Abstract

In order to handle the increasingly strict environmental standards we looked at the electronic management of the engine, as used for marine applications. This holds one of the most effective solutions to reduce antimony NOx and CO2 emissions, and at the same time. Electronic-managed two-stroke engines have been with us for some time, though not yet for the four stroke engine, this is because of the high cost. The development of this project is aimed at improving combustion efficiency, NOx reduction, and minimizing the cylinder lubricant dosage rate. This in the operating area, not only of the rated power zone, but also the partial load zone. By managing electronically, the performance excels in a wide operating range. The characteristics of fuel injection, intake and exhaust valve operating time, and the cylinder lubricator, utilize the inherent advantages of the four stroke engine.

1. Introduction

There are social needs to reduce NOx emission and CO2 gas reduce as environmental measures of the main engine for the ship. An electronically managed system is an effective and indispensable means to make them unite these conflicting needs. The low speed two-stroke diesel engine that adopts an electronically managed system for fuel injection and exhaust valve drive was developed, and this has already been on service in the market. Middle and high speed four-stroke diesel engines adopt the common rail method, and only fuel injection is electronically managed.

On the other hand, an electronically managed system for low speed four-stroke engines is not developed yet. Then, the development of electronically managed system for low speed four-stroke engines was executed by joint development with Nabtesco Corporation and Hanshin.

2. Target of this project

The following targeted values were set by adopting electronically managed method for both fuel injection device and, intake and exhaust valve drive device.

- Amount of NOx emission : 30% reduce based on the engine qualified for NOx Tire 1.
- Fuel consumption and amount of CO2 emission : decrease from 5 to 10% including partial load in total, based on the engine qualified for NOx Tire 1.
- Initial cost: system that can get back increase a initial cost within 5 years for engine of 2200kW class.
3. Design and production of electronically managed system

After minute examination of control item, control techniques, and operation method of the system specification was decided. Then, design work was started. During development, to reach the objective in a short term, computer aided analysis and simulation for combustion performance and control system were executed. Hydraulic control system chart is shown in Fig. 1. System configuration chart is shown in Fig. 2.

Fig. 1 Hydraulic control system

Fig. 2 System configuration chart

4. Element test

Element tests had been executed to confirm operation of fuel injection device, intake and exhaust valve drive device before electronically managed system was assembled to test engine.

4.1 Element test of fuel injection device

Simulation test of characteristics of mechanical cam type, boots type fuel injection and fuel injection pressure control examination were executed with fuel injection device unit, and it was confirmed to be able to control fuel injection pressure waveform optionally by adjusting servo valve.

(boots type injection: fuel injection wave form of which pressure diagram looks like boots.)

Element test device is shown in Fig. 3. Wave of boots type fuel injection comparison with cam drive, and hydraulic oil pressure wave are shown in Fig. 4.
4.2 Element test of intake and exhaust valve drive device

It was confirmed to operate these valves equally to cam drive type by controlling servo valve. Intake and exhaust valve lift curve of electronically managed system comparing with cam drive type is shown in Fig. 5.

5. Engine test

Electronically managed system was assembled to test engine (SLT32 1295kW/250min⁻¹). Operation of control part and hydraulic part were confirmed. Afterwards, engine performance confirmation and engine performance improvement examination were done. Specification of 3SLT32 type test engine is shown in Table 1. Engine, Controller, Servo valve external is shown in Fig. 6, 7, 8.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>3SLT32</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYLINDER BORE</td>
<td>mm</td>
<td>320</td>
</tr>
<tr>
<td>PISTON STROKE</td>
<td>mm</td>
<td>1050</td>
</tr>
<tr>
<td>NUMBER OF SYLINDER</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>STROKE / BORE RATIO</td>
<td></td>
<td>3.28</td>
</tr>
<tr>
<td>RATED OUTPUT</td>
<td>kW</td>
<td>1295</td>
</tr>
<tr>
<td>RATED ROTATION</td>
<td>min⁻¹</td>
<td>250</td>
</tr>
<tr>
<td>AVERAGE PISTON SPEED</td>
<td>m/s</td>
<td>8.75</td>
</tr>
<tr>
<td>NET AVERAGE EFFECTIVE PRESS</td>
<td>MPa</td>
<td>2.454</td>
</tr>
<tr>
<td>MAXIMUM COMBUSTION PRESSURE</td>
<td>MPa</td>
<td>17.7</td>
</tr>
</tbody>
</table>
5.1 Fuel injection pressure change test

It was confirmed that fuel consumption was decreased, and NOx emission was increased when fuel injection pressure was raised with keeping fuel injection timing constant. Result is shown in Fig. 9.

5.2 Fuel injection timing delay test

When fuel injection timing was delayed, fuel consumption was increased, and NOx emission was decreased. Result is shown in Fig. 10.

5.3 Intake valve close timing change test
As intake valve close timing was about 0 degree(B.D.C.), fuel consumption was minimum, and NOx emission was maximum. It was also confirmed that the engine ran the lower load, closing timing of intake valve affected more. Result is shown in Fig. 11.

5.4 EGR test (Internal)

Effect of NOx emission decrease was confirmed by controlling exhaust valve while intake valve opened. As exhaust valve open period was extended, fuel consumption was increased and NOx emission was decreased in Fig. 12.

5.5 Boots type fuel injection test

The servo valve fuel injection pressure wave was made boots type by controlling fuel injection. Then, engine performance and NOx emission was confirmed.

When ratio of pre-injection in boots pattern was increased, fuel consumption was increased and NOx emission was decreased in Fig. 13.
5.6 Integrated confirmation of engine performance

Based on the test result through the above-mentioned engine performance improvement test engine performance was confirmed after optimizing the setting of fuel injection timing, fuel injection servo valve, intake and exhaust valve open and close timing at part load, 25%, 50%, 75%, and 100% load considering comprehensively to achieve the target performance. Engine performance curve of best setting for marine load is shown in Fig. 14.

Fig. 13 Ratio of pre-injection in boots pattern modification test

Fig. 14 Engine performance curve of best setting for marine load

(1) Fuel consumption
The result of fuel consumption is shown in Fig.15.

- mechanical type 1: Fuel consumption value when optimizing mechanical type engine (SLT32), not correspondence with NOx emission regulation.
- mechanical type 2: Fuel consumption value when optimizing mechanical type engine (SLT32), with 30% reduction in NOx emission with NOx regulation Tier 1.

The result of fuel consumption by electronically managed engine can be reduced largely in lower load. The fuel consumption reduced by 8.8% at 25% load and 4.2% at 100% load. Finally, the electronically managed engine achieved 5% reduction from mechanical type engine considering each part load. (the distribution factor is as same as E3 mode of NOx regulation.)

(2) NOx emission

The result of NOx emission E3 is shown in Fig.16. NOx E3 10.38g/kWh achieved the target of 30% reduction from NOx emission Tier 1 level.

6. Summary

Fuel injection pressure wave made boots type by controlling fuel injection servo valve and improvement of engine performance and NOx emission was confirmed especially in low load.

The fuel consumption including part load was 94.4% comparing with mechanical one, and 30% reduction comparing with NOx Tier.1 level. It was confirmed that NOx reduction was compatible with fuel consumption reduction. Based on this study, we are going to proceed merchandising this system in the market with brushing up engine performance, optimizing the management system and cost reduction. We are confident that this electronically managed system contributes to marine field in environmental and economical views with reducing not only fuel consumption but also NOx emission.