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Development of NIIGATA new medium-speed diesel engine “28AHX”

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Abstract: Niigata Power Systems Co., Ltd. (NPS) has developed new medium speed diesel engine ”28AHX” which covers output range of 2070-3330kW by inline 6-9 cylinder engines.

In recent years, as container ships become bigger size, the higher output of tug boat is demanded in the world. Also demand of supply vessels of PSV (Platform Supply Vessel) and AHTS (Anchor Handling Tug Supply) vessel are increased. To accommodate to this market demand, this new engine has been developed for the main engine driving azimuth type propulsion system ”Z-peller” mainly.

28AHX has 280mm bore and 390mm stroke, and its maximum output is 370kW/cyl. at 800min-1, and 345kW/cyl. at 750min-1 respectively. The engine can comply with the exhaust emission regulations in the next stage such as IMO NO_x Tier II, and it is considered the performance of low load operation and transient response as a main propulsion engine.

To achieve these performance targets for the environment without increase of the specific fuel consumption, the following technical expedients are applied.

- Optimization of combustion: piston design and injection system etc.

- Miller cycle and optimization of intake and exhaust valve timings

- Adoption of variable intake valve timing mechanism

- Improvement of a turbocharging system : air bypass and waste gate

In addition, for the purpose of the decrease of engine and auxiliary equipment space in the engine room, and of easy maintenance, the following construction is designed.

- ”Cylinder unit” : assembling of cylinder parts

- ”Front end unit” : integrated unit of auxiliary machinery on engine front side

This paper reports the design feature and engine structure of 28AHX, and also the performance and mechanical results of the prototype engine.

The engine performance are well accepted, especially the quick load increase operation characteristic is very good. The fuel consumption is improved compare to existing medium size engine of Niigata, even 28AHX keeps Tier II NO_x emission.

INTRODUCTION

Niigata Power Systems Co., Ltd. (NPS) produces marine engines, propulsion systems, and related devices to meet current needs, efforts that have earned the company an outstanding reputation worldwide and in Japan.

On the other hand, while in recent years an environmental issue is most important worldwide, it has brought growing demand worldwide for improved efficiency and for compliance with exhaust emission regulations including IMO NOx Tier II in marine diesel engine.

In response, NPS has developed the 28AHX engine to succeed the engines in the Niigata HX series, a best-selling series designed especially for use with azimuth thrusters. The 28AHX is a new medium-speed engine that is built on previous NPS diesel engine technologies[1] and is newly applied, to provide significantly improved performance while meeting anticipated next environmental regulations.

DESIGN CONCEPT

On developing the new 28AHX medium-speed engine, the following design goals were targeted.

1) Environmental considerations

Reducing NOx emissions by 30% from current engines and compliance with future emission regulations, including IMO Tier II.

Improving fuel consumption while reducing NOx emissions. Development of an engine contributing to GHG reductions.

2) Smokeless engine

Invisible smoke emissions over the entire load range ; To be clean smoke over the whole operating range for propulsion system engines.

3) Improvement of low-load and transient characteristics

To meet the operating condition as tug boat engines, improved performance at idling and at acceleration load.

4) Lightweight and compact

Reduced weight and size compared to existing engines of similar output class.

5) Easy maintenance

Advantage for individual component reliability and easy maintenance works.

SPECIFICATIONS

Table 1 shows the engine specifications of the 28AHX.

With bore and stroke of 280 mm and 390 mm, there are two full output power specifications.

The mean effective pressure is kept to around 2.3 MPa.

Table1 28AHX Main specifications

Engine model			28AHX	
Cylinder bore	mm		280	
Stroke	mm		390	
Continuous maximum output	kW	6L	2220	2070
		8L	2960	2760
		9L	3330	3105
Engine speed	min^{-1}		800	750
Mean effective pressure	MPa		2.31	2.30
Mean piston speed	m/s		10.4	9.75
Maximum cylinder pressure	MPa		18	

DESIGN FEATURES

Based on 3D-CAD systems, engine design makes full use of 3D modeling, including performance simulations and structural analysis. This allows front-loading examination of the systems required and various methods for achieving performance goals while facilitating optimization and component weight reductions.

Figure 1 shows a cross section of 28AHX.

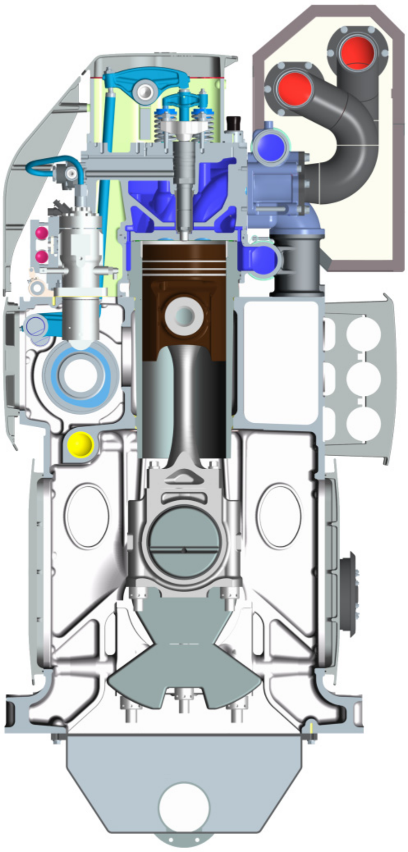


Figure1 Cross section of 28AHX

The main components and their characteristic systems are described below.

1) Cylinder block

The hanger-type integrated with the crankcase is adopted, by using the high-strength nodular cast iron manufactured in-house.

The cylinder block and related components are subjected to FEM structural analysis to ensure adequate stiffness near the bearings and optimal, light-weight construction. (Figure 2)

2) Cylinder liners and cylinder heads

As parts of the combustion chamber, the cylinder liners and cylinder heads are one of the parts subjected to the harshest load conditions.

The cylinder liners are made of a special cast iron manufactured by centrifugal casting. The upper part is composed of optimal thickness, cooled via a surrounding water jacket. Using CFD with 3D models, the flow of cooling water from the water

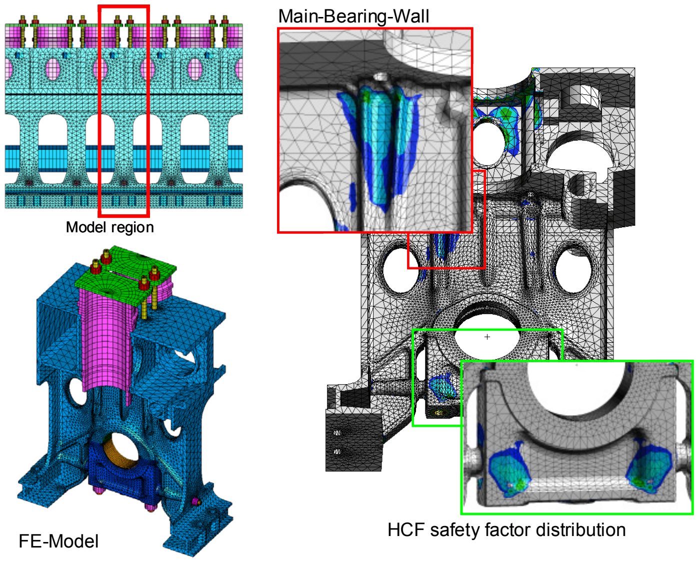


Figure2 FEM analysis of engine block and bearing cap

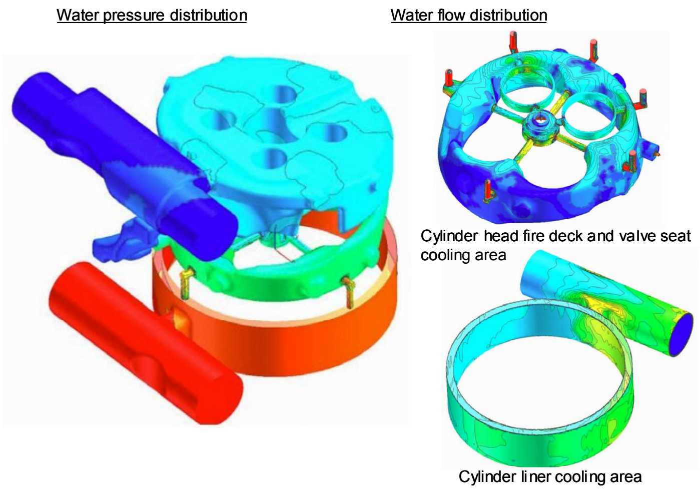


Figure3 Cylinder cooling CFD analysis results

jacket to the cylinder head interior and intake/exhaust manifold were analyzed. (Figure 3) Efficient and uniform cooling water passages were formed to optimize temperature conditions based on evaluations of cooling water flow velocity distribution and pressure.

3) Pistons

The piston is monoblock type with nodular cast iron, it ensures easier maintenance. (Figure 4). The combustion bowl shapes were optimized by using combustion CFD analysis to improve engine performance such as fuel consumption, NOx emission, smoke emission and lubrication oil consumption. The configuration of fuel injection nozzle is also considered during CFD analyses, and then some of feasible combinations of bowl shape and fuel injection nozzle were installed and tested to investigate the best engine performance.

Piston rings configuration consist of three rings, with two compression rings and one oil scraper ring. Cr-ceramic coating is applied to the top ring.

4) Connecting rods

Depending on the specific marine use application, a horizontally three-split type connecting rod is adopted. It's enabled to remove the piston without disassembling the crank pin bearing. FEM analysis was carried out to evaluate strength and fretting resistance. (Figure 5)

Then stress measurements and fatigue testing was performed using a high-load pulsed test machine to confirm reliability and provide feedback for analysis. (Figure 6)

5) Cylinder unit

The cylinder head and rocker arm unit, cylinder liner, piston, and connecting rod comprise a sub-assembly unit to facilitate assembly and removal to and from the engine, simplifying maintenance tasks and spare parts stocking onboard marine vessels. (Figure 7)

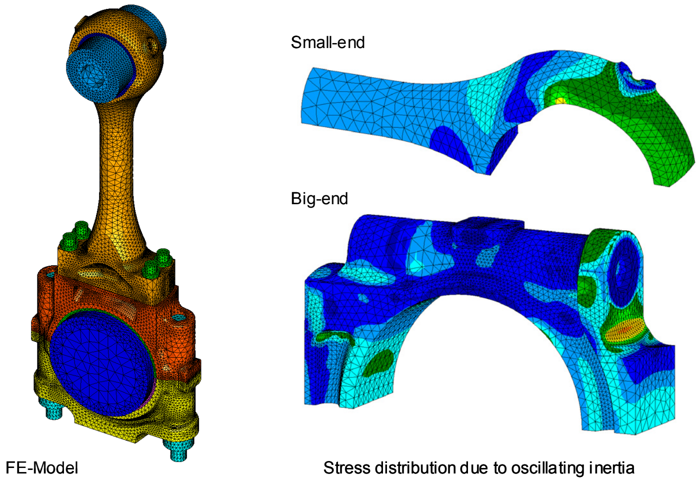


Figure5 Connecting-Rod FEM analysis

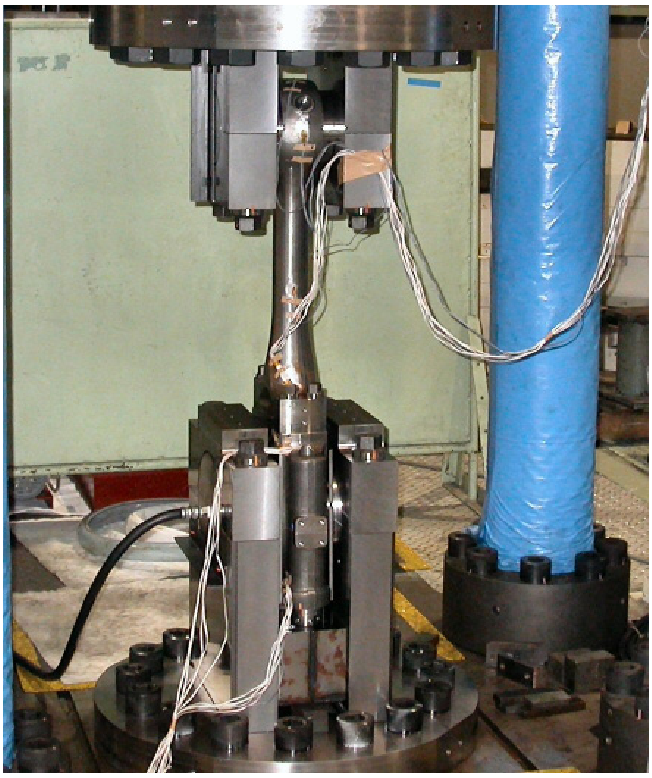


Figure6 Fatigue test of connecting rod

Figure4 Monoblock type piston

6) Front-end unit (optional)

Auxiliary equipment including the lubrication oil system (LO pump, pressure regulating valve, thermo-control valves, LO cooler, filter), fuel system (fuel supply pump, filter), and cooling water system (high-temperature/low-temperature cooling water pumps, thermo-control valves) are integrated into a single unit located at the free end of the engine. This means that space for pipes is no longer required, contributing to space-saving in the engine room. (Figure 8)

7) Gage board “*Grafico*”

The newly-developed “*Grafico*” *electrical* gage board shows engine speed, pressure, and temperature digitally and as bar graphs using LEDs for excellent visibility and rapid assessment of engine status, contributing to engine safety operations. The interfaces are industry-standard communications systems to ensure compatibility with external systems. (Figure 9)

Figure 10 is a photograph showing the exterior of the prototype six-cylinder engine.

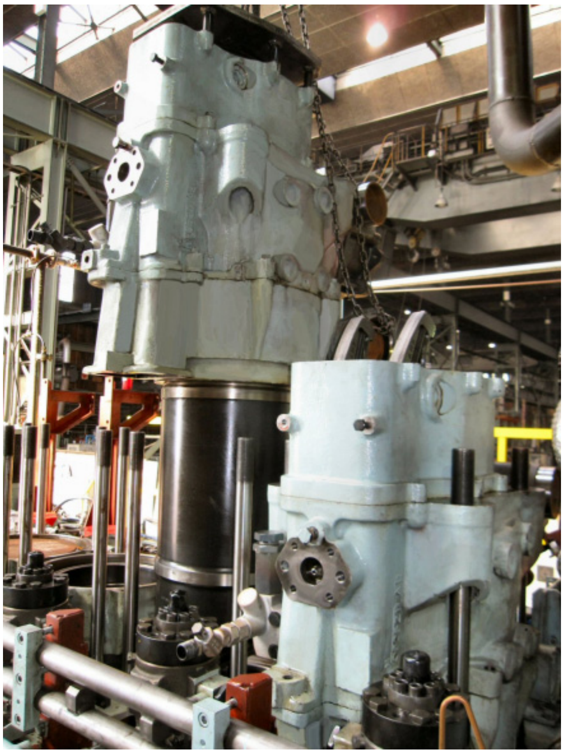


Figure7 Cylinder unit

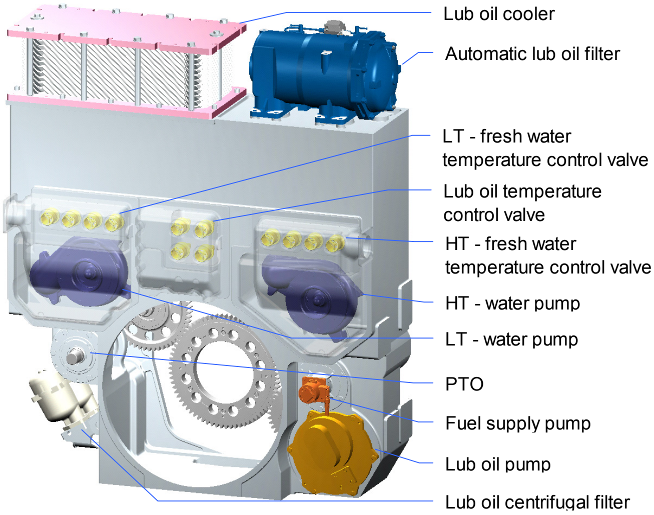


Figure8 Front end unit

Figure9 Gage board “Grafico”

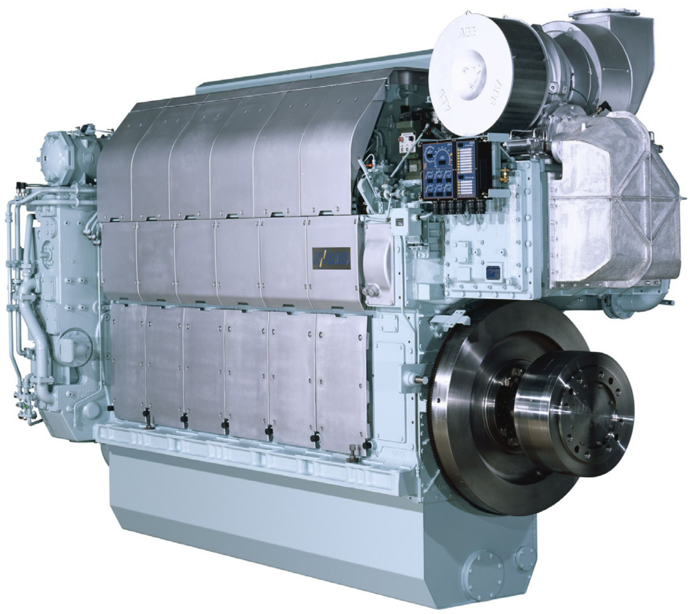


Figure10 New developed engine 6L28AHX

ENGINE PERFORMANCE

1. Technologies applied to achieve target performance

This engine was primarily developed for use as a marine engine meeting the following requirements:

- Compliance with future exhaust emission regulations
- Improved low-load performance and load acceleration characteristics
- Invisible smoke over the entire load range

The following measures were examined to achieve these performance targets:

1) Employment of Miller cycle and optimized inlet/exhaust valve timing

A Miller system with early-closing inlet valves was used; internal cylinder pressures and combustion temperature were reduced for securing lower NOx emissions.

2) Variable inlet valve timing system

A mechanical VIVT (Variable intake valve timing) system was used to achieve compatibility of high-load and low-load engine performance. The system shifts the intake valve timing as Figure 11, intake close timing and valve overlap are changed, simultaneously.

For low-load condition, this mechanism helps improvement of engine efficiency due to shortened valve overlap. On the other hand, the Miller cycle is achieved by advanced intake valve close timing and it leads lower NOx emission and good fuel consumption.

3) Improved turbo charging system
(air bypass and waste gate)

The turbo charging system includes the air bypass and waste gate shown in Figure 12 to maximize the effectiveness of the turbocharger over the entire load range.

TEST RESULTS

A prototype six-cylinder engine was assembled and performance-tested. The results of these tests are described here.

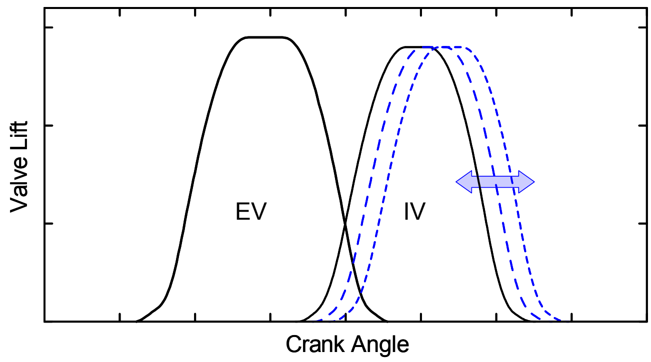
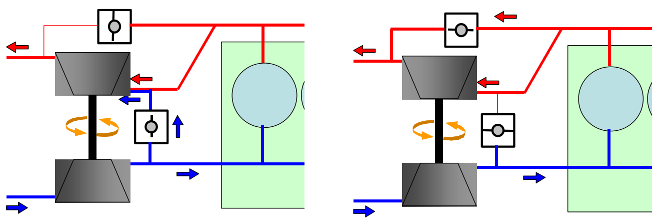


Figure11 Variable Intake Valve Timing



Air Bypass System Waste Gate System

Figure12 Air bypass and Waste gate

Figure 13 shows an example of measurement result of smoke emission. The air bypass system was functioned up to 50% load condition, and the waste gate system was employed above 100% load, on the marine propulsion load. A smokeless target of less than 0.5 BSU was achieved over the whole operation range from idling to 110% load.

NOx emissions was in compliance with IMO NOx Tier II regulations, it can be also adjusted by altering the upper lead on the fuel injection pump plunger to suit engine usage. (Figure 14)

Fuel consumption level was improved lower than conventional engines even if auxiliary systems such as lubrication oil and cooling water pumps were driven, with low NOx emissions.

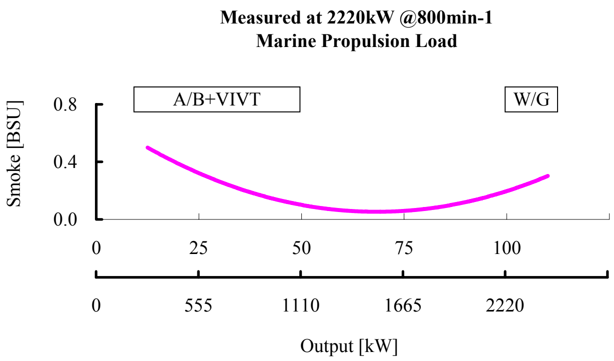


Figure13 28AHX smoke measurement (example.)

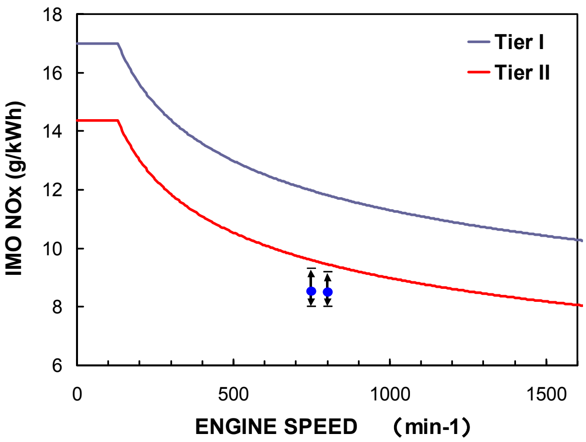


Figure14 Complying with IMO Tier II

Figure 15 shows the operating line of the turbocharger. Two operating points are plotted with and without air bypass at 50% load. Air pressure and flow volume were well increased by using air bypass. The increased air volume improves combustion efficiency and reduce smoke emissions, in addition, it ensured adequate surge margins on these load area. This makes it possible to set the turbocharger matching more effective at high loads.

Figure 16 shows one of the typical operating load pattern of tug boat by monitoring a similar output class engine installed with Z-pellers (NPS azimuth propulsion system). A significant proportion of tug boat operations occurs in the low to middle load range, with a key requirement being accelerating rapidly to high output.

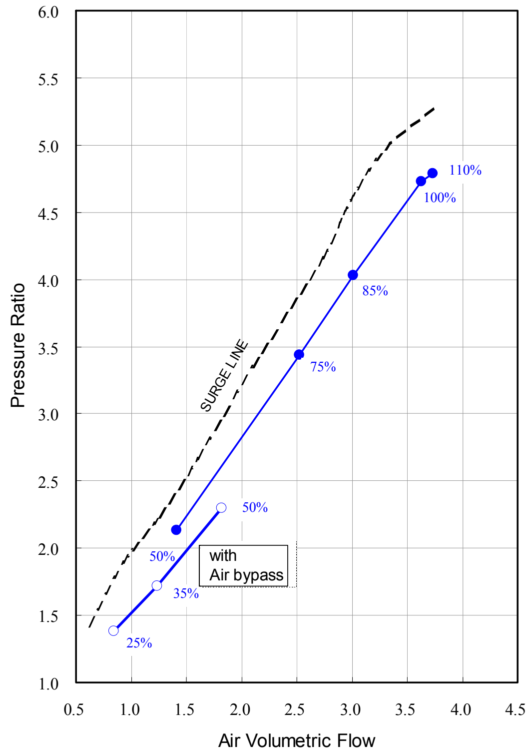


Figure15 Operating line of Turbocharger

The comparison of fuel consumption between conventional engine and 28AHX engine is shown in Figure 17. The 28AHX engine improves fuel consumption over the entire load range comprated to conventional engine, with especially marked improvements in the low to middle load range where such ships spend much of their time. Therefore, total amount of fuel consumption for an operation should be saved by roughly 6%. This fact can be considered as Niigata's contribution for reduction of greenhouse gas emissions.

Figure 18 shows a comparative test data for acceleration characteristics. In this case, the acceleration from idling speed (400 min^{-1}) to rated output (800 min^{-1}) was set within 15 seconds. Regarding the picking up engine speed, 28AHX could arrive to rated speed more smoothly, along the linear acceleration operation. And the opacity-meter measurements indicate significant reductions in exhaust smoke concentrations and length in comparison with an existing engine.

These constitute impressive progresses -including improvement of fuel consumption- in usage characteristics for the main propulsion engine such as a tug boat.

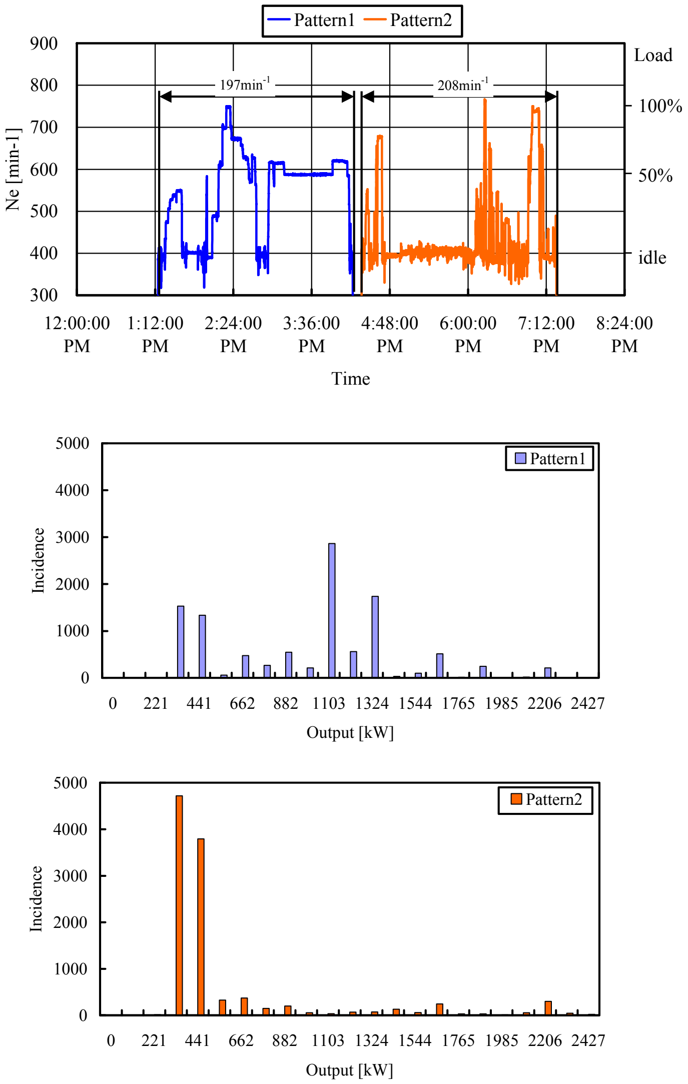


Figure16 Monitoring results of operation pattern for Tug boat

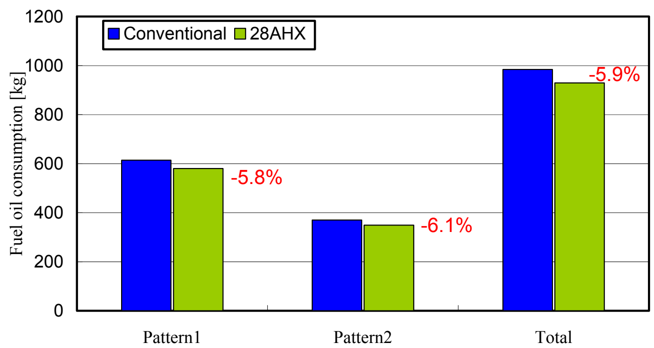


Figure17 Estimation of fuel saving benefit through an operation

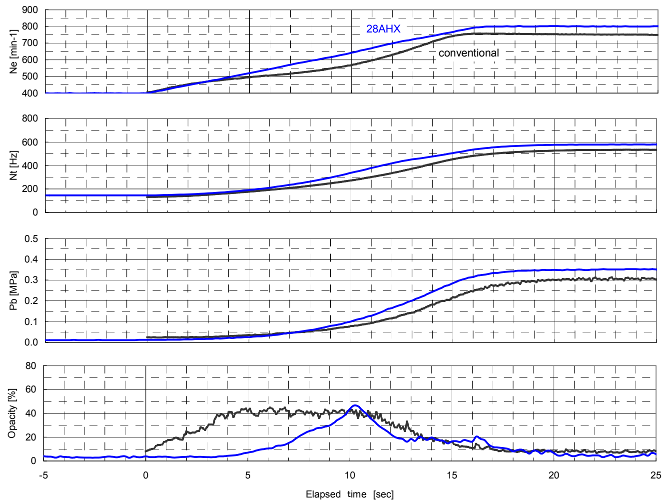


Figure18 Load acceleration characteristic

DURABILITY

The prototype engine has been test-operated for more than 900 hours. Test operations include continuous endurance test at maximum output and rapid cycle test from idle speed of 400 min^{-1} to rated speed and power of 800 min^{-1}, followed by overhaul inspections.

Figure 19 shows photographs of the cylinder heads, pistons, cylinder liners, and main bearings after endurance testing.

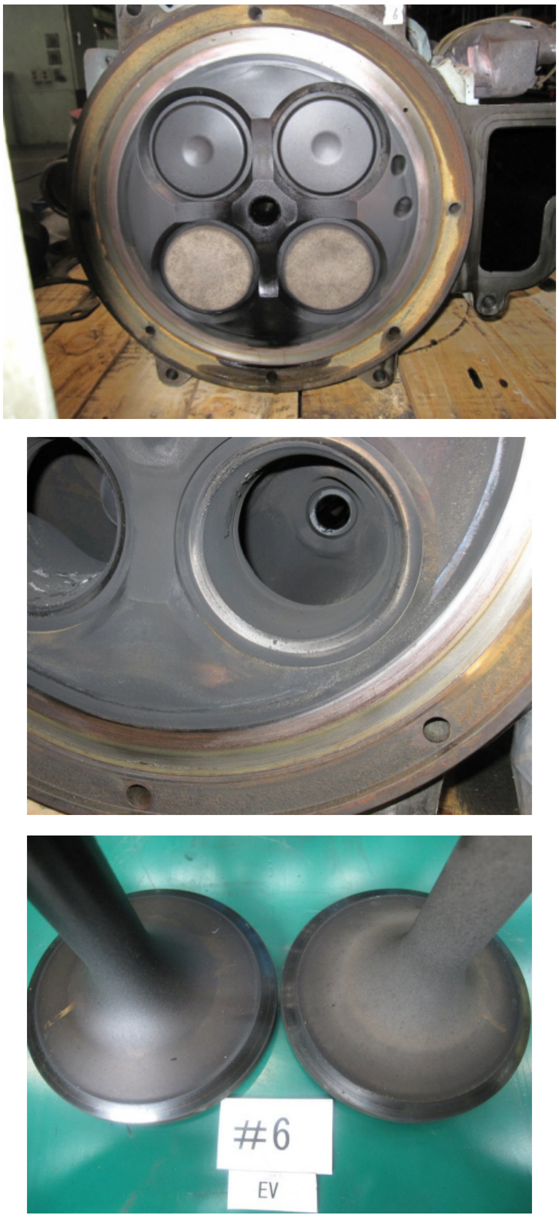
The cylinder heads were found to be in good condition, also around the intake and exhaust valves and valve seats.

The pistons showed minimal carbon deposits on the top land, attesting to the effectiveness of the fire rings. Some white calcium deposits were detected on the perimeter of the combustion faces; after referring to piston temperature measurements, cooling oil flow rates were increased to further reduce the piston material temperatures.

The cylinder liners showed no tendency of strong contact against the pistons, and the honing patterns remained well visible like for the new liners.

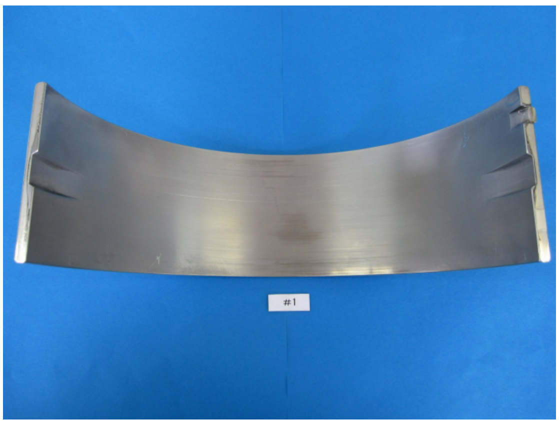
The bearing metals showed only typical early-stage wear, with no signs of cavitation or fretting.

All components disassembled for inspection were reassembled in the engine without any modification or repairs to continue test operations.



Cylinder head and valves

Piston



Main bearing metal

Cylinder Liner

Figure19 Inspection after almost 800 hours operation

CONCLUSIONS

The newly developed 28AHX engine incorporates a range of new technologies, based on experience with previous diesel engines in the field operations.

This has achieved major performance progresses suitable for marine use and has met IMO NOx Tier II regulations.

After the development of inline 6-cylinder 28AHX completed, an inline 9-cylinder test engine has also been produced, and testing has begun. (Figure 20)

NPS has already received many inquiries, and orders for more than 10 engines by 2009.

And commercial production engines will be shipped in 2010.

Niigata will continue to refine these engines based on the needs expressed by users in the field.

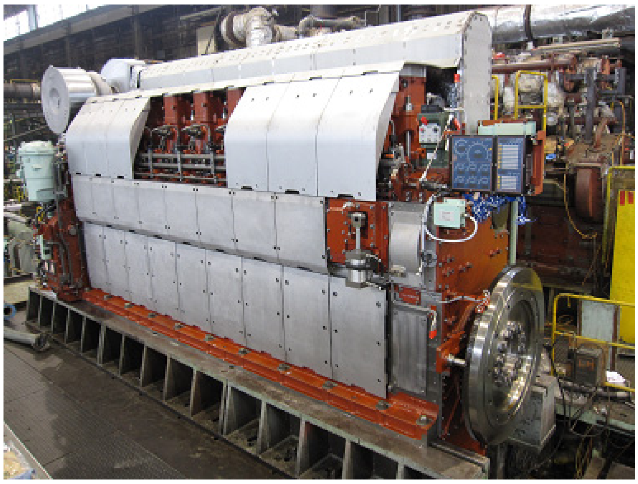


Figure20 Photo 9L28AHX

ACKNOWLEDGEMENTS

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They also acknowledge the contributions of numerous colleagues and parts suppliers to these developments.

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[1] Itoh, Y., Kawakami, M., Mouri, Y. and Goto, S., “Development of Niigata 4 stroke engines”, 25th CIMAC Vienna, 2007, Paper No. 27