Development of Marine Dual Fuel Engine “28AHX-DF”

HIRONAKA Keitaro : General Manager, Research & Development Group, Engineering & Technology Center, Niigata Power Systems Co., Ltd.
MIMURA Takahisa : Fundamental Technology Research & Development Group, Engineering & Technology Center, Niigata Power Systems Co., Ltd.
WATANABE Koichi : Manager, GE Development Team, Design & Development Group, Engineering & Technology Center, Niigata Power Systems Co., Ltd.
KURAI Tomohiro : GE Development Team, Design & Development Group, Engineering & Technology Center, Niigata Power Systems Co., Ltd.
YUKI Kazuhiro : GE Development Team, Design & Development Group, Engineering & Technology Center, Niigata Power Systems Co., Ltd.

As exhaust gas regulations are strengthened in the marine field, the application of gas fuel engines in marine vessels is attracting more and more attention as one way to satisfy the IMO NO_x Tier III regulation. However, conventional gas fuel engines have some technical problems to be solved, such as low transient performance and lack of redundancy. Niigata’s newly developed dual fuel engine, the “28AHX-DF,” succeeded in improving transient performance, and has realized transient performance equivalent to Niigata’s conventional diesel engine. Also, the “28AHX-DF” has the same level of redundancy as a diesel engine, thanks to the new dual fuel engine.

1. Introduction

Niigata Power Systems Co., Ltd. (Niigata) has developed the “28AHX-DF,” the first marine dual fuel engine in Japan that can clear the NO_x Tier III regulation put in place by the International Maritime Organization (IMO). Significant improvement in the transient response achieved by this engine as compared to conventional gas fuel engines opened the way to application to marine vessels.

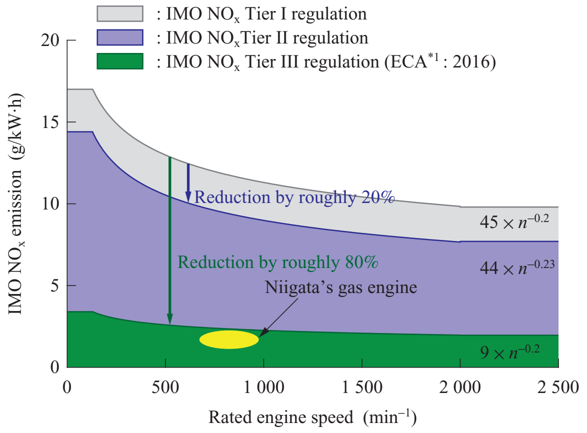
A dual fuel engine is an engine that operates on two different types of fuels. In this article, the engines referred to run on a gas fuel and Marine Diesel Oil (MDO), Marine Gas Oil (MGO), or some other petroleum fuel.

Regulations on harmful substances in exhaust gas are tightening to keep pace with the greater attention paid to global environmental protection in the use of marine vessels. The IMO NO_x Tier III regulation is a case in point.

Lean-burn gas engines are widely known for their low emission of Nitrogen Oxides (NO_x) combined with high output and excellent efficiency.$^{(1)}$ Such an engine can independently comply with the IMO NO_x Tier III regulation without relying on any post-exhaust treatment system as demonstrated in **Fig. 1**.

It is crucial for gas fuel engines employed in marine vessels to continue their operation regardless of how conditions may change. In other words, they must be as reliable as conventional diesel engines by ensuring redundancy. Niigata developed such an engine adopting a dual fuel engine.

The engine holds promise as an effective way to comply with environmental regulations on marine vessels.



(Note) $45 \times n^{-0.2}$: Regulatory value for IMO NO_x Tier I
$44 \times n^{-0.23}$: Regulatory value for IMO NO_x Tier II
$9 \times n^{-0.2}$: Regulatory value for IMO NO_x Tier III
n : Rated engine speed
*1 : Emission Control Area

Fig. 1 Regulation of IMO NO_x

2. Technical challenges

The greatest challenge in the application of gas fuel engines in marine vessels is improvement in transient response.

Figure 2 demonstrates that more time is required for increasing the output of typical gas fuel engines as compared to diesel engines. The figure also indicates the longer time required for output increase according to the propeller curve of marine vessels compared to operation with a constant engine speed as commonly practiced with generators and controllable-pitch propellers.

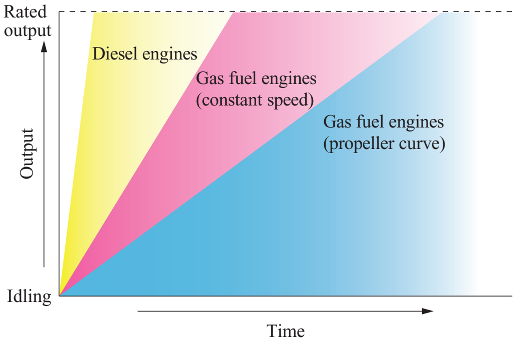


Fig. 2 Comparison of transient speed up to rated output

In addition, the load input ratio of gas fuel engines is smaller than that of diesel engines both in the case of load input starting from an idling state and in the case of load input starting from a base load.

A critical technical challenge here is the operational range of a gas fuel engine, which is presented in **Fig. 3**. The horizontal axis represents the air-fuel ratio, wherein the amount of intake air relative to fuel is greater on the right-hand side and smaller on the left-hand side. The vertical axis represents the net average effective pressure as an indicator of engine output. As demonstrated in **Fig. 3**, an excessively small air-fuel ratio results in abnormal combustion called knocking that can cause engine failure. An excessively large air-fuel ratio causes misfire, which increases combustion fluctuation. Moreover, an increase in output narrows the proper range of the air-fuel ratio. Accordingly, gas fuel engines need fine adjustment of the air-fuel ratio.

However, in an attempt to rapidly increase the output of a gas fuel engine, continued operation is sometimes disrupted by knocking due to the reduced air-fuel ratio (i.e., insufficient air supply in relation to the increased amount of fuel gas) when the response of the turbocharger is too slow or control of the air-fuel ratio is delayed. A diesel engine also experiences reduced air-fuel ratio during rapid output increase, but operation can be sustained despite the soot generated from incomplete combustion. This is why gas fuel engines have poorer transient response than diesel engines.

In this article, knocking refers to autoignition of air-fuel mixture under high pressure from a flame. Robust computerization is essential given that gas fuel engines require complex control as compared with diesel engines. Since engines mounted on marine vessels must continue to operate under any circumstances, redundancy that accommodates robust computerization is another challenge.

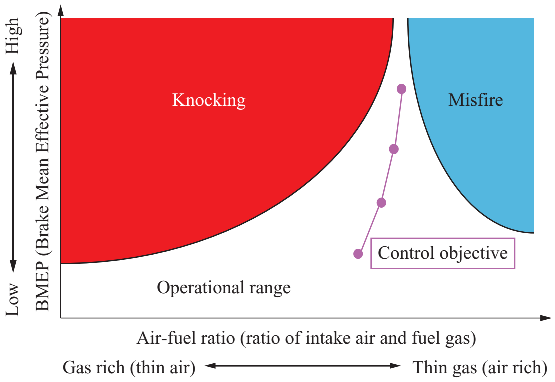


Fig. 3 Operational range of gas fueled engine

3. Developed engine

Niigata has developed the “28AHX-DF” as a marine dual fuel engine. The specifications and appearance are presented respectively in **Table 1** and **Fig. 4**.

The same fuel injection valves as in conventional diesel engines were mounted onto the cylinder heads. In addition, common rail injectors were mounted for the micro pilot fuel oil. In this manner, the reliability of the engine in the diesel mode became comparable to diesel engines and low NO_x emission and stable ignition were achieved in the gas mode by injection of a small amount of a pilot fuel (**Fig. 5**).

Switching between the diesel mode and gas mode can be done freely at any output. Redundancy was ensured for continued operation by enabling gas mode operation in the entire output range along with instant switching to the diesel mode in the event of an abnormality.

The system presented in **Fig. 6** was adopted for controlling intake air temperature and pressure in order to maintain the optimized air-fuel ratio in the gas mode.

4. Engine’s operational performance

The necessary amount of air intake was secured for the engine’s

Table 1 Specification of “28AHX-DF”

Item	Unit	Specifications		
Combustion system (gas mode)	—	Direct injection micro pilot oil lean-burn system		
Number of cylinders	Cylinders	6	8	9
Rated output	kW	1 920	2 560	2 880
Rated speed	min^{-1}	800	800	800
Fuel gas	—	Natural gas		
Liquid fuel	—	MDO		

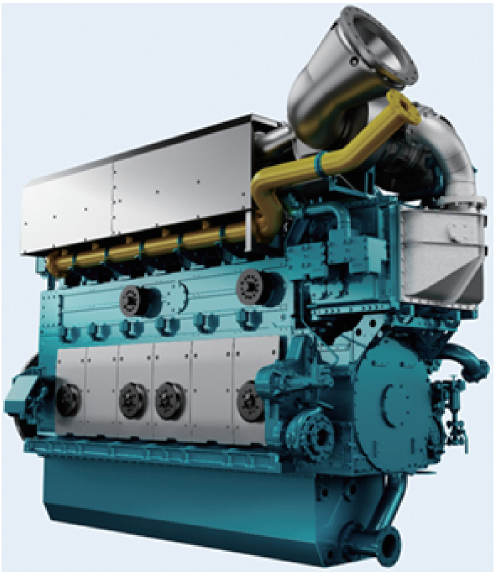


Fig. 4 Appearance of “28AHX-DF”

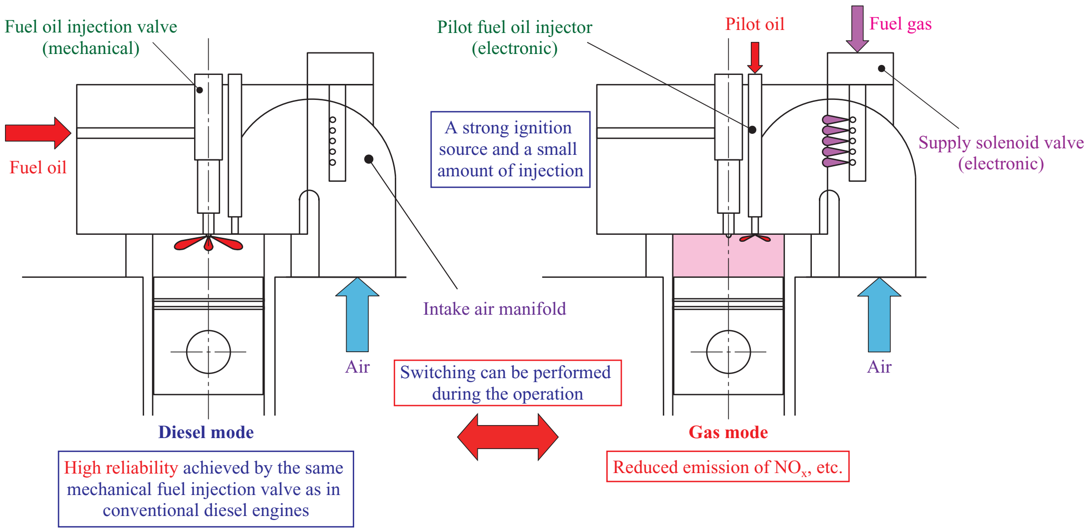


Fig. 5 Operational mode change of dual fuel engine

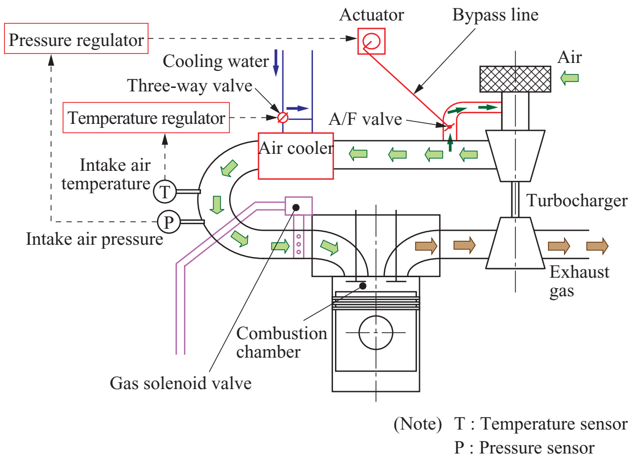


Fig. 6 Systematic sketch of A/F control (2)

operation and acceleration by adopting a system capable of controlling intake air temperature and pressure. Anti-knocking techniques were applied, for example, by adjusting the common rail injection timing properly if knocking occurred. As shown in **Fig. 7**, the engine's operational range was expanded and the transient response was significantly improved as compared to conventional gas fuel engines by combining these technologies and techniques.

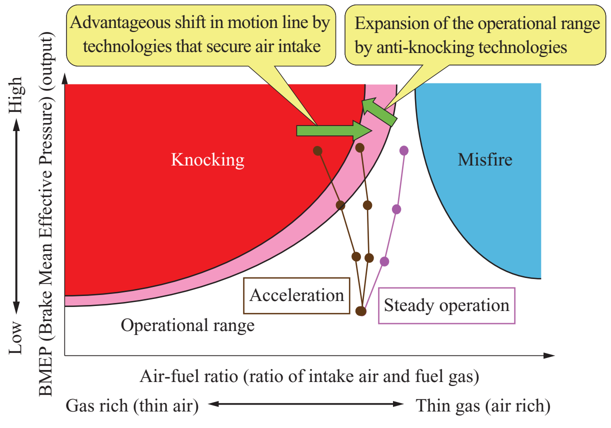


Fig. 7 Improvement of transient performance

Figure 8 presents the test results of transient performance when the engine's output was increased from the idle speed to rated speed. The test was conducted on propeller curve. The rated speed on the vertical axis representing the rotation speed corresponds to rated output. The engine achieved an output rise time of around 20 seconds within the temperature range according to the design specifications. Even under a temperature as high as 37°C, the output rise time of 15 seconds was achieved by using an additional technology to ensure adequate air intake.

Furthermore, an operational check was performed with a test engine both in the diesel mode and gas mode by simulating the actual operational patterns involved in maneuvering a tag boat in order to verify that the engine demonstrates transient characteristics comparable to conventional diesel engines. **Figure 9** presents the comparison results(2) of transient response. Almost perfect overlap of the profiles in both modes indicate that the new engine compares favorably with conventional diesel engines.

These tests were conducted by simulating the operational patterns of a fixed pitch propeller. The results demonstrate

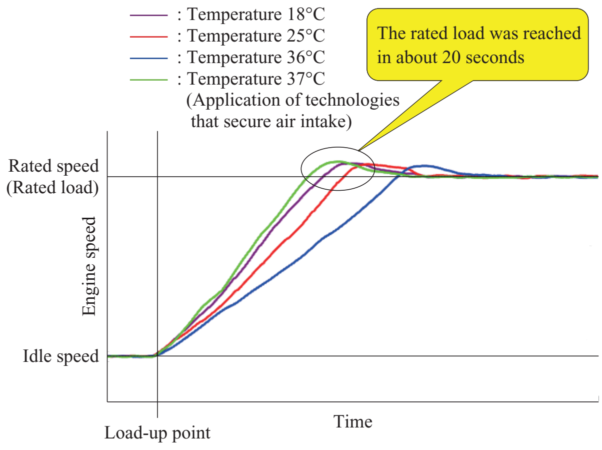


Fig. 8 Test result of transient performance

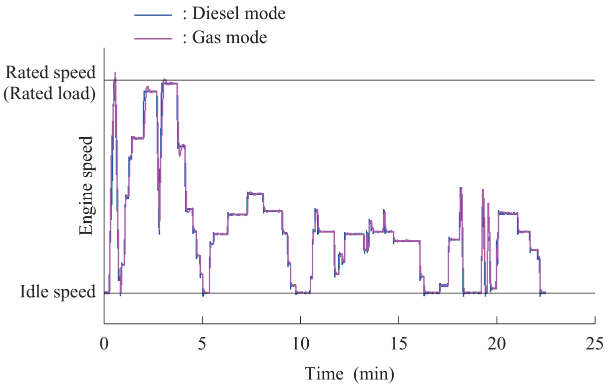


Fig. 9 Comparison of transient performance (2)

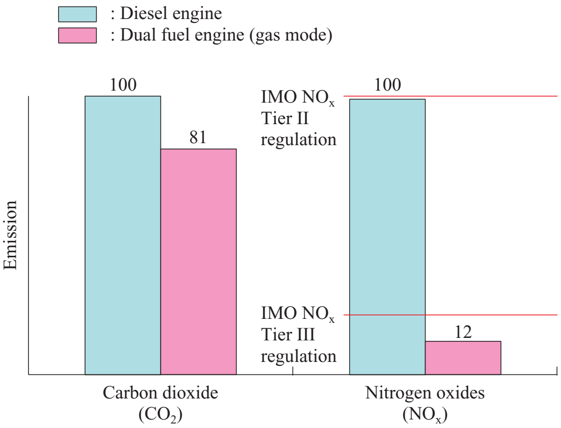


Fig. 10 Comparison of emission in exhaust gas

that a gas fuel engine can be applied to propulsion systems for marine vessels just like conventional diesel engines.

Meanwhile, with respect to environmental performance, the properties of the exhaust gas from the engine are presented in **Fig. 10**. The gas mode complies with the IMO NO$_x$ Tier III regulation and the diesel mode complies with the IMO NO$_x$ Tier II regulation. The gas mode was confirmed to cut CO$_2$ emission by 19% compared to that of diesel mode.

5. Conclusion

The application of technologies to secure air intake and prevent knocking in the newly developed engine significantly improved the transient response in the gas mode to a level comparable to that of diesel engines. Thus, it was proven that the engine can be employed in a gas fuel vessel using the most simple propulsion system with direct connection to a fixed pitch propeller. By adopting a dual fuel design, the engine ensured the redundancy required of every marine propulsion system. It also successfully satisfied the IMO NO$_x$ Tier III regulation.

The "28AHX-DF" presented in this article was adopted in the first Japanese marine vessels that are fueled by natural gas (excluding LNG transportation vessels).

— Acknowledgements —

The Dual Fuel marine propulsion engine 6L28AHX-DF introduced today uses part of technology from the research development which was selected as a supported project of "Research project of CO$_2$ reduction from marine vessels" by Ministry of Land, Infrastructure, Transport and Tourism, selected as a supported project by Nippon Kaiji Kyoukai (Class NK), selected as a joint research with Japan Ship Technology research association and financially supported by the NIPPON Foundation.

Niigata expresses sincere appreciation to these associations and foundation.

REFERENCES

(1) K. Watanabe, S. Goto and T. Hashimoto : Combustion improvement at the transient performance of the lean-burn gases fuel engine 24th Internal Combustion Engine Symposium paper72 (2013. 11)

(2) K. Watanabe : High transient performance dual fueled engine 84th Annual Meeting of the Japan Institute of Marine Engineering (2014. 11)