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STUDY ON COOPERATIVE MATCHING PERFORMANCE OF PUMP IN MARINE BIOMASS DIESEL ENGINE-ORGANIC RANKINE CYCLE COMBINED SYSTEM BASED ON GT-SUITE

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ABSTRACT

GT-Suite software is used to build a marine biomass diesel engine-organic Rankine cycle system. The accuracy of the simulation models of marine biomass diesel engine and organic Rankine cycle are verified. On the premise of verifying the accuracy, the influence of pump speed on the combined system is studied under the operating condition of engine speed 2100 r/min, 100% load. After design of experiment (DOE), the artificial neural network (ANN) prediction model is built under the premise of engine speed 2100 r/min, 100% load. And the speed of pump is predicted to maximize the output power of the combined system. The result show that the output power of the optimized combined system is 2.5 percentage points higher than the primary engine.

Keywords: Marine biomass diesel engine, Organic Rankine cycle, Combined system, Design of experiment, Artificial neural network

NONMENCLATURE

Abbreviations	
DOE	design of experiment
ANN	artificial neural network
ORC	organic Rankine cycle
HC	hydrocarbon
CO	carbon monoxide
NOX	nitric oxide
PM	particulate matter
WHR	waste heat recovery
BSFC	brake specific fuel consumption
Symbols	
$\Delta\eta$	combined system power growth rate
$\dot{W}_{en}$	Output power of the original internal combustion engine
$\dot{W}_{com}$	combined system output power

1. INTRODUCTION

Biodiesel is an engine alternative fuel composed of long-chain fatty acid methyl esters, which is obtained by esterification of vegetable oil or animal fats.The results show that when the engine is not modified or adjusted, the emission of hydrocarbon (HC), carbon monoxide (CO), particulate matter (PM) and smoke can be effectively reduced by the mixture of biodiesel and diesel, while the power decrease and the fuel consumption increase slightly, Moreover the emission of nitric oxide (NOx) increased in different degrees[1]. In addition, although with the progress of engine technology, engine thermal efficiency has been greatly improved. However, from the perspective of heat balance, nearly one-third of the total combustion energy is still wasted with exhaust gas. The waste of energy and the discharge of pollutants not only aggravate the energy crisis, but also cause serious environmental pollution[2]. The waste of energy and the discharge of pollutants not Therefore, while using biomass diesel as fuel, effective utilization of waste heat is the main measure to improve thermal efficiency and reduce engine fuel consumption[3-5]. Organic Rankine cycle (ORC) is widely concerned because of its superior effect in waste heat recovery (WHR)[6-8].

The theoretical analysis is carried out under presupposed conditions without considering the influence of the structure's specific form and dynamic error on the system[9]. Experimental research also has obvious limitations due to long development cycle, low fault tolerance rate, large investment and high cost.Therefore, numerical simulation is favored by researchers for its can quickly and reliably study the research problems on the basis of a large number of experimental and theoretical analysis. Although researchers have done a lot of research on organic Rankine cycle[10-14], there are few related studies on the collaborative matching of pump, which is the key component of ORC under different operating conditions in the combined system. Because of the dynamic fluctuation of engine operating conditions, the coordination and matching of pump, a key component of ORC, is particularly important.

In this paper, GT-Suite software is used to build a marine biomass diesel engine-organic Rankine cycle system. Under the premise of verifying its accuracy, the influence of pump speed on the combined system at 2100r/min engine speed, 100% load is studied. After design of experiment, the artificial neural network prediction model is established, and the prediction of pump speed in the combined system under 2100r/min, 100% load are carried out.

2. SIMULATION MODEL OF MARINE BIOMASS DIESEL ENGINE-ORC COMBINED SYSTEM

The schematic diagram of marine biomass diesel engine-ORC combined system is shown in Fig. 1. The working fluid is pressurized by pump and enters the evaporator to absorb the energy from the high-temperature heat source and turns into high-enthalpy gas, then enters the expander to expand and output useful work. The spent gas after work is condensed into saturated liquid through the condenser and starts the next cycle again.

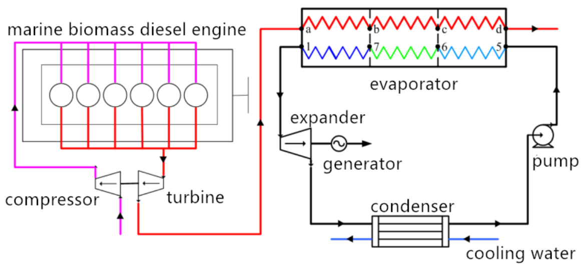

Fig 1 Schematic diagram of marine biomass diesel engine-ORC combined system

2.1 Simulation model of the marine biomass diesel engine

The simulation model of engine is built by GT-Suite software. By comparing the experimental value with the simulation value, the error values of torque, power and brake specific fuel consumption (BSFC) are all within 10%, so this simulation model can well predict the performance of marine biomass diesel engine.

2.2 Simulation model of the ORC system

After investigation, the evaporator in this study chooses tube-fin evaporator, and the condenser chooses plate condenser. The single-screw expander is selected for the expander. single-screw expander is a new type of screw expander, which is mainly composed of shell, rotor and star wheel[15].Pump chooses volume pump.

The ORC model is verified by comparing theoretical calculation with numerical simulation. It can be obtained that the maximum deviation between simulated value and calculated value of evaporator and condenser heat transfer value are 4.5% and 4.3% respectively. The maximum error between the calculated and simulated values of inlet and outlet temperature of the expander are 0.027% and 3.24%, respectively. The maximum error of the calculated and simulated values of the working fluid at the outlet of the pump is 0.14%. Therefore, the simulation model of organic Rankine cycle system is accurate.

2.3 Integrated simulation model

The process of coupling is accomplished by connecting the explicit solver of engine model with the implicit solver of ORC through "Flow Circuit Splitter", and the integrated simulation model of marine biomass diesel engine-ORC combined system is constructed as shown in Fig 2.

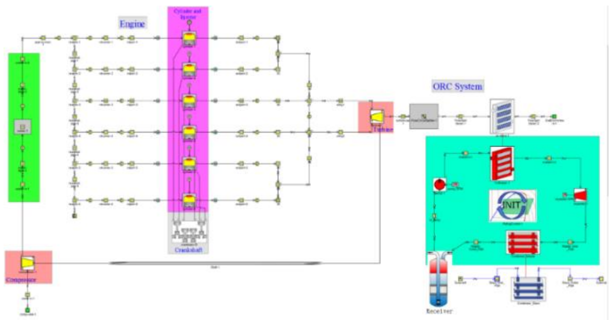

Fig 2 Integrated simulation model

3. THE INFLUENCE AND OPTIMIZATION OF PUMP SPEED

3.1 The influence of pump speed

Pump is one of the important parts of ORC system. The performance of pump directly affects the change of key parameters such as mass flow rate of working fluid. The influence of pump on mass flow rate of working fluid is studied under the operating condition of engine speed 2100r/min, 100% load. As shown in Fig 3, with the increase of pump speed, the average mass flow rate of working fluid shows a fluctuating increase.

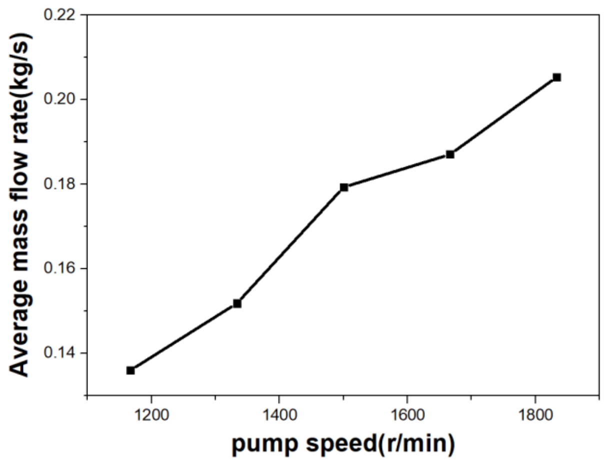

Fig 3 The change of average mass flow with pump speed

3.2 Establishment of predictive optimization model

3.2.1 Establishment of design of experiment

Design of experiment (DOE) can scientifically and systematically arrange experiments so that the relationship between various parameters can be more easily presented for optimization[16]. Fig 4 is the DOE data distribution diagram of marine biomass diesel engine-ORC combined system.

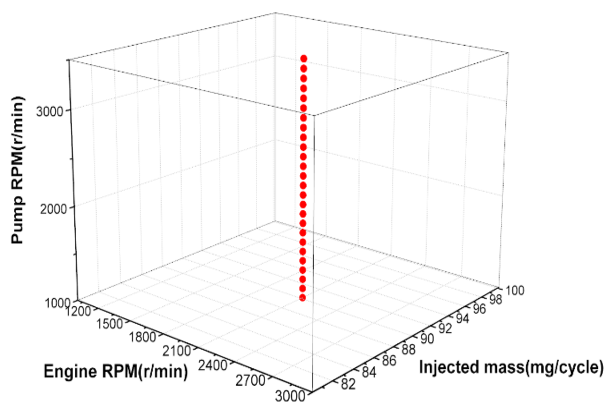

Fig 4 DOE data distribution for testing

3.2.2 Establishment of artificial neural network

Artificial neural network (ANN) has become a research hotspot in recent years because it is superior to general AI technology in parallelism, nonlinearity and fault tolerance. The main structure of artificial neural network is shown in Fig 5.

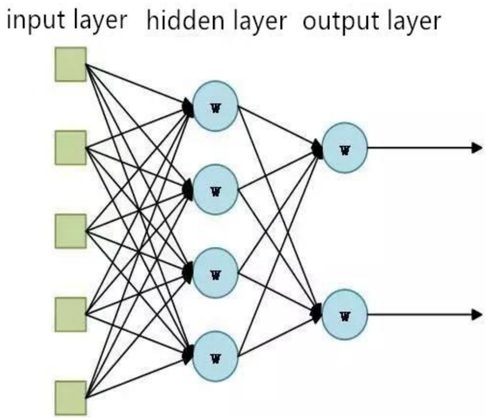

Fig 5 Structural diagram of artificial neural network

Fig 6 shows the artificial neural network regression diagram, in which the R value is far higher than 0.93. Thus the artificial neural network model selected has a high prediction accuracy.

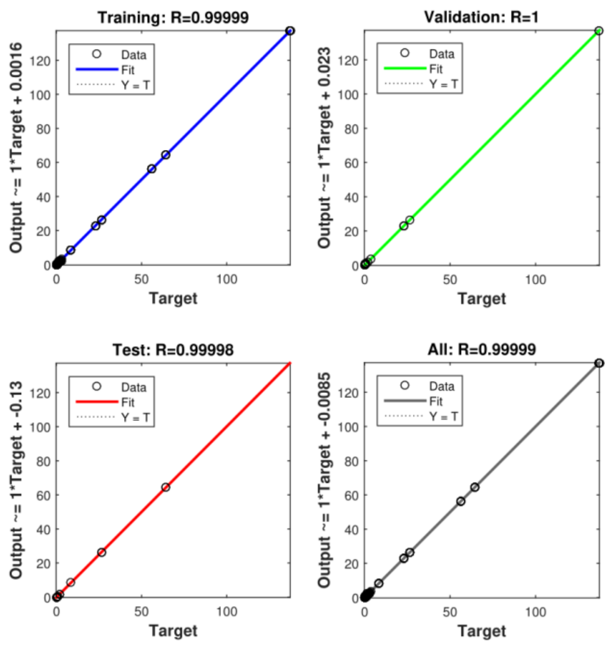

Fig 6 artificial neural network regression diagram

3.3 The optimization of pump speed

In order to evaluate the performance of combined system, the evaluation indexes of combined system power growth rate are proposed. The calculation formulas are as follows:

$$\Delta\eta = \frac{\dot{W}_{com} - \dot{W}_{en}}{\dot{W}_{en}} \times 100\%$$

In formula,

$\dot{W}_{en}$ —Output power of the original internal combustion engine;

$\dot{W}_{com}$ —combined system output power. The value is the output power of the engine minus the power lost due to exhaust back pressure plus the output power of the expander minus the pump power;

The speed of the pump in the combined system of marine biomass diesel engine -organic Rankine cycle is optimized at 2100r/min, 100% load by artificial neural network prediction.As can be seen from Fig 7, when the engine speed is 2100 r/min and the load is 100%, the output power of the combined system increases by 2.5 percentage points when the pump speed is 2930 r/min.

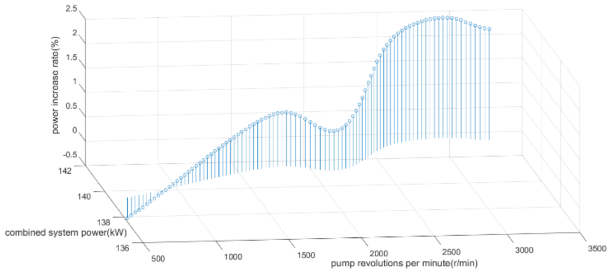

Fig 7 Prediction and optimization result

4. CONCLUSIONS

1) Because of the dynamic coupling effect between engine and waste heat recovery device, the average mass flow rate of pump increases undulately with the increase of the pump speed.

2) When the pump speed increases within the normal range, due to the dynamic coupling effect, there is fluctuation in operation. When the pump speed is too high, the heat absorption of working fluid per unit mass decreases, resulting in a decrease in the combined system power growth rate.

3) When the engine speed is 2100r/min, 100% load.The pump speed with the maximum output power of the combined system is 2930r/min. The output power of the combined system is 2.5 percentage points higher than that of the original engine.

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