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Design of Fault Simulation Software for Intake and Exhaust System of Marine Diesel Engine

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ABSTRACT

Aiming at the problems of high operating cost, high training cost and large site requirement of traditional marine engine platform, the software of fault diagnosis system for marine diesel engine intake and exhaust system is developed by using Visual Studio 2012 platform. The relevant mathematical model is established by numerical method, and the conversion from mathematical model to code is realized to simulate the working status of marine intake and exhaust system in normal operation and failure. The results show that the simulation system runs well with low cost and small site requirement. It can accurately simulate the normal operation and fault state of the ship intake and exhaust system. It can be used for training work and improve the actual response ability of the trainers to the fault of the ship intake and exhaust system.

Keywords: marine diesel engine; intake and exhaust system; fault simulation; mathematical model

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1. INTRODUCTION

Intake and exhaust system is an important part of marine diesel engine, which plays an important role in ensuring the normal operation of marine diesel engine and safe navigation of ships. In recent years, with the rapid development of computer technology, computer simulation technology has been widely used in many different fields, such as product simulation design, virtual simulation of engineering, medical and health fields. The advantages of computer intelligence technology lie in its low risk, high efficiency, low investment, short cycle and repeatability. Nowadays, computer simulation technology has been applied in most disciplines, and it has become a cutting-edge technology in combination with other fields. In the research of marine equipment, computer simulation technology has also been widely used, such as the simulation control of marine engine room, ship bridge, ship centralized control room and other equipment.

Compared with traditional ship training, marine engine simulator can greatly reduce the cost of education, so that students can have a specific and intuitive understanding, but also can provide more information for students. More learning opportunities, further familiarity with the operation process, in addition, the marine simulator can also set up some common marine faults, further improve the students'business ability [2]. At present, marine engine simulation system has realized the functions of main engine start-up simulation, main engine speed control, fault setting and troubleshooting, and has played an important role in the development of the marine industry.

This paper studies the mechanism of intake and exhaust system of MTU20 Marine High-speed Diesel engine. It summarizes the working principle of this type of marine high-speed diesel engine and the faults and troubleshooting during its operation. It is designed as a fault simulation software. Find the relevant laws and regulations, such as classification societies, ship building codes, etc., abide by international conventions, and according to these, establish mathematical models of corresponding systems and corresponding equipment. When establishing mathematical models, reasonably use computer simulation, establish intelligent mathematical models of intake and exhaust systems, and finally carry out fault analysis.

2. MATHEMATHEMATICAL MODEL OF INTAKE AND EXHAUST OF MARINE DIESEL ENGINE

In the simulation system, the reasonable construction of mathematical model is a very important part, which is the basis of system design and implementation. We simulate the data generated by each device through modeling method [3]. In this paper, MTU20V956TB92 is taken as the research object. It is a four-stroke direct-injection water-cooled turbocharged diesel engine with medium V configuration. Its basic parameters are as follows.

Table.1Basic Parameters of Diesel Engines

Serial number	Name	Parameter
1	Model	MTU20V956TB92
2	Cylinder number	20
3	Bore diameter (mm)	230
4	Rated power (kw)	4380
5	speed(r/min)	1500

2.1 Basic Equation of Energy Conservation in Cylinder

The combustion process in cylinder of diesel engine can be simplified as a thermal cycle system in a closed combustion chamber consisting of cylinder head, cylinder and cylinder liner, which includes mechanical, chemical and physical factors. The energy conservation in the combustion chamber can be shown in Figure 1.

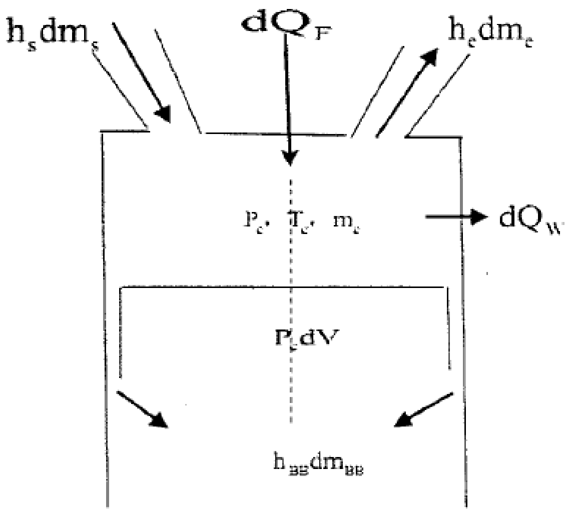


Fig.1Energy Conservation in Combustor.

According to the first law of thermodynamics, the energy changes in combustion chamber include the mechanical energy obtained by piston, the internal energy of fuel exothermic, the heat exchanged between cylinder liner wall and the outside world, the energy brought by fresh air and the energy taken by exhaust gas. The expression is [4].

$$\frac{d(m_c \cdot u)}{d\varphi} = -p_c \cdot \frac{dV}{d\varphi} + \frac{dQ_F}{d\varphi} - \sum \frac{dQ_w}{d\varphi} - h_{BB} \cdot \frac{dm_{BB}}{d\varphi} \quad (1\text{-}1)$$

Formula: φactual crank angle, m_c: change of working substance in cylinder, V: volume of cylinder, Q_F: heat released from fuel combustion, p_c: pressure in cylinder, Q_w: heat transfer loss of cylinder walls, h_{BB}: enthalpy of leakage, m_{BB}: mass of leakage.

2.2 Equation of State for Ideal Gas

In the study of diesel engine intake and exhaust working fluids, it is generally assumed that working fluids are ideal gases, and their equation of state can be expressed as:

$$p_c \cdot V = m_c \cdot R \cdot T \quad (1\text{-}2)$$

Formula: R: Ideal Gas Constant, T_c: Gas Temperature in Cylinder

According to the energy conservation equation (1-1), the mass conservation equation (1-2), the physical parameters in the cylinder of diesel engine are calculated.

2.3 Calculation of Instantaneous Volume in Cylinder

There is a certain relationship between piston and crank angle, so the instantaneous volume of cylinder can be deduced according to the change of crank angle[5].

$$V = V_0 + \frac{\Delta V}{2}\left[(1 - cos\varphi)\lambda \cdot \left(1 - \sqrt{1 - \lambda^2 sin^2\varphi}\right)\right] \quad (1\text{-}3)$$

The change rate of cylinder volume can be expressed as:

$$\frac{dV}{d\varphi}=\frac{\Delta V}{2}sin\varphi\left(1+\frac{\lambda^3 cos\varphi}{\sqrt{1-\lambda^2 sin^2\varphi}}\right) \tag{1-4}$$

Formula: V_0: clearance volume, ΔV actual effective volume, λ: crank-connecting rod ratio

2.4 Calculations of Heat Release Law of Combustion

The combustion process in the combustion chamber of diesel engine is related to many factors, so it is difficult to describe it with precise mathematical methods in the process of research. At present, Weber's formula is widely used to simulate the actual combustion process of diesel engine by modifying the combustion process through empirical coefficient.

In Weber's formula, the percentage of change X and its rate of change in fuel combustion process [6]:

$$x=1-e^{-0.6908\left(\frac{\varphi-\varphi_B}{\varphi_Z}\right)^{m+1}} \tag{1-5}$$

$$\frac{dx}{d\varphi}=6.908\frac{m+1}{\varphi_Z}\left(\frac{\varphi-\varphi_B}{\varphi_Z}\right)^{m}\cdot e^{-0.6908\left(\frac{\varphi-\varphi_B}{\varphi_Z}\right)^{m+1}} \tag{1-6}$$

In the formula: m:combustion quality index, φ: instantaneous crankshaft rotation angle, φ_Z: combustion persistence angle, φ_B: combustion start angle. m exponent is a parameter representing the distribution of heat release rate.

2.5 Basic Theory of Exhaust Gas Turbocharger

The exhaust gas turbocharger is composed of a turbine and a compressor, which is connected by a shaft. When the exhaust gas passes through the turbine, the exhaust gas works to drive the compressor to work, thus realizing the recovery and utilization of exhaust gas energy. The principle of the exhaust gas turbocharger is shown in Fig. 2 as the schematic diagram of the exhaust gas turbocharger [8]. The structure of the exhaust gas turbocharger is mainly composed of the front end of the turbine and the compressor end.

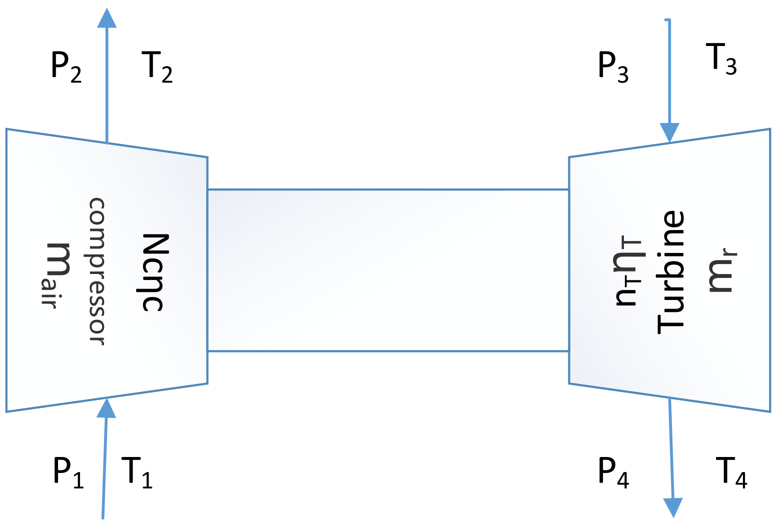


Fig.2 Schematic diagram of exhaust gas turbocharger.

In the figure: P_1 and P_2 represent the inlet and outlet temperature of the compressor end, T_1 and T_2 represent the inlet and outlet temperature of the compressor end, n_c represents the rotational speed of the compressor end, η_c represents the efficiency of the compressor end, $\dot{m}_{air}$ represents the air mass flow rate, P_3 and P_4 represent the inlet and outlet pressure of the turbine end, T_3 represents the inlet and outlet temperature of the turbine end, n_T represents the rotational speed of the turbine end, η_T represents the efficiency of the turbine end, m_r represents the exhaust gas flow at the turbine end. Gas mass flow rate.

2.6 Friction and Heat Transfer Calculation of Straight Tube Wall

For the wall friction F_R, the wall friction coefficient lambda_f can be calculated as follows:

$$\frac{F_R}{V} = \varphi \cdot \frac{\lambda_f}{d_{hyd}} \cdot \rho \cdot u \cdot |u| \qquad (1\text{-}7)$$

In the formula, φ—the friction correction factor depends on the cross section area of the pipeline. λ_f-friction coefficient of pipe wall. d_{hyd}--hydraulic Diameter of Pipeline

2.7 Friction and heat transfer calculation of elbow tube wall

In the calculation of elbow or abrupt pipeline, not only the friction loss along the pipeline but also the local pressure loss should be taken into account. The calculation formula is as follows:

$$\Delta p = \xi \cdot \frac{\rho \cdot u^2}{2} \qquad (1\text{-}8)$$

In the formula, ξ-- is a function of sum theta.

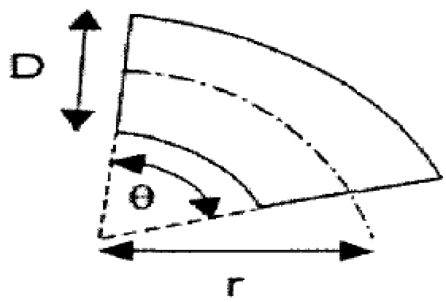


Fig.3 Schematic diagram of elbow

In the process of heat transfer in elbows, the following modifications are made

$$N_{u.b} = N_{u.s} \cdot F_B \qquad (1\text{-}9)$$

$$F_B = 1 + \frac{2 \cdot L_{pipe}}{{R_e}^{0.14}} \cdot d_{hvd} \cdot d_B \qquad (1\text{-}10)$$

In the formula, b-subscript denotes elbow; ξ--local pressure loss coefficient; L_{pipe} --pipe-length; d_B-bending diameter.

2.8 Heat Transfer Law of Air Cooler

Air temperature will rise after compression. In order to improve the combustion quality of diesel engine, it is necessary to cool the supercharged air to improve the intake quality. Therefore, it is necessary to introduce an air cooler. For air cooler, it can be regarded as a heat exchanger in terms of its function, and the heat transfer capacity can be expressed as:

$$Q = M_a \cdot C_p \cdot (T_{a\,in} - T_{a\,out}) = M_a \cdot C_p \cdot \Delta T \qquad (1\text{-}11)$$

In formula Q: thermal load. M_a: Air quality flow. C_p :Specific heat capacity of air at constant pressure. $T_{a\ in}$、$T_{a\ out}$:indicate the inlet and outlet temperatures of air coolers. The cooling efficiency of air coolers is as follows:

$$\eta_{\text{cool}} = \frac{T_{a\ in} - T_{a\ out}}{T_{a\ in} - T_{cool}} \quad (1\text{-}12)$$

In formula: η_{cool}: is the cooling efficiency and T_{cool} is the cooling medium temperature.

3. SYETEM IMPLEMENT

3.1 Overview of System Implementation

In order to realize the normal operation of marine diesel engine intake and exhaust system, not only the correct mathematical model, but also the correct response sequence and logical control model are needed as the support. By modeling the exhaust gas turbocharger, pipeline, cooler and filter in the intake and exhaust system, and through the interaction of mathematical models, the flow, pressure, temperature and other parameters can be output in the simulation equipment when the data are input. The development process of system fault simulation is shown in Figure 4.

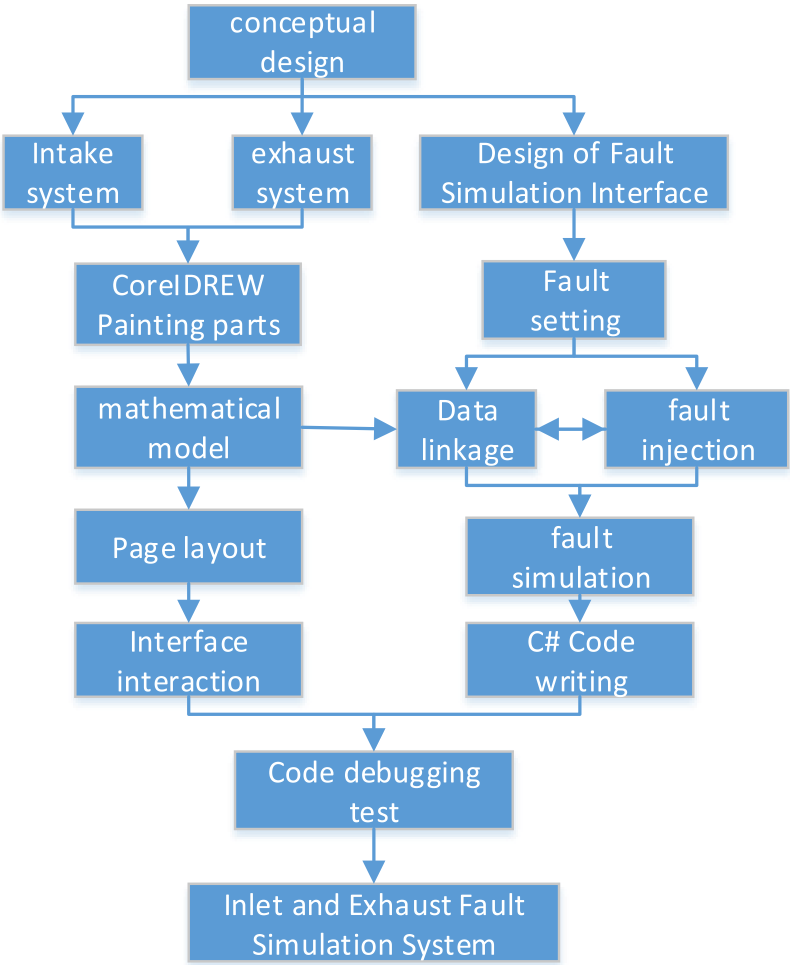


Fig.4System Development Flow Chart

3.2 Data linkage in the system

In the system, the relevant parameters of each component are constantly changing, and the parameters of other parts of the system will change after a fault occurs in one part. After establishing the correct mathematical model, the system runs under given conditions, and the results of the system are judged according to the logical control model, and finally the real-time parameters of the mathematical model are displayed. The system uses PID control [9,10]. Figure 5 shows the block diagram of the PID control algorithm.

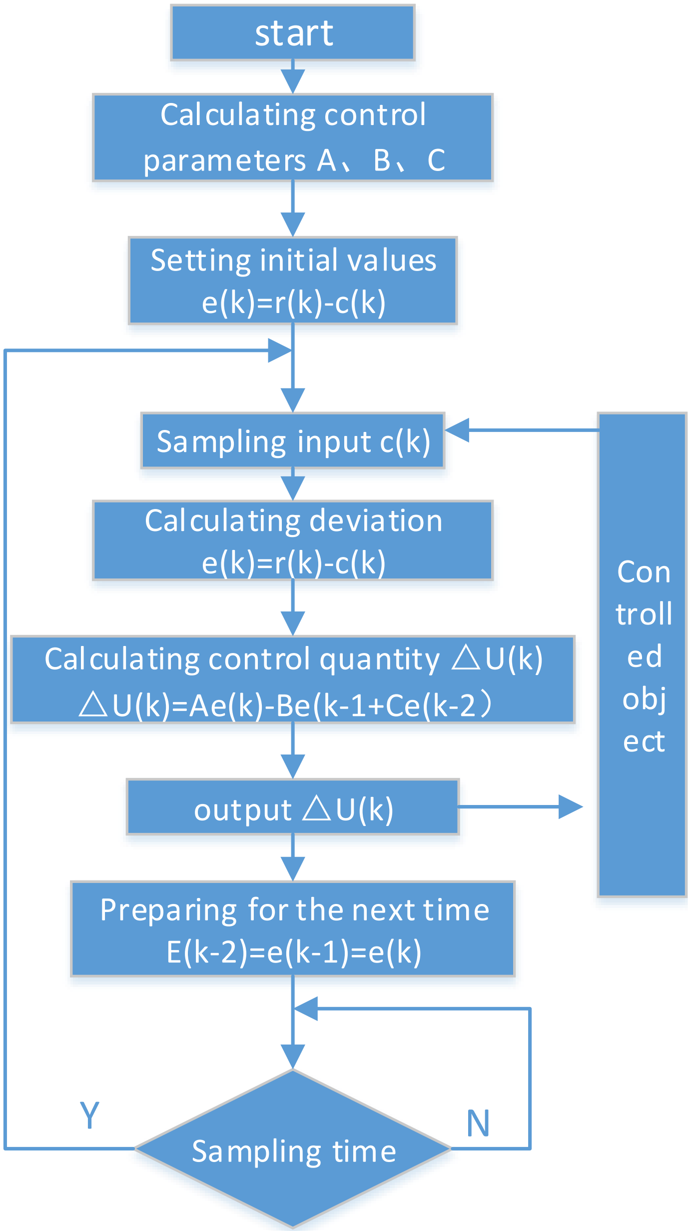


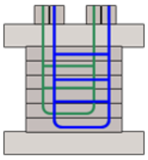
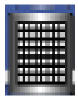
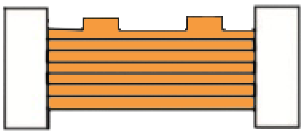
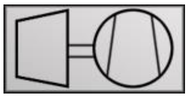
Fig.5The block diagram of the PID control algorithm.

3.3 Main Structure and Interface Design of the System

The system is mainly composed of intake system, exhaust system and fault simulation system. Each subsystem has the functions to be realized by each subsystem. Each function needs to establish links with the database, read data from each other, and then present on the system interface.

CoreIDRAW is used to draw the control of water pump, pipeline, button, valve and instrument in the intake and exhaust system. Component technology is used to increase the reusability of the code to meet the design requirements of the system.

Tab.2Drawings of Intake and Exhaust Systems

		
a. Freshwater cooler	b. Thermostatic valve	c. Filter
		
d. Fresh water pump	e. Inlet and Exhaust Heaters	f. Supercharger

4. BRIEF INTRODUCTION OF SYSTEM FAULT EXAMPLES

4.1 Fault Interface Description

In the fault interface of pneumatic system, the basic idea of design is to select faults. There are two buttons to choose in the interface, one is fault injection, click the fault injection trigger drop-down box, select the fault to be simulated in the drop-down box; the other is fault reset, click the fault reset, you can eliminate the set fault, make the system work normally. The most important part of the interface is the function of curve display. It can read data in the form's mathematical model, simulate the changes of the parameters of the fault points according to the set faults, and display them in the form of curves.

There are many kinds of faults in the system, and the system can be changed slightly according to the need. The following is an example of the wear fault and fault of supercharger bearing to show the effect of the system after completion.

4.2 Wear Failure of Supercharger Bearing

Figure 6 simulates the wear failure of supercharger bearing. Fault from the normal situation to the specific situation of the panel when the bearing wear failure of the supercharger occurs. In the figure, we can find that the speed of turbocharger is stable at 1700 r/min and the temperature of exhaust gas passing through turbocharger is also stable at 320 C when the bearing is working normally. When bearing wear occurs, the speed of turbocharger decreases obviously, while the exhaust gas emission temperature is on the high side. After 6 seconds or so, the speed and temperature of turbocharger tend to be stable. If the trainee has no other operation, the failure will continue.

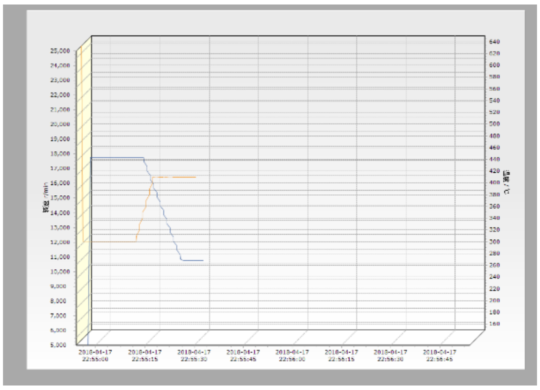


Fig.6Turbocharger Bearing Wear Failure

Figure 7 simulates the process of pressurization from normal operation to bearing wear and then reset. It can be concluded from the figure that when the wear fault of the supercharger bearing is reset, the fault is quickly eliminated and the speed and temperature under normal conditions are restored.

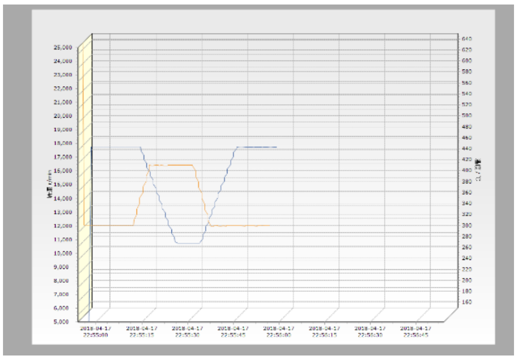


Fig.7Reposition of Turbocharger Bearing Wear Failure

5. CONCLUSION

1) The pneumatic simulation system can simulate the abrasion of seawater pump and dirty blockage of submarine door. It solves the high cost of traditional marine simulator and the limitation of site requirement. It is close to the real engine operation condition, and the system is easy to popularize. Based on this system, operators can be trained on pneumatic system faults, which can reduce the training cost to a certain extent and improve the training efficiency of operators. The simulation results of the system are accurate, the mathematical model is mature and reliable, and there are many application cases. The scheme is feasible.

2) This paper takes into account as many relevant factors as possible, but due to the coupling effect of various subsystems such as ship fuel system, lubricating oil system, cooling water system and so on, this reduces the simulation accuracy of the aerodynamic system to a certain extent. In the future, models will be established and decoupled for each subsystem, and the simulation process will be continuously improved and improved.

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