

Analysis of waste heat utilization of ship main engine

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Abstract: In order to protect the environment, save energy and reduce emissions, and promote the utilization of wave energy, this paper reviews the development history of application generation technology, summarizes its development from two aspects of optimization and application of wave energy conversion devices, analyses the application examples of wave energy generation devices on ships. This paper summarizes the application trend of wave power generation devices on ships: wave power generation should be used as auxiliary and domestic electricity for ships and wave energy should be combined with other new energy sources. Wave energy application in marine power generation can effectively reduce emissions from ships, which is conducive to the sustainable development of human society. The system mainly included low speed marine main diesel engine, waste heat boiler, electricity generation sub-system of power turbine, electricity generation sub-system of steam turbine, the heat exchange equipment, electricity generation sub-system of organic working medium steam turbine and other equipments. Based on experimental data of main engine and later theoretical calculation, this paper studied the effect rules of electricity generation power, waste heat utilization potential and related parameters of the waste heat utilization system under different main diesel load and ambient temperature.

1 INTRODUCTION

With the development of the shipping industry, 90% of the world's transportation trade is borne by ships, and ship transportation consumes 3% of the world's energy. Diesel engines are the main power output devices for ships. The main emissions are water vapor, CO₂, CO, and NO_x, hydrocarbons and granules, etc., and their emissions are huge, and the exhaust gas emitted by the exhaust gas is increasingly serious. In recent years, the International Maritime Organization (IMO) has introduced two measures of ship energy efficiency operation index (EEOI) and new ship energy efficiency design index (EEDI) for ship energy efficiency in order to implement green shipbuilding and limit ship greenhouse gas emissions, of which EEOI To operate the ship, EEDI is built for the new ship and clearly sets out the implementation schedule for these two standards. According to IMO data, in 2007, the ship industry emitted 10.46×10⁸ t CO₂, accounting for 3.3% of the total global CO₂ emissions. If it does not improved, by 2020, the ship industry's CO₂ emissions will be based on 2007. It can be seen that the development of ship energy-saving and emission reduction technologies is of great significance for building a resource-saving and environment-friendly society.

2 COMPOSITION AND ANALYSIS OF WASTE HEAT OF MARINE DIESEL ENGINE

2.1 Diesel engine waste

2.1.1 Exhaust heat

The oscillating water column wave power generation device is currently the most researched and used wave energy device. The basic principle is to use compressed air to drive the steam turbine generator set. According to the installation location, it can be divided into offshore, nearshore and docking. The oscillating water column type wave energy device has good reliability because there are no moving parts under water. The disadvantage is high cost and power generation efficiency of less than 30%.

The marine diesel engine is the power source for the ship to sail at sea. The waste heat from the exhaust gas will account for nearly 40% of the total heat energy. The exhaust heat temperature of the exhaust gas is between 350 °C and 410 °C. If it is directly discharged into the atmosphere, it will waste a lot of heat energy that has not been utilized.

The total amount of diesel exhaust heat is:

$$Q = C_p^{T_2} \cdot M \cdot T_2 - C_p^{T_1} \cdot M \cdot T_1$$

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Where: Q---the heat contained in the exhaust of the Q diesel engine;

$C_P^{T_2}$, $C_P^{T_1}$ --- The constant pressure specific heat of the flue gas at temperatures T1 and T2;

M---the quality of the smoke exhaust;

T₂---the exhaust turbocharger turbine outlet temperature;

T₁---is the ambient temperature.

In summary, the larger the exhaust volume of the diesel engine, the higher the exhaust temperature, and the more heat of the exhaust gas. Therefore, if the exhaust heat is to be reduced, the excess air ratio can be lowered by reducing the exhaust gas temperature.

2.1.2 Heat available in the exhaust

When the exhaust gas temperature is less than 125 ° C, the oxide formed by the sulfur in the exhaust gas and the oxygen in the air causes low-temperature acid corrosion to equipment such as a diesel engine. In order to mitigate low temperature corrosion, the exhaust gas temperature should be greater than 150 ° C, so the residual heat that can actually be used in the exhaust gas:

$$Q_2 = C_P^{T_2} \cdot M \cdot T_2 - C_P^{150} \cdot M \cdot 150$$

Where: $C_P^{150} = 1.083 \text{KJ/KG} \cdot \text{K}$

$C_P^{30} = 1.0412 \text{KJ/KG} \cdot \text{K}$

2.1.3 Cooling medium waste heat

During the working process of a marine diesel engine, many components are working at high temperatures. In order to ensure the overall strength and service life of the diesel engine, the metal components need to be cooled. Therefore, it is often necessary to consume a large amount of cooling water in a diesel engine. Air, inert gas or mineral oil is also used as a cooling medium.

Normally, the total amount of heat taken away by the cooling water is calculated as:

Where:

C_{R_1} , C_{P_2} ---The constant pressure specific heat of the cylinder coolant and the piston coolant respectively;

m_1 , m_2 --- The mass flow rate of the cylinder cooling water and the piston coolant respectively;

T_1 , T_2 --- The temperature difference between the inlet and outlet of the cylinder cooling water and the piston coolant.

2.1.4 The rest of the heat

About 16% of the total energy generated by fuel combustion is dissipated. Most of this residual heat is lost through the diesel engine itself, air cooling device, charge air, oil cooling device, etc., and a small part of the chemical reaction waste heat generated by the chemical reaction of the fuel. If this part of waste heat is

used, the economic cost is high and the operation is difficult, and it is not practical.

3 WASTE HEAT RECOVERY TECHNOLOGY

3.1 Rankine cycle

The Rankine cycle is a cyclical way of converting thermal energy into mechanical energy. The ideal Rankine cycle includes isentropic compression, isobaric heating, isentropic expansion, and an isobaric condensation process.

At present, the Rankine cycle has been considered as the best technical means to recover waste heat. According to the principle of the Rankine cycle, Yalcin Durmusoglu et al. explained a set of organic Rankine cycle waste heat recovery system for container ships, and adopted energy utilization and thermal efficiency. The efficiency of the organic Langken cycle waste heat recovery system was analyzed. The calculation results show that the combined cycle can save 17.1%; save 4 076 tons of fuel per year; reduce 128 tons of CO₂ emissions per year; energy of combined cycle system The utilization rate is 58% and the thermal efficiency is 56%. Yang Dong of Jiangsu University of Science and Technology designed an organic Rankine cycle waste heat recovery system. Based on the analysis of engine exhaust heat parameters, the Langken cycle exhaust heat recovery system and organic Rankine cycle exhaust heat recovery were proposed. The system and the combined turbine exhaust heat recovery system have found that the organic Rankine exhaust heat recovery system achieves the highest efficiency when using the working fluid R141b; the combined turbine exhaust heat recovery system has the largest net output power; Under the premise of the mainframe structure, the investment recovery period of the Rankine cycle waste heat recovery system is the smallest.

3.2 Making fresh water from residual heat of cooling water

The salts in seawater are mainly NaCl, MgCl₂, etc. Desalination of seawater is to remove this part of the salt or impurities to meet the needs of drinking and domestic water. At present, the most used method is to obtain fresh water by distillation. Distillation method for fresh water is to heat the seawater to vaporize it. The salt is separated from the low-pressure steam, the salt in the seawater is separated, and the steam is condensed into water to obtain fresh water that meets the living and drinking standards. Due to the high salt content in seawater, if the evaporation temperature is high, the salt in the seawater will foul on the evaporation surface, which will increase the heat transfer resistance, reduce the heat exchange efficiency, and corrode the metal surface after scaling. In practical applications, vacuum distillation is often used to reduce the evaporation temperature of seawater. At this time, the cooling water

of the ship's main engine can be used as a heat source for seawater. According to the water demand of the ship, single-stage evaporation and multi-stage evaporation can be selected. The research shows that the increase of the residual hot water temperature will increase the efficiency and water production of the evaporation equipment. The higher the residual heat temperature, the easier the seawater evaporation is, and the demand for seawater is not large. In this case, a single stage of evaporation can be used. In order to achieve better energy-saving benefits, the researchers designed a hot-draft seawater desalination system. The principle is to pass the seawater through the condenser, condense the water vapor in the evaporation chamber, then pass the seawater into the preheater and cool it with a diesel engine. The water is heated and then sprayed into the evaporation chamber to be sprayed on the heat pipe to form water vapor, and the water vapor is then condensed into water in the condenser, so that fresh water is obtained by circulating, and the method can fully utilize the residual heat of the ship.

There is also a seawater lightening scheme that uses the residual heat of the engine cooling water. The scheme adopts a counterflow four-effect vacuum evaporation system, and uses the engine cooling water waste heat to obtain hot water, which is used for the heat source of the first effect evaporator, and cools down. After the hot water, the seawater preheated by the condenser is preheated again, and after cooling, the residual heat of the engine cooling water is absorbed by the heat exchanger to form a hot water circulation.

3.3 Cooling with residual heat of cooling water

Absorption refrigeration is the use of a pair of working fluids with special properties. The absorption and release of one substance to another produces a change in state of matter. The process of changing state of matter is accompanied by an endothermic and exothermic process to complete the refrigeration cycle. The working medium of absorption refrigeration often uses a binary solution composed of two different boiling points. At present, the commonly used working medium pair is ammonia-water and lithium bromide-aqueous solution. The working principle is to use the heat source to heat the solution in the generator. , the low-boiling refrigerant in the solution is evaporated, and the refrigerant vapor enters the condenser, is condensed into a refrigerant liquid by the cooling medium, and enters the evaporator through throttling, and the refrigerant absorbs heat of the external environment in the evaporator. It becomes a refrigerant gas to achieve the purpose of refrigeration.

3.4 Waste heat power generation

During the working process of the marine diesel engine, a large amount of waste heat resources of high temperature exhaust gas are discharged outward. A typical waste heat recovery system converts this heat energy into hot water or steam for the machine to operate or to live. However, this type of thermal energy

utilization is often subject to the working conditions of the ship and in many cases it cannot be fully utilized. The waste heat can be directly converted into electricity for use and transmission by waste heat power generation technology, which significantly increases the economic benefits of ship transportation.

3.5 Using cooling water waste heat to heat

Heat pump technology is similar to refrigeration technology in that it uses reverse Carnot cycle. At the same time, heat pump technology is also one of the effective means to recycle and utilize low-grade heat source. It has attracted much attention in energy conservation. Its workflow is: liquid refrigerant in evaporator The medium absorbs the heat of the low-grade heat source to evaporate into a gas, and becomes a high-temperature and high-pressure refrigerant gas through the compressor, and then passes through the condenser to transfer the heat, is cooled to a low-temperature high-pressure liquid refrigerant, and then depressurizes through the expansion valve and then evaporates. The device reciprocates to complete the heating process. In order to better recover the residual heat of the cooling water of the ship, the high-temperature heat pump technology can be used to recover the residual heat of the cooling water of the ship. After the thermal cycle, the refrigerant can heat the circulating water in the condenser to generate high-temperature steam, which supplies the heat source for the daily needs of the ship.

3.6 Other waste heat utilization

(1) Recovering the lower temperature residual heat through the heat exchange device, such as: heat exchanger, heat pipe boiler, the recovered waste heat can provide air conditioning heating on the ship, and can also heat and heat the fresh water for the life needs of the ship.

(2) The high-temperature residual heat is recovered by the fuel hot water heating device (waste heat boiler). The main engine of the ship has a large residual heat due to its exhaust gas. In order to reasonably recover a large amount of residual heat, the fuel hot water heating device is used to heat the water in the boiler and be heated to produce A large amount of saturated steam and superheated steam are used to provide steam and heating for the crew's life and for the marine equipment.

In small vessels, steam is used to heat domestic water, rice cooking and cabin heating; in large ships, steam is used to drive generator sets through steam turbines in addition to warming up the engine and fuel oil for main engine start-up. To provide power to the ship; on the tanker, steam is used to heat the cargo and clean the tank. In the current waste heat recovery system, the waste heat boiler is an extremely important system unit for the utilization of waste heat of the ship.

4 NEW UTILIZATION AND PROSPECT OF WASTE HEAT

Gas turbines are ideal Carnot cycle machines, and because of their high exhaust temperatures, gas turbine efficiency is not much higher than turbine efficiency. Modern high-temperature gas turbine exhaust temperatures have reached about 600 ° C, which is higher than the initial temperature of the turbine cycle. Such high-temperature exhaust gas is discharged into the atmosphere, causing huge waste of energy. Therefore, high-temperature exhaust gas is used to heat the water to generate steam, which leads to the steam turbine to drive the motor to generate electricity. This constitutes a gas-steam combined cycle waste heat recovery system. Absorb the residual heat energy of the marine diesel engine, convert the thermal energy into sound energy, and then use the thermal effect to consume the sound energy to achieve refrigeration. The thermoacoustic refrigeration system has no moving parts and is highly reliable and does not have a negative impact on the environment.

The status quo of the diesel engine as the main engine of the ship will not change in the short term, and the environmental problems are becoming more and more serious. In particular, the ship energy efficiency design index is officially effective, making green technology, energy saving and consumption reduction become the current theme. In this paper, the existing waste heat utilization technology of marine diesel engines is summarized. The recycling of waste heat is mainly concentrated in two aspects of heat energy and kinetic energy. The requirements for ship mainframes in the future will definitely develop towards high efficiency, low emissions, environmental protection and energy conservation. The application of waste heat utilization technology has a significant effect on improving the efficiency of marine diesel engines, and has broad development prospects.

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