Technical Paper

Development of D61EXi/PXi-23 Bulldozer with automatic control system of work equipment

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In accordance with the recent spread of the machine control bulldozers utilizing information technology, efficiency improvement of the entire execution of works has been in progress including abolishing of finishing stakes. However, current machine control system could be applied only to the limited works such as finishing ground leveling.

Accordingly, combining Komatsu's machine component control technology and GNSS survey technology, we developed D61EXi/PXi-23. It features new functions starting with the automatic control of work equipment load, and expands the application range of machine control to a series of bulldozer works from digging and soil carrying to leveling work.

This has enabled mitigation of fatigue of an operator during work and also enabled even an inexperienced operator to perform work equivalent to that of a skilled operator.

Key Words: *D61EXi/PXi-23, Machine Control Bulldozer, GNSS survey technology, GNSS antenna, Inertia sensor unit (IMU), Cylinder with stroke sensor, Leveling control, Digging control, Design surface, Work equipment load*

1. Introduction

The work equipment automatic control system of bulldozers utilizing the GNSS survey technology has substantially improved the efficiency of the entire execution of work by abolishing finishing stakes and enabling inexperienced operators to perform finishing execution equivalent to that of skilled operators.

However, when an excessive load is applied to the work equipment, manual adjustment of the load on the work equipment is required, and therefore, automatic control of the work equipment could be applied only to light load works such as leveling work.

By combining the Komatsu's many years of machine component control technology for hydraulic pumps, motors, etc. with the GNSS survey technology, the innovative 18-ton class bulldozer D61EXi/PXi-23 (**Fig. 1**) is developed. This new machine control (hereafter MC) bulldozer, different from conventional MC bulldozers, integrates various sensitive components into the frame and adopts the intelligent automatic work equipment load adjusting function; which expands the work application of the MC bulldozers, ranging from digging and soil carrying work to leveling work. This paper introduces the features of this "innovative", "integrated", and "intelligent" MC bulldozer.

2. Machine system

2.1 GNSS survey instrument

In a bulldozer equipped with a conventional MC function, sensors of the GNSS antenna and the inertia sensor unit (hereafter IMU+) were installed on the work equipment to measure its edge position directly. This means that precision sensors are installed on the work equipment at the front of the machine that directly contacts earth and sand, which poses a problem of reliability. In contrast, this machine, in which the GNSS antenna is installed on the cabin top and IMU+ is built into the vehicle frame, has gained the following superiority over conventional machines (**Fig. 2**).

(1) Visibility has improved due to abolition of a GNSS antenna mast and cables on the work equipment.
(2) Reliability has improved due to abolition of cables exposed to the outside of the frame (by eliminating possibility of broken wire by hitching during work).
(3) Safety has improved because removal work of the GNSS antenna after the completion of a day's work has become unnecessary.
(4) The position under the crawlers can be measured and thus the present topography can be grasped in real-time only by traveling.

For the GNSS survey instrument, a field-proven instrument made by TOPCON CORPORATION is installed at the time of shipment from our plant.

2.2 Cylinder with stroke sensor

The relative coordinate of the work equipment edge from the GNSS antenna needs to be measured because the GNSS antenna was relocated to the top of the vehicle cabin from work equipment.

In this machine, the use of Komatsu-made cylinders with a stroke sensor for hydraulic cylinders (lift cylinder, tilt cylinder and angle cylinder) of work equipment has allowed the real-time measurement of the relative coordinate of the GNSS antenna and work equipment edge in the machine coordinate system. The coordinate of the work equipment edge in the worksite coordinate system is calculated by adding vehicle position information from the GNSS antenna and the machine attitude calculated by IMU+ to the above.

The cylinder with a stroke sensor is, based on the conventional cylinder, additionally equipped with a mechanism to detect its stroke through the rotation of roller and a mechanism to correct an error that could be caused by slippage of the roller (**Fig. 3**).

Fig. 1 External view of D61EXi/PXi-23

Fig. 2 Conventional MC bulldozer image

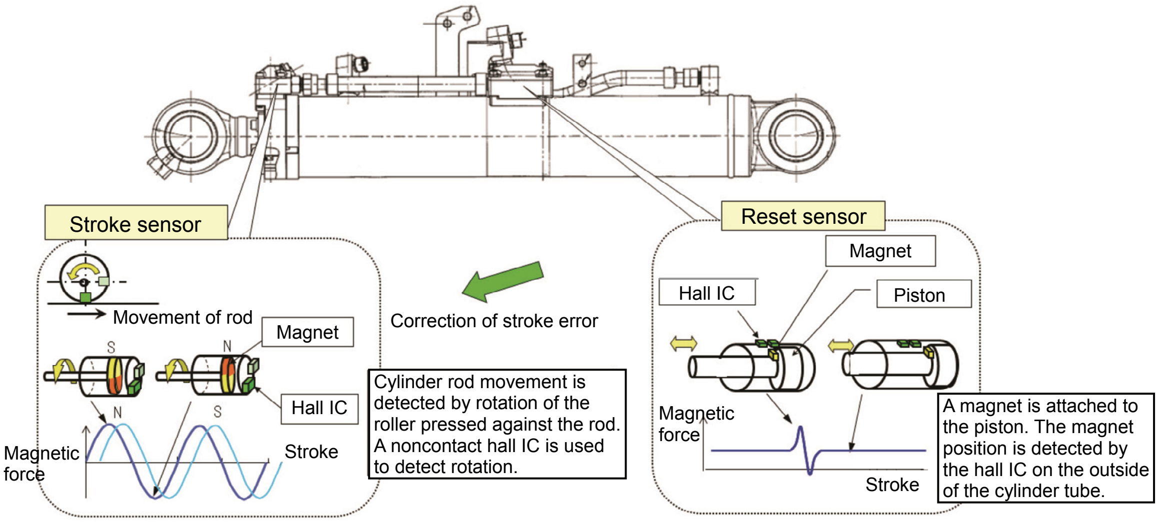


Fig. 3 Cylinder with stroke sensor

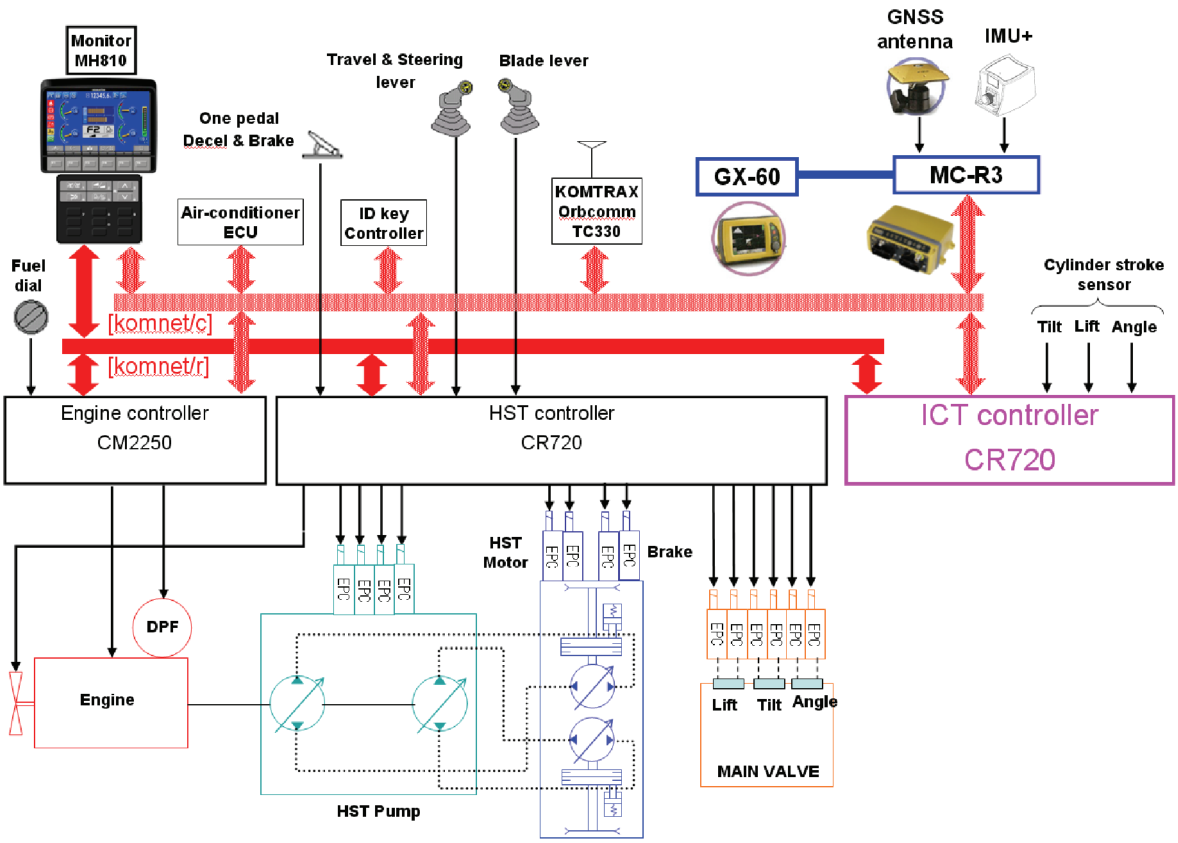


Fig. 4 System chart of D61EXi/PXi-23

2.3 Electronically-controlled work equipment valve

For the automatic control of hydraulic cylinders, a work equipment valve operated by an electric instruction from the controller is required and the electronically-controlled work equipment valve with EPC (Electric Pressure Control) valve which was already proven in heavy-duty bulldozers has been adopted.

3. Automatic control of work equipment

The biggest feature of this machine is automation of digging and soil carrying work by optimally controlling a load applied to the work equipment even if there is digging depth to some extent up to the finishing surface, while the work application range of conventional MC bulldozers was limited mainly to finishing leveling work under light load.

Seamless automatic execution without concern for damage to a finishing surface has been enabled by automatically switching from digging control to leveling control as the work progresses and approaches the finishing surface.

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

3.1 Leveling control

This is a function to control the hydraulic cylinders so that the work equipment edge coordinate agrees with the target coordinate determined by the design surface data of the job site. This is the same function as that on the conventional MC bulldozer.

3.2 Digging control

The hydraulic cylinders are activated to control the height of the work equipment edge so that a load applied to the work equipment agrees with the target load preset on the controller (**Fig. 5**).

As a hydrostatic transmission (hereafter HST) is adopted for the powertrain of this machine, a tractive force of the vehicle can be calculated from the circuit pressure and number of revolutions of hydraulic motors installed in the right and left sprockets. A load on the work equipment is calculated based on this tractive force with correction items taken into consideration.

(1) A load on the blade increases.

(2) The blade is automatically lifted to adjust a load so that no shoe slip occurs.

(3) Work equipment height is adjusted so that the load on the

work equipment is always constant.

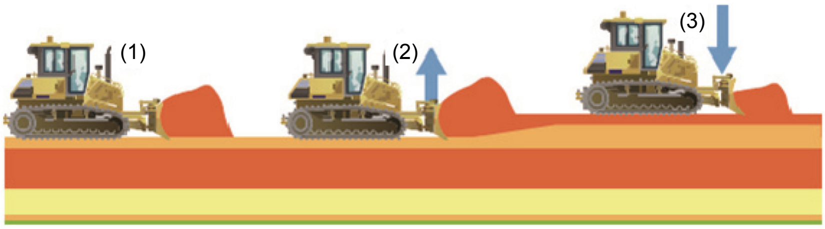


Fig. 5 Images of digging control

3.3 Automatic switching between leveling control and digging control

The controller judges automatically which of the digging mode and leveling mode is more suitable according to the distance in the height direction between the current work equipment edge height and design surface height of final finish, and switches the control mode.

When the work equipment edge is at a higher position than a certain distance ⊿Z from the design surface, a load on the work equipment is adjusted by digging control, and when the edge is lower than the above distance, finishing is performed by leveling control (**Fig. 6**).

However, even the height of the work equipment edge is lower than ⊿Z, if a load above a certain level is applied to the work equipment,the control mode is switched from leveling to digging to adjust a load applied to the work equipment. On the other hand, if the load on the work equipment falls below a certain level, the control mode is switched from digging to leveling and aligns the work equipment edge height with the design surface.

During digging control, as the work equipment approaches the design surface, the work equipment angle is brought closer to the design surface angle so that the design surface is not cut when digging control is switched to leveling work control.

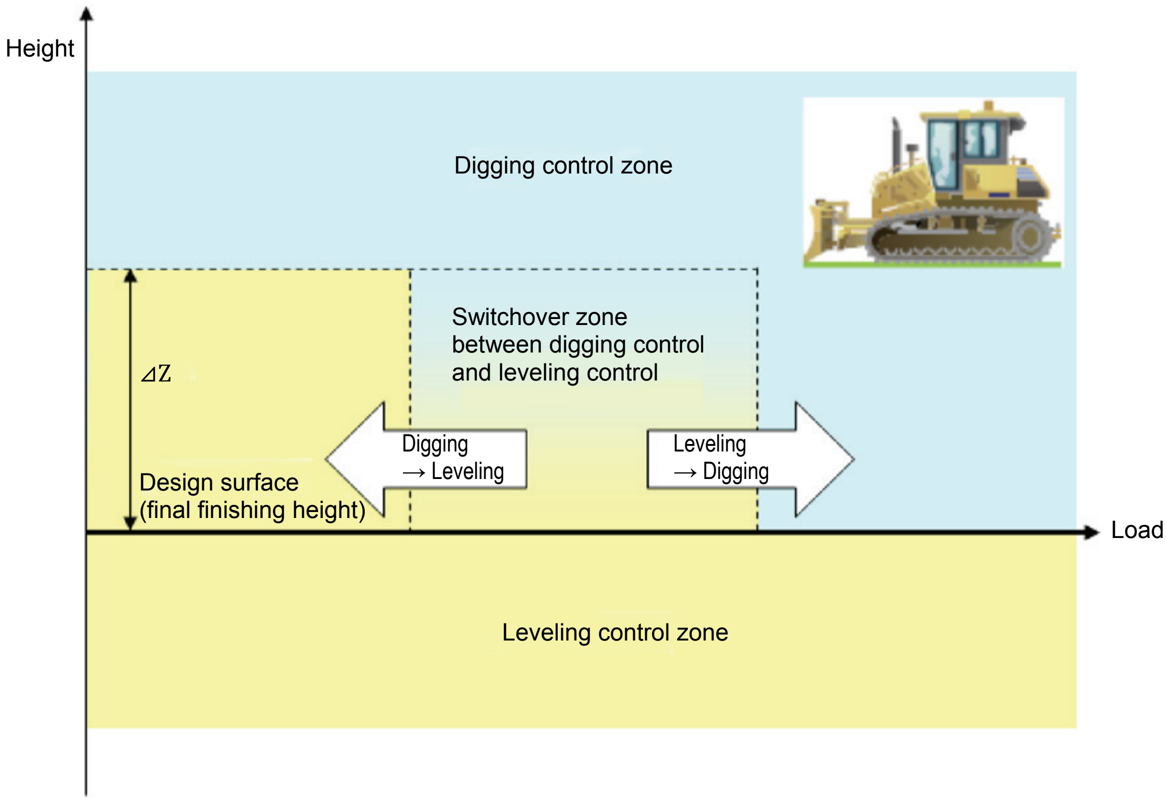


Fig. 6 Automatic switching between digging control and leveling work control

3.4 Smooth start control

When starting the digging from a state in which no load is applied to the work equipment, the work equipment is controlled so that its edge gradually cut into the ground (**Fig. 7**).

This control allows for stable start of digging independent of the soil character or worksite topography and the surface is finished smoothly, which greatly contributes to the mitigation of fatigue of operators.

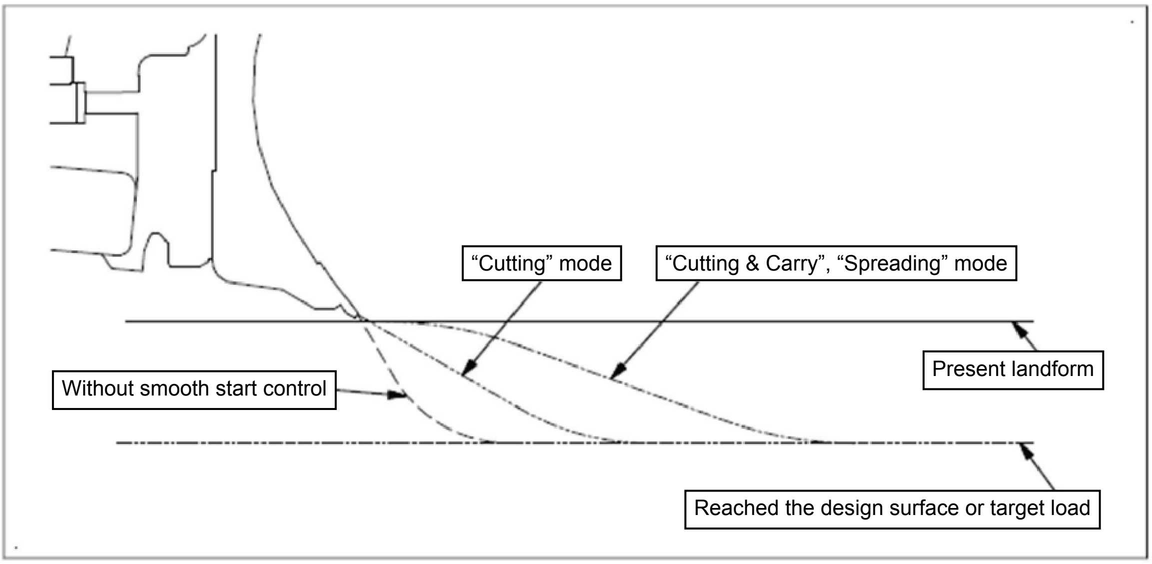


Fig. 7 Image of digging start control

3.5 Shoe slip control

The moving speed of the machine can be obtained from the position information measured in real-time from the GNSS antenna installed on the machine. On the other hand, the theoretical vehicle speed can be obtained from the sprocket speed. A slip of crawlers is detected from the ratio between these two. If a certain amount of a slip is detected during work, the load on the work equipment is lowered by automatically lifting the work equipment to avoid the slip.

3.6 Selection function of dozing mode

For automatic control of the work equipment, the operator can select the optimal dozing mode from four modes according to the work content. The mode is cyclically switched when the icon on the control box screen is touched (**Fig. 8**).

As the icon showing the image of selected mode is displayed, the operator can visually recognize the presently selected mode with ease.

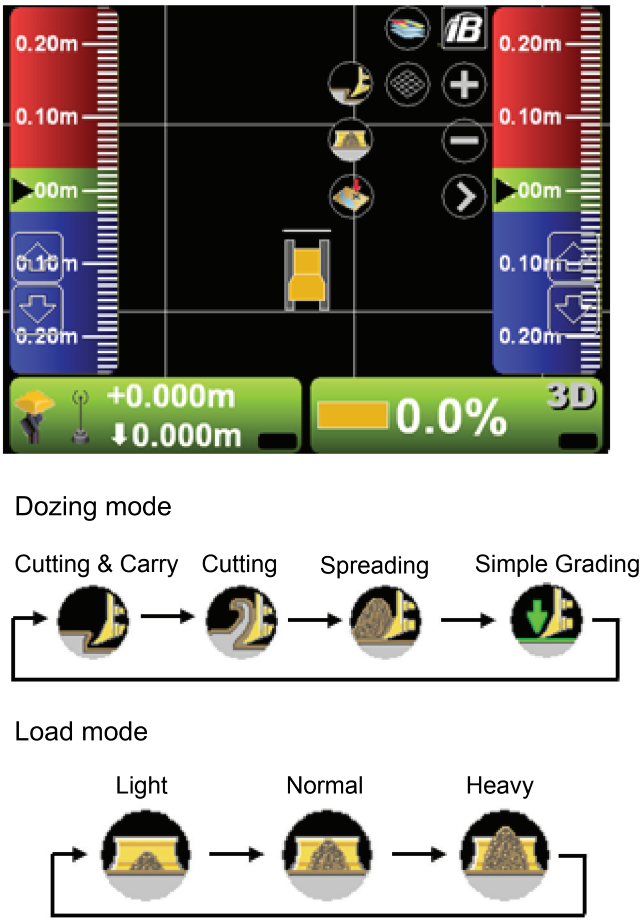


Fig. 8 Mode selection screen

(1) Cutting & Carry mode

Suitable to work that digs a shallow depth, and digs and carries soil for a long distance. Even if a load applied to the work equipment decreases, the edge height is not lowered to ensure smooth digging traces and to permit fatigue-free operation over a long distance.

(2) Cutting mode

Suitable to work that digs somewhat deep depth and digs a short distance. Work at the maximum efficiency is performed and efficiency of an amount of soil per hour is good by always keeping a load applied to the work equipment at the target value.

(3) Spreading mode

Suitable to work that spreads and grades set soil discharged by a dump truck. Even if a load fluctuates suddenly at the time of digging in the set soil, the target load is raised temporarily so that soil does not fall off.

(4) Simple Grading mode

This mode, which has only leveling control and has no digging control, is suitable to finishing leveling work. In this mode, the work equipment only follows the design surface (**Fig. 9**).

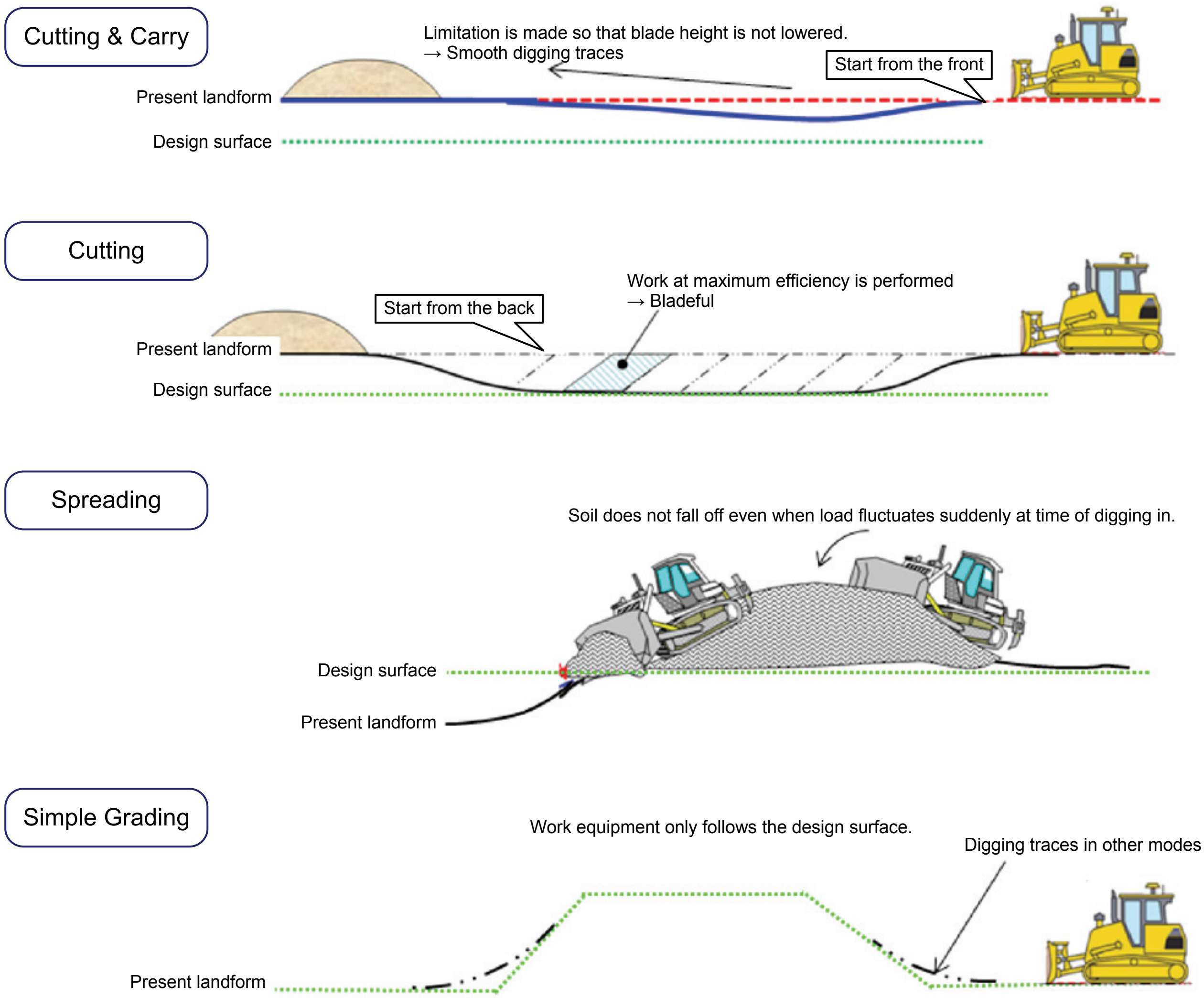


Fig. 9 Images of dozing modes

3.7 Selection function of work equipment load

The target value of work equipment load in digging control can be selected from three modes depending on the soil character and work content. The mode is cyclically switched by touching the icon on the monitor. As the icon showing the image of selected load level applied to the work equipment is displayed, the operator can visually recognize the presently selected mode with ease (**Fig. 8**).

(1) Light mode: Suitable for light load work

(2) Normal mode: Suitable for general work

(3) Heavy mode: Suitable for heavy digging work

4. Effect by system

While a high level of skill is required for operating a bulldozer, the support of this work equipment automatic control system described so far has enabled inexperienced operators to perform work equivalent to that of skilled operators regardless of work content from digging and soil carrying to leveling work.

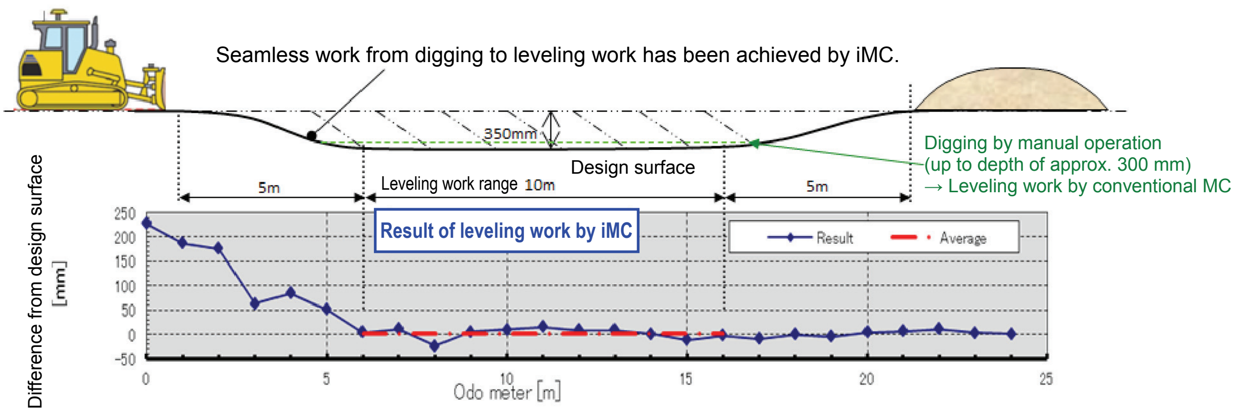
To confirm the effect of this control system, the comparison data of a standard model work test is shown below.

This work test involved a series of bulldozer work from digging to leveling work toward a design surface.

It compared the operation of conventional bulldozer which digging was performed by manual operation with attention paid not to damage the design surface and then finishing leveling work was performed by conventional MC bulldozer in several passes to avoid the occurrence of a slip with the operation of this new bulldozer which performed seamless work from digging to leveling work without concern for damage to the design surface. According to the result,when the conventional method was assumed to be 1, the new system was assumed to be 0.87 in terms of required time per moved amount of soil, which resulted in improvement of efficiency by around 10%.

Table 1 Comparison of standard models

		iMC	Manual + conventional MC control
Digging	Amount of soil	1.25	1.00
	Required time	1.27	1.00
Leveling work	Amount of soil	0.21	1.00
	Time	0.38	1.00
Total	Amount of soil	1.04	1.00
	Required time	0.91	1.00
	Time per amount of soil	0.87	1.00
Fuel consumption	Fuel consumption	1.05	1.00
	Amount of soil per fuel	0.99	1.00



5. Conclusion

This document has introduced the MC bulldozer "Komatsu D61EXi/PXi-23" featuring its new structure that has substantially improved the work environment of operators and reliability of equipment, and the digging and soil carrying control function that has created new added values. The automation technology for work equipment not only mitigates fatigue of operators, but leads to further improvement of execution efficiency by combining with the job management system and optimal work procedure guidance function. We are confident that this is a great step forward toward the autonomous and unmanned job site operation near future. Continuous progress is constantly required in an area utilizing the ICT technology, and we will continue to make efforts to be an indispensable business partner for customers by commercializing user needs timely.

Introduction of the writers

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Joined Komatsu Ltd. in 1995.
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[A few words from writers]

This development has become possible because the "current" state of a bulldozer can be grasped owing to the development of the sensing technology including GNSS survey instruments and stroke sensors installed to cylinders.

In the future, we intend to proceed with further automation and efficiency by capturing topographic information with a stereo vision camera or some other tool and incorporating the control based on "forecast" such as how the topography will change by the work and how the work should be performed to improve efficiency.