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Study on the Testing Method for Marine Diesel Engine

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Abstract

For the high-power low-speed diesel engine's performance and reliability evaluation, this paper studies the engine's running-in norms, presents the Test Scheme about the combustion process, the Inlet swirl control, the cooling system control, and the distribution and emission. The whole engine's test methods and systems are established. By using the combined method of the test platform research and the theoretical model analysis, the diesel engine's performance and reliability tests are made to evaluate the engine's design.

***Keywords**: testing method and system, running-in criterion, performance evaluation, high-power low-speed diesel engine*

1. Introduction

China has a large fleet that is the front ranks of the world in the total tonnage, and is the first in the world's great shipbuilding capacity and the supporting capacity of the marine equipments. The shipbuilding industry and the shipping business has become a major pillar industry of the national economy. Along with that South Korea, Japan and China continue to consolidate themselves as a shipbuilding center, together with that China continues to increase the new ship's orders received in North America, the marine engine's market is bright in prospect. It is worth mentioning that, by the impact of that the fuel's price continues to rise, the marine engine burning the heavy oil will be more favored by the ship owners in future, and the order quantity is constantly increased.

The modern merchant ship generally uses the large low-speed two-stroke diesel engine to drive directly the propeller as the main propulsion power plant whose performance determines the dynamic performance of the entire ship. As the main engine of the ship propulsion, the diesel engine must have not only the good dynamic and steady performance, but also improve the fuel economy and minimize the pollution emission. On the other hand, the main diesel engine is an important factor impacting the ship's safety. The statistics of the four world's major diesel engine manufacturing companies show that the main engine's failure is 38% of the total failure 7521 times, that is 2858 times. The main engine is the most important in the power plant, but also the weakest in the reliability. Under the storms and other adverse sea conditions, the ship moves sharply so as to result in the over-speed and over-load of the engine and the propulsion shaft. This will speed up the fatigue damage of the shaft and bearing, and even cause serious marine accidents. Therefore, the further research must be made on the engine's tests of the load characteristics, safety devices, emissions, and the test platforms and measuring system are built as the foundation and prerequisite of the low-speed marine diesel engine's design and operation management, especially the optimizing design of the control system.

2. Test Method of High-power Low-speed Diesel Engine

2.1. Test Method of Low-speed Diesel Engine's Combustion Process

The multiple pressure sensors are used to measure the combustion pressure in the cylinders. So the impact of the locations of the sensors and the structure parameters of the measuring channels to the pressure measurements inside the cylinders is studied. The

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instantaneous speed changes for the engines are measured to study the working uniformity of each cylinder, and to optimize the intake and fuel supply control system.

2.2. Intake Swirl Control Test Method of Low-speed Diesel Engine

Controlling the intake swirl intensity is the principal means to solve the fuel oil efficiency and the emission question under the diesel engine's different speed condition. The invariable intake swirl system is applied in the low speed diesel engine to study the oil atomization in the cylinder and the combustion process to the intake swirl intensity's request under the different operating modes in order to realize the reasonable match of the intake swirl intensity with the fuel injection process. On the foundation of the twin inlet structure, the intake swirl control area and its influence to the gas charging efficiency are analyzed to provide the basic data for the design of the variable intake swirl control system.

2.3. Controlled Test Method of Low-speed Diesel Engine's Cooling System

In order to meet the low-speed diesel's power and economy requirements, the variable flow method and system is applied to control the diesel engine's cooling water. The test system controlling the cool process is shown in Figure 1. The air through the exhaust-gas-turbo-supercharger of the diesel engine 11 is cooled by the intercooler 4 into the diesel engine's scavenge box. The intercooler 4 is cooled by the High and low temperature heat exchanger 2 with the sea water pump 1 and the fresh water pump 3. The cooling water in the diesel engine's body is cooled by the High and low temperature heat exchanger 6 with the sea water pump 5 and the fresh water pump 7. The lubricating oil of the diesel engine is cooled by the lubricating oil cooler 9 with the lubricating oil pump 10 and the flow control valve 8. The dynamometer 12 is used for measuring the engine's power output.

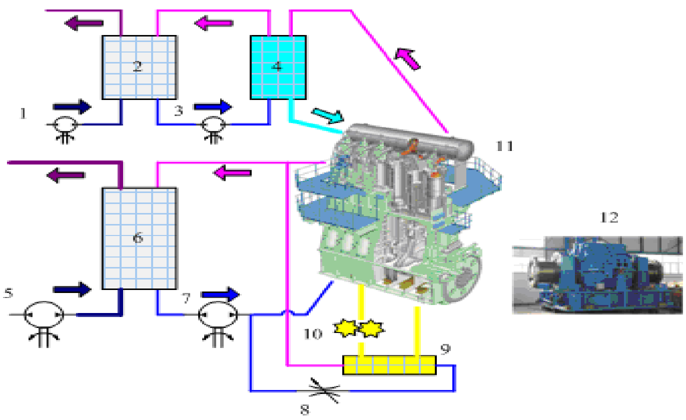

Figure 1. The Structure of Cooling System

2.4. Intake and Emission Test Method of Diesel Engine

The valve timing that is one of the key factors affecting the intake process of the marine diesel engine, directly affects the whole power, economy and emission performance. In order to measure the dynamics of the valve gear in the different valve timing, the dynamics test system of the valve gear is applied for the basis adjusting the variable valve timing, as shown in Figure 2. In order to study the influence laws of the different injection to the combustion process and the emission performance of the diesel engine, the emission testing system of the diesel engine is built up, as shown in Figure 3. Through the experimental research, the best injection law is revealed under the different conditions of the diesel engine to provide the technical support for the diesel engine's design and operation management.

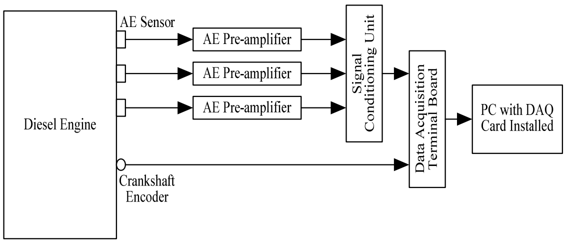

Figure 2. The Dynamics Test System of the Valve Gear

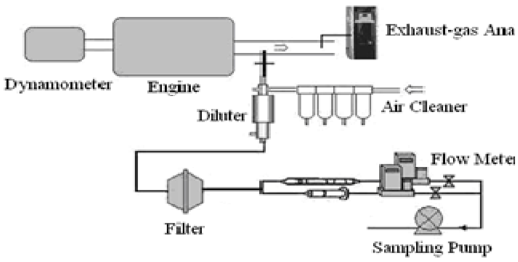

Figure 3. The Emission Testing System of the Diesel Engine

3. Diesel Engine's Combustion Process

In the low speed diesel engine design, the combustion process optimization mainly solves the carbon smoke and the NOx emission. Regarding the high-power marine diesel engine's emission, what most mainly must be solved is the carbon smoke discharge in the slow-speed and the low operating mode. Firstly, in the entire operating mode, the black smoke that the naked eyes can see should not be produced including the starting mode. The emission value of the marine diesel engine is easy to be satisfied according to the IMO's NOx stipulation. Figure 4 is a group of curves. They are obtained on the experimental contrast in the Wartsila46 medium-speed engine. As can be seen from the figure, when the electrically controlled fuel injecting system with the high-pressured common rail is used, in the entire operating condition, the smoke is below FSN0.15. That is, the smoke color does not be seen, and is below the guarantee FSN0.4. But with the conventional oil supply system, for the entire operating mode the smoke surpasses the guarantee value in the load below 45%. But the biggest value is FSN0.9, also not too high. If the supplement air measure is taken in the low operating mode, the FSN value also possibly is below the guarantee value. If the requested NOx is below 70% of the IMO standard value, the FSN value has surpassed the guarantee value in the load below 60%.

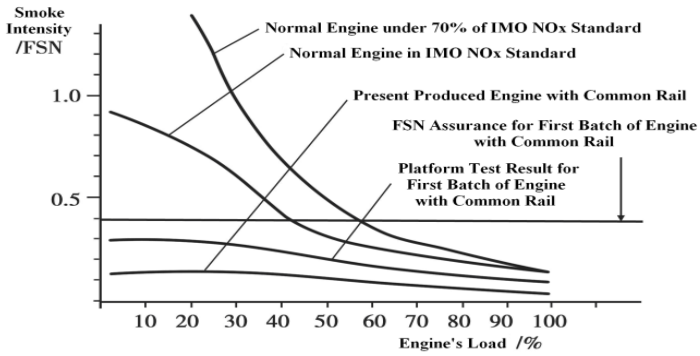

Figure 4. The Influence of the Electrically Controlled High-pressured Common Rail to the Smoke Intensity

The high-power low-speed diesel engine uses the scheme of the electrically controlled fuel injecting system with the high-pressured common rail. The two-cylinder common rail made the high-power low-speed diesel engine small in structure against the engine with the high-pressured oil track. The high pressure oil circuit controlled by a high speed magnetic valve can avoid the low operational reliability which governing directly a fuel injector needle brings.

In the electrically controlled fuel injecting system with the high-pressured common rail, the high-pressured oil feed pump provides the pressured oil to the common rail, but the injection discharge and injection timing is controlled by the high speed magnetic valve in the fuel injector. The electronic control unit (ECU) of the fuel injection system acts according to the operator's order and the operating condition of the diesel engine, and controls the injection start point and the injection end point as well as the injection times by controlling the fuel pressure and the magnetic valve's operating time in the common rail. Thus it can be seen, the electrically controlled fuel injecting system with the high-pressured common rail may control independently the system injection pressure, the injection timing, the injection discharge and the injection rule. In comparison with the mechanical type fuel injection system, its superiority lies in:

3.1 Realizing the High-pressure Injection

One of the most remarkable characteristics for the fuel injecting system with the high-pressured common rail is to realize the high-pressure injection. The high injection pressure may guarantee the good fuel atomization, thus can reduce the PM, CO, and HC emission. The injection pressure of the mechanical type fuel injection system is adjusted through the speed and the injection discharge. Because the mechanical type cannot guarantee the high-pressure injection, it causes easily the bad atomization, thus makes the PM, CO, and HC emission to increase. For example the diesel engine produces easily two times of injection under the high speed and the high load. The fuel oil in the two times of injection comes into the cylinder by the very low pressure, and causes the fume discharge to increase.

3.2. Guaranteeing the Accurate Injection Timing

To a great extent the injection timing is to affect the pollutant emission. Postponing the injection can cause the NOx emission to reduce, but possibly causes the CO and PM emission to increase. The injection timing also is very sensitive to the HC emission, and has the best value. The injection timing above or below the best value will possibly increase the HC emission. Therefore, choosing an accurate value of the injection timing is very important. It may enable the emission to achieve a best compromised value. However, the mechanical type fuel injection system adjusts the injection timing by the injection pump and the timing advance unit. Its setting range and the precision has been restricted. In the fuel injecting system with the high-pressured common rail, the injection timing is controlled by the ECU and the fuel injector. According to the electronic control signal from the ECU, the fuel injector takes the high-pressured fuel oil in the common rail to inject into the engine's combustion chamber by the best injection timing, the injection discharge, the injection rate and the atomization condition.

3.3. Implementing the Optimized Control of the Fuel Injection Rate

In the fuel injecting system with the high-pressured common rail, the injection start point and the duration time are decided by the command pulse, and they have nothing to do with the speed and the load. Therefore the injection time may be controlled freely. In addition the injection pressure may be controlled flexibly. So the ideal premix combustion can be formed. The pre-injecting start point, the main injecting start point and the injecting end point may be adjusted freely. The pressure in the pre-injecting section may be selected freely. The pressure rise rate after the main injecting start is suitable. The oil can be broken fast. The peak pressure of the injection may be chosen flexibly. The full combustion of the fuel oil may reduce the CO, HC, and PM emission. But the delay period reduced as far as possibly can lower the NOx emission.

3.4. Setting the Parameter Freely and Flexibly

In the fuel injecting system with the high-pressured common rail, the Injection nozzle parameter and the other various parameters may be set freely. Each parameter may satisfy the corresponding request independently. The aspect in satisfying the request is not restrained, the flexibility is good. These are the essential conditions to atomize the fuel oil good and reduce the emission.

Matching reasonably the high-pressure fuel injection system and controlling the parameters of the fuel injection pressure and the injection time, are important to improve the internal combustion process, optimize the diesel engine's power, efficiency and emission.

3.5. Optimization of Combustion Process

The difficulty of the diesel's emission control lies in the mutual checks of the NOx's formation and the carbon black's formation. The emissions of the NOx and the carbon black are mainly related with the combustion process in the diesel engine's combustion chamber. So reducing the diesel's emissions is carried out from improving the combustion process. In order to achieve the desired heat release curve and reach the desired purpose of reducing the emissions, the premixed combustion quantity is suppressed in the pre-mixed combustion phase to reduce the initial combustion temperature and the NOx emissions. In the diffusion combustion period, the good mixing and the high combustion temperature is maintained to promote the diffusion combustion and to reduce the carbon black's emissions. That requires the good mix and match for the diesel fuel injection system, the combustion chamber shape, and the air movement. Improving the fuel injection system is the most important. From the fuel injection law to consider, it is important to reasonably allocate the fuel injection quantity in the various sections. Specifically, to reduce the amount of the pre-injection leads to reduce the NOx emissions, and to strengthen the mixture of the main injection leads to reduce the carbon black's emissions. These put forward the higher requirements to the performance of the fuel injection system. Thus enabling the ideal fuel injection process is one of the keys to improve the diesel combustion process, improve the economy and reduce the harmful emissions.

The fuel injection system has a direct and decisive impact to the diesel engine's combustion and emissions. With the development for the diesel engine technology of the electronically controlled injection, the injection strategy has been an important breakthrough to reduce the NOx and carbon black's emissions. By studying the different control strategies, comparing and analyzing the influence rules of the different main injection timing, the different pre-injection quantity and the different interval between the main injection and the pre-injection to the emission performance of the diesel engine, the best match on the different conditions can be obtained.

4. Running-in Criterion of High-power Low-speed Diesel Engine

The low-speed diesel engine has two strokes, the direct-current scavenging with a single valve, the constant pressure supercharging, the long stroke, the high compression ratio, and the crosshead structure near to the isobaric combustion. Its speed is usually lower than 250r/min, the mean effective pressure (pme) is 1.9~2.0MPa, the maximum combustion pressure (pmax) is 15~16MPa, the consumption rate is 164~170g/(kW • h) or so, the single-cylinder power is close to or more than 5000kW.

The very low speed and very high cylinder power result in the poor lubrication condition of the various bearings in the "crankshaft-connecting rod-piston" motion pairs, and are easy to produce the faults of the bearing bush's scratching and burning. In the design phase, to increase the bearing bush's loaded area, to reasonably choose the bearing bush's gap, and to ensure the lubricating oil pressure of the bearing bush can improve the engine's reliability. In the whole engine's test phase, the whole engine's running-in is executed and the thin burr in the motion pairs' gap is eliminated so as to improve the contact surface's smooth finish and ensure the motion pairs' reliability.

The running-in conditions of the diesel engine are closely related to the speed, the load, and the lubricating oil. In the running-in process of the diesel engine, the specific lubricant for the diesel engine's running-in is chosen. According to the oil film thickness of the main motion parts and the surface roughness of the contact elements, the speed and the load are set. The oil film thickness of the key motion parts is studied under the different conditions, and the running-in conditions and cycles are set to improve the running-in criterion of the high-power low-speed diesel engine.

5. Whole Engine's Test Method and System of Low-speed High-power Diesel Engine

The whole test provides the reference and verification base for the diesel engine development, manufacturing and assembly, is one of the important essential links, and is also the central manifestation of the technical level. The low-speed diesel engine's power exceeds 10,000 kW, and the measurement in the test platform has considerable difficulty. To meet the requirements of the diesel engine's test, the test platform is designed for the diesel engine's test. After analyzing the diesel engine vibration, the shock-absorbing structure is applied to avoid the test platform's resonance caused by the mechanical vibration of the diesel engine. The engine connection reliability with the dynamometer is studied, and the reliable shock-absorbing mechanism achieves the flexible connection between the engine and the dynamometer to avoid the connection failure caused by the vibration of the diesel engine's crankshaft. The large-power marine diesel engine's assembly and test platform is shown in Figure 5. It undertakes the tasks of the whole assembly, the bench test, the inquisition, the disassembly, the oil seal, the painting, the stacking, and the shipping and so on for the low-speed marine diesel engine. The air system, the lubricating oil system, the fresh water system, the sea water system, and the fuel system are arranged in the auxiliary room to provide the energy for the diesel engine's test. The assembly test plant has the diesel engine's test stand, the whole assembly and pre-installed stand of the diesel engine, the auxiliary room and so on. The diesel engine's test stand configures three hydraulic dynamometers. The maximum test powers are 50,000 horsepower, 36,000 horsepower and 120,000 horsepower. The auxiliary room configures three auxiliary systems. Their two sets are 4.4 million horsepower which can meet the largest diesel engine 6S90MC-C's test. Their one set is 20,000 horsepower which can meet the largest diesel engines 5S60MC-C's test. The auxiliary systems consist of the subsystems of the fuel, the lubricating oil, the fresh water, the sea, the air, the waste water, and the smoke. The subsystems are composed by the boxes, the pumps, the filters, the coolers, the valves, the piping and other components.

Figure 5. The Large-power Marine Diesel Engine's Assembly and Test Platform

6. Diesel's Performance Evaluation and Testing Platform

Study on performance evaluation	
Evaluation of whole engine's design	Performance evaluation of key components
	Reliability evaluation of key components
Test method of intake swirl control system	Measuring method of intake flow field
	One-dimensional analysis of whole flow
	Three- dimensional analysis of inlet flow
Evaluation of combustion process in cylinder	Evaluating combustion pressure using multi-sensor's data fusion
	Uniformity and sealing performance in cylinder using transient speed method
Matching and optimization of cooling system	Heat transfer analysis in cylinder
	Analysis of optimal heat dissipation in engine
	Evaluation of heat dissipation in cooling system

Development of test platform	
Project design of test platform	Whole performance index
	Type selection of dynamometer
	Design of auxiliary system
	Performance requirement for key components
Structural design of test platform	Strength analysis of test platform
	Vibration performance analysis of test platform
	Design of shock-absorbing structure
	Vibration performance experiment of test platform
Performance analysis of key components	Structural design of shaft coupling
	Strength and reliability analysis of shaft coupling
	Vibration performance analysis of shafting
Design of auxiliary system	Design of cooling system
	Design of compressed air system
	Design of data measuring system
Prototype test	Performance test of prototype
	Reliability test of prototype

Figure 6. The Performance Evaluation and Test Platform for the Marine Diesel Engine

In the low-speed diesel engine's design, due to the long cycle and the high cost of processing parts, the repeated trials and a lot of the prototype tests generally can not be made and the consistency of the theoretical analysis and experimental results is the key factor affecting the component designs. Therefore, the combining method of the testing platform research and the theoretical model analysis is applied to evaluate the design program, as shown in Figure 6. It can be seen from the figure, the diesel engine's performance evaluation is started from the overall design. In the hardware and software test platform, through the analysis and experimental research on the intake, combustion and cooling systems and the key components, the engine's prototype design and development work is completed, and finally the prototype's performance and reliability tests are made.

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