Technical Paper

Development of PC210LCi-10/PC200i-10 Machine Control Hydraulic Excavator

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In recent years, the efficient construction work thanks to the computerized construction utilizing the ICT technology has been expanded in the market, which contains shortening of a construction period by abolishing the finishing stake which was necessary in the conventional construction work, improvement of execution accuracy, and execution progress management. From this trend, there are growing needs for construction machinery responding to it. When it comes to hydraulic excavators, machines installed with Machine Guidance (MG) have been commercialized including after-market products. However, finishing grading was somewhat dependent on skills of operators monitoring the display. Accordingly, we have developed the machine-controlled hydraulic excavator highly improved in construction efficiency, which enables machine control in a series of operations from rough digging to grading, thanks to the combination of the hydraulic control technology from Komatsu unique components and the GNSS surveying technology. This excavator has released on the computerized-construction-advanced markets of Japan, U.S. and Europe ahead of other competitors.

Key Words: *PC210LCi-10/PC200i-10, Machine Control Hydraulic Excavator, Automatic Grading Assist, Automatic Stop Control, ICT Construction, Construction Management, GNSS*

1. Introduction

Construction machinery utilizing GNSS surveying technology contributes greatly to the reduction in man-hours through abolishing of finishing stake. For construction machinery which performs finishing grading such as a bulldozer and motor grader, the system called Machine Control (hereafter MC) which performs control so that work equipment moves automatically along the design surface has been commercialized. In 2013, Komatsu marketed D61EXi/PXi-23 for which the application range of work equipment automatic control was expanded in addition to a series of bulldozer operation from digging/soil carrying to grading, and it earned an excellent reputation, giving a big impact to the market. However, as far as hydraulic excavators are concerned, the control function was limited up to the machine guidance (MG) function, so that an operator should perform work at a construction site without finishing stake according to the guidance while looking at the guidance monitor. Therefore, final finishing accuracy was largely dependent on the skill of operator.

We have developed an innovative 20-ton class MC hydraulic excavator, PC210LCi-10/PC200i-10 (**Fig. 1**) combining the hydraulic control technology of Komatsu unique components with GNSS surveying technology. This unit realizes the MC work equipment control from rough digging to finishing grading and improves construction efficiency thanks to various components integrated in the machine body, and "Automatic Stop Control" which stops the work equipment at the design surface (construction surface) and "Automatic Grading Assist" which performs control so that the work equipment moves along the design surface. This report introduces the features of this model centering on three "I"s - "Innovative", "Integration" and "Intelligent".

Fig. 1 PC210LCi-10/PC200i-10 External view (left) Conventional MG hydraulic excavator (right)

2. Machine Body System

<Integrated>

2-1. GNSS surveying instrument

In conventional MG hydraulic excavators, the GNSS antenna was installed on a dedicated pole erected on the counterweight. In this machine, it is installed on the handrail in the rear of the cab so that damage risk due to contact with trees is reduced and safety during attaching/detaching is improved. (**Fig. 2**)

Fig. 2 GNSS surveying instrument

2-2. Stroke sensing cylinder

To control the work equipment with high precision, it is necessary to precisely detect the position and speed of the work equipment.

This machine adopts stroke sensors (**Fig. 3**) made by Komatsu for hydraulic cylinders (boom cylinder, arm cylinder and bucket cylinder) of work equipment. These sensors can precisely detect the stroke (length) and speed of each cylinder, which are used for work equipment control and calculation of work equipment position.

The stroke sensor has a function to detect stroke by rotation of the roller caused by expansion and contraction of the cylinder rod and combined with a function to correct an error due to slippage of the roller. As compared with an after-market product which detects the work equipment posture with a clinometer, this sensor is superior in dynamic responsiveness and does not cause sway of the edge on the monitor.

Fig. 3 Stroke sensing cylinder

2-3. IMU

To calculate the precise work equipment posture, it is necessary to detect the attitude angle of the machine body. IMU (Inertial Measurement Unit) (**Fig. 4**) which can detect the attitude angle of the machine body with high precision is installed on the machine body frame to enable precision work equipment control even for work on a slope.

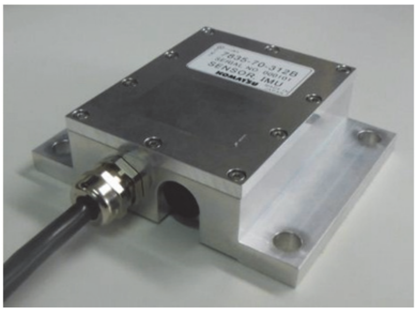


Fig. 4 IMU

2-4. Electronically-controlled work equipment valve

The lever operation of an operator is transmitted to the hydraulic control valves which control cylinder actions through the hydraulic pilot valves, where the operation feel same as that of the base machine is maintained. The difference from the base machine is that EPC (Electric Pressure Control) valves (**Fig. 5**) are provided between the pilot valves and control valves to electronically control the pilot pressure for work equipment control. Each control valve is installed with a sensor. The sensor precisely detects the positon of the spool which determines the flow rate for improvement of control performance.

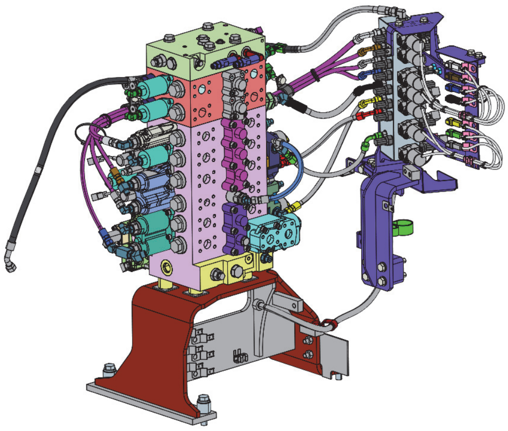


Fig. 5 Electronically-controlled work equipment valve

2-5. Electronic controller

Electric signals of each component already introduced are connected to the controller (**Fig. 6**) which outputs commands for work equipment control. This controller uses a hardware which is field-proven in large-sized construction machinery. It is connected to other controllers with a communication network to obtain necessary information from other controllers.

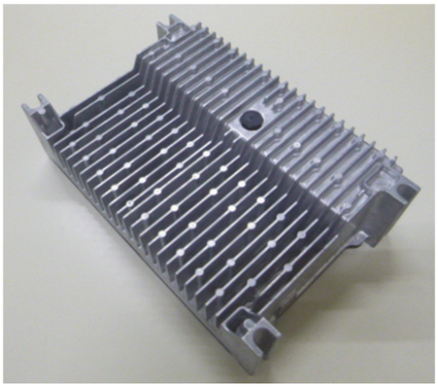


Fig. 6 Electronic controller

2-6. Large-screen control box

Although a display which displays design drawing information, edge position, distance and machine condition necessary for execution is predominantly 6 – 7 inch size in general, a large-sized 12.1 inch, touch panel type display (**Fig. 7**) is installed in consideration of function as an interface easy to see, understand and use. Functions of start-up/termination in combination with machine key on/off and LCD screen automatically dimming during the use of a working lamp are also incorporated. 3D bird's eye view display and displayed character positions are well thought of for easy viewing, and the light bar and sound guidance function for easy understanding, provision of function keys for easy use and various customizing functions are also equipped. Thus, not only visibility of operator has been improved but also the function as an interface has been improved. The monitor is mounted with a ball joint and can be adjusted to a position where visibility can be secured regardless of the seating position of the operator.

Fig. 7 Large-screen control box

2-7. Others

Calibration of work equipment dimensions and various sensors and precision inspection are already completed at a manufacturing plant. Therefore, in a worksite, registering dimensions of buckets to be used as a file alone enables the MC operation. For design surface data and bucket files, the data can be easily read and written using a USB memory device. When an Internet modem is connected, finished work shape information and design surface data can be transmitted and received using the electric reference point and the construction management system.

3. Work Equipment Control

<Intelligent>

In conventional MG hydraulic excavators, an operator performs operation manually while checking the positional relationship between the design surface and the edge shown on the screen. In this machine, on the other hand, an operator can perform operation without worrying about digging down into the design surface thanks to MC work equipment control. This is the biggest feature of this machine.

For the operation itself, when digging toward the design surface as with a MG hydraulic excavator, if the edge reaches the design surface in boom lowering and bucket digging/dump operation, the work equipment is automatically stopped (automatic stop control). In arm operation, if the controller judges that the edge digs down into the design surface based on the positional relationship between the work equipment and design surface, a boom raising command is automatically outputted and the work equipment is controlled so that the edge moves along the design surface (automatic grading assist).

Features of work equipment control incorporated into this machine are introduced below.

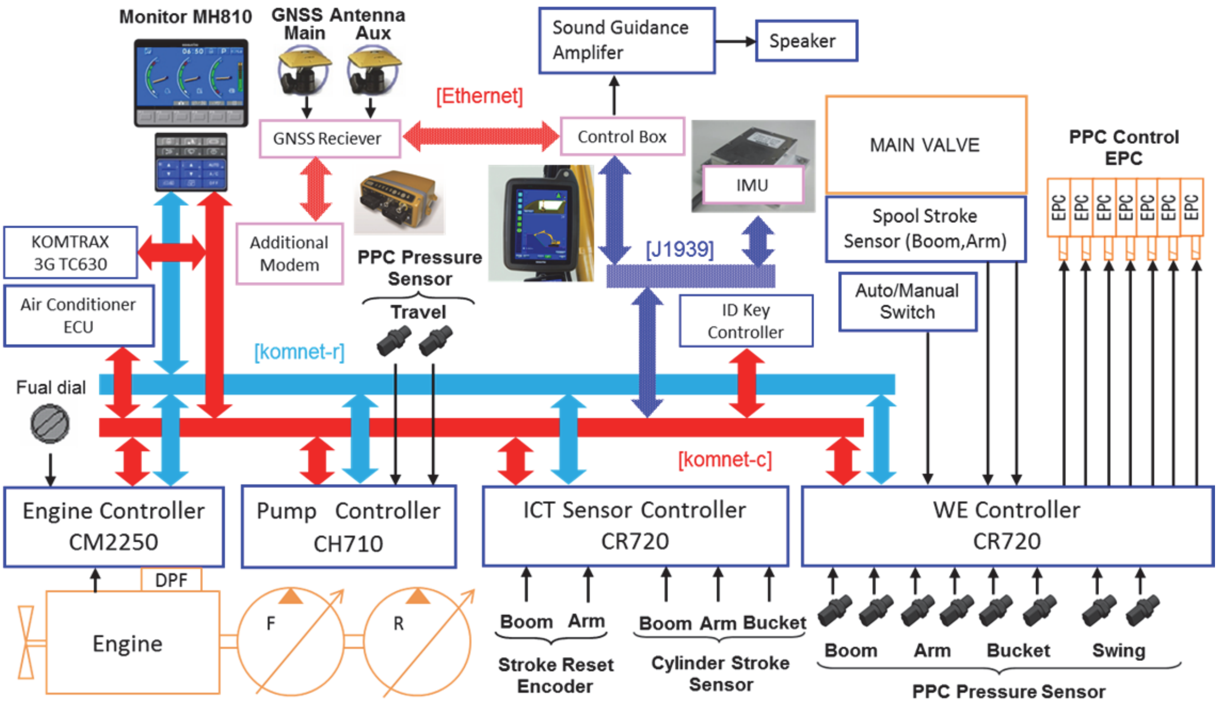


Fig. 8 PC210LCi-10/PC200i-10 system chart

3-1. Automatic stop control (Fig. 9)

The controller constantly calculates the distance between the design surface and the edge, edge speed and direction. It calculates the edge speed from detected pilot pressure caused by operator's operation, and also calculates the allowable speed in relation with the distance to the design surface. If it judges that control intervention is necessary, it converts the target speed to the target speed of each cylinder geometrically, and lowers the edge speed to the allowable speed by changing the current to EPC valve to control the pilot pressure for cylinder. And finally it stops the edge at the design surface.

Automatic stop control is a very effective function when aligning the edge with the design surface at the start of digging or when the edge is used for a survey.

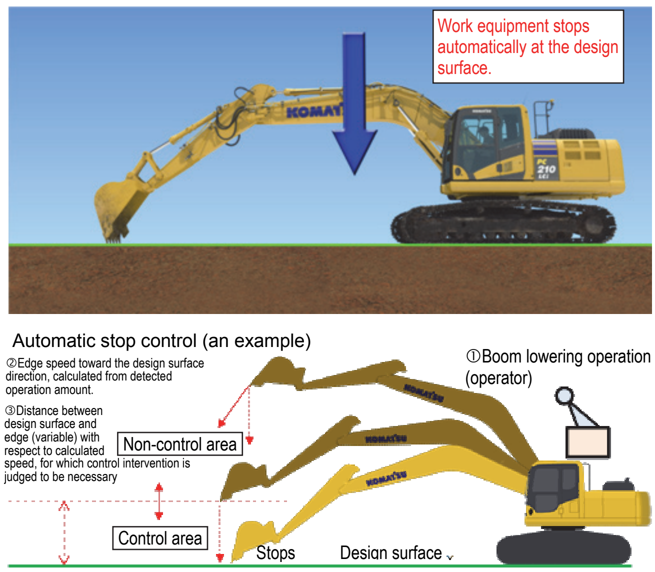


Fig. 9 Automatic stop control

3-2. Automatic grading assist (Fig. 10)

As with the automatic stop control, if the controller judges, based on the distance between the design surface and the edge, edge speed and direction, that the edge will dig down into the design surface by operator's arm operation, a boom raising command is automatically outputted and control intervention is activated so that the edge moves along the design surface. It also reduces the arm speed as required. Automatic grading assist, which performs optimal control according to an operator's arm operation amount, covers operation from rough digging for which execution accuracy is not so much required to crawling speed operation requiring accuracy such as finishing grading with a bucket bottom by performing bucket operation and boom lowering operation.

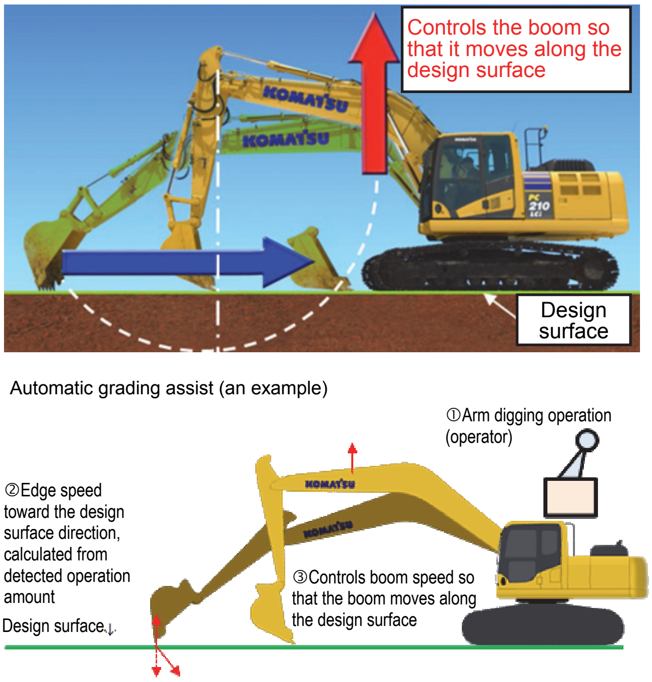


Fig. 10 Automatic grading assist

3-3. Shortest distance control and facing angle compass

When a surface to be executed is a slope and the machine does not face the surface directly, digging down occurs, affecting finished work quality unless control intervention is activated with reference to the point of edge closest to the design surface. For the selection of control intervention reference point of the edge, the "shortest distance point" selection is available in addition to selecting the center and ends. If the "shortest distance" is selected, control intervention is activated with reference to the point closest to the design surface. Areas subject to control include not only the edge but the bottom and profile of a bucket. Therefore, edge finishing and bottom finishing are possible.

In the case of execution of a slope face, the facing angle compass function which displays the facing condition between the machine body and design surface on the screen contributes to the improvement of usability. (**Fig. 11**)

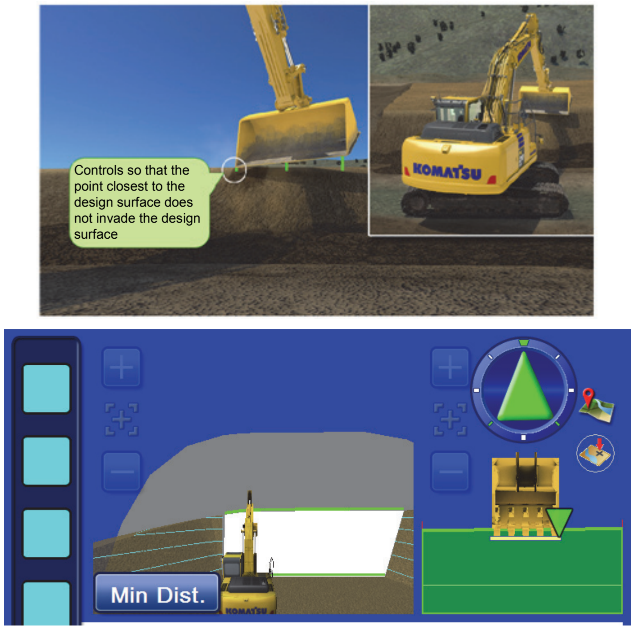


Fig. 11 Shortest distance control (left)
Facing angle compass function:
▲display on upper right of screen (right)

3-4. Others

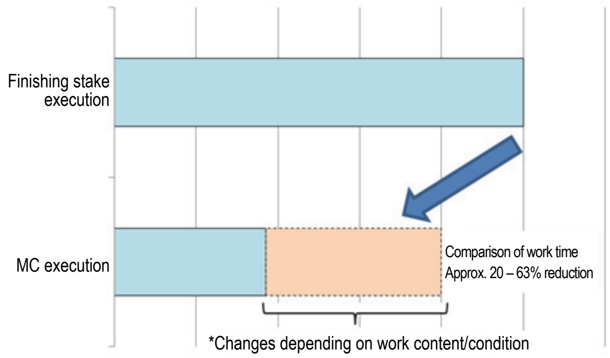
A hydraulic excavator replaces its bucket with a suitable one according to the execution content. When a bucket with tilt operation capability is used, MC is made possible by only adding an inclination sensor to the bucket. Although the bucket weight varies depending on a bucket installed, control accuracy can be secured from a heavy bucket to a light bucket by changing the bucket weight setting on the machine body monitor. MC function can be easily switched to MG function with a single button operation.

4. Effect of Machine Control

<Innovate>

The above work equipment control and information on the large screen have shortened work time by approximately 20 – 63% in in-house standardized model work compared to conventional finishing stake execution and an aftermarket MG hydraulic excavator. This experiment was conducted in a series of execution from digging toward the design surface to grading. Shortening of work time differs depending on the work content and conditions.

Table 1 Comparison of work time between finishing stake execution and MC execution



5. Conclusion

We have introduced the features of the MC hydraulic excavator, "Komatsu PC210LCi-10, PC200i-10", developed ahead of the competition, with three "I"s of Integrate, Intelligent and Innovate. It is expected that the function/technology of machine control of hydraulic excavators will lead to the reduction of operator fatigue, enable experienced operators to perform more efficient work and reduce the difference of skills between experienced operators and inexperienced operators. It can be said that the improvement of construction efficiency will bring merits also to owners such as the reduction in construction costs and the shortening of construction period. We are committed to positively taking endlessly developing ICT technologies into construction machinery and making efforts as a manufacturer so that the ICT construction industry will further develop by realizing its possibilities.

Introduction of the writers

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Entered Komatsu in 2009
Engaged in machine body control system development of ICT hydraulic excavators.
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[A few words from writers]

We have succeeded in the world's first commercialization of machine control hydraulic excavator thanks to Komatsu's accumulated technological strength and organizational strength and partnership of cooperative companies. This, however, is just the starting point. In the future, we will further increase construction efficiency such as further expansion of the control areas, improvement of control accuracy and guidance of optimal execution techniques so that anyone can perform work. We believe that the way to full automatization will come into view.