Technical Paper

DBA127 Engine

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Komatsu has developed and introduced the DBA127 diesel engine to the market, incorporating our latest technology and featuring a completely redesigned basic structure. This engine achieves high fuel efficiency and output while maintaining high reliability and ensuring ease of maintenance. Additionally, it balances reduced environmental impact with excellent economic efficiency. This paper reports on the development process and technical features of the engine.

Key Words: *Construction machinery, Diesel engine, Improved fuel consumption/efficiency, Improved engine output, Improved reliability, Improved maintainability, Monitoring of engine state*

1. Introduction

Construction machinery engines used in harsh environments must offer high reliability and durability. They must also deliver performance to suit the characteristics of various machine types. Another feature of these engines is that they are the subject of various requirements such as less environmental impact and lower running costs.

While engines in Komatsu's mid-range class continue to meet these requirements and comply with the increasingly stricter exhaust gas regulations of different countries, we aimed to raise the bar yet again by developing and bringing to market the DBA127 engine, shown in **Fig. 1**, which has been updated from its platform.

This paper is intended to provide the details that led up to the development of the DBA127 engine and its technical features.

Fig. 1 Appearance of the DBA127 engine

2. Story behind the development of the DBA127 engine and its aims

Conventional engines have been developed from the previous base engine for over 40 years, and they have continued to lose their market competitiveness in terms of essential performance such as output and fuel consumption. That is why we developed a new engine in which we reviewed the base engine design from the ground up. In the planning stage of this development project, the engine designers visited users and dealers to ask about what they thought of the conventional model and their wishes for the new engine. We got a lot of feedback asking for not only essential performance like fuel efficiency and output but demands unique to construction machinery, which are capital goods, such as “it won’t break” or “it can be fixed quickly if it does.” Based on these requests, we aimed to update the standard structure by adopting the three pillars of “Clean,” “Lean,” and “Free” as the basic concepts behind the goal of developing the DBA127 engine. “Clean” means low emissions and compliance with the exhaust gas regulations of countries such as Japan, America, as well as those in Europe. “Lean” means low lifecycle cost, with the aim to reduce fuel consumption and increase the engine output. “Free” refers to low downtime, and we aimed not only to improve the tangible aspects such as improving the structure, longevity, and maintainability of robust equipment, but to also reduce downtime by enhancing the monitoring of the engine using data from Komtrax *[1], which is installed on Komatsu’s construction machines. Of these three pillars, the emphasis was placed on “Free” as an engine for construction machinery.

*1: A construction machinery management system that utilizes the internet and mobile communication technology.

3. The technologies of the DBA127 engine

This section will introduce the technologies incorporated into the DBA127 engine under the categories of “Clean,” “Lean,” and “Free.” The main specifications are shown in **Table 1**.

Table 1 Main engine specifications

		Developed model	Conventional model
Engine model		DBA127	SAA6D125E-7
Piston displacement	L	12.74	11.04
Number of cylinders		6	6
Bore	mm	130	125
Stroke	mm	160	150
Compression ratio		21.0	16.7
Maximum output	kW/min^{-1}	420/1,900	302/2,000
Maximum torque	Nm/min^{-1}	2,803/1,100	1,707/1,400
Fuel injection		Direct injection type	
Super charging system		Fixed turbocharger (with air-cooled aftercooler)	Variable turbocharger (with air-cooled aftercooler)
EGR system		None	Cooled EGR
Moving valve system		OHC	OHV

3.1 Incorporated “Clean” technologies

For the DBA127 engine, a Komatsu Diesel Particulate Filter (KDPF) and Selective Catalytic Reduction (SCR) system, shown in **Fig. 2**, were newly developed to comply with the latest exhaust gas regulations of each country.

KDPF captures soot emitted from the engine to keep within the limits of exhaust gas regulations. While the captured soot needs to undergo regular combustion, the DBA127 engine has been improved to keep the inside materials and shape of the KDPF at a high temperature, extending the regular combustion interval by five times that of the conventional model.

Next, with regard to the SCR system, the DBA127 engine has adopted a large-capacity injection system and the urea mixing device and SCR have been improved to keep the NOx produced during combustion within the exhaust gas regulation limits. The urea mixing device sees urea deposits form as a result of injecting urea solution in great volume, indicating a drop in the purification efficiency of the device. As highlighted by the flow field in **Fig. 2**, the DBA127 engine has been structured to reduce the adherence of urea solution and prevent drops in its purification efficiency by generating a swirl flow in the exhaust gas that flows into the urea mixing device.

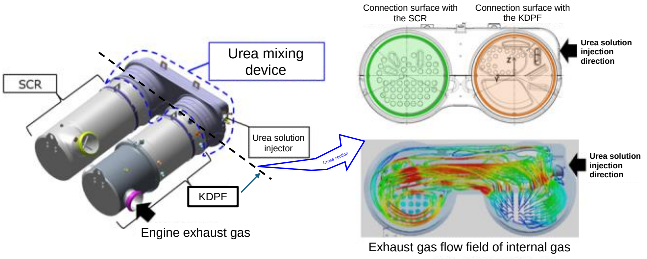

Fig. 2 DBA127 engine's exhaust gas purification system

3.2 Incorporated "Lean" technologies

Aiming to reduce fuel consumption and increase the output of the conventional model, we improved the combustion and energy loss, adopted a two-stage turbocharger, and improved the permissible in-cylinder pressure. The piston displacement was increased by 15%, with the goal of optimizing the machines in which the engine will be installed. Consequently, as shown in **Fig. 3**, we increased the engine rated horsepower over the conventional model by 40% and the maximum torque by 64%. We also significantly reduced fuel consumption and achieved a low lifecycle cost, which was a "Lean" target. The key technologies are introduced below.

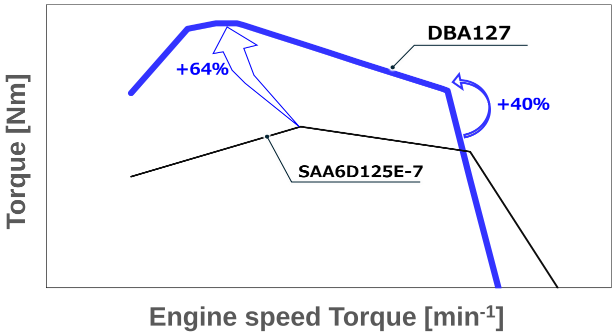

Fig.3 Torque curve comparison of DBA127 engine

3.2.1 Increase in specific power

The DBA127 engine has achieved an increased specific power, with over a 40% increase in the maximum in-cylinder pressure compared to the conventional model. Also, in order to reduce the engine's rpm from the perspective of reducing fuel consumption, for some applications *2, we adopted a two-stage turbocharger for the first time ever in a Komatsu engine. The turbocharger specification drawings are shown in **Fig. 4.**

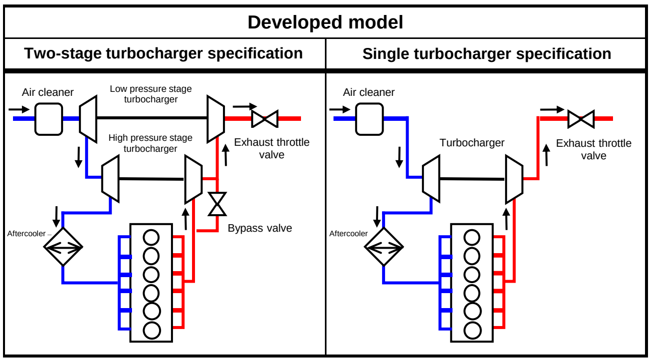

Fig. 4 Turbocharger specification drawings

The two-stage turbocharger arranges two turbochargers in series and achieves efficient super charging from the low-speed range to the high-speed range. This enables efficient super charging throughout the engine's whole speed range and makes it possible to generate high torque from the low-speed range. In the air intake piping that connects the low pressure stage to the high pressure stage, consideration was given to improving the super charging efficiency of the high pressure stage and preventing breakage of the impeller due to an unbalanced load applied to the blower. As shown in **Fig. 5**, the shape of the piping was designed using simulations so that we would achieve a uniform flow speed at the blower inlet of the high pressure stage turbocharger.

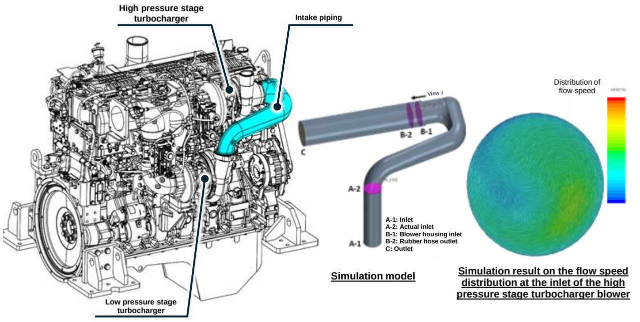

Fig. 5 Example of air intake piping simulation results

The high pressure stage turbocharger is fitted with an electronically controlled variable bypass valve and has a mechanism to curb the occurrence of overboost due to excessive turbine rotation. This resulted in improved engine and turbocharger robustness and delivered highly reliable engine performance.

*2 The DBA127 engine has two models: one with two-stage turbocharger specifications and one with single turbocharger specifications.

3.2.2 Improved combustion

As improvements to combustion, the design of the DBA127 engine features multi-hole nozzles, an increased common rail pressure, and a new combustion chamber optimal for this design. The design of the combustion chamber shape balances both combustion improvements and soot reduction, optimizing the common rail pressure, number of injector holes, and hole angles using the 3D-CFD combustion simulation shown in **Fig. 6**.

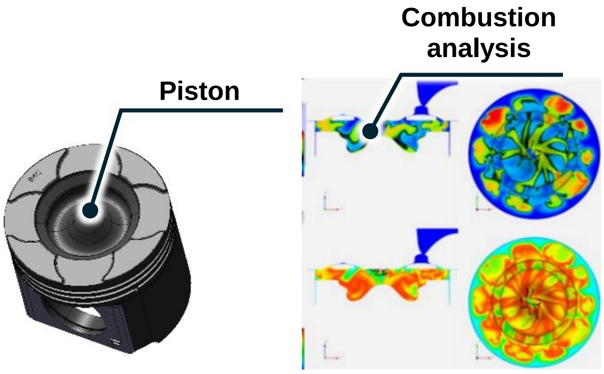

Fig. 6 Example of combustion simulation results

3.2.3 Energy loss improvement

As shown in **Fig. 7**, the DBA127 engine adopts a crank offset to offset the center of the crankshaft from the center of the cylinder. The piston reciprocation is converted into rotational movement of the crankshaft via the connecting rod. However, lateral pressure occurs during this process. As a result, friction loss occurs between the piston and cylinder liner. By minimizing the lateral pressure with the crank offset, however, the friction loss was reduced, contributing to greater fuel efficiency.

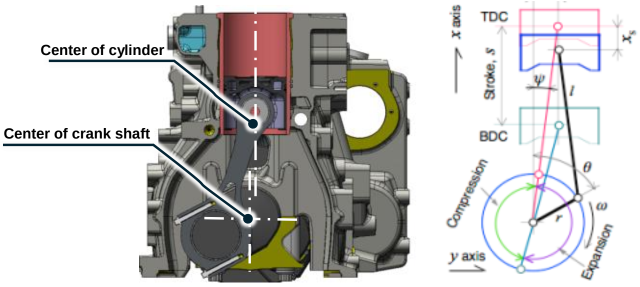

Fig. 7 Crank offset sectional view

Next, we reduced the pumping loss (energy loss within the air intake/exhaust process) by modifying the cylinder head intake port. By getting rid of the push rod installed on the side of the intake port along with changing to an overhead camshaft (OHC), as mentioned later, we enhanced the flexibility of the intake port shape. By optimizing the port shape as a result of conducting simulations to ensure the target swirl (air swirl flow within the cylinder) is maintained while minimizing inflow resistance, the average flow rate characteristics, which highlight the ease at which air enters the intake port, improved by approximately 30% compared to the conventional model.

Furthermore, the injector that significantly reduced the fuel leak amount in the SAA3D95E-1 [*3] model was used in the mid-class DBA127 engine, reducing the drive horsepower of the fuel supply pump.

*3: See *Development of 3D95 Engine,* the technical paper in the Komatsu Technical Report FY2020.

3.2.4 Increase in permissible in-cylinder pressure

To establish an engine that can withstand the increase in the maximum in-cylinder pressure mentioned earlier, efforts were taken to enhance the core parts, and this improved the permissible in-cylinder pressure.

For the cylinder head, compacted vermicular (CV) graphite cast iron with high tensile strength and toughness was adopted. Also, by integrating the six cylinder heads of the conventional model into a single unit, the rigidity between cylinders was increased, and the number of cylinder head bolts was increased from six to eight. In order to make the hot fuel injector cool efficiently, the cooling performance was also improved by adopting a wet-type injector sleeve, as shown in **Fig. 8**. There were concerns that eliminating the support at the center of the cylinder head might cause a reduction in rigidity, however, durability was ensured as a result of the high-strength CV graphite cast iron combined with the design of the rib optimized through thermal stress simulations.

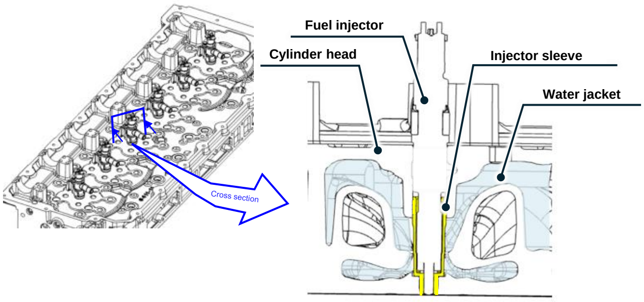

Fig. 8 Injector sleeve sectional view

As for the cylinder block, its rigidity was improved by adopting a barrel structure that makes use of an oil drain rib from the cylinder head, as shown in **Fig. 9**.

For the piston, adopting materials with twice as much tensile strength compared to the conventional model helped to increase its durability and reliability.

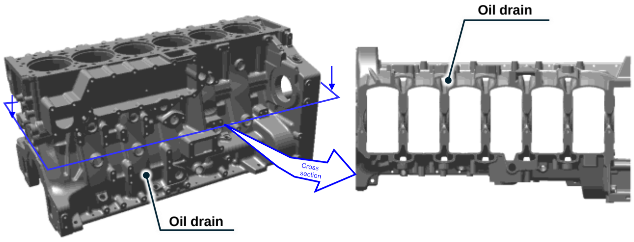

Fig. 9 Cylinder block general view and sectional view

To suppress the increase in noise and vibration due to the rise in maximum in-cylinder pressure, the overlap amount of the crankshaft was increased by 25% compared to the conventional model to enhance rigidity. The counterweight, meanwhile, was also optimized through undertaking simulations.

A gear train was installed on the rear side near the flywheel with little torsional vibration. The aforementioned crank offset also reduces piston slap energy (the phenomenon in which the piston hits against the cylinder wall), helping to reduce noise. With these improvements, we have increased the maximum in-cylinder pressure over the conventional model while also minimizing noise to the same degree.

3.2.5 A more compact design

While the DBA127 engine has a 15% increase in piston displacement compared to the conventional model, it has been designed to be roughly the same size as the conventional model in consideration of what machines it will be installed into. For the accessory belt, for which two were used in the conventional model, the overall length was reduced by changing the layout of the auxiliaries and changing to a one-belt design. In the aftertreatment device, as shown in **Fig. 10**, the S-shaped urea mixing device of the conventional model was changed to a U-shape. This enabled the reduction in the axial distance between the KDPF and SCR, achieving a 15% size reduction. While the role of the urea mixing device is to mix urea and exhaust gas, by making design improvements to the U-shaped internal gas flow path, it achieves both the original goal of mixing as well as becoming more compact.

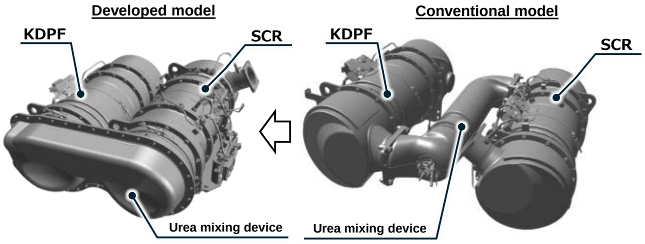

Fig. 10 Comparison of aftertreatment devices

3.2.6 Shift to OHC design

In the DBA127 engine, the conventional model's overhead valve (OHV) has been changed to an OHC design. Compared to OHV, OHC has a simple structure with fewer components because the valve operation does not involve a pushrod. A general view of the parts around the DBA127's camshaft is shown in **Fig. 11**.

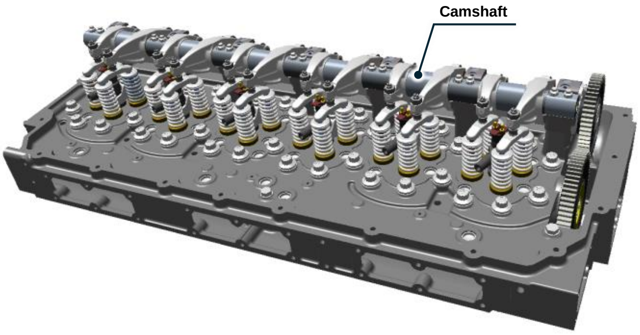

Fig. 11 General view of parts around the camshaft

The OHC makes the in-cylinder pressure stable and contributes to improving engine performance. It does this by the valve opening and closing quickly and accurately, with the variation in the compression-end temperature at the piston's top dead center reduced.

Also, in response to future emission regulations and performance requirements, we adopted a structure that takes into account expandability such as introducing variable valve timing technology.

A challenge in the shift to an OHC design was how to drive the camshaft. While there are various ways to drive the camshaft such as using a belt or chain, as the DBA127 engine is used in construction machinery that operate at high load factors, we choose to adopt a drive method in which the camshaft is powered by a gear train via a very reliable idler gear. A design challenge to establish this method was that the idler gear installed between the cylinder head and the cylinder block was prone to gear tooth misalignment. We worked with a subcontractor of Komatsu to improve the precision of gear parts to resolve this issue and establish the OHC design.

3.3 Incorporated "Free" technologies

To achieve low downtimes, we not only took tangible measures such as improving periodic maintenance, repairability, reliability, and durability, but also incorporated preventive maintenance through utilizing data. This section introduces these incorporated technologies.

3.3.1 Periodic maintenance improvements

Efforts were taken to extend the periodic maintenance intervals to reduce downtime. Firstly, for the KDPF, we reviewed the cell structure of the soot filter to increase its permissible ash accumulation amount by 28%. Also, by reducing the amount of oil consumption, which forms the base of ash, we extended the cleaning interval from 4,500 hours of the conventional model to 8,000 hours. Furthermore, by minimizing oil deterioration as a result of improving combustion, we extended the engine oil and oil filter replacement interval by a factor of two. The valve clearance inspection and adjustment intervals were also extended by a factor of two compared to the conventional model due to improved wear resistance of the valve train components. Furthermore, by changing the blow-by gas and oil mist separator installed in the crankcase ventilation system from a conventional filter type, which had required periodic replacement, to a centrifugal separation type that uses engine oil pressure, we eliminated the need for periodic maintenance.

As shown in **Fig. 12**, the serviceability of the engine was also improved in terms of the equipment layout by integrating filters that require replacement onto the air intake side of the engine. Examples of extensions to periodic maintenance intervals is shown in **Table 2**.

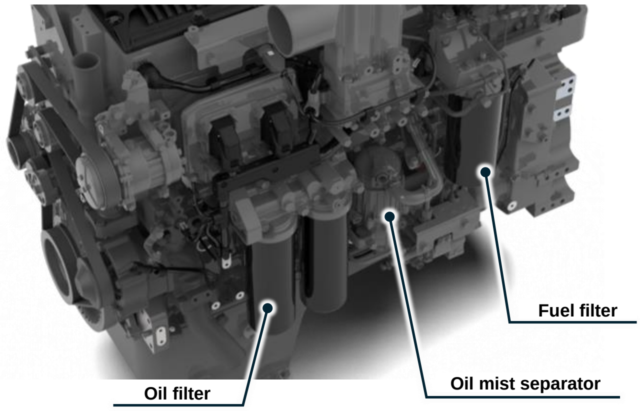

Fig. 12 Auxiliaries layout on the intake side

Table 2 Example of extension to periodic maintenance intervals and times

		Developed model	Conventional model
Engine oil change	h	1,000	500
Engine oil filter change	h	1,000	500
Valve clearance inspection and adjustment	h	4,000	2,000
KCCV filter change	h	Not required	2,000
KDPF cleaning	h	8,000	4,500

3.3.2 Repairability improvements

We creatively altered the equipment layout with the feedback of being “able to fix any problems quickly if they occur” in mind. As for the lubricating oil and coolant circuits, we minimized external piping as much as possible and reduced parts that have to be removed when being replaced. Access to the area near the cylinder head cover, which must be opened and closed, especially for inspections, on top of the engine has been improved, with no need to navigate whatsoever through wiring or piping. Furthermore, the water pump was changed from a gear-driven model to a belt-driven model, improving the ease with which it can be replaced in the event of a failure. Efforts such as modularizing the auxiliaries shown in **Fig. 13** reduced the number of parts by approximately 20% compared to the conventional model. This helps improve the engine’s maintainability by making disassembly and reassembly for repairs easier.

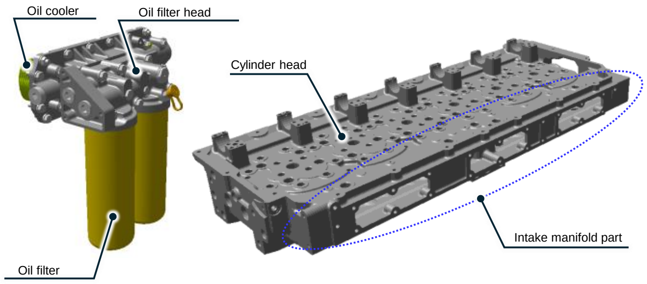

Fig. 13 Example of modulization

3.3.3 Reliability and durability improvements

In the development of this engine with almost entirely updated parts, we performed thorough quality checks to ensure its reliability and durability. In endurance testing, various tests were conducted, including not only long-duration high-load endurance tests but also simulations of harsh environments where construction machinery is used, such as dusty, low-temperature, and high-altitude worksites. We also carried out simulated endurance tests that replicated the actual usage conditions of the chassis. The total duration of these endurance tests exceeded 20,000 hours.

With regard to parts that are subject to wear like bearings, valves, and valve seats, by changing to parts that have a higher wear resistance compared to those of the conventional model, we not only accommodated the aforementioned increase in maximum in-cylinder pressure but also extended the service life. Consequently, we extended the overhaul interval by at least 30% compared to the conventional model.

3.3.4 New automated troubleshooting system

For the DBA127 engine, a new troubleshooting system to monitor the state of the engine was introduced. The system monitors the sensor values such as the temperature or pressure of each part and the actuator drive state. This troubleshooting system is equipped with a “Quick Assessment” function that identifies failure points using error information and monitoring data when a failure occurs. It also features a “Predictive Maintenance” function that detects signs of potential failures from daily data trends. Collected engine information is sent to a server through Komtrax, which is installed as standard in Komatsu construction machines, before it is then analyzed on the server. If there are any abnormalities in the analysis results, a notification is sent to service personnel and the content can be checked online. This enables machine maintenance before a failure occurs, and, even in the unlikely event a failure does occur, it is possible to significantly reduce downtime by quickly identifying where the failures exist. This function will also be incorporated into engines developed later down the line.

4. Conclusion

This paper introduced the technical features of the newly developed DBA127 engine. The DBA127 engine was developed with a clean-sheet design, in which we developed it as an engine that incorporated VoC (Voice of Customer) feedback collected during the planning stage. Almost all of the key components were developed in-house, with many of them produced by Komatsu or a subcontractor. Thus, we were able to release this engine on the market as an "All Komatsu" achievement. In machine development as well, from the examination stage, we undertook simulations that coupled a machine with the engine and undertook development efforts while checking that the engine development work matched the machine development concept. We believe that installing the DBA127 engine can contribute significantly to improving the product appeal of our machines due to improved power, fuel consumption, and maintainability over the conventional model.

With front-loading of model-based development needed, the development of this engine involved simulations of the structural, main motion, moving valve, intake and exhaust, cooling, lubrication, combustion injection, and electrical control systems, leading to an improved level of examination. Among these efforts, as a first-ever means of evaluation, we introduced the use of augmented reality (AR) technology to make assessments of engine maintainability. Before settling on the design, we grasped the key points of onboard engine maintenance and were thus able to prevent any rework in the engine design. We believe the model-based development achievements made in the development of the DBA127 engine will serve as the foundation for engines developed next term.

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[A comment from the authors]

With the need to reduce greenhouse gas (GHG) emissions to realize carbon neutrality, expectations are focused on different power sources such as electrification and hydrogen engines. Thus, diesel engines have entered a new chapter. We believe that diesel engines, which offer high energy density, excellent durability, reliability, and the ability to perform under harsh conditions, will remain a much needed power source in construction machinery. As the newly developed DBA127 engine has achieved high economic efficiency and low fuel consumption, it is expected that it will also contribute to reducing GHG emissions.