Introduction of Products

Introducing the HB335/HB365-1 Hybrid Hydraulic Excavators

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Based on the hybrid technology we fostered through PC200-8E0 and HB205-1 models, we have developed and released the HB335/HB365-1 30-ton class hybrid hydraulic excavators which enabled great reduction in fuel consumption. This report introduces the main features of the new models.

Key Words: *Hydraulic excavator, 30-ton class, Hybrid, Reduced fuel consumption, Generator/motor, Electric powered swinging, Capacitor, Inverter*

1. Introduction

To cope with global warming and rising fuel prices, various types of hybrid automobiles have been released in recent years. In the field of construction machines, Komatsu released PC200-8E0, the world's first hybrid hydraulic excavator in 2008. This model was upgraded to HB205/HB215LC-1 in 2010, and the total number of these hybrid hydraulic excavators sold worldwide exceeded 2,450 units by the end of October 2013. Based on the expertise we acquired through marketing and supporting these models, we have developed and released the HB335/HB365-1 (hereafter refereed to as HB335-1) 30-ton class hybrid hydraulic excavators. This report describes the main features of the new series (**Fig. 1**).

2. Purpose of the Development

The early PC200-8E0 and HB205-1 models achieved a tremendous improvement in fuel economy. The new HB335-1 was developed to extend this advantage to the 30-ton class. It is targeted to the strategic markets* where we will strive for acceptance and growth of the Komatsu market. Its overview and features are shown below.

* Strategic markets: China, South and Central America, Asia, Oceania, Africa, Middle East, and CIS

(1) Great reduction in fuel consumption by using the hybrid technology
20% reduction as compared with PC300-8
(Based on average operation pattern comparison by KOMTRAX analysis)

(2) Advanced appearance and structure based on PC300-10 model, and adoption of reliable components

(3) Capable of meeting 3rd emission control regulations of strategic market countries (We expect to obtain certificates.)

(4) Adoption of large, high-definition multi-monitor

(5) More detailed KOMTRAX information

(6) Greater versatility to support a wide range of attachments

Fig. 1 HB335-1 (Australian specification)
(From Komatsu catalog)

3. Selling Points

The selling points of HB335-1 and the methods and technologies used to achieve these advantages are described below.

3.1 Reduction in fuel consumption using the hybrid technology

A great reduction in fuel consumption was achieved using the hybrid technology we fostered through the 20-ton hybrid hydraulic excavators. The outline of this technology is described below.

3.1.1 Hybrid system overview

The hybrid system of HB335-1 consists of an electric swing motor, a generator/motor, an inverter, and a capacitor all developed by Komatsu.

The kinetic energy generated by the upper structure when the swing brake is used is converted into electricity and supplied to the capacitor (which stores the electricity). Hydraulic losses can be eliminated by fully motorizing the swing operation, allowing all of the energy generated during deceleration to be recovered. The generator/motor uses this electric power to assist the engine during acceleration, and also generates electricity when the electric power in the capacitor has reduced. The inverter controls this electric power that frequently goes in and out of the capacitor.

One of the main features of this hybrid system is the use of the capacitor to allow electric energy to be efficiently and instantaneously stored and discharged (**Fig. 2**).

For HB335-1, we developed a number of components to support the increased power of higher class models than the 20-ton hybrid hydraulic excavators.

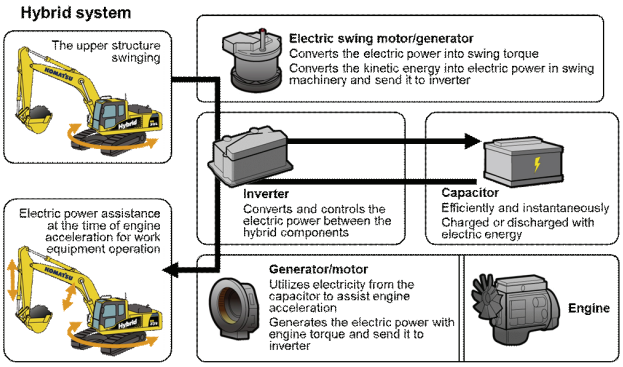

Fig. 2 Hybrid system
(From Product Bulletin)

3.1.2 Components of the hybrid system

By optimizing the shapes and layout of the components of the hybrid system, we were able to incorporate them in the standard 30-ton machine without changing their external dimensions (**Fig. 3**).

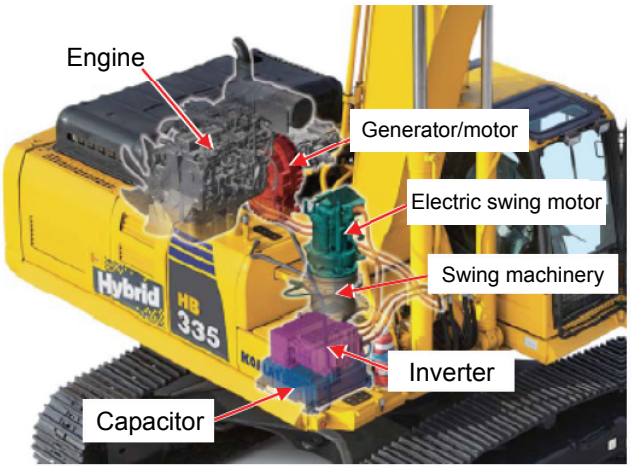

Fig. 3 Hybrid system components

(1) Generator/motor

The generator/motor (**Fig. 4**) is positioned between the engine and hydraulic pump for high transmission efficiency. This has achieved efficient power generation and excellent engine acceleration performance as well as low fuel consumption of the hybrid machine.

The generator/motor serves as a generator to charge the capacitor, while on the other hand it supplies electric power to the electric swing motor during swing acceleration.

The generator/motor also serves as an engine acceleration assisting motor. This allows the engine to be run at an extremely low idle during operation stand-by state and to be instantaneously raised to the required speed when a lever is operated. In addition, the pump matching control ensures the required hydraulic output at low engine speeds for reduced fuel consumption.

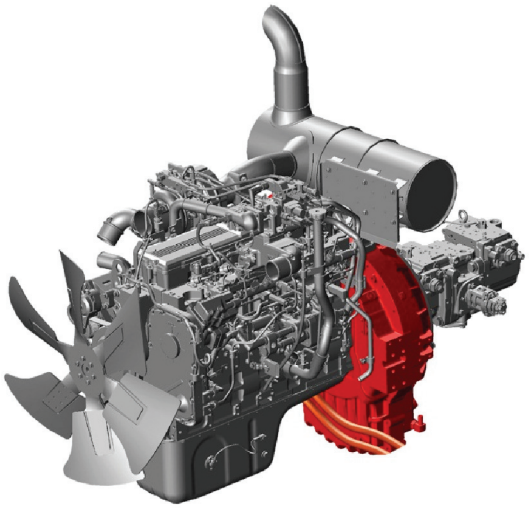

Fig. 4 Generator/motor
(From Product Bulletin)

An SR (switched reluctance) motor is employed for the generator/motor. The SR motor has a simple structure, does not use rare earth magnets, and provides high resistance to heat. This heat resistance helps improve the reliability of the motor positioned between the engine, which can become very hot, and the hydraulic pump. Since permanent magnet is not used, drag rotation losses are minimized when the motor is spinning without assisting the engine or generating power, which contributes to reduction in fuel consumption. However, because SR motors have vibration and noise problems, their use on high-power equipment has been rare. **Table 1** shows the features of the SR motor and PM (permanent magnet) motor. The latter is used as an electric swing motor.

Table 1 Features of SR and PM motors

	SR motor Switched Reluctance Motor	**PM motor** Permanent Magnet Motor
Example of use by Komatsu	Generator/motor	Electric swing motor
Driving force	Attraction force of magnetic coil	Magnetic force of permanent magnet and magnetic field of coil
Structure	Simple	Complicated
Permanent magnet	Not used	Used (rare earth magnet)
Heat resistance	High	Medium
Vibration and noise	Large	Small
Applications	Few	Many
	Oil pump, vacuum cleaner	Hybrid automobile, electric vehicle

The SR motor rotates as the rotor is attracted by the magnetic coil on the stator. The attraction force is repeatedly turned on and off as magnetic coil is turned on and off during rotation, generating vibration and noise (**Fig. 5**).

The generator/motor used on HB335-1 has a higher output than that on HB205-1 to match the higher class machine. Since magnetic force is proportional to output, the attraction force that acts on the stator is greater than that on HB205-1, requiring increased strength to cope with the greater vibratory force that causes vibration and noise. On the other hand, since there is a limitation to the size of a motor that can be mounted on the excavator, we conducted various tests and analyses including FEA (finite element analysis) to optimize the drive control as well as the shapes of the components such as a casing and stator core, thereby solving the problem of vibration and noise.

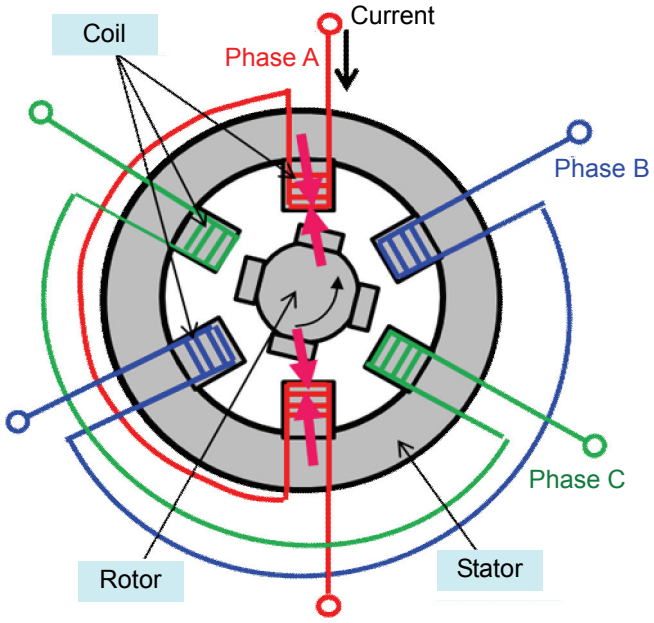

Fig. 5 Structure of SR motor
(From internal document)

(2) Electric swing motor

The electric swing motor allows energy, which used to be released in the form of heat by hydraulic motor during swing deceleration, to be recovered and stored in the capacitor. This energy is reused for driving the machine, achieving a great reduction in fuel consumption. In addition, the electric motor is more efficient in acceleration than hydraulic motors, providing smooth swinging performance. Low speed gears were added to the swing reducer of the standard machine, which allowed the electric motor to be operated at high speeds to achieve the high efficiency and small size of the motor. **Fig. 6** shows the appearance of the electric swing motor.

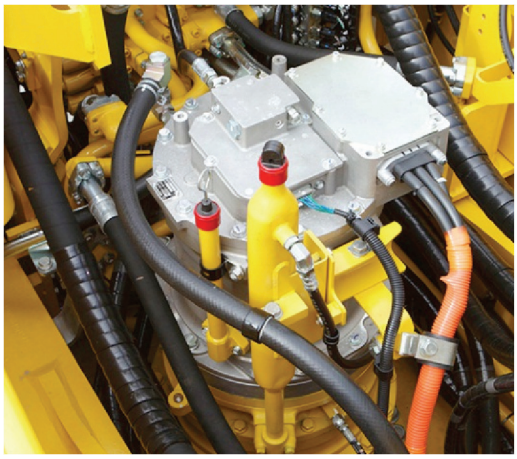

Fig. 6 Electric swing motor
(From Product Bulletin)

(3) Inverter and capacitor

Increase in the sizes of the inverter and capacitor needed to support the increase in output was minimized to maintain their compactness. They can be accessed without tools for easy inspection (**Fig. 7**).

The inverter is a component that is used to convert and control the current and voltage between the capacitor, generator/motor, and electric swing motor. Tremendous improvement in fuel efficiency was achieved by allowing efficient control of storage and output of electricity to be performed instantaneously in accordance with frequently changing operating conditions.

The capacitor is a component to store and output excess energy. Unlike ordinary batteries, it can be charged and discharged only by transfer of electrons or ions without involving chemical reactions, which allows charging and discharging to be completed in a short time. Furthermore, the capacitor features a longer deterioration time than batteries and a longer life, and does not require maintenance such as replenishment of battery liquid, making it ideal for construction equipment that is operated for a long period of time.

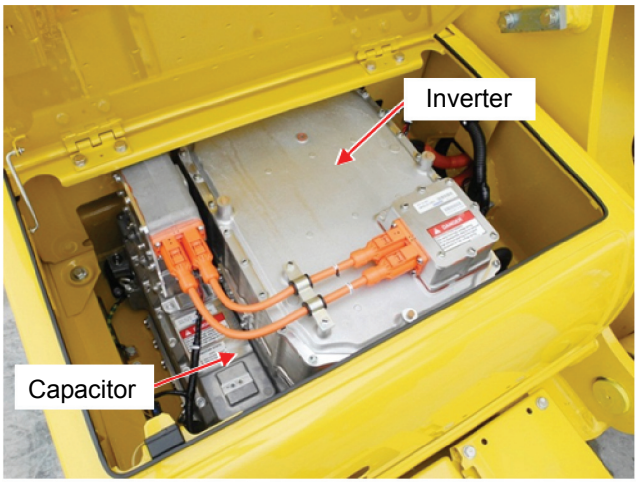

Fig. 7 Inverter and capacitor

3.1.3 Reduction in fuel consumption

By incorporating the hybrid technology described above and the latest technologies for lower fuel consumption developed for PC300-10 described later, we have achieved an average of 20% reduction in fuel consumption for the same amount of work as compared with the standard PC300-8 model (**Fig. 8**). This figure is based on the results of comparison test under typical operating conditions using the internal standard (i.e., typical operation pattern based on KOMTRAX analysis).

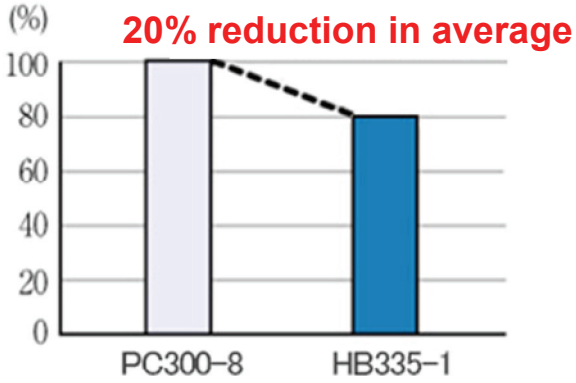

Fig. 8 Average reduction in fuel consumption

3.2 Other features

3.2.1 Adoption of the latest technologies

Using PC300-10 as a base machine, an advanced appearance and structure as well as reliable components were adopted.

(1) Engine

While the 20-ton hybrid hydraulic excavators use a 4-cilinder engine, the HB335-1 model is powered by a 6-cylinder engine as in the standard machine (**Table 2**).

Table 2 Engine

	30-ton hydraulic excavator		20-ton hydraulic excavator	
	Hybrid model	Standard model	Hybrid model	Standard model
	HB335-1	PC300-8	HB205-1	PC200-8N1
Model	**Komatsu SAA6D114E-5**	Komatsu SAA6D114E-3-A	Komatsu SAA4D107E-1-A	Komatsu SAA6D107E-1-A
Number of cylinders	**6**	6	4	6
Rated output (net) (JIS D0006-1)	**189 kW / 1950 min^{-1}**	184 kW / 1950 min^{-1}	104 kW / 2000 min^{-1}	110 kW / 2000 min^{-1}

This engine is based on the one used on PC300-10. The following new technologies (**Fig. 9**) have been incorporated in the engine, allowing it to meet 3rd emission control regulations while achieving a great improvement in fuel economy (fuel consumption map).

1) Variable turbocharger

Adoption of the KVGT (Komatsu Variable Geometry Turbocharger) has achieved low emissions, low fuel consumption, and good response.

2) Cooled EGR and efficient EGR cooler

By adopting an EGR (exhaust gas recirculation) valve and a highly efficient EGR cooler, combustion temperature was effectively lowered, achieving a reduction in NOx emissions and also contributing to the reduction in fuel consumption. The EGR valve uses a hydraulic servo mechanism which was developed based on the hydraulic drive with a proven record on the Komatsu medium- and heavy-duty engines.

3) Others

Increase in the injection pressure (180 MPa) of the electronic-control high-pressure fuel injection system (HPCR: high pressure common rail) which has been adopted since the current models, and further optimization of the combustion chamber shape have contributed to the reduction in NOx and PM emissions, and lower fuel consumption. Furthermore, the improved engine controller (CM2250) integrated with the latest sensors and actuators that have been added has enabled accurate control of EGR rate and fuel injection.

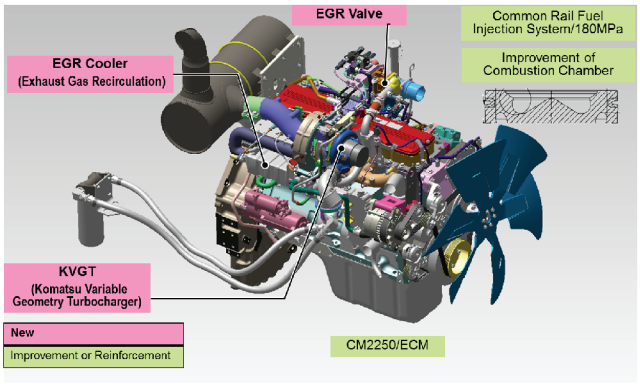

Fig. 9 New technologies incorporated in the engine (From Product Bulletin)

(2) Main pump

The newly developed main pump has a hydraulic pump for lubricating the generator/motor and electric swing motor. The dedicated lubrication system using this lubricating oil pump ensures the reliability of the generator/motor and electric swing motor (**Fig. 10**).

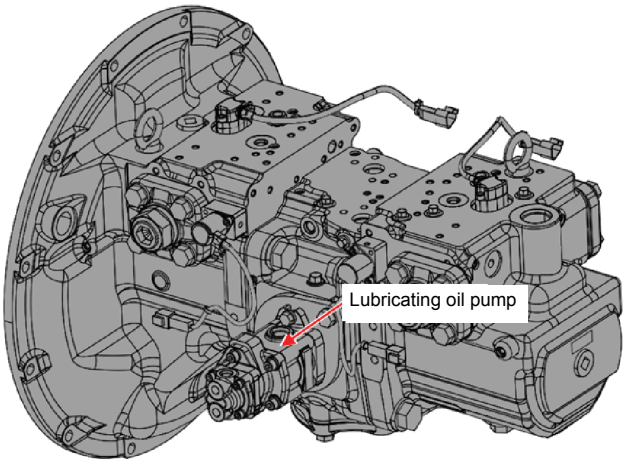

Fig. 10 Main pump

The main pump is equipped with a swash plate angle sensor. By accurately detecting the pump capacity, it has become possible to ensure the required pump displacement while keeping the engine speed as low as possible. This has led to the improvement of the matching control adopted by HB205-1, achieving a reduction in fuel consumption due to further reduction in the engine speed.

(3) ICT

1) Large high-definition multi-monitor

The adoption of a large high-definition LED panel has greatly improved visibility and screen resolution as compared with the current large 7-inch multi-monitor. The display also supports multiple languages, allowing selection from 13 languages.

Furthermore, energy-saving operation is supported and load on the hybrid system can be checked by the following display functions.

a. ECO guidance, ECO gauge, and fuel consumption monitor

To support energy-saving operation, four types of ECO guidance messages, such as “Avoid hydraulic relief pressure” and “Avoid excessive engine idling”, pop up in real time to alert the operator depending on the operating conditions. In addition to the ECO gauge introduced from HB205-1, the bar graph that shows the fuel consumption for the last five minutes, average fuel consumption display has been added (**Fig. 11**).

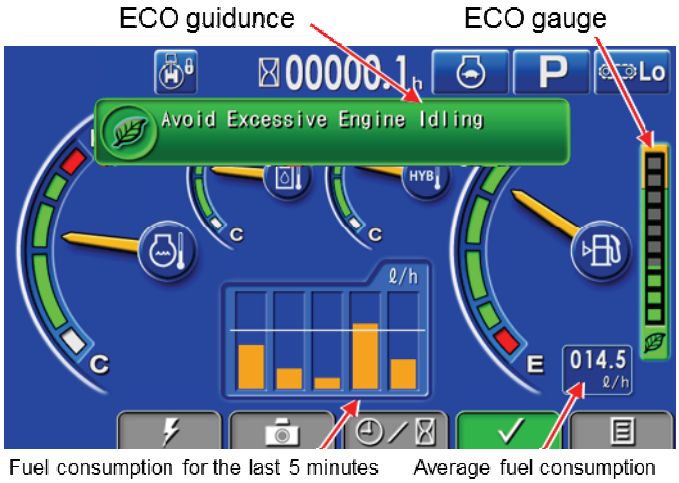

Fig. 11 ECO guidance, ECO gauge, and fuel consumption monitor

b. Operation record, fuel consumption log, and ECO guidance record

From the ECO guidance menu, the operator can check the operation record screen (which displays the operation hours, average fuel consumption, idling time, etc. for the day or in the specified split time), the fuel consumption log screen (which displays the fuel consumption of the last 12 hours or the last one week in a bar graph), and the ECO guidance record screen (which displays the count of each ECO guidance displayed for the day and a brief advice) (**Fig. 12**).

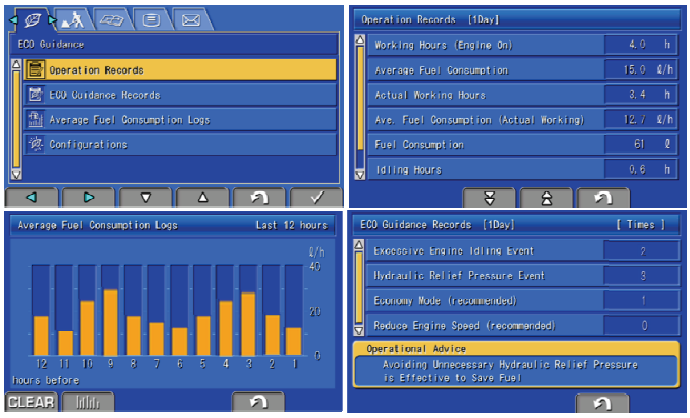

Fig. 12 Operation record, fuel consumption history, and ECO guidance record screens

c. Hybrid system temperature gauge and energy monitor

A temperature gauge for the hybrid system is displayed on the monitor, which allows the hybrid system temperature as well as the engine coolant and hydraulic fluid temperatures to be checked at a glance (**Fig. 13**).

The energy monitor can be displayed from the standard screen with a single touch of a button. It allows the charging/discharging state of the capacitor and the engine assist/generation state of the generator/motor to be checked in the form of an energy flow display (**Fig. 14**).

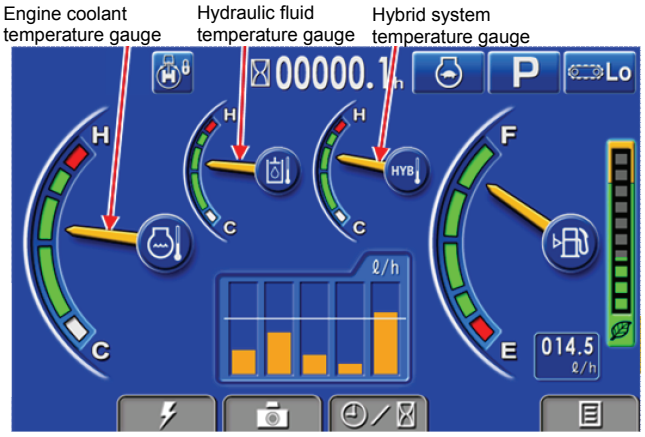

Fig. 13 Hybrid system temperature gauge

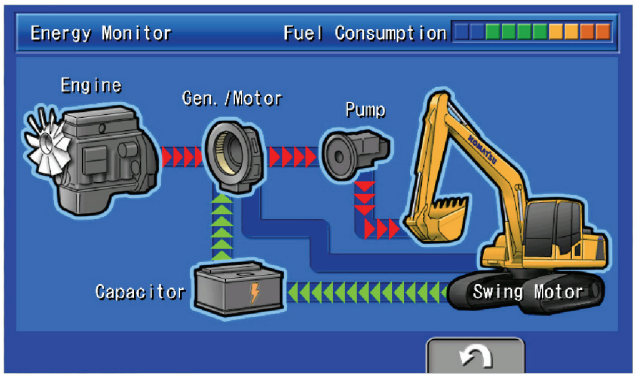

Fig. 14 Energy monitor

2) More detailed KOMTRAX report

In addition to the current KOMTRAX reporting items, the energy-saving guidance record, travel mode usage and other information items have been added (**Fig. 15**).

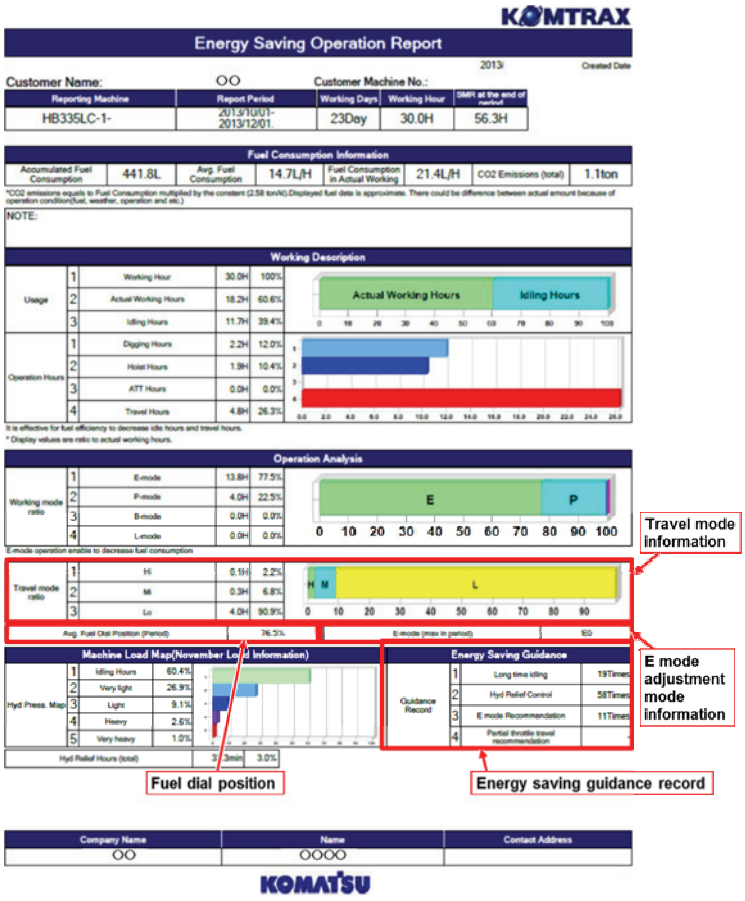

Fig. 15 More detailed KOMTRAX report

(4) Improved driving performance

The tractive force has been increased 10% as compared with PC300-8 by using a travel motor with higher capacity. In spite of the capacity increase of the travel motor, fuel consumption during travel is almost the same as that of PC300-8. This was achieved by incorporating the fuel consumption reducing technologies described above.

3.2.2 Enhanced specifications

When the 20-ton hybrid hydraulic excavator PC200-8E0 was introduced, its primary objective was to commercialize the hybrid system. For that purpose, its sales specifications were limited. On the other hand, HB335-1 was designed to meet the needs of a wider range of customers from the start of its introduction.

(1) Versatility with attachment

Various attachments including a breaker, crusher, and fork grab can be installed, making it possible to perform the same types of operation as can be done with the standard machine (**Fig. 16**).

Fig. 16 Breaker installed
(From internal document)

(2) Working mode

PC200-8E0 had only two working modes (P and E modes). On HB335-1 model, like HB205-1, many working modes can be selected as on the standard machine, and adjustment of the E mode is also possible, enabling optimum operation that best suits the conditions of the site and the type of work (**Fig. 17**).

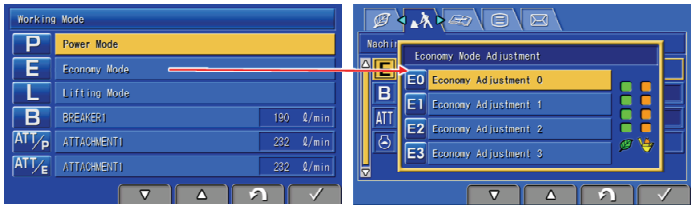

Fig. 17 Working mode selection screen and E mode adjustment screen

4. Conclusion

Since the introduction of 20-ton hybrid hydraulic excavators in 2008, enhancement of the hybrid series has long been awaited. Refinement of the hybrid system has been performed through great cooperation of the related departments, and now HB335-1 is introduced into the market. In developing this model, we incorporated the latest technologies and various improvements, which also resulting in an advance of the hybrid technology.

We will continue to quickly respond to the latest market trend and needs, aiming to achieve smooth introduction of new products into the market and to further enhance the commercial value of our hybrid hydraulic excavators.

Introduction of the writers

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[A few words from writers]

It took more than just applying the technologies of the 20-ton hybrid model to develop HB335-1. Although we encountered many challenges, we were able to reach the goal of mass production by solving the problems one by one. We believe our struggle for development paid off in the form of a good machine. We hope this product will be highly rated and widely accepted in the market.

Finally, we would like to express our deepest gratitude to all those who collaborated with us in the development, mass production and release of this product.