IOP Conf. Series: Materials Science and Engineering **394** (2018) 032052 doi:10.1088/1757-899X/394/3/032052

Design Research of the Double Rupture Disc Safety Relief Device Used on the Long Tube Trailer

Qingwei Yu[a], Hu Hui[*] and Jianguo Gong[b]

School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai, China

*Corresponding author e-mail: huihu@ecust.edu.cn, [a]yqingwei@163.com, [b]jggong@ecust.edu.cn

Abstract. Safety relief device is one kind of safety accessories, which can ensure the safety of transportable pressure special equipment. As a common safety relief device for long tube trailer cylinder, rupture disc cascaded with fusible plug device was fund failure to release in time in the case of fire and abnormal action under conditions, so its safety and applicability are questionable. Double rupture disc safety device is a new kind of safety device used on the long tube trailer cylinders, compared to the traditional rupture disc cascaded with fusible plug device, which has better anti-fatigue and safety performance. However, the lack of corresponding design and test method limits the application of the double rupture disc safety device used on the long tube trailer. This paper gives a new practical design of double rupture disc safety device including structure design, verification of discharge area, and the leak detection system, to provide guidance for the engineering design and development of the double rupture disc safety relief device. Experiment verification is conducted, and the results indicate that the double rupture disc safety relief device meets the requirements of operating performance.

1. Introduction

The development of new clean energy is an inevitable choice for China to ensure energy security, protect the ecological environment and respond to climate change. Natural gas, as an energy saving and environmental friendly clean energy, has significant economic and social benefits, and has been widely promoted. According to statistics, by the end of 2014, the amount of natural gas vehicles in China has reached to 4 million 955 thousand, the gas station is nearly 7000, and the state plans to build 12000 gas station by 2020 [1].

Storage and transportation technology is crucial to the development of energy. Due to the factors such as inflammable and explosive, strong mobility and complex road environment, once the accident happens, the consequence is unthinkable [2]. Long tube trailer is a commonly used vehicle for industrial gas. With the development of clean energy such as natural gas and hydrogen, long tube trailer cylinder has the development trend of large volume accumulation, complex medium and high parameter, and its safety needs to be paid attention to.

Safety relief device is one kind of safety accessories, which can ensure the safety of transportable pressure special equipment. At present, rupture disc cascaded with fusible plug devices are commonly

used on the long tube trailer, as shown in Figure 1. Fusible plug is used to solve the problem of abnormal action of safety relief device caused by the fatigue and corrosion of rupture disc, which also has the function of temperature control. However, related researches show that there is a problem of failure to release in time under fire condition and abnormal operation under normal condition in this kind of relief device [3, 4].

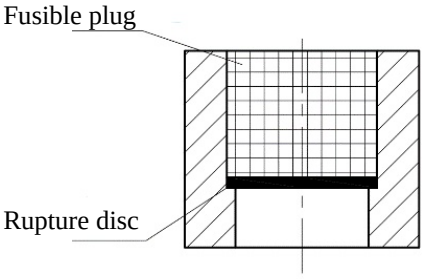

Figure 1. Structure diagram of rupture disc cascaded with fusible plug device

Therefore, it is necessary to research and develop new kinds of safety relief device, such as double rupture disc safety relief device. Double rupture disc safety relief device consists of two rupture discs, which are clamped in the holder in series. There is a vapor space between the two rupture discs, and a leak detection hole in the middle are shown in Figure 2. The double-disc structure has better fatigue and corrosion resistance, but it is seldom used in transportable pressure special equipment, and related research is lacked. This paper designs a new double rupture disc relief device used on the long tube trailer and a detailed case is given including structure design, verification of discharge area, and the wireless leak detection system. In addition, experiment verification is carried out to measure the bursting performance of the new double-disc safety relief device.

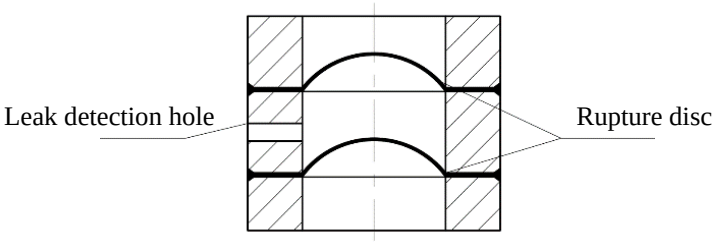

Figure 2. Structure diagram of double rupture disc safety device

2. Design requirements

One kind of long tube trailer cylinder is selected as an example, and the design parameters are shown in Table 1. Because of the particularity of the structure, the safety of gas cylinders is very important during transportation and filling. As one of the important safety accessories, the safety relief device must have enough safety and reliability. Overpressure is dominant factor of relief device action, and traditional rupture disc cascaded with fusible plug safety devices will release only if over-pressure and over-temperature at the same time, which causes the safety devices lagged action because of the fusible plug's melting delay. Based on the traditional rupture disc cascaded with fusible plug safety device, the new double rupture disc safety relief device replaces the fusible plug with another rupture disc in series to ensure the safety of relief device. Compared to the traditional one, double rupture disc safety relief device has more sensitivity than the traditional one, which also has better fatigue resistant and security performance.

Double rupture disc safety relief device for the long tube trailer cylinders must meet the following two requirements that the safety relief device can be discharged in time when the cylinder is over the set bursting pressure, and under the condition of bursting pressure, the safety relief device can not cause malfunction. At the same time, the double rupture disc safety relief device must be able to meet the requirements for safety discharge of gas cylinders.

Table 1. Design spec sheet of the long tube trailer cylinder

Working temperature[℃]	-40～60	Calculate volume[L]	2250
Normal operating pressure[MPa]	20	Air tight test pressure[MPa]	20
Hydraulic test pressure[MPa]	33.4	Minimum tensile strength[MPa]	720
Medium	CNG	Minimum yield strength[MPa]	500
Main material	4130X/30CrMo	Length of the cylinder[mm]	10975
Thermal treatment	Quench & temper	Diameter of the cylinder[mm]	559

3. Design of the double rupture disc safety relief device

3.1. Structure design

In order to guarantee the effect of discharge, the double disc holder adopts the straight through structure as is shown in Figure3. In order to facilitate the replacement of rupture disc, copper gaskets are used as sealing rings. At the same time, the rupture disc should not interfere with each other during operation. Therefore, the height of the junk ring between the two layers should be larger than that after the opening of the internal rupture disc and the internal rupture disc should produce fragments as few as possible after action, so as to avoid the damage of external rupture disc. According to GB567.2-2012 "Second Parts of Safety Device of Bursting disc: Application, Selection and Installation", the anti-arch strip groove rupture disc has the characteristics of good fatigue resistance, no fragments after opening and suitable for gas phase medium [4]. Therefore, anti-arch strip groove rupture disc is preferred for internal rupture disc. The requirements of external rupture disc are not excessive, so that normal arch type one is preferred for the external one.

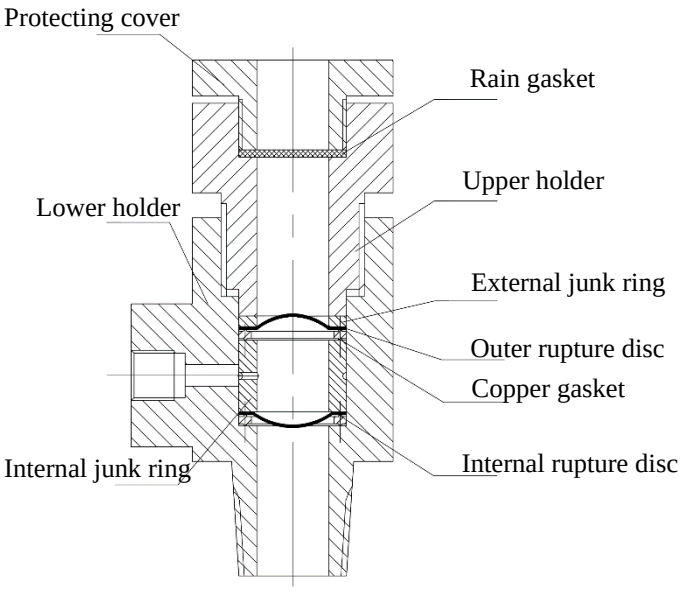

Figure 3. A schematic diagram of the holder of double rupture disc combined safety device

Because the design pressure of safety relief device is equal to hydraulic test pressure of the cylinder, both of the internal and external rupture disc is set to 33.4MPa. The nominal pressure of the long tube trailer cylinder is 20MPa, and the working pressure ranges from 15.2MPa to 26.2MPa according to different filling temperature. The internal rupture disc selects anti-arch strip groove rupture disc, the operating pressure ratio of which is 0.9, so as to meet the working pressure range.

A leak hole in the middle ring is opened to detect the pressure in the combined safety device by a pressure sensor, which would determine whether the internal rupture disc acting or not. In consideration of the problem of matching in the pressure relief hole, the ring groove is opened along the position of the hole to ensure that the internal pressure can be detected.

3.2. Verification of safety discharge area

Calculation of safety discharge should be carried out before verification of safety discharge area. The formula of safety discharge for non-thermal insulation non liquefied gas (permanent gas) is given in CGA S-1.1-2007 [5]:

$$W_{sGas} = 0.176 P_{Gas} V \sqrt{M_{Gas}} \tag{1}$$

W_{sGas} is the safety relief volume of the cylinders, kg/h; V is the volume of the cylinder, L; and M_{Gas} is the molar mass of the actual gas medium, g/mol.

The formula of rated discharge for a single safety relief device is:

$$W_r = 7.6 \times 10^{-2} CKpA \sqrt{\frac{M}{ZT}} \tag{2}$$

C is a gas characteristic coefficient, a function of the gas adiabatic index k; K is the discharge coefficient of the discharge device, 0.6 can be selected to be conservative; P is set bursting pressure (absolute pressure) for a rupture disc, MPa; A is the discharge area of the discharge device; M is the molar mass of the actual gas medium, g/mol; Z is the compression coefficient of the gas; T is the temperature of the discharge device, K.

Under overpressure condition, rated capacity of the safety relief device W_r should not be less than the safety relief volume of the relief device W_{sGas}. The minimum safety relief area under overpressure condition can be obtained through formula 1 and 2.

Under fire condition, the heat generated by external fire is input to the surface of the cylinder, which may cause the temperature of the bottle body too high in a short time to soften the material and cause the explosion. API521-2007 gives the a formula for the minimum effective discharge area of the pressure relief device for the container to store the supercritical fluid, gas, or steam under the exposure of the fire [6]:

$$A = \frac{F' A'}{\sqrt{p_1}} \tag{3}$$

A' is the area of the gas cylinder exposed to the fire, $A' = \pi DL$, which L is the actual length of the bottle body except the actual length of the two ends of the bottle and D is the outer diameter of the cylinder; p_1 is the discharge pressure of the rupture disc, MPa; F' is discharge factor, 0.045 can be selected when calculating.

Discharge caliber d can be calculated by the formula:

$$d = \sqrt{\frac{2A}{\pi}} \tag{4}$$

A is the minimum discharge area, mm^2.

Table 2. Verification results of safety relief area

Items	Overpressure condition	Fire condition	Verification value
Minimum discharge area *A*[mm2]	420.9	305.81	628.32
Discharge calibre *D* [mm]	16.37	13.95	20

Put the relevant parameters into the upper formula, the results of safety relief area of two conditions are shown in Table 2. Select discharge caliber of 20mm and the discharge area is 628.32mm^2, which is larger than the minimum discharge area both under overpressure and fire condition. The discharge caliber of double rupture disc safety relief device is 20mm, which can meet the requirements of safety discharge of cylinders both under overpressure and fire condition.

3.3. Design of the leak detection system

In order to monitor the pressure in the double disc safety relief device and remind users to change broken rupture disc in time, the wireless Bluetooth technology is used in the leak detection system. Figure 4 is the system block diagram of the detection terminal system. The whole system includes the pressure detection terminal and supervision terminal, as shown in Figure 5. The pressure detection terminal mainly includes the pressure sensor MIK-P300, the SCM STC12C5A60S2, the LCD 12864, the wireless Bluetooth module HC-05 and its peripheral circuit, etc. The supervision terminal contains the receiver of the mobile phone and the APP software of the mobile phone.

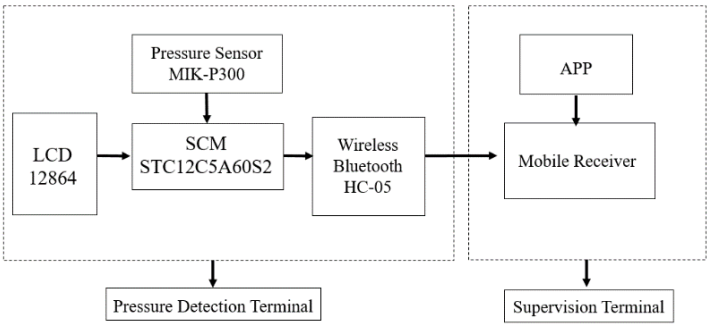

Figure 4. Block diagram of the detection terminal system

Figure 5. Leak detection system diagram

The principle of the leak detection system is that the pressure sensor transmits the pressure signal analog of the real-time detection to the single chip microcomputer, and the single chip processor is converted to digital by AD. After processing, it is displayed on the LCD12864 and sent to the receiver through the Bluetooth module HC-05. After receiving the signal from the cell phone Bluetooth, the APP of the mobile phone is displayed on the screen of the mobile phone, which alerts the overpressure situation in time and the replacement of the rupture disc of the combined safety device.

4. Experiment verification

Experiment verification is conducted to test the performance of the double rupture disc safety relief device. The bursting performance of double rupture disc safety relief device is tested according to the requirement of the bursting test of GB567.4 -2012 [5], and conducted on the self-developed manual bursting test bench, as shown in the Figure 6. The bursting test bench contains two loading circuits, which can be switched via high-pressure and low-pressure value. The experiment data is measured by the pressure sensor and recorded by a paperless recorder. The maximum pressure of the test bench is 100MPa.

The test temperature is at room temperature, and the test medium is hydraulic oil. The results of the test are shown in Table 3, and the bursting pressure in which is the final pressure after the double rupture disc bursting. Because of the short continuous bursting process of the double rupture disc safety relief device, the separated bursting pressure of the internal and external rupture disc cannot be given. According to the test results, the bursting pressure of the double rupture disc safety relief device is within the range of 31.5~33.2MPa, which meets the requirement of -10 to 0%, which is in line with the bursting performance requirements of the safety relief device. At the same time, the detection deviation of the detection terminal is within the range of -0.95 to -1.50%, which meets the design requirements.

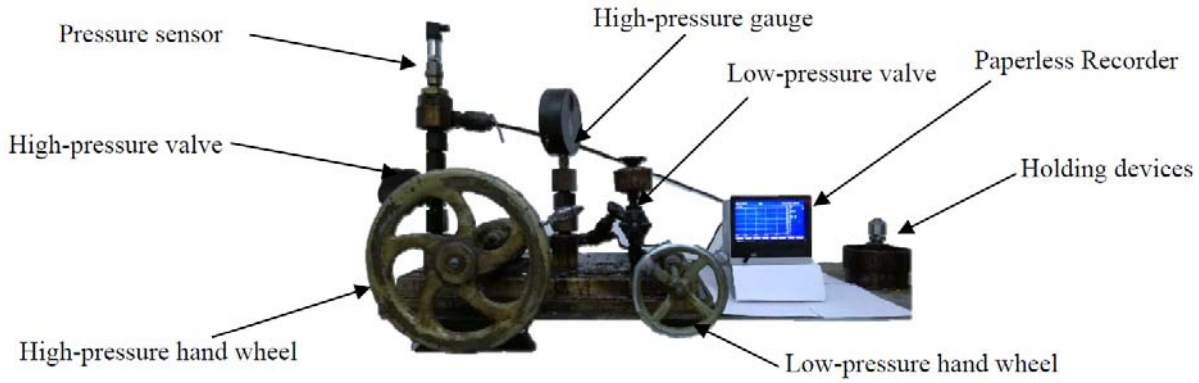

Figure 6. Physical diagram of manual bursting test bench

Table 3. Results of bursting performance test of double-disc discharge device

Number	Bursting pressure[MPa]	Monitor bursting pressure[MPa]	Bursting pressure deviation[%]	Detection deviation[%]
1	33.0	32.5	-1.20	-1.50
2	33.2	32.8	-0.60	-1.20
3	31.5	31.2	-5.69	-0.95

After experiment verification on the self-developed manual bursting test bench, the results show that the double rupture disc safety relief device can meet the operating performance requirements of the long tube trailer safety relief device.

5. Conclusion

Based on the analysis of design requirements of the safety device of the long tube trailer cylinder, this paper designs a new type of double rupture disc safety relief device used on the long tube trailer including structure design, verification of discharge area, and the wireless leak detection system. Experiment verification is carried out to measure the bursting performance of the new double rupture disc safety relief device, and the results show that it meets the requirements of operating performance. This paper provides guidance for the engineering design and development of double rupture disc safety relief device.

Acknowledgments

This work was financially supported by the National Key Research and Development plan "Special Fund for Research on the Key Technologies of Risk Control and Management of Transportable Pressure Special Equipment" (2017YF0805602).

References

[1] Information on http: //www.cir.cn/2/61/CNGYaSuoTianRanQiQiCheYuJiaQiZha.html.
[2] Sanjiang Liu, Zuzhi Chen, Bin Wang, Chaohua Gu, Qianghua Huang, Ke Bo. Research on the Key Technologies of Risk Control and Management of Transportable Pressure Special Equipment, J. Pressure Vessel Technology, 2017, 34 (10): 63-69.
[3] Ke Bo, Liang Chen, Zhewei Li, Guide Deng, Chunlin Gu. Safety Relief Device for Tube Trailer and Its Function in Fire Accident, J. China Special Equipment Safety, 2017, 33 (8): 24-28.
[4] Rifeng Zhou, Jianzhong Zhang, Jianliang Yu. Analysis and Countermeasures of Accidents of Abnormal Discharge of Rupture Disks on Long Tube Trailer of Gas Station, J. Safety Health & Environment, 2017, 7 (9): 5-9.
[5] Bursting discs and bursting disc devices. GB567-2012.
[6] Pressure Relief Device Standards Part 1-Cylinder for Compressed Gases. CGA S1.1-2011.
[7] Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries. API 521.