Simulation Analysis of Experiment Vessel of Explosion-Proof Valve

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Abstract: With the booming development of the shipbuilding industry, ship design process more and more attention to the design of marine diesel engine explosion-proof valve. However, the research on the explosion-proof valve has been stuck in the test of the state of the explosion gas outlet, and the relevant experimental data for the state of the explosion gas entering the explosion-proof valve is lacking. In this paper based on the CFD simulation platform, the explosion of the test vessel of the explosion-proof valve test system is simulated. And the explosion process of premixed gas in test vessel is effectively simulated by establishing the basic combustion model of gas combustion explosion, using the symmetry of the container, and giving the reasonable boundary conditions. The process simulation of gas explosion pressure data and pressure data measured by explosion experiments comparative analysis proved the reliability of the simulation results, provided the initial conditions for further study of the explosion-proof valve, a very important reference for the further study of the explosion-proof valve.

1. Introduction

The standard requires every newly designed explosion-proof valve, which is widely used in various industries, need to go through explosion test to guarantee its function of extinguishing flame and releasing pressure. The explosion test is finished on the platform of the explosion-proof valve test system by igniting and exploding the premixed gas. Additionally, it is mainly judged by observing whether the flame has sprang out of the explosion-proof valve and whether there is the damage to the explosion-proof valve.

Obviously, the explosion-proof valve test system is the basis for the test of the explosion-proof performance of the explosion-proof valve. Therefore, the national shipping industry standards have clear specifications for test schemes, test equipment and test results. Reference introduced the development of explosion-proof valve specification for marine diesel engines and IACS UR M9, M10, M66 specifications developed by the International Classification Society as well as safety protection measures of explosion-proof valve. Reference introduced the working principle of explosion-proof valve, that is, the flame in the crankcase was extinguished due to overheating after it passed through the explosion-proof valve, which reduced the pressure inside the crankcase and the explosion damage. Comparing the properties of explosion-proof valves assembled with different quantities of laminated flame retardants and orifice flame retardants through test methods, Wang Wenquan et al. found out the test methods and test conditions. Huang Lixian et al. carried out the test research of explosion-proof valve, designed a set of explosion-proof valve test device which met the requirements of ship regulations, and successfully completed the performance test of explosion-proof valve. Xu Jianping
et al. invented a set of explosion-proof valve test system, which adopted the negative pressure gas distribution method to save the tedious steps of gas distribution. At the same time, this method obtained the more accurate methane concentration (9.5%). The gas mixture is more uniform, which meets the test requirements of explosion-proof valve.

The state of the exit of the test container of the explosion-proof valve test system is the state of entry into the explosion-proof valve. As the working object of explosion-proof valve, it is important to study the performance of explosion-proof valve. However, since there is a lack of relevant data, it is necessary to study the state of the gas explosion in the test container.

2. Explosion-proof valve test system

The composition of the typical explosion-proof valve test system is shown in Figure 1. Label 1 to 15 in Figure 1 are Test vessels, pressure gauges, amplifiers, data acquisition cards, computers, ignition systems, thermocouples, pressure sensors, spark plugs, mixed gas cylinders, various valves and vacuum pumps respectively. The end of the test container has a hole for installing the explosion-proof valve. The test vessel (also called pressure vessel) is the sealed vessel with high safety, which can bear pressure load [7-8], as shown in Figure 2. The explosion test was carried out in the closed container. The methane and air were premixed to the prescribed concentration and ignited. Then the explosive gas rushed out of the container, entered the explosion-proof valve and rushed into the air through the flame retardant of the explosion-proof valve. The explosion gas flame required to rush into the air had been extinguished.

The test container can be vertical and horizontal. The test container of the test system studied by Kindracki J [9] was vertical, whose height was 490mm, diameter was Φ340mm and volume was 0.04m³. As shown in Figure 2, the test vessel of the test system in this paper is horizontal, which includes the container, ignition device, gas (methane) concentration sensor, pressure sensor, etc. The size of the test container in Figure 3 was Φ1000mm×2000mm, the diameter of the opening hole at one end of the container was Φ135mm and the corresponding flange diameter was Φ650mm.

In the specific test, the air in the test container was emptied by vacuum pump and then filled with the mixture of methane and air with the volume concentration of 9.5%±0.5%. The ignition of the spark plug at the center of the vessel was used to lead in the exploration of the premixed gas. The gas concentration sensor at the end outlet was employed to measure the concentration of methane to meet the test requirements. By setting the pressure sensor at the center wall and the end outlet of the test vessel, the pressure values of the premixed gas from the center of the container to the end outlet into the explosion-proof valve at each time were obtained.

1-test container; 2-pressure sensor; 3-amplifier; 4-data acquisition card; 5-computer; 6-ignition system; 7-thermocouple; 8-pressure sensor; 9-spark plug; 10-mixed gas cylinder; 11-13 valves; 14-vacuum pump

Figure 1 Schematic diagram of explosion-proof valve test system
1-test vessel; 2-high-energy ignition device; 3-methane concentration measurement; 4-pressure sensor; 5-pressure, methane concentration sensor; 6-flange disc; 7-explosion-proof valve; 8-test film bag

Figure 2 Schematic diagram of typical test container

Obviously, the inlet condition of explosion-proof valve was provided by simulating the combustion of the explosive gas in the center of the vessel, propagating and rushing out of the container. Based on the simulation results, the boundary conditions of the explosion-proof valve were confirmed, which was more reasonable than the boundary conditions determined on the basis of the standard requirements. Therefore, it is necessary to simulate and analyze the process of ignition and combustion propagation of explosive gas in the center of the container.

3. Explosion gas simulation model

In the simulation of the combustion propagation process of explosive gas in the container, the following assumptions were made: (1) there were no obstacles in the container; (2) the mixed gas in the container was fully mixed before ignition and it was in the static state at room temperature; (3) the reactant and the product belonged to the ideal gas, which was accordance with the corresponding equation; (4) the specific heat capacity of the mixed gas conformed to the mixing rule; (5) the combustion process was irreversible; (6) the container model was regarded as the insulated model at the time of explosion; (7) the wall of the container was regarded as the rigid body without considering the coupling effect, that is, without considering the influence of the deformation of the container, the wall of the container was the boundary of the explosive gas.

Based on the above assumptions, the test container can be simplified into the axisymmetric structure formed by rotating the section along the central axis. The established two-dimensional calculation model of the test container is shown in Figure 4 and the computational model grid is shown in Figure 5. The grid quality diagram shown in Figure 6 was obtained by verifying the grid quality. It can be seen that the cross shape in the figure is the high quality refined Quadrilateral mesh and the rest parts is the large Quadrilateral mesh. The overall grid quality is better.

The test container has two states, including sealing and opening. When the pressure near the opening of the container is larger than the working condition of the explosion-proof valve 0.015MPa, the outlet of the test container is open under the exit boundary condition. When the pressure is greater than 0.015MPa, the exit boundary is set to Pressure-out manually; when the pressure is less than 0.015MPa, the exit boundary is set to Wall; other wall boundaries are set to normal temperature non-slip insulation wall. The initial condition is that the volume concentration of methane in the test container is 9.5%, that is, the mass fraction is 0.053 and the oxygen concentration is 0.21. At the distance of one third from the bottom of the container on the axis of symmetry, the bottom of the container on the axis of symmetry is the circle with a diameter of 50mm and the ignition temperature is 2000 celsius degree. The mixed gas is considered as the ideal gas. The combustion process is controlled by methane-air- 2step reaction mechanism in Fluent. Based on the k-ε model, the vortex dissipation conceptual model in the general finite rate reaction was selected and the volume reaction option was checked. Other settings include the selection of Transient transient options, the addition of Y negative gravity, the selection of component transport models, the use of EDC models and the check of relevant options. The calculation method of SIMPLE and second order upwind scheme was selected and the convergence condition (the residual error of all equations was less than $10^{-6}$) was set. Based on
the research method in reference [10], the subrelaxation method was used to monitor the change of pressure field of vessel and the change of outlet point pressure with time.

Figure 3 Three-dimensional model of pressure vessel and test vessel

Figure 4 Schematic diagram of two-dimensional calculation model of the test container

Figure 5 Grid of calculation model

Figure 6 Mesh mass diagram

4. Simulation results analysis of test vessel

Taking the simulation result of pressure as the analysis object, this paper analyzed the rationality of the simulation result via comparing the simulation and experimental results, which provided the flow field initial condition parameters for the subsequent simulation research of explosion-proof valve.

From Figure 7, it is found that pressure field in the test vessel changes rapidly as the time. At the beginning of the test, a pressure circle appears at the ignition of the test center. With the combustion of the gas, the pressure circle becomes larger and the clear pressure ring is formed. The maximum pressure on the ring is the most obvious, followed by the pressure in the ring, and the pressure outside the ring is smallest. The pressure field diagram changes from 210ms to 260ms is shown in Figure 7. With the increasing of time, the pressure ring gets bigger. After contacting the wall surface, the pressure of the wall surface becomes larger. The wall and bottom wall is red. After contacting the bottom wall, the pressure of bottom wall becomes large. The pressure on both sides of the wall will rebound and radiate, as shown in the pressure field of 268 ms in Figure 7. Then, the pressure mainly
develops towards the outlet, producing the outlet pressure, as shown in 275 ms of Figure 7. From Figure 7, it is seen that the pressure range at the exit is between 0MPa and 0.35MPa, which is consistent with the pressure value obtained by the test. The pressure is transmitted in a circular shape from the ignition with the form of pressure wave and it is deformed and spread after the collision of the wall.

The state of combustion gas pressure at the outlet position is the state of combustion gas at the inlet of explosion-proof valve. This not only solves the problem that the test system cannot reflect the pressure change in the test vessel, but also provides the initial pressure range for the simulation research of explosion-proof valve flame retardant plate.

In summary, the comparison between the simulation results and the experimental results shows that the simulation results can reflect the internal changes of the explosion-proof valve test vessel and the rationality of the simulation is verified to a certain extent. Therefore, the established combustion simulation model and the calculation method are feasible. Their results are helpful to analyze the antihypertensive flame retardant and flame extinguishing performance of explosion proof valve flame retardant sheet. Based on the change of pressure field caused by combustion and explosion of mixed gas in container, the boundary conditions of flame retardant plate simulation of explosion-proof valve are more accurate.

5. Conclusions
This paper studied the explosion simulation of the test container of the explosion-proof valve test system. By establishing the basic model of gas combustion and explosion, using the approximate symmetric model and constructing reasonable boundary conditions, the explosion process of premixed gas in the test container was simulated effectively. The analysis of the paper is helpful to understand and analyze the flow field of flame entering explosion-proof valve and make the simulation result of explosion-proof valve closer to the actual situation, which provides reliable initial conditions for the next step of explosion-proof valve simulation and lays a foundation for further research.

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