Introduction of Product

Development of CLSS System for 4t-class Engine Type Forklift

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A variable pump CLSS (closed-center load sensing system) to reduce fuel consumption and to meet the safety standard has been developed as a hydraulic system for 4-ton class engine type forklifts and high volume production of the system has been started. The features and technologies of the system are described.

Key Words: *Forklift, Closed-center Load Sensing System, Control valve, Variable pump*

1. Introduction

Industrial vehicles and construction machinery have recently required improved fuel consumption and compliance with safety standards and environmentally friendly emission regulations as urgent requirements to be met. These requirements are important elements that also need to be met in the development and manufacture of forklifts.

Systems that move the work equipment and operate steering systems of forklifts are hydraulic in nature, and their fuel consumption and compliance with safety standards must be improved.

Previously, systems using mainly fixed displacement pumps were used in hydraulic forklifts. However, these do not necessarily provide optimum results from the standpoint of hydraulic losses, hence a variable pump CLSS (Closed-center Load Sensing System) was developed for forklifts to reduce hydraulic losses. This system enabled the curbing of horsepower during engine operation at low speed, thus allowing the engine to be downsized and significantly reducing fuel consumption.

The functions to meet an ISO standard being proposed as a safety standard for forklifts were reviewed from a system design viewpoint and could be embedded in a valve with a minimum number of parts required.

A variable pump CLSS system with the foregoing features was developed and placed into mass production for engine type 4t-series forklifts as outlined below.

2. Features of Forklifts

1) Types of forklifts

Forklifts can be roughly classified into counterbalance and reach types in accordance with the shapes of their product appearances and the engine and battery types, in accordance with their motive power. **Fig. 1** shows appearance photographs of forklifts. As standard provisions, the work equipment is provided with lift cylinders that raise and lower the forks and tilt cylinders that tilt the mast forward and backward. As attachments, side shifts to move the forks left and right, clamps to grab rolled and used paper and other attachments are available.

Counterbalance type　　　　Reach type

Fig. 1　Appearance photographs of forklifts

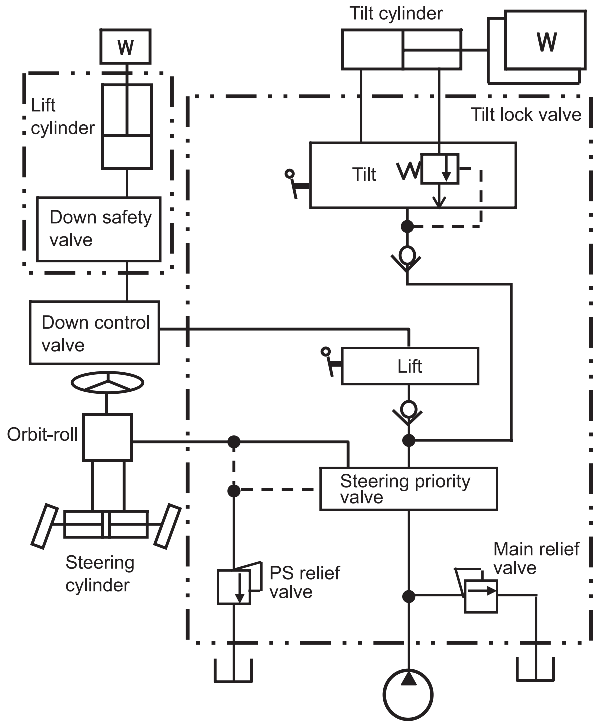

Fig. 2　Configuration of ordinary hydraulic circuits of forklifts

2) Hydraulic system of forklift

The configuration of the hydraulic circuit of ordinary work equipment and a steering system for a forklift is shown in **Fig. 2**. The hydraulic pump is mainly one of fixed displacement and a discharge flow rate is supplied to the steering circuit via a steering priority valve on a priority basis. Using an orbit-roll, the steering system drives the steering cylinder.

The lift cylinder uses a single-acting cylinder and stretches the cylinder during lift lowering under its own weight. A flow control valve called a “down control valve” is provided to ensure a predetermined descending speed irrespective of the load. Moreover, a lowering control valve called a down safety valve is provided as a safety device in the case when the lift circuit is damaged.

Generally, the lever actuation system of the forklift is a direct pull structure and the cylinder actuates if the lever is operated while cargo is loaded, even when the engine is stopped. A tilt lock valve is provided with the tilt circuit to prevent this.

3. Use of Variable Pump CLSS

The effect that can be gained by using the variable pump CLSS now used in the 4t-class engine type forklift and the circuit configuration of CLSS is described.

1) Effect gained through the use of the variable pump CLSS

①Reduction in hydraulic loss

Via this system, losses during the relief, neutral and fine control modes can be reduced compared with ordinary fixed pump systems. The effect in reducing hydraulic losses is shown in **Fig. 3**. As an effect of reducing fuel consumption, a reduction exceeding 20% is achievable compared with a conventional model in conjunction with downsizing of the engine described in (2). (See **Fig. 4**)

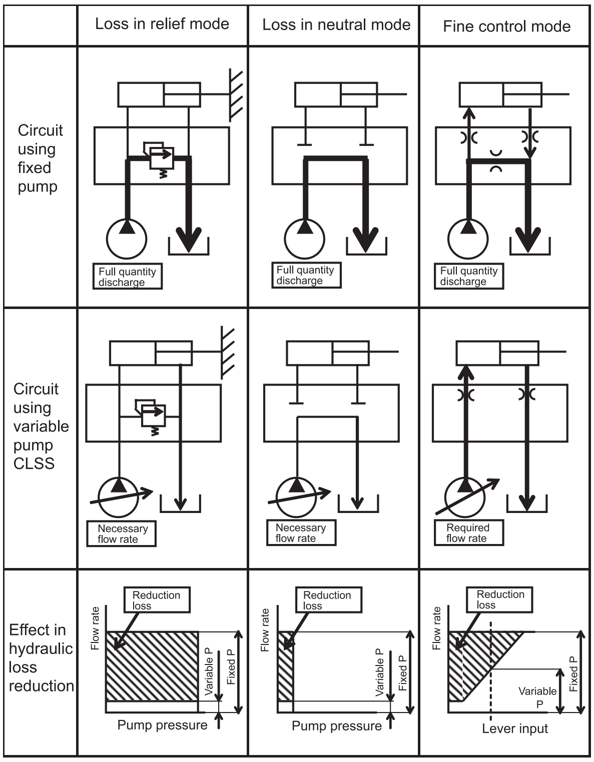

Fig. 3 Effects gained in reducing hydraulic loss

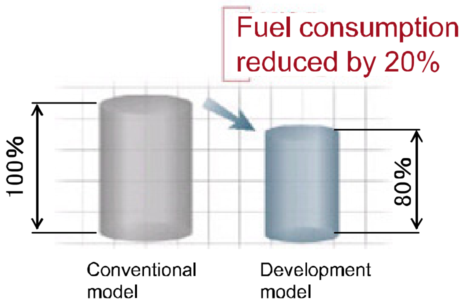

Fig. 4 Effect gained in fuel consumption

②Engine downsizing

In the fixed pump system, downsizing the engine causes it to stall as the pump torque exceeds that of the engine during the relief mode when the engine operates at a low speed. Engine downsizing could be achieved by lowering the pump torque in the relief mode by using a variable pump. **Fig. 5** illustrates the relationship between the pump torque in the relief mode and engine torque. The conventional models used an engine with a piston displacement of 5.9 liters, while the development model uses one with a piston displacement of 3.3 liters. (See **Fig. 6**)

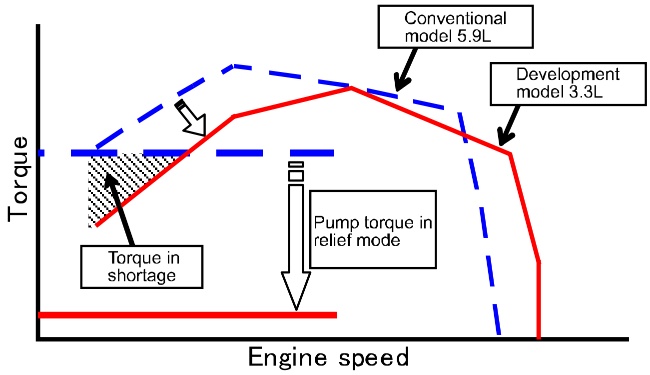

Fig. 5 Relationship between engine torque and pump torque

	Development model	Conventional model	Same class from another manufacturer
Piston displacement	3.3L	5.9L	4.6～5.0L

Fig. 6 Comparison of engine piston displacement with a forklift made by another manufacturer

③Enhanced controllability

Compared with an open center circuit system, predetermined fine control that is immune to load impacts is possible with the CLSS system. **Fig. 7** compares the latter with the open center circuit system. In the conventional models, fine control of the fork height was difficult during low idling when a heavy load was placed, due to a narrow fine control range. In the development model however, the fork height can be finely and easily adjusted as this range remains unchanged even in the low idle mode.

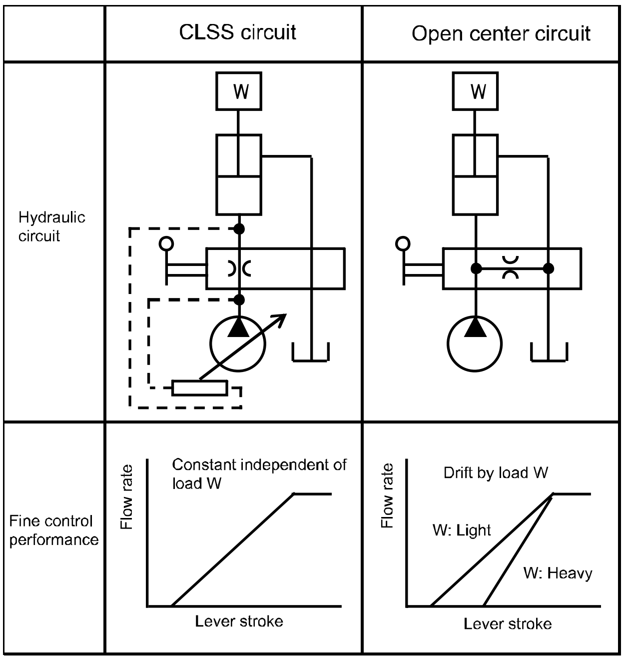

Fig. 7 Comparison with the open center circuit

2) Configuration of the CLSS circuit

The configuration of the newly developed hydraulic circuit of the variable pump CLSS for forklifts is shown in **Fig. 8**.

The work equipment valve detects a maximum pressure of the load pressure of each piece of work equipment by a shuttle valve and outputs it to a capacity control valve (LS valve) of the variable pump in the form of load sensing (LS) pressure. The variable pump functions to have the LS valve actuate the pump discharge pressure and LS pressure from the work equipment valve and controls the swash plate so that the differential pressure (LS differential pressure) between these values becomes the set pressure of the LS valve. In this way, only the flow rate requested by the work equipment valve is delivered.

Simultaneous controllability is one of the important quality requirements for construction machinery such as hydraulic excavators. For this reason, a pressure compensation valve is installed to meet this quality requirement, while forklifts also perform simultaneous operation work. However, high accuracy quality is not required and the pressure compensation function has not been previously provided. For these reasons, no pressure compensation valve is incorporated in this development project.

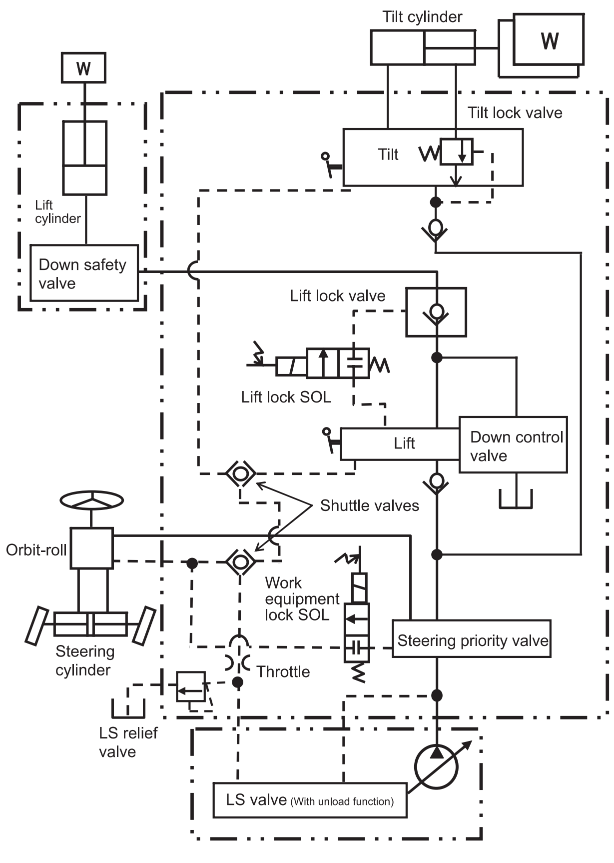

Fig. 8 Circuit configuration of variable pump CLSS

4. Development of Hydraulic Equipment Dedicated to Forklifts

The hydraulic systems of forklifts have been manufactured under severe price competition. As mentioned initially, however, safety and environmental friendliness have recently become urgent requirements. In the new development project for a CLSS valve and pump dedicated to forklifts, reductions of 60% and 40% could be achieved in volume (space) and weight respectively compared with a conventional model of the 5t class by achieving an optimum configuration while meeting safety and environmental requirements. This could be achieved mainly through the following five elements:

①Two lift cylinder circuit ports reduced to one.
②Built-in down control valve
③Unload valve eliminated by integrating the unload function of the LS valve
④Main relief valve eliminated through pump zero swash plate structure
⑤Material handling interlock function added to the steering priority valve

Appearance photographs of the work equipment valve and work equipment pump are shown in **Fig. 9** and **Fig. 10** respectively. The configurations of typical functions of the work equipment valve and work equipment pump are described next.

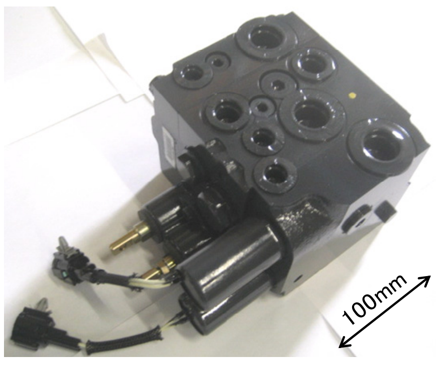

Fig. 9 Appearance photograph of the work equipment valve

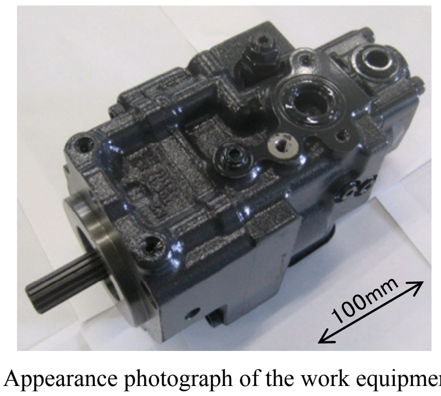

Fig. 10 Appearance photograph of the work equipment pump

1) Configuration of the work equipment valve

①Steering priority valve

A steering priority valve is installed in systems that have one pump for both steering function and work equipment to preferentially supply a pump discharge flow rate to the steering circuit. The configuration of the steering priority valve is illustrated in **Fig. 11**. The steering priority valve detects the load pressure of the steering cylinder and feeds it back, thereby preferentially supplying oil to the steering circuit.

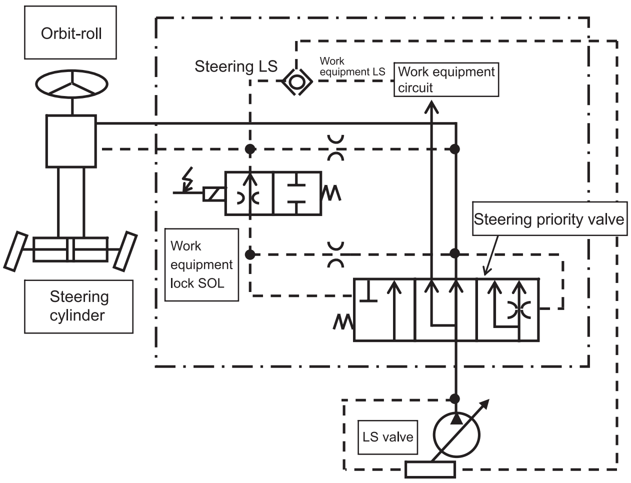

Fig. 11 Configuration of the steering priority valve
(During combined operation of steering and work equipment)

②Down control valve

A flow control valve called a down control valve is provided to gain a predetermined lowering speed during lift lowering, regardless of the load. In the development model, a down control valve that was provided separately is contained in the work equipment valve. The lift spool and down control spool are placed coaxially to achieve a compact structure. **Fig. 12** and **Fig. 13** show the configuration and flow rate characteristics of the down control valve respectively. The flow rate (Q1) on the lift spool side increases when the load pressure is high because the opening area is decided after the stroke of the lift spool is determined. The down control spool is an automatic control valve that operates by reacting to pre- and post-throttling differential pressure. Feedback control applies to the flow rate (Q2) on the down control spool side to curb the flow rate when the load pressure is high. Thus, the total flow rate (Q), namely, the lift descending speed is controlled to approximately maintain a predetermined descending speed, regardless of the load.

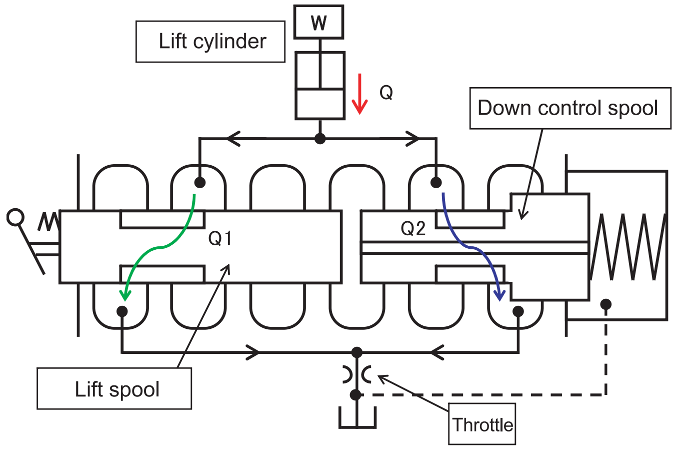

Fig. 12 Configuration of the down control valve
(When lift is lowering)

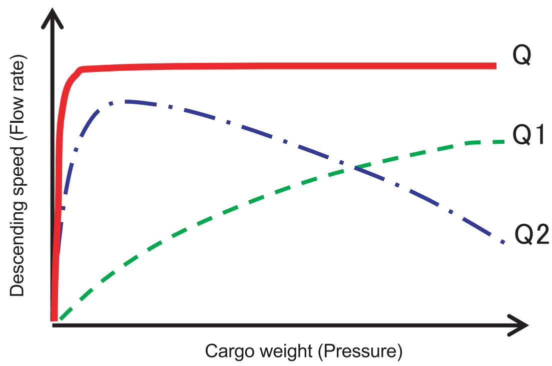

Fig. 13 Characteristic of the down control valve

③Safety functions

At present, the ISO is amending the international safety standard for forklifts in its ISO/DIS3691-1. **Fig. 14** summarizes the measures taken on the representative safety standard requirements.

Item	Development model	Conventional model
Material handling interlock	★Steering priority valve • Tilt lock valve ★Lift lock valve	• Tilt lock valve
Lift descending speed	• Down safety valve • Down control valve (Built in)	• Down safety valve • Down control valve (Installed separately)
Spontaneous lowering of lift	★Lift lock valve	• Control for spontaneous lowering in neutral gear shift

★: Device added to the development model

Fig. 14 Measures taken on representative safety standard requirements

i) Work equipment lock function (Material handling interlock)

A scheme is being made in the ISO/DIS3691-1 to make the "Prevention of tilting of the mast and lowering of the carriage by manipulating a main control part while the operator is away from the usual operation and steering position" obligatory. Previously, an unload valve installed separately prevented tilting of the mast and lowering of the carriage. In the development model, a steering priority valve is utilized to satisfy this requirement. The configuration of the work equipment lock function is illustrated in **Fig. 15**. An electric switch is installed at the operator seat and the work equipment lock solenoid valve is energized when the operator sits down. When the operator leaves the seat, the work equipment lock solenoid valve is closed and the steering priority valve is set to Position A, cutting off the supply to the work equipment circuit and thus preventing actuation of the work equipment by the pump when the operator is not on the operator seat. A bypass circuit is provided as a redundancy so that steering can be actuated even if the work equipment lock solenoid valve fails.

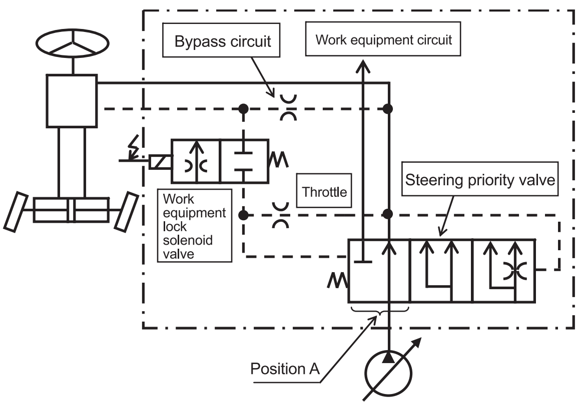

Fig. 15 Work equipment lock function (When operator is not seated)

ii) Tilt lock valve

Forward tilting operation of forklifts is performed in a descending direction under its own weight and the above-mentioned work equipment lock function cannot prevent forward tilting of the mast. Therefore, a lock mechanism must be separately installed. **Fig. 16** illustrates the configuration of a tilt lock valve, which actuates pump pressure as pilot pressure to open and close the tilt cylinder return and tank circuits and is contained inside the tilt spool. When the operator leaves the operator seat, the foregoing work equipment lock function cuts off the work equipment pump circuit, deactivating the tilt lock valve so that the mast does not tilt forward, even if forward tilting operation is performed.

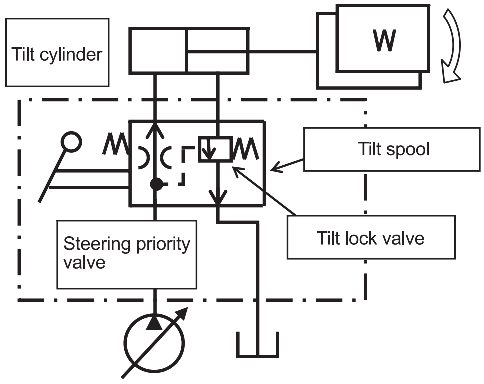

Fig. 16 Tilt lock function (During forward tilt operation)

iii) Lift lock valve.

As in the forward tilting mentioned above, the lift also lowers in the lowering direction under its own weight and a lock mechanism needs to be provided. **Fig. 17** illustrates the configuration of a lift lock valve. As in the work equipment lock function, the lift lock valve is closed when the operator leaves the operator seat and the lift lock valve can cut off the lift cylinder and tank circuit. By this function, the lift does not lower when the operator is not on the operator seat, even if the work equipment lever is operated.

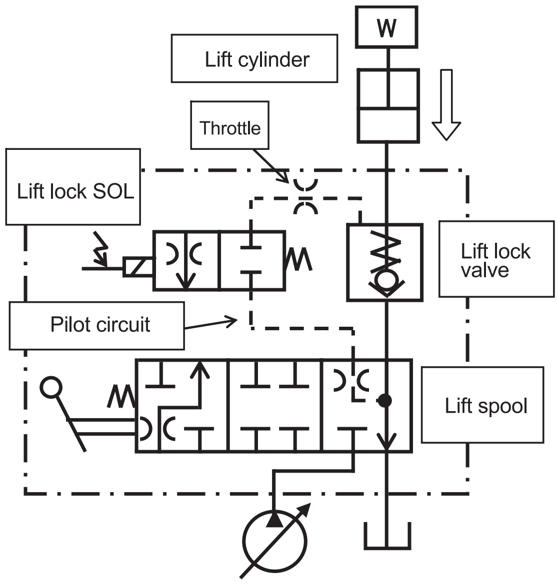

Fig. 17 Lift lock function (When operated during lift lowering)

As the lift lock valve has a conical seat structure, a zero leak structure is set during spontaneous lowering of the lift when the operator leaves the operator seat while the lever is set to neutral shift. The pilot circuit is also closed by the lift spool when the operator is on the operator seat so that the amount of hydraulic drift is negligible.

2) Configuration of the work equipment pump

①LS valve with unload function

Ordinary variable pumps for CLSS have a minimum swash plate capacity and contain an unload valve to release the flow via the work equipment valve. Noticing that both the LS and unload valves actuate by differential pressure between the pump pressure and LS pressure, the development model has eliminated the unload valve of the work equipment valve by adding an unload function to the LS valve. **Fig. 18** and **Fig. 19** show the configuration of the LS valve with an unload function and the flow rate characteristics of the variable valve for forklifts.

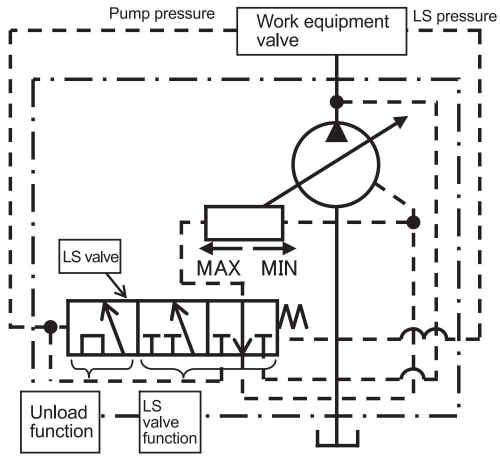

Fig. 18 Configuration of LS valve with an unload function

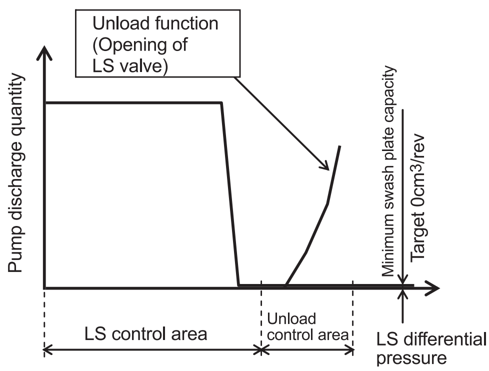

Fig. 19 Flow rate characteristics of the variable pump for forklifts

②LS relief system

For ordinary hydraulic circuits, the entire amount of a pump discharge flow rate has to be relieved and a main relief valve of size commensurate with the pump discharge flow rate is required. The development model has an LS relief system and work equipment pump of a zero wash plate structure, eliminating the main relief valve. The development model has only a small LS relief valve. By reducing the pump discharge flow rate during relief to almost "0," losses during relief can also be reduced. **Fig. 20** illustrates the configuration of the LS relief system, while **Fig. 21** plots the loss reduction effect during relief.

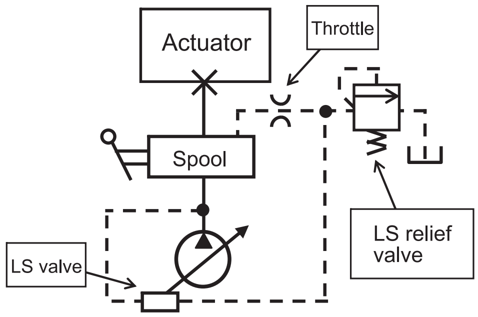

Fig. 20 Configuration of the LS relief system

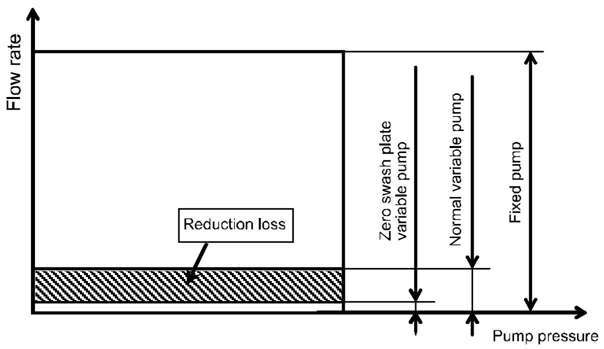

Fig. 21 Loss reduction effect during relief

5. Conclusion

The variable pump CLSS system for forklifts introduced above has enabled the use of a compact engine by reducing hydraulic losses, thereby achieving significantly reduced fuel and costs. Both the Machine Body Design Group and Hydraulic Component Technical Center collaborated in the development work to produce a machine body with outstanding commodity power.

The next task is cited as how to reduce losses of the travel system. Some manufacturers have already installed a hydro static transmission (HST) as a component in the travel system and it will be necessary to study efforts to take a reduction of losses in the travel system into consideration.

The writers wish to contribute to the development of machine bodies that appeal to customers by refining the system through a higher synergy effect with the Machine Body Design Group.

Introduction to the writers

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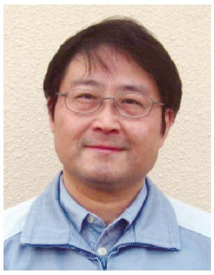

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[A few words from the writers]

Many problems were encountered, ranging from the advance research phase to the high volume production phase in developing this new development model and new valve series with which the Hydraulic Component Technical Center had no experience. Nevertheless, a good product could finally be developed and produced thanks to the cooperation of various departments.

Taking this opportunity, the writers would like to express their deep appreciation to all those having rendered their cooperation, especially Mr. Kazuaki Ozawa, Mr. Takehito Shimbashi and Mr. Takushi Kawakami who came from Komatsu Utility Co., Ltd. to the Corporate Hydraulic Component Technical Center to provide their assistance.