Structural Design and Numerical Analysis of the Electric Explosion Valve for Quick-opening Marine Gas Cylinder

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Keywords: Marine cylinder, the electric explosion valve, mechanical linkage, quick opening.

Abstract: To meet functional requirements of the electric explosion valve for quick-opening marine gas cylinder, a quick, reliable and safe opening mechanism is designed, which is driven by electric explosion pressure. The structures of electric explosion cavity and over-pressure exhaust are designed respectively to assure the fast sex and security. The article analyses detonation pressure of squib start. The mechanics calculation and strength check are conducted to the electric explosion valve opening and closing. Finally, stress conditions of the safety diaphragm are simulated and analyzed. The results indicated that the designed the electric explosion valve of quick-opening marine gas cylinders responds rapidly and stable performance that can address the needs of the security, reliable and fast input for naval ship fire fighting system, rationality of the mechanism design of the electric explosion valve is confirmed. It has much more practical value in engineering.

1 INTRODUCTION

The electric explosion valve is the key component of naval ship sprinkler system as a control valve and plays a role in controlling gas in the system. After research, it found that the universal electric explosion valve is bulky, complex, slow response and poor stability naval ship fire fighting system, and it's difficult to meet the requirement of rapid opening of pneumatic valves and other equipment in special places such as ammunition depots and oil depots, which affects the performance of the whole spray system seriously. In this paper, a kind of the electric explosion valve of quick-opening marine gas cylinders is designed, which uses detonation pressure caused by the electric explosion valve detonation. Then the mechanism can be opened fast by mechanical linkage between the components. It characterize by its simple structure, small volume, fast reaction speed, high reliability, etc.

2 FUNCTIONAL REQUIREMENTS ANALYSIS

The marine cylinder is used to store compressed air and provide a driving gas source for pneumatic valve opening. The electric explosion valve can realize starting control and media isolation of marine cylinder. As an isolation valve, the electric explosion valve is the key component of marine cylinder, which is normally close on standby. Once request signal is received, the electric explosion valve will be detonated instantaneously, driving the valve body to open. At this point, compressed air in the cylinder discharge rapidly under the high voltage, achieving the function of fast gas supply about marine cylinder. The electric explosion valve is the key component of the spray system , which directly influence the vitality of naval vessel and various high-risk places.

3 QUICKLY OPEN THE ELECTRIC EXPLOSION VALVE FOR MARINE GAS CYLINDER

3.1 The Electric Squib

In general, marine cylinders are located in equipment tanks or ship corridors, therefore, reliable remote control is required when opening, so it is necessary to provide the opening power. we adopt ignition that is electric detonator in accordance of a small footprint, fast opening speed, secure and requirements. It has the characteristic by small volume, light weight, great power and high adaptability to circumstance.

On duty, once request signal is received, the electric explosive valve will be detonated instantaneously. The high-temperature and high-pressure air produced by detonation with rapid pressure rise. The electric explosion valve opens mechanically under the action of the detonation pressure of the electric detonator. Ignition timing of the electric detonator tube can reach millisecond, characterized by quick, powerful and small scope of action. It can not only meet the need of quick opening , but also ensure the safety and reliability of use.

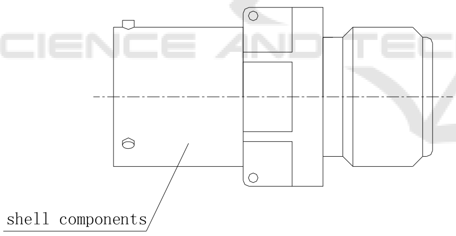


Figure 1: The structure diagram of electric tube.

3.2 Mechanism Design

According to the functional requirements and characteristics of the electric detonation tube, the electric explosion valve of quick-opening marine gas cylinders is designed, which is mainly composed of electric explosion cavity, safety diaphragm, piston, crank, rotating shaft, pressure arm, valve core, etc, as shown in Figure 2.

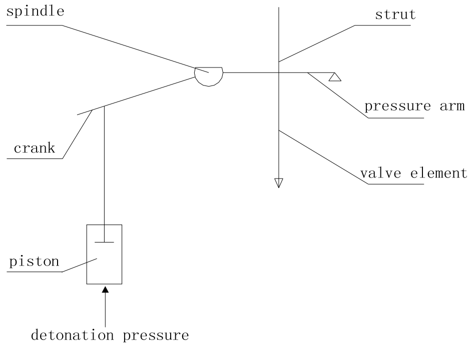


Figure 2: The schematic diagram of electric valve device.

(1) Electric explosion cavity

The electric explosion cavity is designed on the electric explosion valve, and the effective isolation was realized between the electric detonation chamber and the valve body cavity. To ensure that the gas flow into the piston cavity while the explosion debris is isolated by the angle design between the electric explosion cavity and the piston bore. The electric detonation tube is installed on the electric detonation chamber to ensure the rapidity of the electric explosion valve.

Safety diaphragm

In order to prevent the cylinder from cracking due to high pressure, over-pressure exhaust structure is designed, the main principle of which is to install the safety diaphragm in the over-pressure exhaust structure. To ensure the cylinder intact and the personal security, the safety diaphragm will burst automatically, releasing the gas in the cylinder, when pressure in the Marine cylinder exceeds the set pressure value of 13MPa~15MPa.The design of safety diaphragm realizes the security features of the electric explosion valve. The schematic diagram of the over pressure exhaust structure is shown in Figure 3.

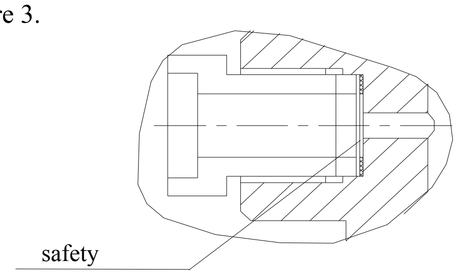


Figure 3: The diagram of over pressure exhaust structure.

3.3 Operating Principle

There are three types of working conditions: closing, opening and inflating.

(1) Closed state

Because the marine cylinder will supply the air source for the pneumatic valve only when spraying, the electric explosion valve is normally closed. In the initial state, the detonator tube is not activated. The crankshaft is driven to rotate, so that the shaft is locked with the pressure arm, and then the pressure bar is manually turned. At this point, the valve core is pushed down and the vent is closed, so that the valve is closed, as shown in Figure 4.

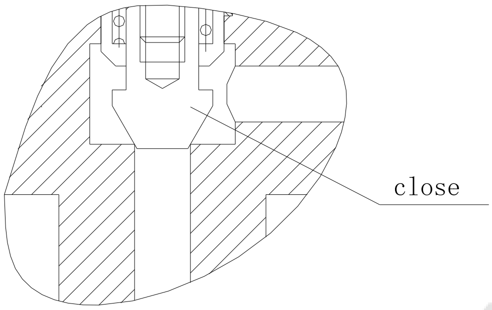


Figure 4: The diagram of electric valve closed state.

(2) On state

In case of danger, the electric explosion valve should be opened reliably when the marine cylinder needs to provide air source. At this point, the detonator explodes when an electrical signal is received. The resulting explosive pressure pushes the piston up and the piston rod hits the crank. The crank turns the shaft, forcing the shaft to separate from the buckle of the press arm. The compression force on the valve core is released, and the pressure arm rotates, causing the pressure bar to turn over. Meanwhile, the valve core moves up rapidly under the action of spring force, the valve opens, and the compressed air is sent out. The opening linkage design of the electric explosion cavity, the spring structure and the electric explosion valve mechanism realizes the fast and reliable opening of the Marine rapid opening gas cylinder electric explosion valve. In addition to the electric detonation drive, Marine quick-opening valve of cylinder can also be manually opened by turning crank, as shown in Figure 5.

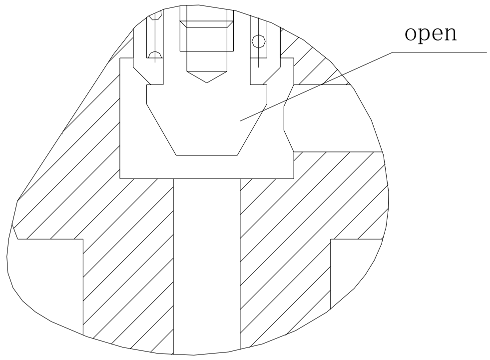


Figure 5: The diagram of electric valve open state.

(3) Plenum

The marine gas cylinder needs to be refilled by use or other reasons, which causes drop in pressure. By Rotating the hand wheel, drive the needle valve stem and make the needle valve center move to the right. Finally, needle valve is open and the air vent is connected to the cylinder(as shown in Figure 6). The cylinder is filled with compressed air from air vent by the ship's air source. The needle valve will be closed when the pressure in the cylinder reaches the set value. At this point, the ship's cylinder is in normal standby.

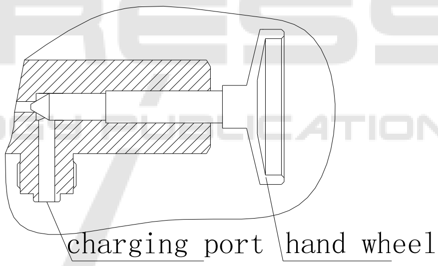


Figure 6: The diagram of electric valve inflatable state.

4 NUMERICAL ANALYSIS

4.1 Analysis of Detonation Pressure During Explosion of Electric Detonator

The electric detonation tube contains detonators, transition agents and main charge agents, including C, H, N, O and other elements. Chemical reaction equation of explosives:

$$C_aH_bN_cO_d \rightarrow \frac{1}{2}cN_2+\frac{1}{2}bH_2O+(\frac{1}{2}d-\frac{1}{4}b)CO_2+(a-\frac{1}{2}d+\frac{1}{4}b)C \quad (1)$$

The explosive pressure of ammunition is related to charge density, ammunition composition and calculate reaction. Engineering calculation formulas of detonation pressure:

Formula of explosive detonation velocity is as follows.

Type: Pj is explosive pressure, GPa; ρ0 is ammunition composition, g/cm3; D is detonation velocity, km/s; Φ is property value of ammunition; N is the amount of gas produced per gram of explosive, mol/g; M is the average molar mass of the gas component of the explosive, mol/g; Q is the heat of chemical reaction per unit of explosive, J/g.

Including:

$$N = \frac{2c+2d+b}{48a+4b+56c+64d} \quad (5)$$

$$M = \frac{56c+88d-8b}{2c+2d+b} \quad (6)$$

$$Q = \frac{120.9b+197.7(d-\frac{1}{2}b)+\Delta H_f}{12a+b+14c+16d} \quad (7)$$

Type: △ Hf is the production enthalpy of explosives, J/g.

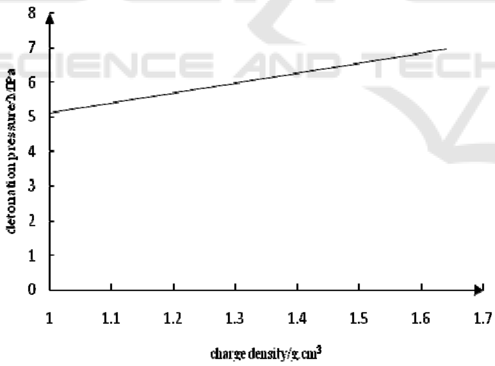


Figure 7: The relationship between blast velocity and powder density of TNT ammunition.

$$P_j = 1.558\varphi.\rho_0^{\,2} \quad (2)$$

$$D=1.01\sqrt{\varphi}(1+1.3\rho_0) \quad (3)$$

$$\varphi=N\sqrt{MQ} \quad (4)$$

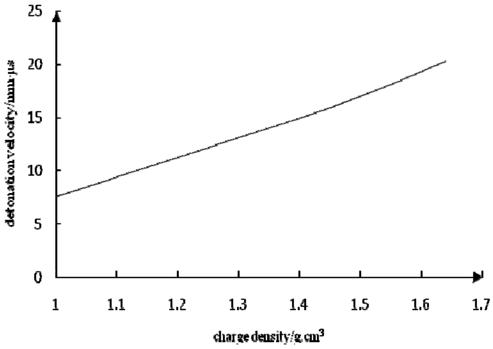


Figure 8: The relationship between blast pressure and powder density of TNT explosive.

It can be seen from the above that explosive property is closely related to charge density. As long as charge density of explosives is mastered, detonation speed and pressure of electric detonator can be determined accurately.

4.2 Force Analysis and Strength Check of Electric Explosion Valve Mechanism

(1) Closed state

The electric explosion valve is closed when the marine gas cylinder is on standby. At this point , the valve body is balanced by the friction of the CAM bite between the shaft and the pressure arm, as shown in Figure 9.

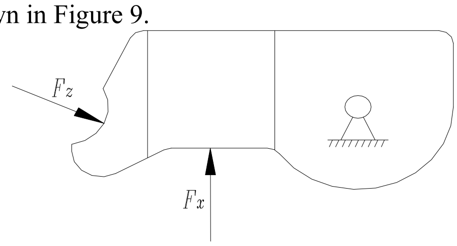


Figure 9: Force analysis of pressure arm.

The force exerted by the valve core on the pressure arm:

$$F_x=F_t+F_h \quad (8)$$

$$F_t = P_q S_1 \quad (9)$$

$$F_h = kx \quad (10)$$

Type: Fx is the force of the valve core on the pressure arm, kN; Ft is the force of air pressure on the valve body, kN; Fh is the force of spring on the valve core, kN; Pq is the pressure of the gas in the cylinder, MPa; S1 is the area of action of gas on valve body, m2; k is the spring coefficient, kg/mm; x is the spring compression amount, mm.

By analyzing bearing condition of arm under the closed state of the electric explosion valve, we find force of the shaft on the pressure arm using the lever principle.

$$F_x \times L_x = F_z \times L_z \quad (11)$$

Type: Fz is force of the rotating shaft on the pressure arm, kN; Lx is distance from Fx to the fulcrum, mm; Lz is distance from Fz to the fulcrum, mm.

(2) On state

When the electric detonator receives a certain current signal, the electric detonator ignites and explodes, breaking the balance. By overcoming the friction between the rotating shaft and the pressure arm, the pressure arm rotates and the pressure arm is separated from the rotating shaft. At this point, the valve core can overcome the gravity of itself and the pressure arm and the pressure bar and moves up rapidly under the action of spring elastic force and gas pressure in the cylinder. Results the compressed air in the gas cylinder flows out through the valve body outlet.

a. Force analysis

Since the crank is connected with the shaft by solid state, they can be regarded as a whole, so the crank bearing is the shaft bearing, as shown in Figure 10.

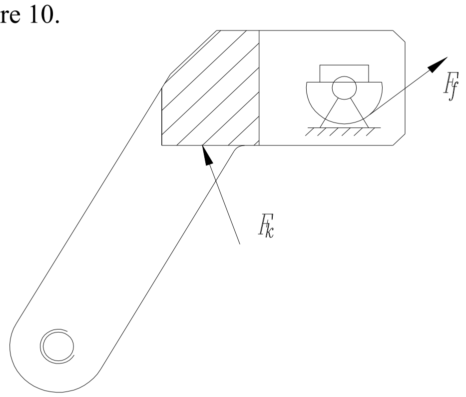


Figure 10: Force analysis of the axis and crank.

$$F_k \times L_k = F_f \times L_f \quad (12)$$

$$F_f = F'_z \mu \quad (13)$$

Type: Fk is the opening force required for the rotation of the rotating shaft, kN; Lk is the distance from Fk to the fulcrum, m; Ff is the static friction between the rotating shaft and the pressure arm; Lf is the distance from Ff to the fulcrum point; F'z Is the force exerted by the pressure arm on the rotating shaft; μ is the friction coefficient between the axis of rotation and the pressure arm.

Between the axis of rotation and the pressure arm is the force and the reaction force.

$$F_z = F'_z \quad (14)$$

Through equations (11), (12) and (13), the opening force F_k required for the rotation of the rotating shaft can be obtained.

$$F_H = P_j S \quad (15)$$

Type: S is the area of action of electric detonator explosion on piston.

When the explosion pressure is greater than the of the opening force, the electric explosion valve can be opened quickly in linkage.

Strength check

The strengths of crankshaft and spindle are checked because they bear the maximum stress at the moment of explosion pressure. Crankshaft and spindle are stainless steel with the following characteristic parameters:

a) Elastic modulus: E=2.06 * 1011Pa;

b) Poisson's ratio: u=0.3;

c) Yield strength: σ s⩾ 540MPa.

According to the conditions above, finite element modeling is carried out for cranks and spindle. The model size is in mm and the stress is in Pa, as shown in Figure 11.

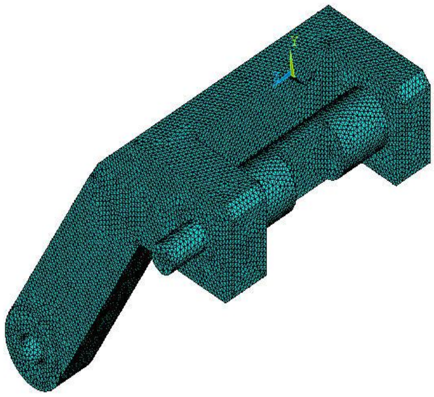


Figure 11: Finite element model of crank and shaft.

The forces of crankshaft and spindle are analyzed, when a certain explosion pressure is applied. The strengths of crankshaft and spindle can meet the demand when the force of crankshaft is not greater than its yield strength, so it is reasonable. The detonation pressure of the electric detonator tube is about 15MPa, which imposes a constraint on the contact surface of the rotating shaft and the pressure arm. At the same time, 15MPa detonation pressure is applied to the contact point between crank and piston rod, as shown in Figure 12.

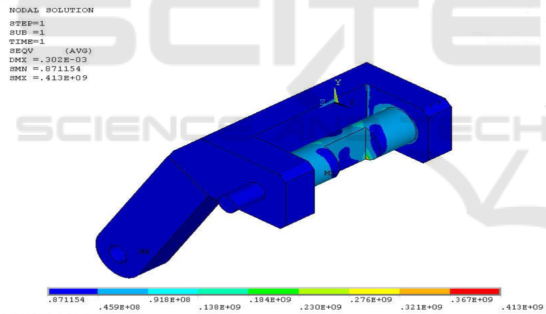


Figure 12: Pressure distribution of crank and spindle.

As you can see from the figure above, the maximum stress value of crankshaft and spindle is 413MPa, which less than yield strength. The results demonstrate that it meets the requirements of design .

4.3 Simulation Analysis of the Safety Diaphragm

The safety of the safety diaphragm is determined by blasting under certain pressure. Blasting can be realized when pressure is greater than tensile strength.

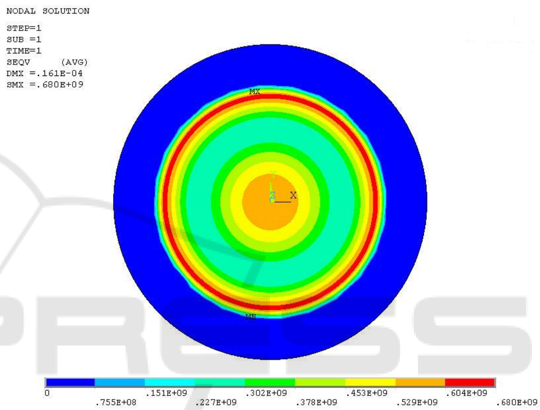
In order to ensure that the gas pressure can be discharged safely between 13MPa to 15MPa, the appropriate safety diaphragm needs to be selected. The pressure resistance of the safety diaphragm is related to its materials and thickness. Here, the material of the safety diaphragm is tin bronze, and its characteristic parameters are as follows.

a) Elastic modulus: E=1.24 * 1011Pa;

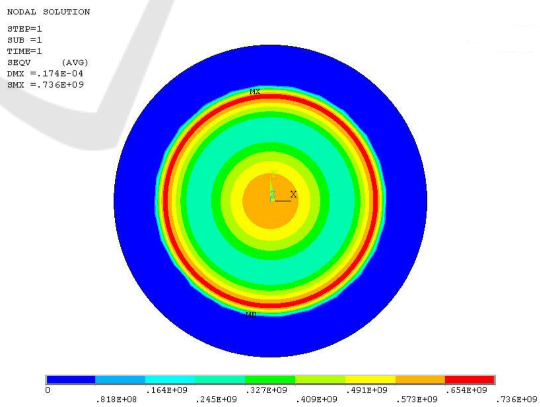
b) Poisson's ratio: u=0.34;

c) Tensile strength: σ b= 700-800MPa.

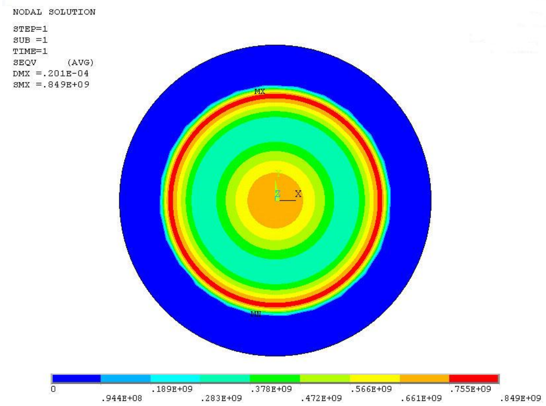
According to the conditions above, finite element modeling and force analysis are carried out for the safety diaphragm.The model size is in mm and the stress is in Pa. As the thickness of the safety diaphragm is only 0.1 mm, shell element PLANE63 is adopted. One side of the safety diaphragm is restrained from contact with the pressure ring, and different forces are applied on the other side, as shown in Figure 13.



a)12MPa.



b) 13MPa.



c) 15MPa.

Figure 13: Pressure distribution under different pressure of the safety diaphragm.

As you can see from the figure above, the contact part between the safety diaphragm and the pressure ring has the maximum force. At 12MPa, the maximum stress is 680MPa, less than σ_b, then the safety diaphragm does not burst; At 13MPa, the maximum stress is 736MPa. Within the range of tensile strength, so it may be blasting; At 15MPa, the maximum stress is 849MPa, more than σ_b, which satisfies the blasting condition.

5 CONCLUSIONS

The electric explosion valve for quick-opening marine gas cylinder is one of the important parts of spray system. In this paper the following conclusions are made through mechanism design and numerical analysis:

(1) The mechanism is designed with electric explosion chamber and over-pressure exhaust structure. By means of electric detonation tube drive, spring structure, lever principle and mechanical linkage, the electric detonation valve can be. Some features including reliable closed, security inflatable and rapid opening quickly are implemented.

(2) It is proved that the characteristics of the electric explosion valve are simple structure, little volume, quick response and high reliability through numerical analysis of the closed and open state of the valve mechanism, and strength check of crankshaft and spindle with the maximum force..

(3) The safety of the valve is verified through the finite element simulation analysis of the force of the safety diaphragm. At the same time, the electric explosion is a more practical marine mechanism and recycled.

(4) The electric explosion valve for quick-opening marine gas cylinder can be applied to marine compressed air cylinder. In addition, the method of mechanism design and numerical analysis can also be applied to the design of valve body structure on marine cylinders such as inert gas, corrosive gas and various liquids.

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