Introduction of Products

Machine Control Hydraulic Excavator PC200i-11

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In recent years, effectiveness improvement of construction works using ICT technology has advanced. For bulldozers, machines that can reduce the burden on the operator by controlling the position of the work equipment during leveling and hauling work are introduced in the market. Ahead of competitors, we introduced machine control hydraulic excavators, which also reduce the operator's effort by assisting the excavation operation, contributing greatly to increasing the efficiency. Even after the release of these well received machines, we continued with our activities to expand model series in North America and Japan, adopt surveying functions using stereo camera technology, provide the comprehensive service "Smart Construction" which supports the entire construction work, and introduce other attractive products to the market. Especially in Japan, the "i-Construction" concept was announced by the Ministry of Land, Infrastructure and Transport in 2015. As a result, the movement to aim at the efficiency of the construction site by utilizing information technology has become active. We like to introduce our newly developed machine control hydraulic excavator, equipped with new functions aiming at improvement of usability and construction efficiency for operators.

Key Words: *PC200-11, PC210LCi-10 / PC200i-10, Machine control hydraulic excavator, Automatic leveling assist, Automatic stop control, Computerized construction, Construction management, GNSS, Stereo camera*

1. Introduction

Construction machines that utilize GNSS surveying technology have greatly contributed to reducing man-hours by eliminating finishing stakes. For construction machines such as bulldozers and motor graders which perform finish leveling, a system called machine control (hereinafter referred to as MC) that controls the work equipment automatically to follow the design surface has been commercialized. In 2013, Komatsu released the D61EXi/PXi-23 which expanded the adoption range of automatic machine control to a series of bulldozer work from excavating/carrying soil to leveling. These machines received a very high reputation and greatly affected the market. For hydraulic excavators, Komatsu introduced in 2014 to the European market the PC 210LCi-10, which can support the operator's operation to excavate the design surface. This machine was also accepted with high reputation by the market. In Japan, Komatsu started renting PC 200i-10 machines in 2014, and started general sales of stereo camera installed machines in 2016. (**Fig. 1**)

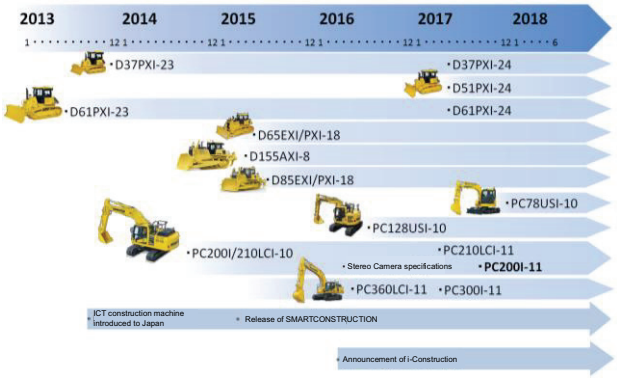
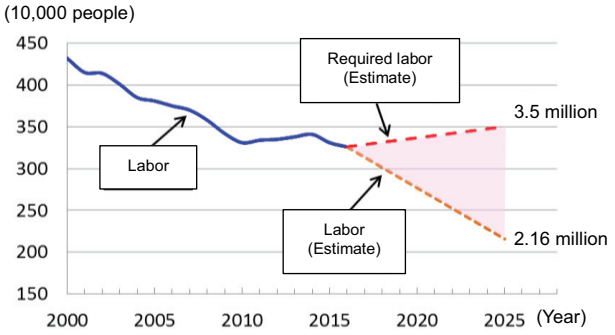


Fig. 1 Introduction of Komatsu ICT construction machines to market

In the Japanese market at that time, few worksites used information construction work. In the market, the penetration rate was low except for some advanced customers. However, Komatsu has received high praise from many customers by providing SMARTCONSTRUCTION services which comprehensively support not only the construction part but the whole process including information construction work together with the machines.

Also, looking at the Japanese market, the gap between the reducing number of construction workers and the number of workers actually needed in the construction industry in the

future is estimated to increase (**Fig. 2**). Efficiency improvement is urgently needed for achieving the goal of improving the overall construction production process by 20% by 2025, which has been announced by the Ministry of Land, Infrastructure, Transport and Tourism with their i-Construction concept. It is also indispensable for the actual site to introduce surveying instruments and construction machinery conforming to this concept accordingly.



<Reference>
Ministry of Internal Affairs and Communications "Labor Force Survey"
General Corporation Japan Construction Federation "Towards rebirth and evolution: long-term vision of construction industry"

Fig. 2 Trends and Estimates of Construction Skill Labor

This article introduces the background of the market and also introduces the features of the 20 ton class MC hydraulic excavator PC200i-11 (**Fig. 3**), focusing on newly installed functions. The PC200i-11 aims at improving efficiency not only for operators but also for construction sites, compared with conventional MC hydraulic excavators. Many of the desires actually received from the market, since the introduction of the world-first machine control, have been satisfied.

Fig. 3 External view of PC200i-11

2. New Functions

In addition to the conventional MC hydraulic excavator, which assists the operator by raising the boom while moving the cutting edge along the design surface according to the arm operation by the operator, the assist range of this machine is expanded by features such as lowering the boom while holding the bucket at a fixed angle against the design surface, seamless transition to soil compaction (frequently done in many construction sites), a payload meter that contributes to efficient loading work, stereo cameras that can easily capture the terrain at the work site, etc. The machine can contribute greatly to information processing at the construction site.

2.1 New Functions of Machine Control

2.1.1 Auto Boom Down (Fig. 4)

The conventional automatic ground leveling assistance controls the cutting edge to follow the design surface by automatically outputting a boom raising command whenever the system thinks that the operator's arm control lets the cutting edge dig in further than the design surface, judging based on the distance between the design surface and the cutting edge, speed, and direction. In addition, the function also decelerates the arm speed as necessary. However, in some situations where the cutting edge moves away from the designed surface unless the boom is lowered, the operator had to manually perform a boom lowering control because the boom lowering speed was controlled not to exceed the calculated speed. The operators sometimes held the boom lever in the lowering direction to smoothly switch the boom raising and lowering.

With the new function, it has been changed to output a boom lowering command whenever it is necessary according to the arm control by the operator, to let the cutting edge follow the design surface.

In ordinary operation patterns, the boom and the bucket are operated with the same lever. In order for the operator to finely adjust the bucket angle, it was necessary to finely adjust the bucket while lowering the boom. With this new function, however, the operator no longer has to worry about controlling the boom, and this contributes to reducing the effort of the operator.

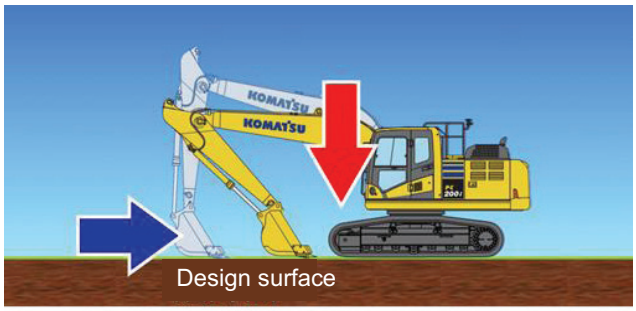


Fig. 4 Auto Boom Down

Fig. 5 Bucket Angle Hold Control

2.1.2 Bucket Angle Hold Control (Fig. 5)

In the conventional follow-up control, a boom raising command is automatically output so that the cutting edge does not dig into the design surface by the arm operation of the operator, and the cutting edge is controlled to follow the design surface. When actually excavating the ground, the bucket must be manually adjusted during the work because its angle against the ground changes depending on the arm angle, and the excavation performance and leveling will change. However, this operation for keeping the bucket angle constant required a lot of attention from the operator and was a burden for the operator. The new function keeps the relative position of the controlled object and the bucket (when the arm operation was started while MC control was enabled) constant by automatically moving the bucket based on the command output from the controller. However, since the state of the ground actually dug is not constant, the operator is allowed to change the bucket angle to any angle by operating the lever, even when the arm is being operated. Also, excavation can be continued with the angle of the bucket against the design surface fixed at the time when the operation of the lever is stopped. Thus the operator can concentrate on the construction without feeling stress.

An EPC valve for pressure reduction is included in the PPC circuit from the bucket operation lever of the MC excavator to the control valve. The lever main force pressure is controlled by the command value from the controller with respect to the output pressure of the lever. This new function detects the output pressure of the lever and causes EPC to supply the output pressure to the control valve. In this way, the lever can move smoothly as requested by the controller while machine control is in progress, or as operated by the operator.

2.1.3 Compaction Control

When using an excavator in a general civil engineering work in Japan, the construction surface is often compacted as a finishing process by hitting the bottom of the bucket. (**Fig. 6**) This is to apply earth pressure on the soil and harden the surface of the ground to prevent collapse and also to prevent water such as in rainy weather from seeping into the completed surface. In order to do this, it is necessary to lower the boom and press the bottom of the bucket strongly to the ground. However, the conventional MC excavator automatically controls the speed of boom lowering and stops the cutting edge at the design surface so that construction can be carried out without damaging the design surface. Therefore, the speed was insufficient for soil compacting, so it was necessary to turn off the machine control.

However, it is very troublesome to switch modes every time soil compacting is frequently performed during civil engineering work. Also, since construction is done by machine guidance, operation needs to be performed while confirming that the stop position does not damage the design surface. This function has been developed to increase the efficiency of construction in such situations.

This function is made up of two functions. One is to read from the pattern of boom lowering operation by the operator the fact that the operator is attempting soil compacting. It then automatically switches the deceleration table of stop control to adjust the speed to be able to apply sufficient earth pressure at the time of contact with the ground. This function enables stopping smoothly as usual except when doing soil compaction, and when performing soil compaction, it allows to hit the construction surface by fast boom lowering. Thus the work can be done without interrupting the series of operations.

The other function is to switch the temporary cancel of offset control surface for the design surface which has been arbitrarily set by the angle between the bucket and ground without performing on-screen or other operations. When performing soil compaction, it is necessary to stack extra soil

from the final finished surface considering the compression of the soil after compacting. By using this function, it became possible to stack extra soil by offsetting, perform construction by assistance, and then perform soil compacting with a controlled bucket bottom without worrying about damaging the design surface. (**Fig. 7**)

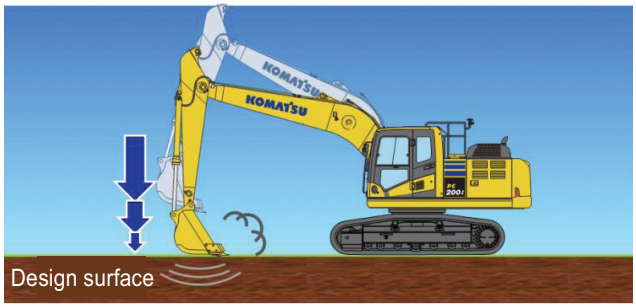


Fig. 6 Compaction Control operation

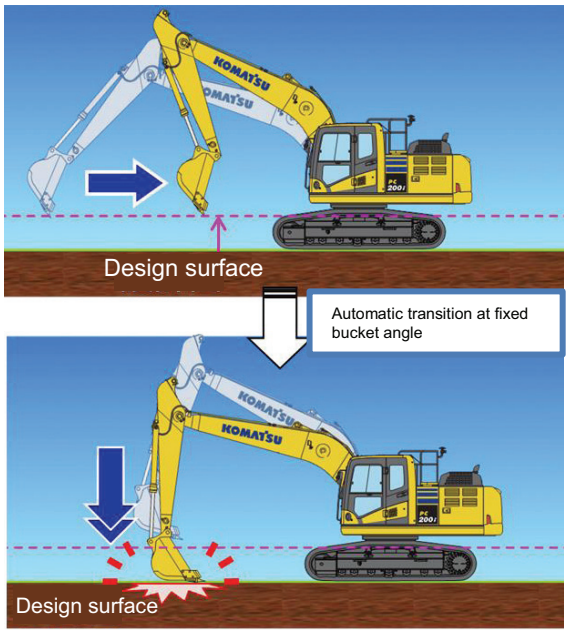


Fig. 7 Work example using Compaction Control and design surface temporary cancellation together

2.1.4 Auto Tilt Bucket

A tilt bucket (**Fig. 8**) equipped with a cylinder with a stroke sensor is available as a genuine Komatsu product, which makes it possible to measure the bucket tilt angle at a high accuracy regardless of the posture. Using this bucket makes it possible to assist the operator under machine control even for tilt operation.

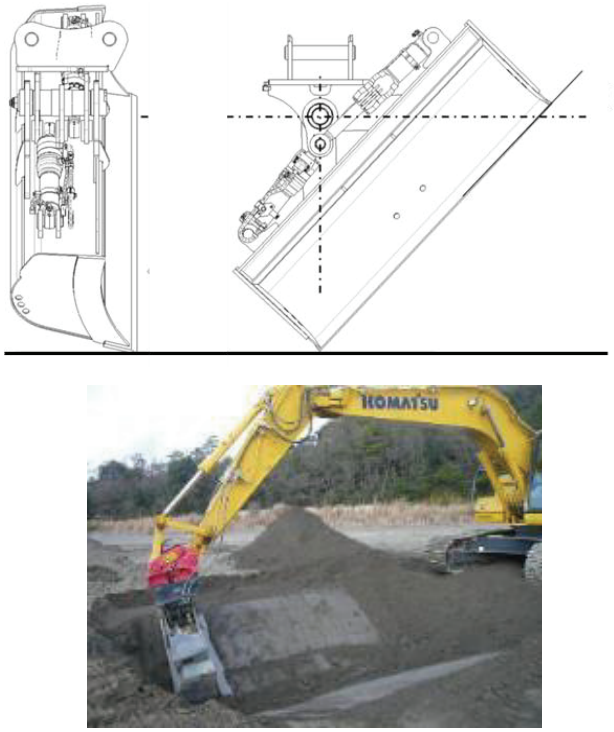


Fig. 8 Auto Tilt Bucket

By using the tilt bucket with a sensor, it became possible to prevent the cutting edge from digging into the design surface even during bucket tilt controls. The tilt bucket has one more operation axis than an ordinary bucket. Therefore, construction can be carried out even if the machine cannot be faced straight against the construction surface for various reasons. Although it is a useful tool for improving the construction efficiency at the site, the operator must use more care than the usual bucket during construction because the operation is complicated. By using this function, the operator now can easily perform shaping work without damaging the design surface by tilt operation while the cutting edge of the tilt bucket is controlled not to leave the construction surface at all times. Unlike the stop control for other operations, this function is effective even during profiling work. By using this together with the Bucket Angle Hold Control function described above, working on complicated design surfaces can be performed more effectively. (**Fig. 9**)

Fig. 9 Result of Construction Using Auto Tilt Bucket

2.1.5 Improved User Interface of New Function

Among the new functions introduced this time, the Auto Boom Down function, the Bucket Angle Hold function, the Compaction Control function, and the design surface temporary offset canceling function can be added as icons to the HMI installed in the operator cab, so the operator can easily enable or disable the functions as needed. Also, when the functions are enabled, the corresponding icons turn green, so the operator can visually confirm whether or not the control is working. (**Fig. 10**)

Fig. 10 HMI Screen with New Function Icons Added

2.2 SMARTCONSTRUCTION/Worksite Efficiency Improvement

2.2.1 Stereo Camera

When excavation is carried out using an excavator, the daily progress situation must to be checked to manage the construction by tracing the terrain after excavation. Until now, we had to record the position of the cutting edge after the ICT excavator excavated and update its trajectory as the current surface, or perform measurement using a drone or laser measuring instrument. It took time and effort to measure the accurate current surface in this way.

Therefore, a stereo camera system is standardly installed in the ICT excavator that is introduced in Japan, and it can acquire the terrain information by image processing and send the data to the server.

The system is equipped with two pairs of cameras, one pair for long distance and the other for short distance (**Fig. 11**). When the operator presses the measurement switch, the system measures the terrain and automatically transmits the terrain data to the construction management server. In the conventional machine, the cameras were installed in the operator cab, but by installing the cameras outside the operator cab from this machine, a wider space could be secured inside the operator cab.

Conventionally, only one shot was possible at a time to ensure the accuracy of position information at the time of shooting, but this machine uses position information at the start and end of swing, thus enabling continuous shooting during swinging, and shortening the time taken for a wide range of shooting. In addition, guidance sound effects are provided for the operation during shooting. This makes it easy for the operator to check the condition of the machine body when capturing images. The operator can confirm the view through the camera on a handheld tablet via the wireless communication network in the operator cab by downloading the dedicated application to the tablet. (**Fig. 12**) The upper and lower camera images can be checked respectively.

In addition, the single shot function also supports interim payment by volume control promoted by the Ministry of Land, Infrastructure and Transport. By conducting the prescribed inspection at regular intervals, the acceptance inspection data of a site worked by machines other than this ICT excavator or other operators can be acquired without the need for additional equipment.

Fig. 11 Stereo Camera

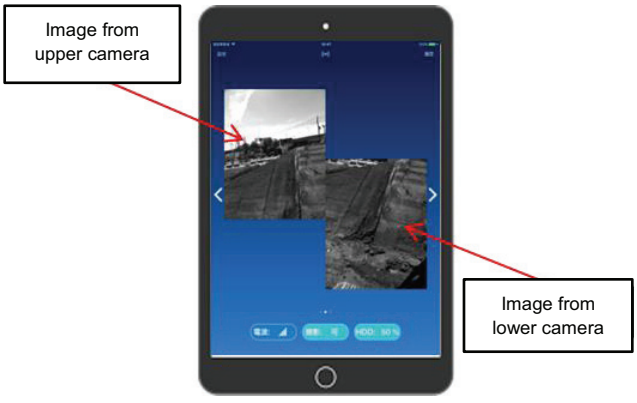


Fig. 12 User Interface Screen

2.2.2 Payload Function

Civil engineering work using a hydraulic excavator includes a large proportion of loading earth and sand (either excavated or being used for construction) onto dump trucks, in addition to digging and levelling. In many cases dump trucks travel on public roads to transport earth and sand, so management of the hauling capacity is an important issue. Since the cost to hire a truck occupies a decent proportion of the cost of construction, it is desirable to raise the volumetric rate per truck, but overloading will be illegal. Truck scales are often installed at the worksite to check overloading. However, reworking such as unloading excessive load leads to loss of efficiency. During a sequence of loading operations, this machine calculates its own posture by sensors on the work equipment, and calculates the weight of the earth and sand in the bucket with the pressure sensors attached to the boom head and the bottom piping to visually indicate the load amount to the operator.

With this function, the operator can check the weight of the load currently loaded on a pre-registered truck and the loading history using a tablet (**Fig. 13**). The function makes it easy to know the current loading rate and how much room is left. It is possible to maximize the loading capacity without worrying about overloading. In this way, the actual loading amount and efficiency is improved.

Since the positional relationship between the hydraulic excavator and dump truck, and the vessel height of the dump truck vary in actual loading, the actual weight measurement timing can be freely set by the bucket height. Since the calculation value may be incorrect if the weight changes due to bucket exchange or earth and sand adhering to the bucket, compensation for the weight change of the end can be done by simple calibration.

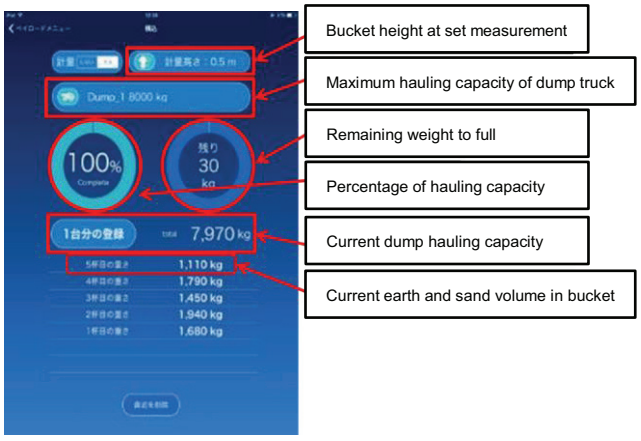


Fig. 13 User Interface Screen on Tablet

2.3 Utilizing Market Infrastructure

2.3.1 Supporting Multi-GNSS

Currently, satellite positioning systems are used in various fields. In recent years, not only the commonly used GPS (US) and GLONASS (Russia), but also other satellites launched by various countries contribute to improving the number of available satellites and preventing accuracy degradation in some regions. Japan also launched the first "MICHIBIKI (Quasi-Zenith Satellite System)" satellite in 2010, aiming to start location information service in a 4-satellite system from fiscal 2018 and a 7-satellite system in 2025. When the operation of the 4-satellite system is officially started, three satellites will be available at all times in the Asia/Oceania region. Using them together with GPS satellites, the number of satellites required for stable high precision positioning will be ensured.

Conventional MC hydraulic excavators could use two types of satellite information, the GPS (US) and GLONASS (Russia). In the progress of infrastructure development, the new machine is equipped with a new surveying equipment (Figure 14) which is compatible with multi GNSS. It is now possible to use QZSS (Japan), BeiDou (China), and Galileo (EU), and the stability of position information during construction work has been improved.

Fig. 14 GNSS Surveying Equipment

4. Reputation of New Functions

The following are opinions of users who actually used the new functions introduced this time.

· Auto Boom Down function

Since the range of work that can be machine-controlled has been extended beyond 90 degrees of arm angle, the working time shortened, and the ground leveling work became very easy in a wide range.

· Bucket Angle Hold Control function

While the conventional machine controlled excavators required manual operation of the bucket, this new function eliminated the need to worry about the bucket angle and made it possible for even operators with less experience to form a neat shape.

· Compaction Control

It became possible to perform the work from compacting to shaping in sequential operations with the machine control remaining effective throughout, and the work efficiency has been improved. In addition, the need for operating the semi-automatic buttons and monitor functions when performing compaction has been eliminated and the work has been simplified. The overall construction time has been shortened.

· Auto tilt bucket

This bucket is useful because it can be easily used for working on slopes that cannot be faced straight with a standard bucket. It is also effective for V-ditching and road construction. Also, since the bucket can be held at a constant angle together with the Bucket Angle Hold Control function, combined operations of bucket and tilt (or swing) have been simplified and considerably improved, allowing the operator to concentrate on finish shaping. The operator can work while watching the HMI monitor, and it became easier to hold the facing of the bucket during tilt control.

· Stereo camera

Although stereo cameras are installed outside the cab, there is no strangeness in the appearance and looks well-coordinated with the cab. Addition of shooting sounds makes it easier to shoot with the stereo camera.

5. Conclusion

We have introduced the 20 ton class MC hydraulic excavator “KOMATSU PC200i-11”, focusing on the functions that have been newly adopted from this machine.

Conventionally, the operator had to concentrate on their hands to operate the hydraulic excavator as desired, before concentrating on the construction work. By utilizing the assistance of the new functions introduced this time, the operator can operate the hydraulic excavator more easily, and concentrate more on the construction work.

As the aging of operators and the decrease in labor population have come to an issue in construction sites, this machine will help reduce fatigue of aged workers and shorten the training of new operators. Together with the spread of computerized construction, we believe that this hydraulic excavator will become an absolutely necessary machine in future markets.

The machine control function and technology of hydraulic excavators has been progressing day by day while the demand from the market is changing faster. Especially in the world of computerized construction, a hydraulic excavator is no longer a standalone product. We will continue to work on product development considering further contribute to the efficiency of the entire construction site.

Introduction of the authors

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Joined Komatsu Ltd. in 2007.
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[A comment from the author]

Based on the accumulated technical and organizational strength of Komatsu, we kept the viewpoint of what makes the work by the customer most efficient, and also held attention to improvement of not only the machine alone but the whole site in which the machine is used while progressing with the development. We finally managed to introduce this machine to the market.

We will continue to work for reducing the burden on operators by expanding the range of assistance by the machine, installing systems to improve the efficiency of the entire construction site, and developing machine bodies with a higher expandability, so that we can quickly respond to new demands in the field and changes in the industry structure that will emerge in the future. We believe this machine will greatly contribute to the society.