Development of Low Pressure EGR System
Complied with IMO NOx Tier III Regulations

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To comply with IMO NOx Tier III regulations, Japan Engine Corporation (J-ENG) has developed a new and unique technology called “Low Pressure Exhaust Gas Recirculation (LP-EGR) system”. The J-ENG’s LP-EGR system is a system which recirculates a part of the low pressure exhaust gas emitted from an engine turbocharger outlet into a turbocharger intake after scrubbed by an EGR scrubber. Now, we have applied integrated on-engine LP-EGR system into a commercial engine 6UEC45LSE-Eco-B2 aiming for onboard durability confirmation. We confirmed its NOx emission level complied with IMO Tier III regulations and the increase of fuel oil consumption was less than approximately 1%. Adaptation of the LP-EGR system for IMO NOx Tier III regulations is the world’s first effort for marine low speed two-stroke diesel engine. Furthermore, we installed the system into a 34,000DWT Bulk Carrier and now are conducting long-term durability confirmation during the sea trial and commercial voyages. The installation of the LP-EGR system complied with IMO NOx Tier III regulations into an actual vessel is also the world’s first effort for marine low speed two-stroke diesel engine.

1. Introduction

Regulations for preventing air pollution from ships are being further tightened up. As for the regulations on low speed marine diesel engines of the International Maritime Organization (IMO), the International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted at IMO for the purpose of the prevention of pollution of the marine environment by ships. The amendment of the MARPOL Annex VI entered into force on 1st July 2010. Regarding Tier III, after many consensus-building among IMO, it was finally approved at MEPC66 as shown in Fig.1. Tier III regulations which provide for a reduction of NOx emissions by approximately 76% compared to Tier II regulations within NOx ECA (Emission Control Area), are applied to ships keel laid on or after 1st January 2016. For J-ENG(former: MHI-MME)’s “UE-Engine”, several candidate technologies have been developed. This paper introduces our approach to NOx reduction using unique and highly competitive Low Pressure Exhaust Gas Recirculation (LP-EGR) technology.

2. NOx reduction technologies

An NOx reduction technology map that includes in-engine modifications and after-treatment is shown in Fig.2 and Table 1. For the IMO Tier II regulations, UE-Engines adopt in-engine modifications in the form of optimized engine parameters such as fuel injection timing retard and optimizing of fuel injection nozzle arrangement and scavenging/exhaust system. To comply with the IMO NOx Tier III regulations, measures should be fundamentally different from those for Tier II. There are two
3. Low Pressure EGR system

3.1 Principle of EGR technology

Recently, EGR technology has been adapted to many types of small and medium internal-combustion engines, which are used in cars, locomotives, generators and so on. In an engine equipped with EGR, a part of the exhaust gas is introduced into the scavenging air or air intake, after that these gases are led to the combustion chamber. Consequently, the low O2 concentration gas makes the combustion reaction slow and high CO2 concentration gas makes high heat capacity, then the peak temperature of the local flame surface drops; as a result, the amount of thermal NOx emissions decreases.

3.2 EGR technology for marine diesel engine

When the EGR technology is adapted to marine diesel engines, the system is divided into two categories, as shown in Fig.3: Low Pressure loop EGR (LP-EGR) and High Pressure loop EGR (HP-EGR) [2]. In the case of the LP-EGR, a part of the exhaust gas is branched out after the turbocharger turbine and returned to the turbocharger compressor intake. On the other hand, in the case of the HP-EGR, the exhaust gas is branched out before the turbocharger turbine and returned to the scavenging air trunk which is downstream of the turbocharger compressor.

The characteristics of these EGR technologies depend on solely these EGR gas features, and they have both merits and demerits. For example, an advantage of the LP-EGR is that a return line of the EGR gas is simple structure because of its low pressure and low temperature. In addition, the EGR blower power, which needs to draw the EGR gas into the turbocharger intake, is smaller than that of HP-EGR because turbocharger suction pressure is utilized. However, due to the low pressure, the volume of the EGR gas is big and therefore equipment for the LP-EGR

Table 1 – Comparison of NOx reduction technologies

<table>
<thead>
<tr>
<th>Item</th>
<th>NOx Reduction Rate (vs. Tier 1)</th>
<th>FOC penalty</th>
<th>CAPEX</th>
<th>OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Size Oxydation (Mechanological engine)</td>
<td>30%</td>
<td>+2% ± 3%</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>Eco-Engine</td>
<td>40%</td>
<td>+2% ± 5%</td>
<td>Middle</td>
<td>Small</td>
</tr>
<tr>
<td>HP (SM)</td>
<td>47%</td>
<td>+4% ± 10%</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>Water injection</td>
<td>Approx. +10%</td>
<td></td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>EGR</td>
<td>60%</td>
<td>+4% ± 10%</td>
<td>Large</td>
<td>Small</td>
</tr>
<tr>
<td>SCR</td>
<td>80% – 90%</td>
<td>0% ± 5%</td>
<td>Large</td>
<td>Large</td>
</tr>
</tbody>
</table>

Figure 2 – Technology map for NOx reduction

Figure 3 – a) LP-EGR, b) HP-EGR
system tends to become larger than for the HP-EGR. A merit of the HP-EGR is its compact size, but the system has demerits: a scrubber for cleaning the EGR gas is a complicated structure because of the high pressure and high temperature and the EGR blower power is bigger than for the LP-EGR because of joining EGR gas into scavenging air with raising the pressure.

From the above viewpoints, we made the decision to develop the LP-EGR system because of its simplicity and superior operability including operating cost.

3.3 Schematics of LP-EGR

Details of the LP-EGR system are as follows.

1. A part of the exhaust gas is branched from the main flow downstream of a turbocharger turbine or exhaust gas economizer.
2. The main flow is discharged from the funnel. On the other hand, the branched exhaust gas (EGR gas) is led to the return gas line.
3. In the return gas line, there is a scrubber which cleans the exhaust gas. The EGR gas is passed into the scrubber where soot and SOx contained in the EGR gas are removed.
4. After that, the EGR gas is drawn by the EGR blower, and led to the turbocharger compressor intake.
5. The EGR gas is mixed with the fresh air at the turbocharger compressor and led into engine.

In this system, the exhaust gas scrubbing system is a core technology. That is because, the usual marine diesel engines use MDO, HFO and so on, which contain the residue oil, so the exhaust gas contains much soot and SOx. In addition, a large amount of gas is exhausted from marine diesel engines. If this exhaust gas is led into the engine without cleaning, we can easily imagine that a catastrophic failure will occur to the engine. Therefore, we have developed a new wet scrubber with high performance of soot and SOx removal by utilizing the technology of Inert Gas Scrubber (IGS) system. This scrubber cleans gases by using water, and the water is cleaned by the Water Treatment System (WTS) and re-used.

4. On-board verification

We confirmed that the LP-EGR had enough ability to comply with the IMO’s NOx Tier III regulations and minimize the FOC penalty substantially using our 4UE-X3 test engine, then as the next step we decided to perform onboard verification. This project is supported by the ClassNK’s “Joint R&D for Industry Program” scheme and its major aim is a verification of long-term operation.

4.1 LP-EGR design for on-board verification

The target vessel was a 34,000DWT Bulk Carrier named “DREAM ISLAND” (the owner; Shikishima Kisen K.K., the operator; NYK Bulk & Projects Carriers Ltd. and the shipyard; The Hakodate Dock Co., Ltd.) after many consensus-building among affiliated companies.

At first, the entire system of onboard LP-EGR was discussed and decided. Since we had executed performance verification with an integrated type LP-EGR unit modified on-engine, also in this project LP-EGR unit was on-engine and Water Treatment System (WTS) including tanks was installed at ship-side. The EGR gas branch point was downstream of the exhaust gas economizer because of...
superior performance of the overall system. The target engine was 6UEC45LSE-Eco-B2 which was relatively small size type; therefore it seemed difficult to install the EGR unit on-engine. However, we successfully managed to arrange the LP-EGR unit on the upperside of the scavenging air trunk and the auxiliary blower relocated as shown in Fig.4. Regarding the turbocharger, we applied special coatings onto the compressor wheel against erosion and corrosion caused by mist carried over from the LP-EGR unit.

The WTS was designed to be arranged both its equipment and some tanks at ship side as the design policy adhered from the system of 4UE-X3 tests.

The control system is multi-layered. The EGR control panel is responsible for head control for the entire EGR system and a communication interface to the engine control system. The EGR control panel is the master, while the EGR blower inverter and the WTS control panel are slaves.

4.2 Test results of the shop test

We manufactured all equipment for the LP-EGR of engine, conducted the shop test for confirmation of performance and system check. The shop test was held at J-ENG (former: Kobe Diesel Co., Ltd., which was our licensee). Because of the world’s first on-engine LP-EGR system, at first, we confirmed that the control system was working properly as designed, such as mode changes, following capability, 110% load operation and safety.

Figure 5 shows an overview of the shop test and Fig. 6 and 7 show results of the shop test. Figure 6 shows NOx reduction performance versus EGR rate, compared with past test results from 4UE-X3. Boxed marks by red line are shown the results of 6UEC45LSE-Eco-B2, which performed the same as in past tests. As shown in Fig.6, correlation between EGR rate and NOx reduction performance is same as past test results. We optimized the EGR rate for each load and realized FOC penalty within approximately 1% as shown in Fig.7. And we confirmed that our LP-EGR system complied with the IMO NOx Tier III regulations in witness whereof ClassNK and its NOx emission amount was 3.2 g/kWh in the E3 mode, and which was sufficient performance against the regulatory value of 3.4 g/kWh.

4.3 Test results of the sea trial

After we confirmed good performances in the shop test, we conducted two days sea trial at the Hakodate Dock.
Figure 8 shows an overview of the installed LP-EGR system including the WTS.
We confirmed that performances of NOx reduction and FOC penalty were almost the same as the shop test. As in the shop test, we confirmed system reliability in actual vessel operation in combination with the whole system including the WTS and ancillary sensors. Furthermore, we also confirmed that the WTS was working properly together with ClassNK reviewed manuals of ETM, OMM and Record book. Further, we obtained an approval of discharging washwater from the Panamanian Flag. Consequently, our LP-EGR system was objectively verified to have adequate performance and reliability as designed.

5. Conclusions

J-ENG developed a unique LP-EGR system that has sufficient performance for complying with IMO’s NOx Tier III regulations using our test engine. As the next step, we are executing on-board verifications using a 34,000DWT Bulk Carrier. Now we are executing further optimizing the entire EGR system and verifying its long-term durability and operability both at open sea and within port area. By using the achieved results and knowledge, we will brush-up our whole LP-EGR system with the aim of expecting business.

Because of global demand for low emission and high efficiency, we continue to develop and spread new technologies in an effort to contribute to global environmental conservation.

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References