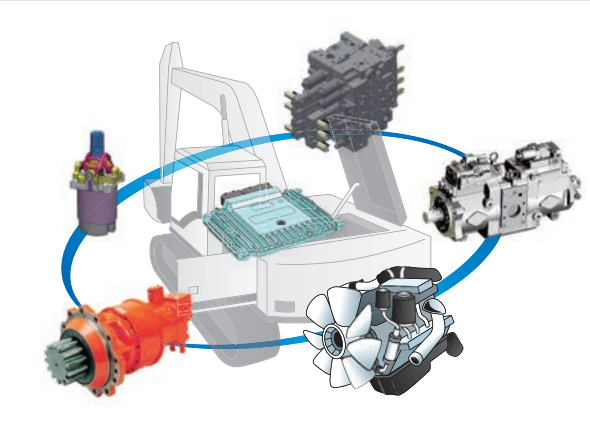
Development of Components for ICT Hydraulic Excavators That Enable the Realization of Computer-Aided Construction



Recently, a shortage of labor mainly due to the aging of construction workers and resigning of skilled workers is becoming a serious issue at construction sites, and the construction industry is making efforts to boost its efficiency by utilizing i-Construction, which uses ICT (Information and Communication Technology) and IoT (Internet of Things) technology. Kawasaki is developing hydraulic components and control devices for ICT hydraulic excavators equipped with the machine control (semi-automatic and full-automatic) functions that support computer-aided construction.

Introduction

Recently, a shortage of labor mainly due to the aging of construction workers, including experienced operators is becoming a serious issue at construction sites. To address this issue, the construction industry is working to boost efficiency and ensure construction quality by utilizing i-Construction, which uses ICT (Information and Communication Technology), IoT (Internet of Things) technology, among other technologies.

1 Background

Hydraulic excavators play a central role in many construction sites. Recently, construction machinery manufacturers are developing hydraulic excavators equipped with machine control functions (semi-automation / full automation) that support computer-aided construction, and therefore, electronic motion control is required. Kawasaki is developing electronically controlled hydraulic components as well as electronic control devices that support ICT hydraulic excavators.

2 Product development concept

(1) Hydraulic excavators and computer-aided construction

The actuators, which are used in hydraulic excavators to perform digging, swinging, travelling, and other operations, are connected to the pump via control valves and are operated by using joysticks. Kawasaki's hydraulic components have been adopted for many excavators and are highly evaluated in terms of controllability and reliability[1)].

Construction machinery manufacturers, which are Kawasaki's customers, have begun putting ICT hydraulic excavators that support computer-aided construction on the market and have been continuing development aimed at further improving construction efficiency and quality. For example, the bucket, arm, and boom need to be finely operated at the same time to move the bucket linearly for digging, which requires experience and skill. However, ICT hydraulic excavators allow inexperienced operators to achieve the same level of construction quality as experienced operators. In addition, ICT hydraulic excavators can be equipped with additional safety features.

(2) Required performance

Pumps and control valves to be mounted in ICT hydraulic excavators need to be electronically controlled. These components need to be electronically controlled, not only to convert command signals from the controller to hydraulic signals and operate actuators in an accurate and responsive manner, but also to exert their performance stably under various load conditions. In addition, to achieve high-functionality, high-performance control, the controller is required to have a microcomputer system that can process a large amount of information and calculations for control. Moreover, measures need to be taken for the increased amount of heat generated in the drive circuit, which is required to drive multiple proportional pressure-

reducing valves.

At construction sites that do not completely support computer-aided construction, excavators need to be operated with electric joysticks, so the joystick is required to have performance and reliability equivalent to or higher than conventional hydraulic pilot control valves.

3 Details of development

(1) Pumps

Pumps serve as the heart of a hydraulic system, and so are required to have high efficiency, low noise, and high reliability. In 2015, Kawasaki put the K7V series pump shown in **Fig. 1** on the market, which has significantly enhanced performance and reliability with the latest technologies.

This pump is equipped with proportional pressure-reducing valves in the regulator, which controls the discharge capacity, as electronically controlled pumps are required for ICT hydraulic excavators. With a combination of proportional pressure-reducing valves and control valves, the movements of the hydraulic cylinder and hydraulic motor are finely controlled by accurately controlling the discharge capacity of the pump in response to the command output from the controller, thereby achieving reduced fuel consumption with an optimally reduced discharge flow rate.

Currently, construction machinery manufacturers are conducting model-based development from the prototyping and evaluation stage in developing increasingly complicated systems. Kawasaki is offering the pump simulation model it developed based on its advanced simulation technology and abundant experimental data to construction machinery manufacturers, thereby contributing to their front-loading development for ICT hydraulic excavators and other machinery.

In the future, the function of monitoring the status of each hydraulic component will become more important as ICT hydraulic excavators are adopted more with more sophisticated machine control. Kawasaki is developing sensors and monitoring technologies that enable stable and accurate detection of the pump status even under harsh conditions specific to construction machinery, including high temperature, with the aim of meeting various future needs, including failure detection.

(2) Control valves

Control valves for excavators are multi control valves that comprehensively control the movement of excavators as shown in **Fig. 2**. In response to the pressure command from the hydraulic pilot control valve, the internal spools of the control valve move to switch the oil passage so that the hydraulic oil discharged from the pump is distributed to the hydraulic motors for travelling and swinging and the cylinders used mainly to drive the boom, arm, and bucket. In addition, the control valve adjusts the opening of the oil passage according to the displacement of the spool to adjust the speed of each actuator, and therefore is required to have high controllability to achieve the intended excavator movements, including very low speed operation and simultaneous operation of multiple actuators.

ICT hydraulic excavators are intended mainly for automation, maneuverability improvement, and fuel consumption reduction. To achieve these, the control valve is required to have electronic control and higher controllability, so we installed the proportional pressure-reducing valves described later on the control valve so that the spool and internal parts, which had been driven by a conventional hydraulic pilot valve, could be driven by the proportional pressure-reducing valves as shown in **Fig. 3**. However, we encountered several technical challenges. For example, (1) ensuring the response-level of equal to or higher than that of conventional control valves, and (2) installing about 20 proportional pressure-reducing valves per control valve and providing primary pressure lines and drain passages for all the proportional pressure-reducing valves. To address these challenges, we designed the control valve so that the oil passages at the upstream and

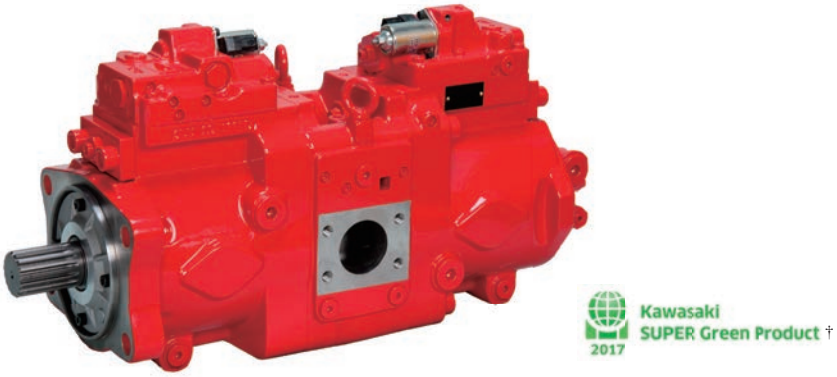


Fig. 1 Pump for excavators K7V125DTP

† The K7V Series, a high-efficiency, low-noise, compact, and high-reliability hydraulic pump, has been widely used for construction machinery (mainly excavators).

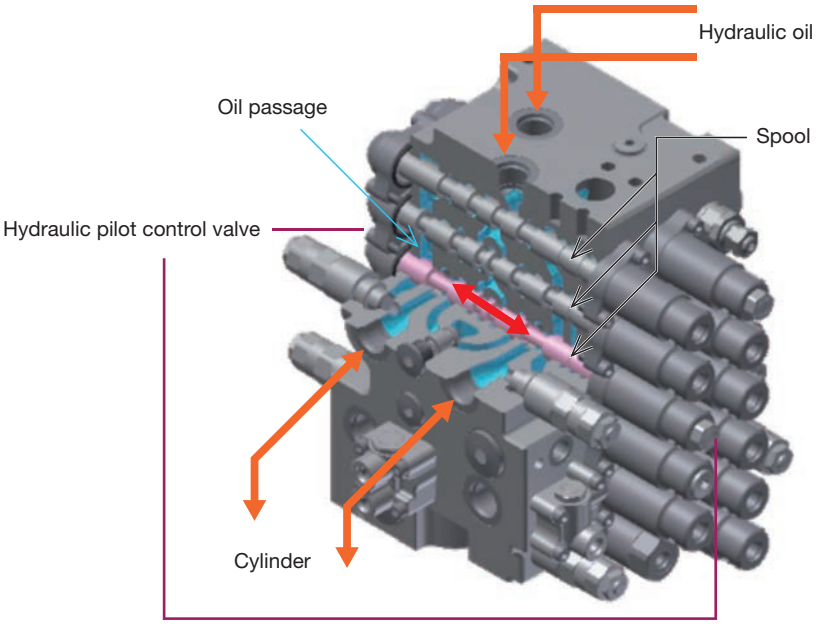
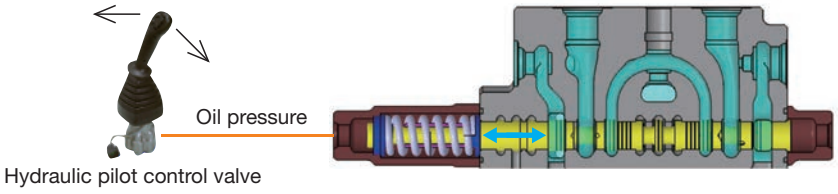
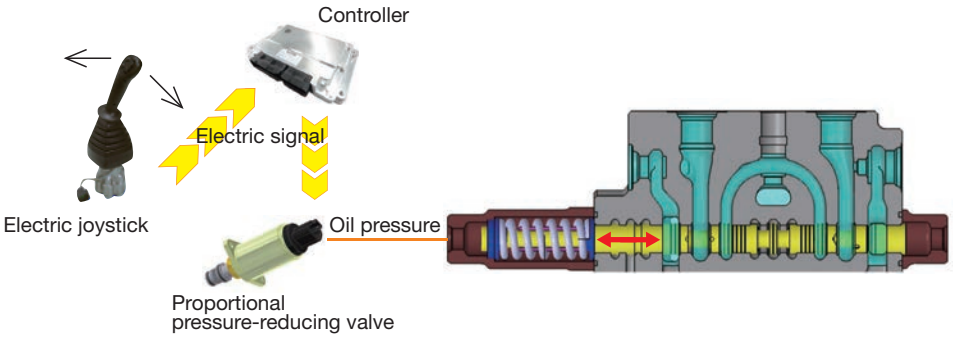


Fig. 2 Control valve for excavators



(a) Spool control with hydraulic pilot control valve



(b) Spool control with proportional pressure-reducing valve

Fig. 3 Spool control types

downstream ends of the proportional pressure-reducing valves have shorter lengths, while having the minimum required area for maintaining the responsiveness, so as to allow air to bleed easily from the oil passages and achieve cost reduction with a compact layout.

We have already developed new models of control valves equipped with proportional pressure-reducing valves by installing proportional pressure-reducing valves on conventional control valves for mid- and large-sized excavators.

The models currently under development use conventional control valves driven by hydraulic pilot control valves as the base model, but we will develop optimal, dedicated valves for electronic control.

(3) Cartridge type proportional pressure-reducing valve

Cartridge type proportional pressure-reducing valves output control pressure proportional to the current command value and are installed directly into the control valve to control the stroke of the spool. Cartridge type proportional pressure-reducing valves are a key component because they affect the performance of the control valve and are required to have high controllability. Multiple proportional pressure-reducing valves are installed into one control valve and if any of them fail, the excavator will no longer work. Therefore, cartridge type proportional pressure-reducing valves are required to have high reliability and durability and not to fail even after prolonged use in harsh conditions.

In computer-aided construction, excavators are automatically controlled, and therefore, the performance of proportional pressure-reducing valves, which control the control valve, is important. We made improvements to optimize the magnetic circuit design of the solenoid and reduce the friction coefficient of each sliding part, thereby reducing hysteresis and variations in output characteristics and enhancing reproducibility as shown in **Fig. 4**.

Many failures in proportional pressure-reducing valves are caused by a broken solenoid coil due to water intrusion or a stuck spool due to contaminated hydraulic oil. To prevent broken coils, we improved the material and waterproof structure of the solenoid coil molding to achieve excellent waterproof properties. To prevent contamination, we installed a filter outside the valve so that contaminants do not reach the sliding portion of the spool. In addition, not to affect the passage design of the control valve, we developed a specially designed, extremely thin filter shown in **Fig. 5**.

(4) Controller

The machine control used in ICT hydraulic excavators and other construction machinery, which electronically controls excavators, provides improved maneuverability and safety and reduced fuel consumption. To achieve such machine control, the controller is required to elicit the maximum performance of each hydraulic component and control the excavator to achieve complicated movements. Therefore, the controller is required to have the ability to process a large amount of information and logic related to control and communication, such as input signals from the sensors and switches, and output signals to the proportional pressure-reducing valves and solenoid-operated directional control valves. Consequently, we adopted the dual microcomputer system shown in **Fig. 6**.

This system uses two microcomputers for input/output

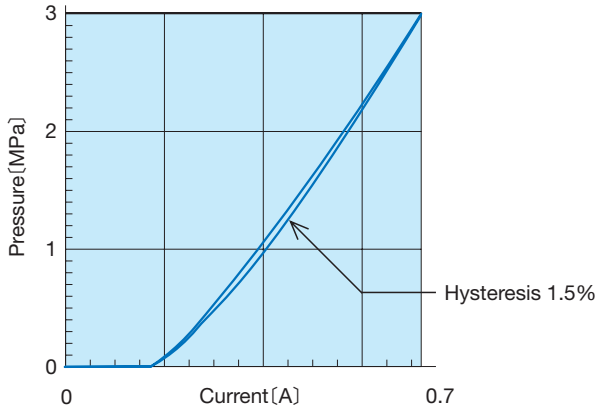


Fig. 4 Reduction of hysteresis (representative characteristic)

Fig. 5 Appearance of cartridge type proportional pressure-reducing valve

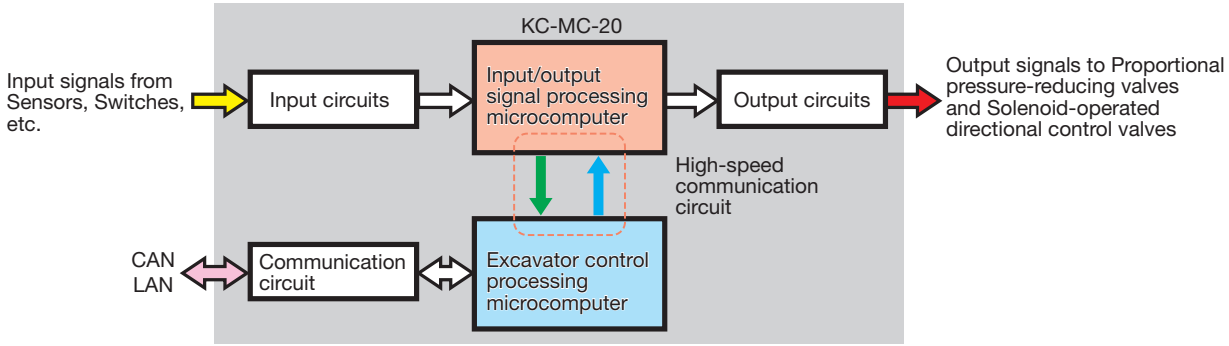
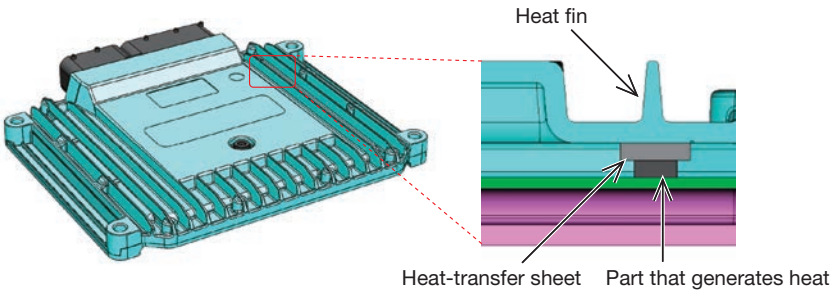


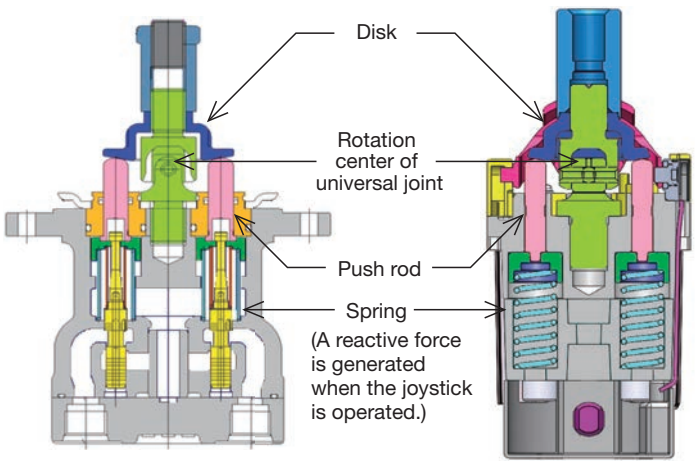
Fig. 6 Dual microcomputer system



(a) Appearance (b) Sectional view

Fig. 7 Heat dissipation structure of case

Fig. 8 Appearance of electric joystick ERU2-7.0



(a) Hydraulic pilot control valve (b) Electric joystick

Fig. 9 Comparing lever return mechanisms

†† ERU2-7.0, an electric joystick used for operating construction machinery, has significantly reduced power consumption and best-in-class durability at the same time.

signal processing, excavator control processing, and communication processing, which have conventionally been done by one microcomputer. This system facilitates control program creation and prevents the microcomputer from exceeding its processing capacity due to increased throughput. In addition, the two microcomputers are connected with a high-speed communication circuit so that they can operate in cooperation with each other.

The controller drives multiple proportional pressure-reducing valves. Heat generation of the electronic circuits due to the proportional pressure-reducing valves drive, deteriorates electronic parts, resulting in reduced service life or failure. For this reason, the controller is required to have a circuit board that generates less heat and is designed to have a structure that efficiently conducts heat from the board to the case.

Therefore, we newly designed a low heat generation circuit to reduce heat sources and adopted a structure that conducts heat from the board-mounted components, which are sources of heat, to the case and radiates the heat from the heat fins on the case shown in **Fig. 7**.

(5) Electric joystick

We adopted a structure that couples the lever and angle sensor by means of sliding coupling to detect the tilt angle. The electric joystick is designed so that the joystick returns to the neutral position by spring action when the operator releases his or her hand as shown in **Fig. 8**. Its structure and components incorporate various design know-how so that they can withstand use in harsh conditions.

(i) Lever return structure

Kawasaki has maintained the top share in the field of hydraulic pilot control valves for conventional excavators for over 30 years. The electric joystick has the lever return structure shown in **Fig. 9**, inheriting excellent maneuverability, reliability, and durability from the previous models.

(ii) Angle sensor

The angle sensor, which converts the operating angle of the lever to electrical signals and is one of the most important parts, is required to have high reliability. Therefore, we adopted a non-contact structure using a hall-effect sensor and a sealing structure, thereby achieving high durability and excellent waterproof properties. In addition, we optimized the electronic circuit including sensors, thereby achieving excellent immunity to noise.

(iii) Size reduction

Electric joysticks are required to be small, but if the size is reduced too much, the strength may decrease, resulting in poor durability or reliability. Therefore, we optimized the design specifications, thereby achieving size reduction with durability and reliability equivalent to or higher than conventional hydraulic remote control valves.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Conclusion

The number of excavators and other construction machines that support computer-aided construction is increasing, and the construction methods used at construction sites are changing accordingly.

In addition to the components we developed this time, we will be developing optimal products for future advanced excavators by combining hydraulic technology and electronic control technology.

Reference

1) Yoshikawa, Muraoka, Akamatsu, Matsuo: "Latest Control Valves for Hydraulic Excavators," Kawasaki Technical Review No.168, pp. 14-19 (2009) (in Japanese)