Development of New Series in Mitsubishi UE Large Bore 2-Cycle Diesel Engines

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The series of Mitsubishi UEC-LSII engines was completed in 1998. Over 200 engines of this series are in service, mainly as main propulsion engines of the vessels for domestic and foreign operators, and their satisfactory results have been well accepted by those clients. Meantime, we are now developing the new series of LSE (E = Economy, Easy operation & maintenance, Environmentally friendly) type engines, in order to meet the continuous demand for higher power and emission regulations. LSE engines have 15% higher power ratio than the equivalent engines LSII type, while staying at the specific fuel consumption lower than the competitors' engines, as was the case for LSII engines, which is one of the advantages of UE engines. For the development of LSE engines, we are utilizing our competent know-how accumulated during long years diesel engine development history, and the latest CAE simulation tool. This process made it possible to overcome the high hurdle of keeping its performance and reliability. For the future emission regulation, our water injection system is available and engine performance diagnosis system has been recently developed.

1. Introduction

Mitsubishi Heavy Industries, Ltd. (MHI) has been developing and manufacturing the UE model engines since 1955, and has gained high reputation from the customers as one of the remaining three brands (the other two being European brands) in the market of long-bore, 2-stroke low-speed diesel engines.

In order to cope with the trend in vessel demand and to meet the social needs such as environmental measures, MHI is proceeding and developing the new series of UEC-LSE (E = Economy, Easy operation & maintenance, Environmentally friendly) type engines as the series with higher power and higher economic performance on the basic concept of the excellent service record of the UEC-LSII type engines. The first type in this series, UEC52LSE engine, was subjected to qualification and verification test at the licensee of MHI before being shipped in April of 2001.

This paper describes the outline of the UE diesel engines with the highest thermal efficiency among the equivalent class diesel engines of other companies and the status of development of the latest series diesel engines, UEC-LSE.

2. Outline and service record of UE type diesel engines

Fig. 1 shows the output range of the UE type diesel engine[(1)]. The first diesel engine in the currently main engine series UEC-LSII was completed in 1987, followed by a line-up of 10 types from 33LSII to 85LSII including the latest type UEC-LSE with the bore sizes arranged, covering the output range from 1 120 kW to 46 800 kW. The engines in the line-up can thus be applied to vessels of different types and sizes including the vessels for domestic use, Cape size bulker, container ship, VLCC, etc. and other large-size vessels.

The principle particulars of the currently main series of medium-size to large-size LSII diesel engines of the UE type diesel engines and of the latest type LSE engines which are presently being put into series are given in **Table 1**. Compared with the equivalent class engines of the other companies, the principle particular of MHI engines feature is that they have the fuel oil consumption 3–4 g/kWh less and they are more compact and light in weight[(2)].

Something over 200 units of UEC-LSII type engine have so far been operating with the maximum running time amounting to 100 000 hours. All engines are presently operating smoothly in various vessels. The engines have gained high reputation for the reliabil-

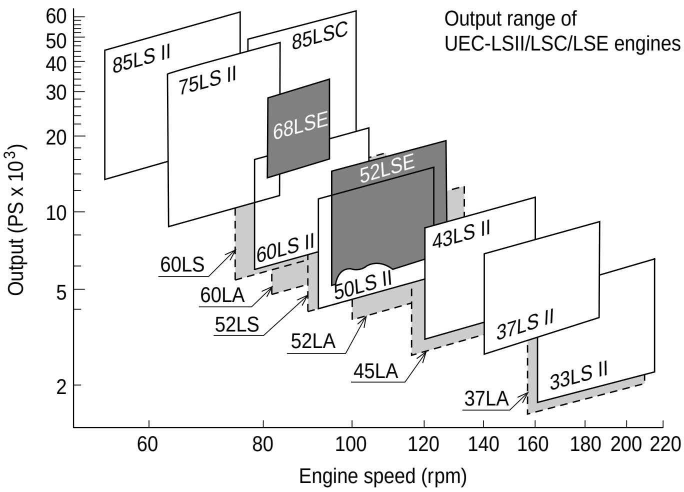

Fig. 1 New series of UE engine
The line-up of UE engines as the main ship engine has a wide range from 1 120 kW to 46 800 kW.

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Table 1 Principle particular of UEC type engine

Model (Type)	UEC 50LS II	UEC 52LSE	UEC 60LS II	UEC 68LSE	UEC 75LS II	UEC 85LS II	UEC 85LSC
No. of cylinders	4–9	4–8	4–8	5–8	4–10, 12	5–10, 12	5–10, 12
Piston diameter (mm)	500	520	600	680	750	850	850
Piston stroke (mm)	1 950	2 000	2 300	2 690	2 800	3 150	2 360
Stroke/bore ratio	3.90	3.85	3.83	3.96	3.73	3.71	2.78
Output per cylinder (kW/cyl.) [PS/cyl.]	1 445 [1 965]	1 705 [2 320]	2 040 [2 780]	2 940 [4 000]	2 940 [4 000]	3 860 [5 250]	3 900 [5 300]
Engine speed (rpm)	127	127	105	95	84	76	102
Brake mean effective pressure (bar)	17.8	19.0	17.9	19.0	17.0	17.1	17.1
Mean piston speed (m/s)	8.26	8.47	8.05	8.52	7.84	7.98	8.02
Fuel oil consumption (g/kWh) [g/PSh]	167 [124]	167 [123]	167 [123]	165 [121]	165 [121]	163 [120]	165 [121]

ity of the combustion chamber subjected to extremely severe operating condition and for the wear rates of cylinder liner and piston ring. Furthermore, the engines have high reputation for the reliability of the main bearing, the part which is difficult to design in recent long-stroke engines. The Mitsubishi-UEC engine is, therefore highly reliable and economic.

Fig. 2 shows the excellent wear record of the cylinder liner and piston ring of UEC-LSII type engine.

3. Development of the latest series of UEC-LSE engine

3. 1 Design concept

The UEC-LSE type diesel engine has the brake mean effective pressure (P_{me}): 19.0 bar and mean piston speed (C_m): 8.5 m/s, with the output 6% higher than that of the UEC-LSII type engine. Further, the cylinder maximum pressure (P_{max}) is increased by 8.7% to 150 bar, and by making use of the high thermal efficiency design (a feature of the conventional UE type engine), the fuel oil consumption has been kept to the same level of UEC-LSII type engine in spite of higher output, ensuring the fuel oil consumption level 3–4 g/kWh lower than the equivalent-class engines of the other companies.

The experience obtained through UEC-LSII type engine is effectively made use of in the design of cylinder linear and piston ring, aiming at low wear rates.

In developing the new engine, all the technical power and knowledge stored in Technical Headquarters (Research & Development Centers), Design and After-sale Service Sections have been most effectively used to verify the target high reliability. Further, the economic performance both for the ship owners and the ship builders has been sought for. Besides, in order to meet with the regulation of exhaust gas emission currently being discussed and regislated internationally, the installation of water injection device capable of reducing the NOx emission level by approximately 50% of the standard level is made applicable (option) to make the engine environmentally friendly.

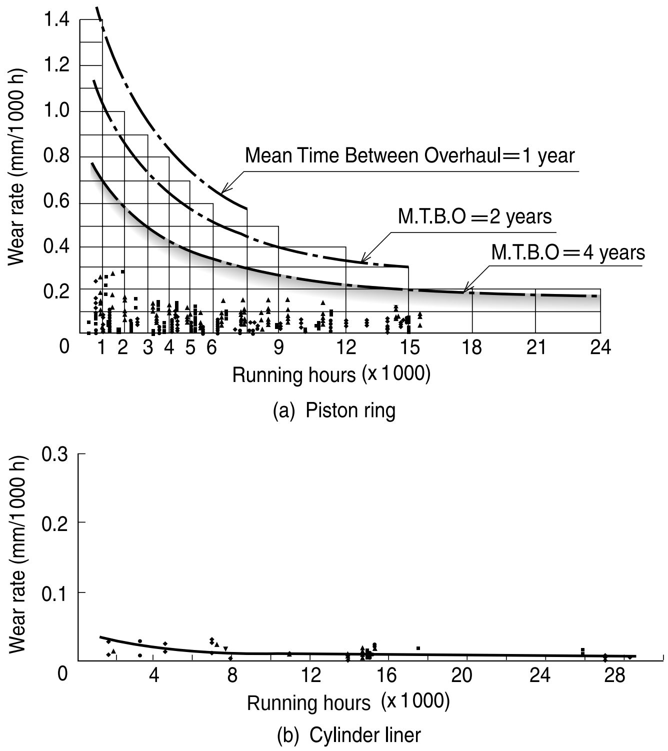

Fig. 2 Service result of piston ring and cylinder liner wear of UEC-LSII type engine
The wear condition of piston ring and cylinder liner, after the UEC-LSII type engine is on service, is shown.

3. 2 Reliability and performance

Since it is difficult to carry out long-term performance test and critical test using the test engine, a simulation calculation tool with high accuracy for preverification is indispensable in the development and design of a heavy-duty engine like UE diesel engine in order to ensure high-performance and high-reliability design.

In the process of developing the new engine, the up-to-date technology such as the latest CAE (Com-

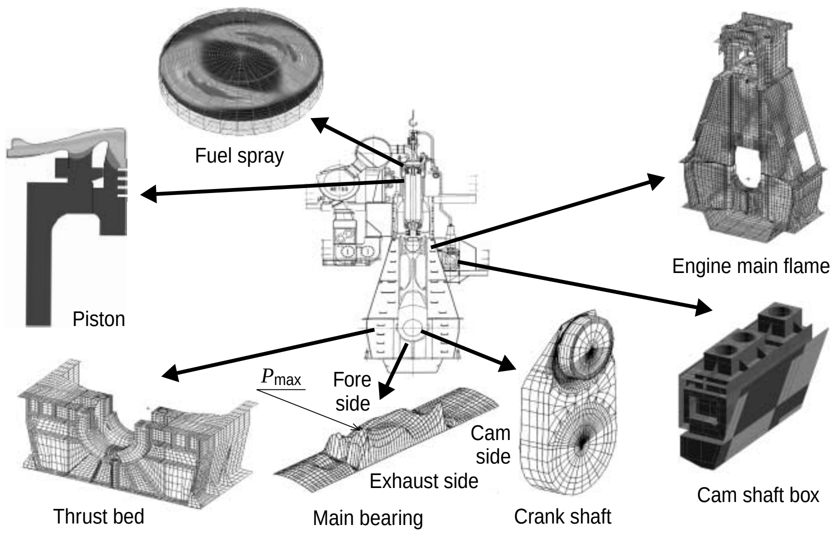

Fig. 3 CAE application for UEC engine design
The CAE technology including mainly FEM and CFD is effectively used at the time of UE engine development to evaluate its reliability.

puter Aided Engineering) developed by Research & Development Centers that supports various MHI products have been effectively used for pre-verification. The simulation calculation tools used in the development of the engine are all the most sophisticated ones in the world, particularly the bearing oil-film pressure calculation method being a high-precision tool not available in the other companies[(3)].

As mentioned above, the latest series UEC-LSE engine has higher output than the conventional engine, so that not only the heat load around the combustion chamber has become stricter, but the dynamic load of the engine unit and main moving parts has also increased.

In order to solve these problems and to carry out optimum design of the engine, the simulators for unsteady flow analysis, etc. were used to develop the engine through the joint cooperation of all Research and Development Centers affiliated with MHI Technical Headquarters, with the application example shown in **Fig. 3**.

3. 2. 1 Combustion chamber

As for the combustion chamber components, it is necessary to upgrade the simulator accuracy in order to evaluate the reliability in the region. Hence, the evaluation and design were carried out in the procedures given below.

(1) Thermal load analysis based on measured data by using measured temperature and simulation calculation of the UEC-LSII type engine with P_{me}: 17−18 bar.

(2) Evaluation of thermal load of actual engine by carrying out high-P_{me} test (P_{me} = equivalent to 19 bar) using the UEC-LSII type engine and high-P_{me} test (P_{me} = equivalent to 21 bar) using the test engine at MHI Nagasaki Research & Development Center.

(3) As for the high-P_{me} engine combustion chamber components, optimized design through FEM calculation based on the results of the aforesaid tests in (1) and (2).

As a result, the thermal load of the combustion chamber when P_{me} is increased to 19 bar was estimated and the maximum temperature was kept below the permissible level to carry out optimum design of shape and cooling method so as to keep the safety factor to the level of the conventional engine.

3. 2. 2 Engine unit (main flame)

The load condition to the engine body structure has become severe because of the increased P_{max}. Consequently, the 3-dimensional FEM calculation was carried out using the full engine model for optimum design to ensure substantially high safety factor. The stress and deformation of each section were evaluated under the main load conditions of cylinder maximum pressure, maximum side thrust force, tie rod tightening force, moving part inertia force, etc., and the stress deformation is kept to the levels of a conventional engine.

3. 2. 3 Main bearing

The high-accuracy EHD (Elasto Hydro Dynamic) simulation calculation (with the related papers announced in international meetings and associations), the most sophisticated one in the world, was used to evaluate the main bearing, and the optimum design of the shape and clearance was carried out to confirm that the white metal is provided substantially high reliability as in the case of a conventional engine. This calculation also takes into account the result of the 3-dimensional FEM compliance calculation of the entire engine and the inertia force and force due to combustion pressure of the entire engine

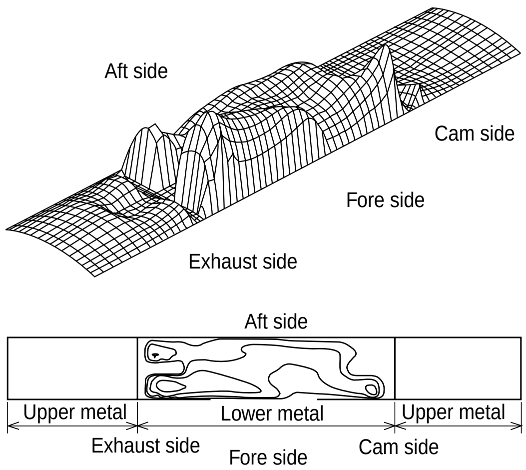

Fig. 4 EHD (Elasto Hydro Dynamic) analysis
The EHD method, an exclusive technology of MHI, is used for evaluation and analysis of main bearing behaviour and oil film thickness to evaluate the reliability of UE type engine.

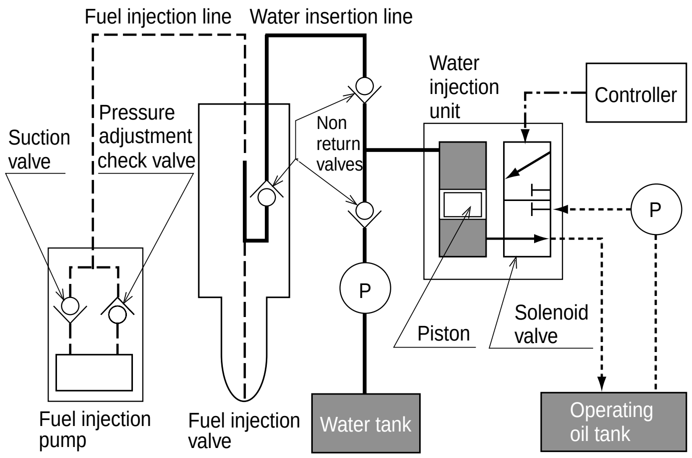

Fig. 5 Outline of stratified fuel/water injection system
The MHI stratified fuel/water injection system is used for injecting water into the cylinder. The system injects water and fuel alternately from the existing fuel injection valve to ensure a high level of NOx reduction.

model.

Fig. 4 shows an example of the calculation of main bearing oil film pressure distribution using EHD (the diagram indicating the cylindrical top/bottom bearings developed at the center).

4. Environmental measures and utilization of IT (information technology)

4. 1 NOx reduction technology

MHI has been making research and development on environment (regulation of exhaust gas emission) related technology to meet with the recent global demand. The UEC type engines including the LSE type ones, can be applied to delayed fuel injection timing, optimum tune-up of low-NOx combustion value, etc. against the present IMO NOx regulation.

The IMO NOx regulation is subject to revision every five years, and the regulation level expected to be stricter in the future. In the case of MHI, however, we have already developed and put into practical use the "stratified fuel/water injection system" shown in **Fig. 5** as a NOx reduction technology to meet with the expected regulation level in the future.

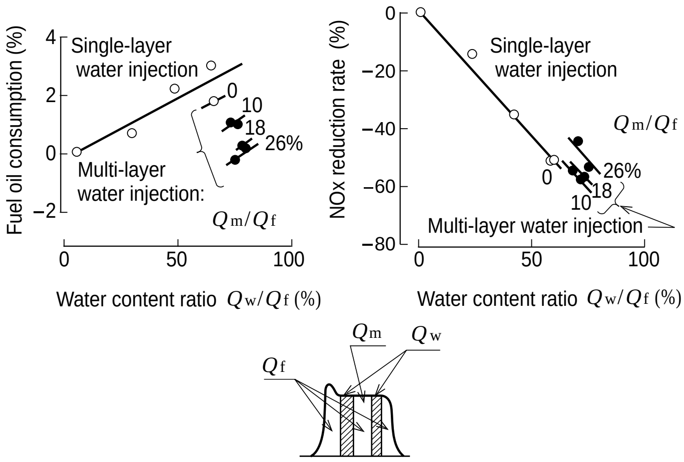

Fig. 6 NOx reduction rate by the MHI stratified fuel/water system
The MHI stratified fuel/water system ensures high NOx reduction rate while keeping the fuel cost intact.

With this system installed, NOx can be reduced approximately by 50% as compared with the case with no measure taken at the cost of a slight deterioration in fuel oil consumption as shown in **Fig. 6**.

The UEC-LSE type engine is designed to allow the installation of this system as option.

4.2 Engine diagnosis system using IT (information technology)

The effective use of IT has become an epochal need, and the ship building industry is also getting ready for this new trend.

MHI has developed an engine diagnosis system equipped with engine performance diagnosis function and parts control function.

As shown in **Fig. 7**, this system uses maritime satellite (Inmalsat) and internet to relay the information (data) related to engine performance and main parts maintenance from the vessel to MHI and ship management company. On the basis of these data MHI carries out diagnosis of the engine and parts.

Through the engine performance diagnosis, it is possible to give advice, on the basis of the main performance data, for maintaining the optimum operation condition, to avert the trouble occurrence in advance, and to take an early and prompt measure should some trouble occur. The engine performance data required for diagnosis can be easily obtained and arranged by collecting the current measured and recorded data of the vessel and installing software and some additional parts, needing no new sensors.

As for the parts control function, the state of aged deterioration of main parts, the information about maintenance and repair condition are controlled to estimate the part life to be able to provide the infor-

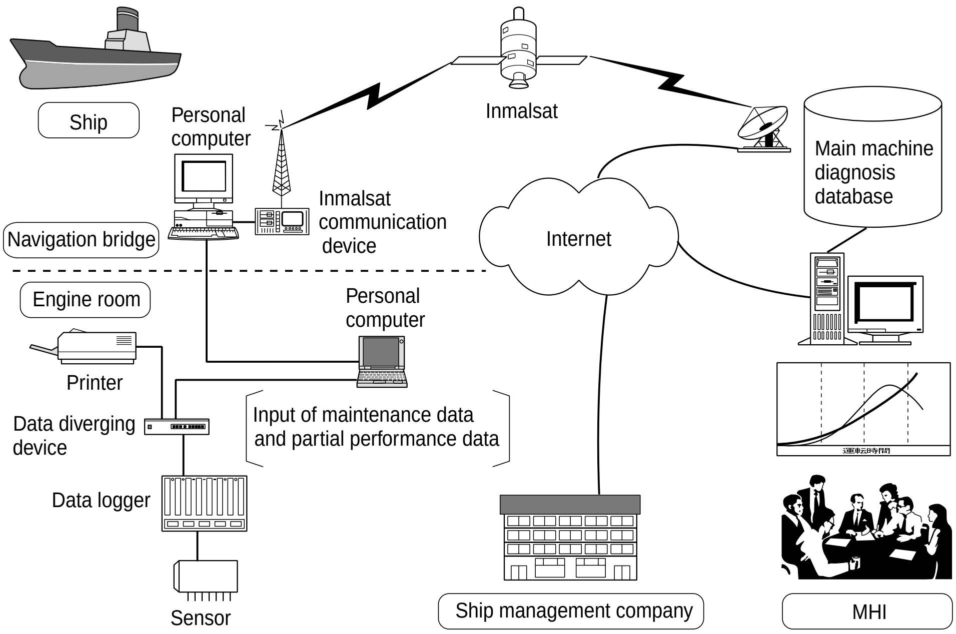

Fig. 7 Diagnosis system utilizing information technology
Diagnosis of the engine and parts is carried out on the basis of the engine performance data and parts maintenance data transmitted to MHI from the ship through Inmalsat and internet.

mation regarding planned maintenance and parts replenishment (budget-making) to the ship management company.

Through the effective use of this system, the information (data) can be shared by the crew of the ship, the ship management company and MHI, contributing to the reduction in operation and management cost of the customer and to the improvement in MHI customer support service.

5. Conclusion

We have described above the outline of the UE type diesel engine featuring in low fuel consumption and high reliability in addition to the development of the new series UEC-LSE type engine and the peripheral technologies to meet with the need of the age.

The main engine for a vessel in service requires of high reliability and economic performance to ensure safe and trouble-free planned (scheduled) operation of the ship. MHI is determined to make use of its sophisticated technical power, to continue efforts in further improving the reliability and economic (cost) performance of the present engine and to develop the peripheral technologies for meeting with the future needs in order to provide higher satisfaction to our customers.

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