlier, can adjust responsiveness. However, changing the timing increases the likelihood of oscillation.

This newly developed product consists of a spool and a sleeve that can alleviate abrupt pressure fluctuations and reduce oscillations by adjusting the opening area, as mentioned above, as well as using the orifice located in the sleeve (sleeve orifice). It is also possible to machine a damper-type orifice on the spool. Optimal adjustment of these elements can solve the performance issues that may arise through combinations with machinery-side controllers.

This newly developed product also addressed the inherent hysteresis of proportional solenoids. We added an outer circumferential groove to the internal plunger of conventional proportional solenoids to improve mechanical hysteresis, achieving a reduction of about 43% compared to conventional counterparts. Variations in secondary

pilot pressure when applied with the specified current (spool stroke) improved by about 20% at the spool activation point.

3.4 Improving Assembly and Maintenance

In conventional PSL products, the spring is located at the end of the pressure-reducing valve (Fig. 6, 8). During assembly, the spring may fall off when inserted into the spool hole. When replacing parts, if the spool is removed, the spring may not be retrievable if it remains in the end of the housing or enters the drain oil line.

The newly developed product uses a spring seat to position the spring at the front, although this increases the number of parts. This front placement improves workability during assembly and maintenance.

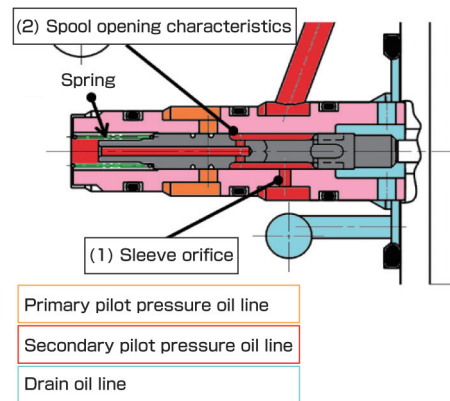


Fig. 6 PSL pressure-reducing valve for agricultural and industrial applications

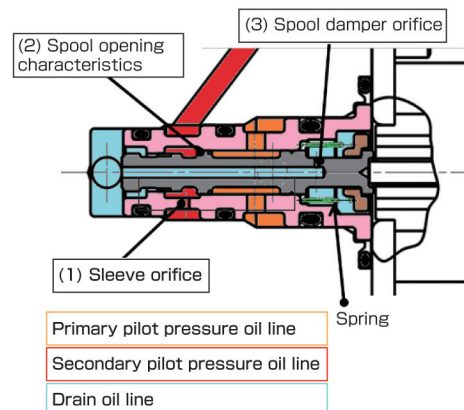


Fig. 7 Newly developed pressure-reducing valve

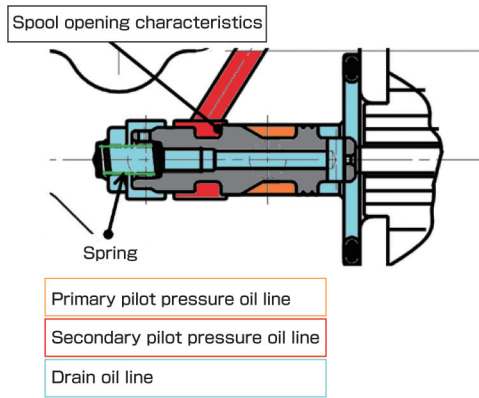


Fig. 8 Pressure-reducing valve with different spool diameters (no sleeve)

4 In Closing

This paper describes the development of an electronic control valve for small hydraulic excavators in the two- to four-ton class.

During development, we overcame various challenges and successfully commercialized the product by implementing required features. There is also a demand for electronically controlled four- to eight-ton hydraulic excavators. Going forward, we plan to deploy this new structure in the KVSX-14C and KVSX-18 series. We are committed to developing these series to be our flagship products for electronic control applications.

We would like to take this opportunity to express our sincere gratitude to the relevant departments that supported us in developing this product.

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