Introduction of Medium-Speed Diesel Engine V28AHX

KATO Shoji : Manager, DE Development, Design & Development, Engineering & Technology Center, Niigata Power Systems Co., Ltd.
SAITO Toshiyuki : Manager, Fundamental Technology, Research & Development, Engineering & Technology Center, Niigata Power Systems Co., Ltd.

Niigata Power Systems Co., Ltd. has added the V28AHX to its NIIGATA 28AHX Series, the bestselling engine series which has sold over 200 units. The V28AHX offers an increased output range, completing a lineup of high-efficiency engines with an output ranging from 2 070 to 6 660 kW.

1. Introduction

1.1 28AHX series engine

Niigata Power Systems Co., Ltd. (NPS) has been providing products and services that meet the needs of the times to users around the world in an attempt to contribute to the development of society with technologies developed throughout its 100-year history of developing diesel engines. The 28AHX series engine was developed in 2008 as the next-generation high performance engine after the previous 28HX engine. It has been delivered as the marine main engine for many purposes around the world.

This engine, which has cleared emission gas regulations including IMO-NO_x Tier II regulations and features improved fuel consumption from the previous engine, is a new environment-conscious, medium-speed engine that reduces smoke emissions throughout the entire operation range as a main propulsion engine.

1.2 Design concept of the 28AHX

The new medium-speed 28AHX engine was developed under the following concept.

(1) Meeting the IMO-NO_x Tier II regulations without deteriorating the specific fuel consumption
(2) Smoke is not visible throughout the operation range
(3) Improving the idling performance and acceleration from idling from the previous engine model
(4) Lighter weight and more compact than conventional engines in the same output class
(5) Easy maintenance

1.3 Engine specifications and features of the 28AHX

The 28AHX is a diesel engine with a cylinder bore of 280 mm and stroke of 390 mm that outputs 370 kW/cyl. (800 min^{-1} specification) or 345 kW/cyl. (750 min^{-1} specification) at a maximum cylinder pressure 18 MPa. In addition to its improved reliability, the 28AHX features compact size and is lightweight. **Table 1** shows the main specifications of the 28AHX engine and **Fig. 1** shows its external and cross section of the engine.

Table 1 Main specifications of the 28AHX engine

Engine		Unit	28AHX main specification	
Model		—	28AHX	
Engine speed		min^{-1}	800	750
Cylinder bore		mm	280	
Stroke		mm	390	
Continuous maximum output	6 L	kW	2 220	2 070
	8 L		2 960	2 760
	9 L		3 330	3 105
Brake mean effective pressure		MPa	2.31	2.30
Mean piston speed		m/s	10.40	9.75
Maximum pressure		MPa	18	

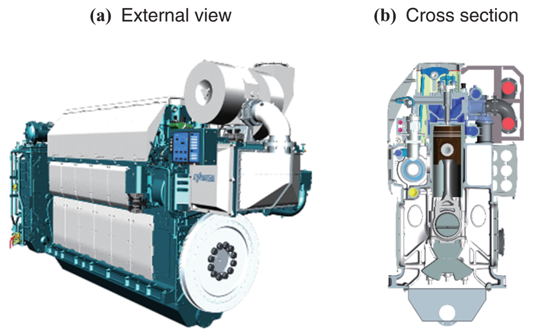


Fig. 1 External and sectional views of the 28AHX engine

With the following new technologies incorporated in pursuit of the development concept, the 28AHX has improved the engine performance including the low load range, achieved no smoke emissions, and enhanced the transient characteristic. The following sections describe the features of each of the 28AHX's new technologies.

(1) Miller cycle
By using the quick closing miller cycle for the intake valve, the internal pressure of the cylinder and combustion temperature are reduced, which decreases the NO_x emissions.

(2) Variable Intake Valve Timing (VIVT)
In order to maintain the appropriate charged air volume in the combustion chamber at a low load range and reduce smoke emissions, a VIVT mechanism for changing the intake valve timing was adopted. By setting the proper intake valve open and close timing in each of the low load and high load ranges as well as the overlap period with the exhaust valves, this mechanism

enables a high level of engine performance to be demonstrated in all load ranges.

(3) Improved turbocharging system

By combining a high-pressure turbocharger with an air bypass and waste gate system, the accelerating characteristics of the engine in the low load range have been improved, and this has reduced the amount of smoke and enhanced the engine performance in the low load range. In the high load range, on the other hand, a high boost pressure is maintained, achieving high engine performance throughout the load range.

1.4 Operating conditions of the 28AHX

With a shipping record of nearly 200 units as marine main engines, the 28AHX series is a flagship product of NPS. **Figure 2** shows trends in the number of 28AHX engines delivered. The operating hours after delivery have exceeded 10 000 hours for some of the longer lasting engines. As a result of our observation of engine performance and main component conditions through much maintenance service performed at the site of the customer, we have confirmed that there are no issues. We will continue to monitor the operating conditions of delivered engines to increase the level of perfection of the 28AHX.

2. Development of the V28AHX

2.1 Development into Vee engines

NPS recently developed the V28AHX (**Fig. 3**) targeting not only marine main engines, but also main generator engines for electric propulsion and other generator engines for land use, with the aim of expanding the output range of the 28AHX series. By using a 3D-CAD system for engine design to fully utilize 3D models for performance simulation, structural and fluid analysis, etc., NPS optimized the part shapes and reduced part weights which were required to achieve the performance goal.

2.2 Development concept of the V28AHX

Before developing the V28AHX, NPS emphasized the following points in its design.

(1) Maintaining and improving the performance of the inline 28AHX engine and increasing its output

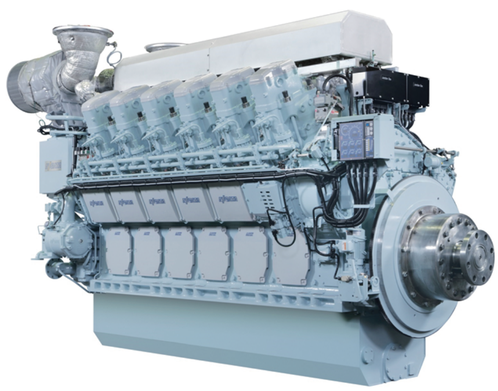


Fig. 3 V28AHX engine

(2) Making the engine lighter and smaller than conventional engines of the same output class

2.3 Engine specifications

The main specifications are the same as the inline engine as follows: a 280 mm cylinder bore, 390 mm stroke, engine output of 370 kW/cyl. (800 min^{-1} specification) or 345 kW/cyl. (750 min^{-1} specification). **Table 2** shows the main specifications of the V28AHX engine.

2.4 Engine external view

The engine was given a slim design by reducing the number of pipes outside the engine by arranging coolant pipes and other pipes in the V bank between the cylinders. By arranging main pumps (coolant pumps, lubricant pumps,

Table 2 Main specifications of the V28AHX engine

Engine		Unit	V28AHX main specification	
Model		—	V28AHX	
Engine speed		min^{-1}	800	750
Cylinder bore		mm	280	
Stroke		mm	390	
Continuous maximum output	12 V	kW	4 440	4 140
	16 V		5 920	5 520
	18 V		6 660	6 210
Brake mean effective pressure		MPa	2.31	2.30
Mean piston speed		m/s	10.40	9.75
Maximum pressure		MPa	18	

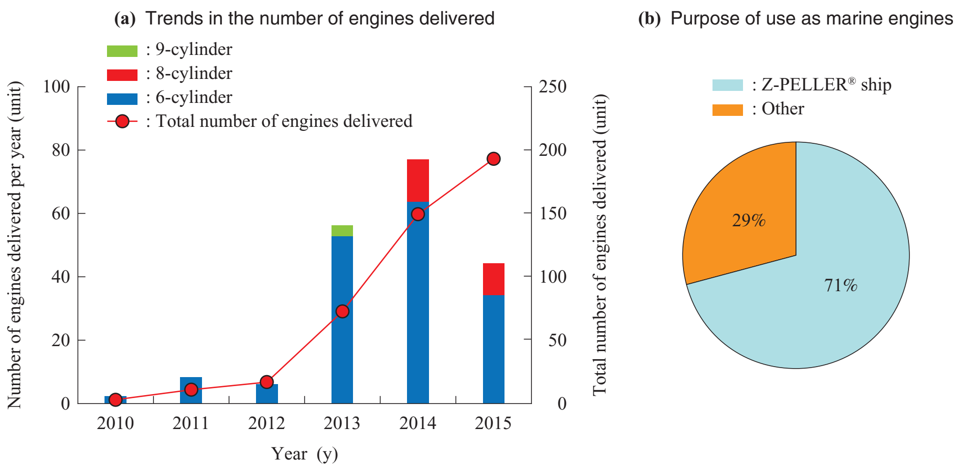


Fig. 2 Trends in the number of 28AHX engines delivered

etc.) on the free end side of the engine, the interface with the ship and the plant is simplified. In addition, for improved maintenance, a turning gear is provided as standard. The exhaust system supports both the pulse turbocharging system and the single pipe turbocharging system. **Figure 4** shows the external and sectional views of the V28AHX engine.

2.5 Optimization of engine components and reducing engine weight

Main parts that have many established results in inline engines were used in common with the V28AHX, which ensured the engine performance and the reliability and shortened the design period. As for unique parts for Vee engines, such as the cylinder block and crankshaft, strength and fluid flow were examined by using 3D-CAD and simulation techniques to optimize the parts shape, reduce the parts weight, and improve the engine performance. The following section explains these parts in detail.

2.5.1 Cylinder block

For the cylinder block, NPS's high strength ductile cast iron was used and the high rigidity hanger type was adopted. The cylinder block was designed through structural analysis using the Finite Element Method (FEM) to optimize the structure and make it lightweight. Since the cylinder block is made of a large size of cast iron, when creating a wooden pattern for casting, the 3D measurement of the wooden pattern was conducted to check for differences with the shape in the drawing in places such as wall thickness. As a result, the product accuracy improved and the engine is 30% lighter than conventional engines. **Figure 5** shows the 3D measurement of the wooden pattern for casting the V28AHX engine and the measurement results. The charge air cooler case containing the charge air cooler also serves as the turbocharger base and it is linked to the cylinder block via the joint block. The joint block also functions as the interface for the coolant, lubricant, and charge air from turbocharger, contributing to the reduction of pipes surrounding the turbocharger base, simplification of the structure, and ease of assembly work.

2.5.2 Crankshaft

For the crankshaft, lightweight and a good balance ratio are achieved by machining the entire crank arms to reduce variations in the weight between crank throws and also with the balance weight attached to each crank throw. In addition, while ensuring the required torsional and bending rigidity in the crank arm shape with the automatic shape optimization technology using the FEM, the crank arm weight was reduced by approximately 15% from conventional engines.

As a result of these weight reduction efforts, the V28AHX is approximately 15% lighter and approximately 10% smaller than NPS's medium-speed diesel engines with a 280 mm cylinder bore and the same output range. **Figure 6** shows a comparison of weights and dimensions.

2.6 Example application of simulation technology

In order to improve the engine performance and reduce the engine weight at the same time, simulation technology is actively used for the development of new engine types. As

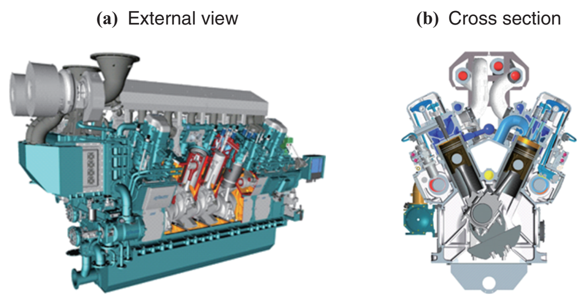


Fig. 4 External and sectional views of the V28AHX engine

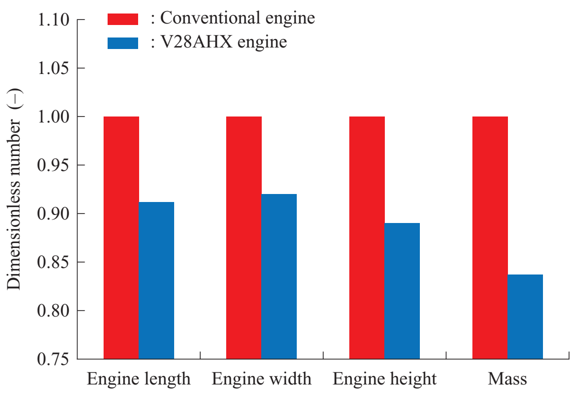


Fig. 6 Comparison of weight and dimensions between the V28AHX and NIIGATA's conventional engines

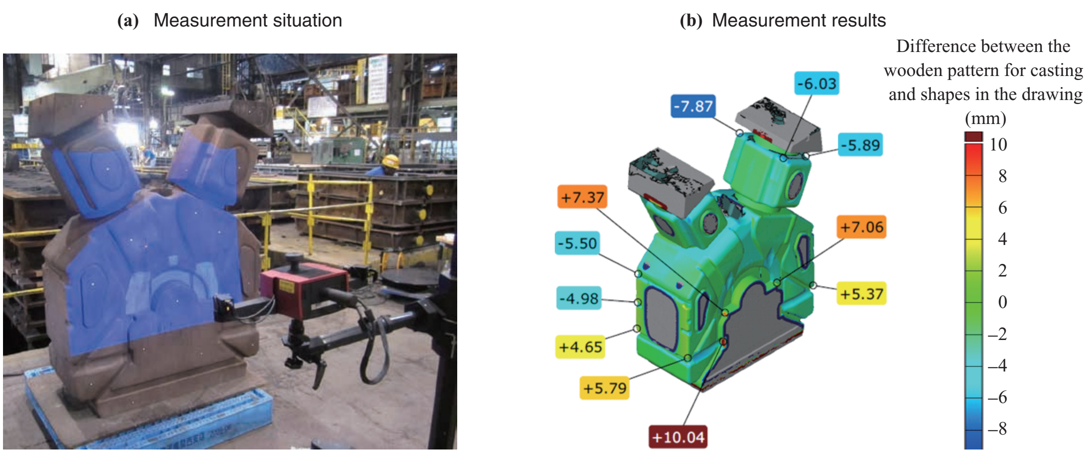


Fig. 5 3D measurement situation and measurement results of a wooden casting mold for the V28AHX engine

explained in **Section 2.5**, unique parts for Vee engines were developed and main parts that have many established results in inline engines were used in common with the V28AHX. When using the parts in common with inline engines in a Vee engine, connections with adjacent main parts may change. Here, NPS also used simulation technology to examine the issue.

As application case studies, the following are introduced in this article: ① Shape optimization of the charge air cooler case, which was developed as a unique part for Vee engines, ② Shape optimization of the intake manifold connecting the cylinder head intake port and the cylinder block, and ③ Shape optimization of the coolant connecting pipe connecting the cylinder head coolant inlet and the main coolant pipe.

2.6.1 Case study on shape optimization of the charge air cooler case

In general, a diesel engine charges the cylinder with high pressure air by using a turbocharger to increase output and efficiency. However, since the temperature of the compressed air is high but its density is low, there is a limitation to improve charging efficiency without any measures. For this reason, a charge air cooler is installed between the turbocharger and the engine so that charge air from the turbocharger can be cooled to increase the charging efficiency. The charge air supplied from the turbocharger is led to the charge air cooler case containing the charge air cooler. After being cooled, the charge air is supplied to the charge air supply surge tank built into the cylinder block. A baffle plate is provided in the inlet duct of the charge air cooler case, which guides a balanced flow of charge air to the charge air cooler. In the development of the V28AHX, Computational Fluid Dynamics (CFD) was used to optimize the shape of the inlet duct and baffle plate in the charge air cooler case, improving the charge air flow inside the charge air cooler case. **Figure 7** shows the velocity distribution in the upstream cross-section of the V28AHX charge air cooler. It shows that there are high and low velocity areas, causing a very uneven flow in the initial shape (**Fig. 7-(a)**). On the other hand, in the final shape (**Fig. 7-(b)**), NPS successfully positioned the baffle plate and added a projection to it to obtain more uniform velocity distribution. These improvements improved the heat exchange efficiency, resulting in the smaller charge air cooler and charge air cooler case that contributed to the compact size and lighter weight as well as the higher performance of the engine.

2.6.2 Case study on shape optimization of the intake manifold

As explained in the previous section, the charge air supplied from the turbocharger is cooled by the charge air cooler and led to the charge air supply surge tank built into the cylinder block. From the charge air supply surge tank, the charge air passes through the intake manifold and the cylinder head intake port for each cylinder and is then supplied to the combustion chamber. In order to improve the engine performance, the flow coefficient of the intake manifold and cylinder head intake port needed to be increased. For this reason, the shapes of these parts were optimized when developing the inline engine. Although the cylinder head of the V28AHX is a part used in common with the inline engines, due to a change in the engine layout, the intake manifold was designed from scratch. Therefore, NPS used CFD to optimize the shape of the intake manifold and arrived at a shape that achieves the same or better flow coefficient than the inline engine.

Figure 8 shows the velocity distribution of the intake manifold and intake port. In the initial Vee engine shape (**Fig. 8-(b)**), due to the sharper bend of the intake manifold than the inline engine shape (**Fig. 8-(a)**), a high velocity area existed inside the bend, while a slow velocity area existed outside the bend. In the final Vee engine shape (**Fig. 8-(c)**), the uneven velocity was eliminated by a smooth bend, and as a result, the flow coefficient of the intake manifold and the intake port was higher than that of the inline engine as shown in **Fig. 9**.

2.6.3 Case study on shape optimization of the coolant connecting pipe

Since the V28AHX is a water-cooled engine, high temperature parts around the combustion chamber are cooled by coolant. The coolant is supplied from the main coolant pipe to each

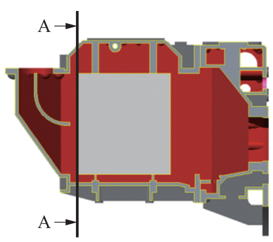
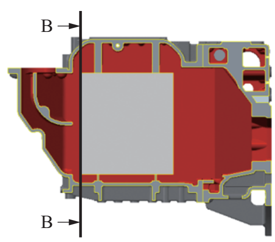
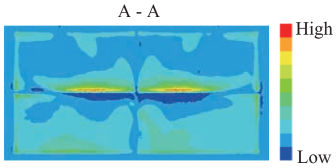
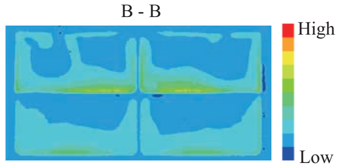
Item	(a) Initial shape	(b) Final shape
Upstream cross-section of the charge air cooler		
Velocity distribution in the upstream cross-section of the charge air cooler	A - A 	B - B 

Fig. 7 Velocity distribution in the upstream cross-section of the V28AHX charge air cooler core

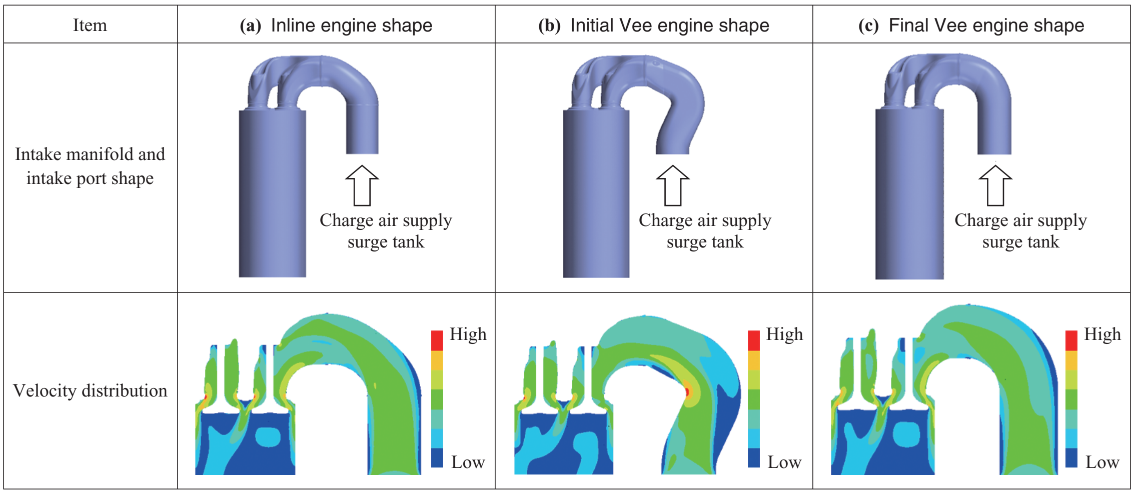


Fig. 8 Velocity distribution of the intake manifold and intake port

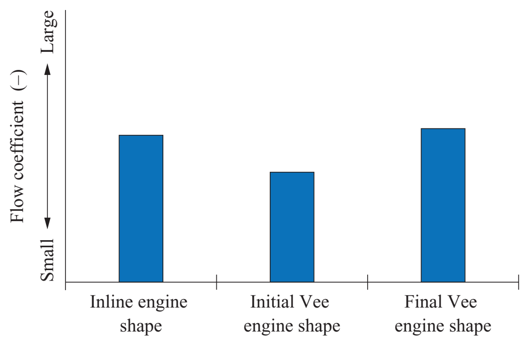


Fig. 9 Comparison of the flow coefficient of the intake manifold + intake port

cylinder liner ring to cool the cylinder liner top and cylinder head, and then it flows out from the engine. Although the cylinder head and liner ring of the V28AHX are parts used in common with the inline engines, the coolant connecting pipe that connects the main coolant pipe and each cylinder liner ring are designed from scratch due to a change of the engine layout.

Figure 10 shows the coolant pipe system viewed from the top of the engine. While the main coolant pipe and each cylinder liner ring are close to each other in the inline engine, they are farther away from each other in the Vee engine. Another characteristic of the Vee engine is that due to the layout of the main coolant pipe arranged at the center of the engine, the coolant flow direction to the liner ring at one bank side of both bank is different from the inline engine by 180 degrees. In an effort to maintain the cooling performance of the Vee engine at the same level as the inline engine under such conditions, NPS used CFD to evaluate the flow in the coolant connecting pipes.

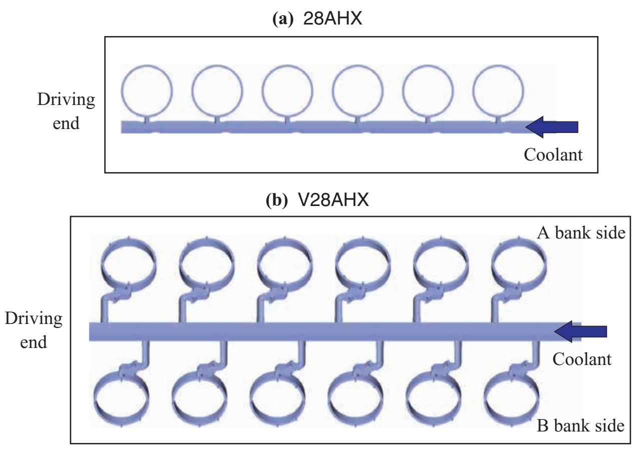


Fig. 10 Coolant circuit layout (Top view)

Figure 11 shows the velocity distribution of the coolant flow from the main coolant pipe toward the liner ring. In the inline engine, coolant that flows in from the main coolant pipe mainly flows to the exhaust valve side, efficiently cooling the exhaust valve side which gets hotter than the intake valve side. On the other hand, in the initial Vee engine shape, more of the coolant that flowed in from the main coolant pipe flowed to the intake valve side at each bank. To solve this issue, NPS changed the sectional shape of the coolant connecting pipe, its bend location, and its connecting location with the liner ring to optimize its shape. In the final Vee engine shape, more coolant that flows in from the main coolant pipe flows to the exhaust valve side at each bank, maintaining cooling performance equivalent to that of the inline engine.

2.7 Engine performance and test results

Figure 12 shows a comparison of engine performance (relative comparison when the performance of NPS's conventional engines is set as 1) between the V28AHX engine and NPS medium-speed diesel engine with a 280 mm cylinder bore and the same output range. The V28AHX reduced NO_x emissions by reducing the combustion temperature with the miller cycle while reducing the specific fuel consumption through proper valve timing with a high-pressure turbocharger and VIVT at the same time. In addition, with the air bypass system and waste gate system, the performance of the turbocharger is exerted effectively in the entire load range, improving the specific fuel consumption by approximately 6% from conventional engines in the high load range. In the low load range, smoke emissions were improved, improving

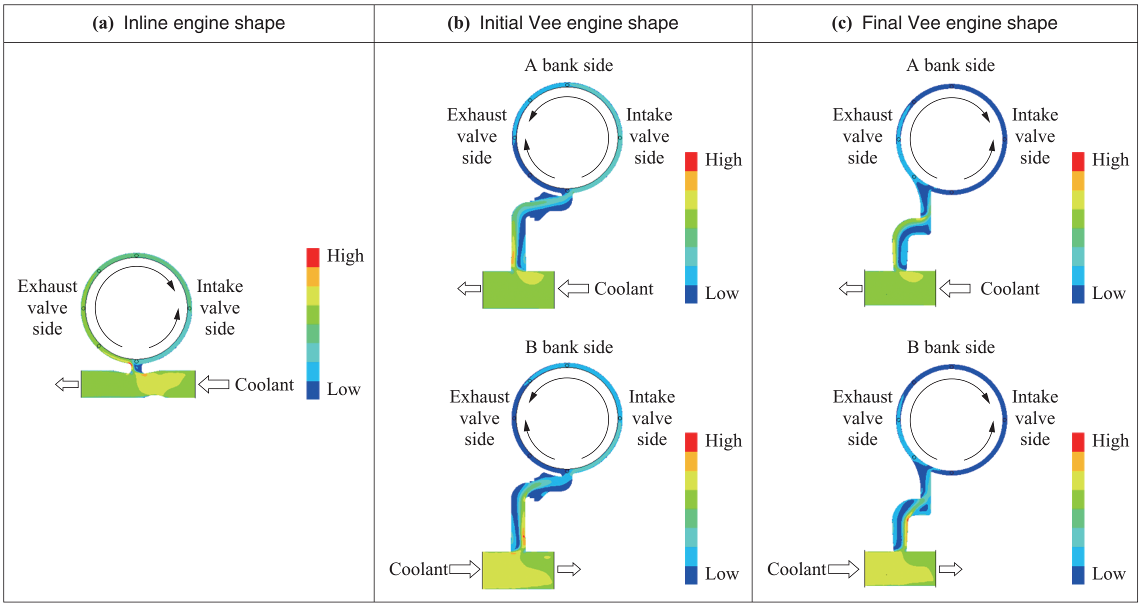


Fig. 11 Velocity distribution of coolant flow from the main coolant pipe toward the liner ring

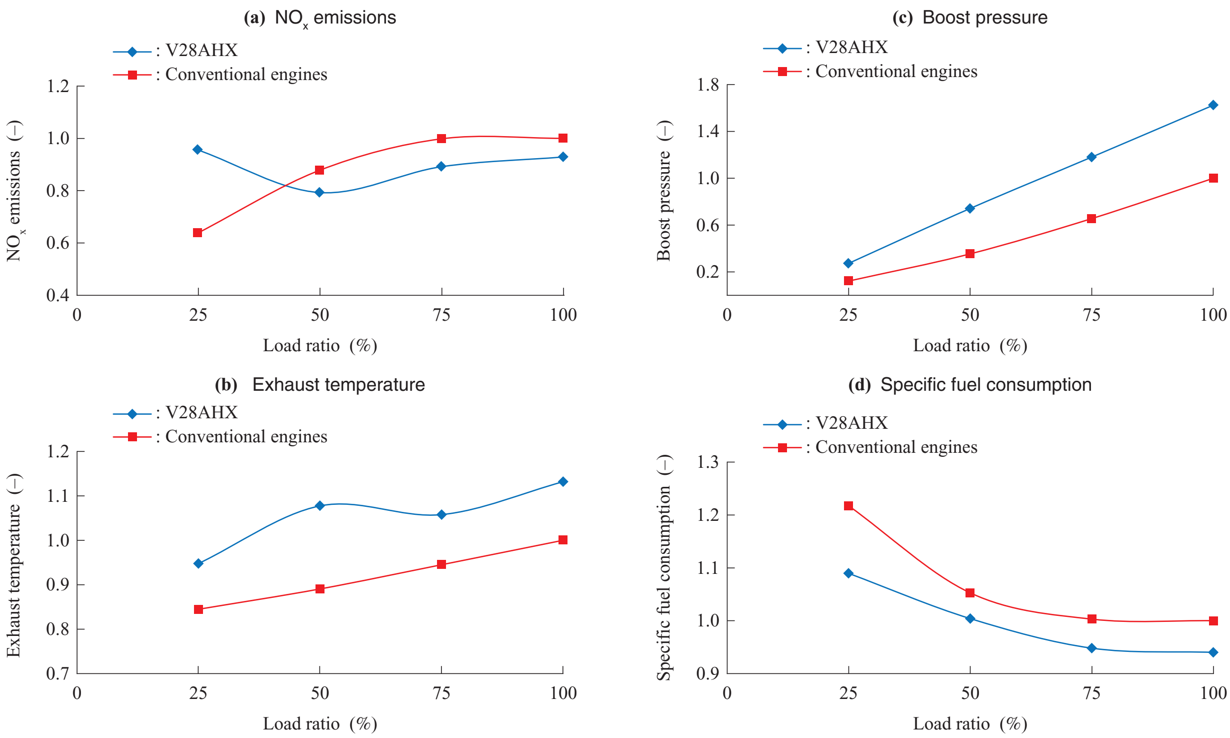


Fig. 12 Comparison of engine performance between the V28AHX engine and NIIGATA's conventional engines

the specific fuel consumption by approximately 11%.

As indicated by the above results, NPS achieved the environmental friendliness goal set out as the development concept of the 28AHX: meeting the IMO-NO_x Tier II regulations and improving the specific fuel consumption. The Vee engine has improved the specific fuel consumption more than the inline engine through optimization of each part based on testing.

During the acceleration test, a smooth increase in speed when the engine is started and improved smoke emissions compared with conventional engines were confirmed. While confirming the soundness of each part of the engine tested during endurance running and cycle testing, NPS also confirmed that there were no vibration noise level issues during the operation of the engine. Furthermore, based on these test results, NPS confirmed that the results of various examinations using the simulations introduced in **Section 2.6** were effective.

3. Future prospects for the 28AHX

As many inline engines have been delivered as marine main engines and have been operating well in the field, they are expected further activities in the future. The recent development of the Vee engine allows the 28AHX series to cover an output range of 2 070 to 6 660 kW. NPS has so far received an order for the 12V28AHX as a marine main engine and another order for the 18V28AHX as a continuous power generator engine for land use, as well as many other inquires on the 12V, 16V, and 18V engines. In the future, the 28AHX series is expected great activities in many fields, not only as marine main engines, but also in many other areas.

— Acknowledgements —

The development of the V28AHX engine was supported partially by the Ministry of Land, Infrastructure, Transport and Tourism's research and development support project for ocean resource development related technologies, "Research and Development of Electric Propulsion System for Large Supply Boats." We express here sincere appreciation to this support.