Research on spark discharge of floating roof tank shunt

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Abstract. In order to quantitatively analyze the spark discharge risk of floating roof tank shunts, the breakdown voltage of shunt has been calculated by Townsend theory, the shunt spark discharge experiment is carried out by using 1.2/50 μs impulse voltage wave, and the relationship between breakdown voltage of shunt spark discharge and air gap is analyzed. It has been indicated by theoretical analysis and experimental study that the small gap is more easily cause spark discharge than the big gap when the contact between shunt and tank shell is poor. When air gap distance is equal to 0.1 cm, average breakdown voltage is 5280 V. When the air gap distance is less than 0.3 cm, experiment data agree well with Townsend theory. Therefore, in the condition of small gap, Townsend theory can be used to calculated breakdown voltage of shunt. Finally, based on the above conclusions, improvements for avoiding the spark discharge risk of shunt of floating roof tanks have been proposed.

1. Introduction

With the development of world economy, consumption of oil is growing rapidly. The large floating roof tanks usually are used to reserve crude oil and the diameter of tanks is from 60 meters to 100 meters. Capacity is up to 150,000 cubic meters at the most. Because the area of floating roof is very large and floating roof is directly exposed in the air, probability of lightning strike increases obviously. If electrostatic charge in floating roof, which is induced by thundercloud, can not quickly discharge, the tank fire accidents could be caused by spark discharge of floating roof tanks. According to the incomplete statistics, 32.5 percent of 529 tank fire accidents are caused by lightning. The main discharge channel of lightning current and electrostatic charge in floating roof is shunts above the secondary seal [1]. In order to analyze the security and reliability of shunts, the risk of shunts is analyzed. Then, breakdown voltage of spark discharge between the shunt and the tank shell is calculated by the breakdown theory and the relationship between the breakdown voltage of spark discharge and the gap of the shunt is obtained by 1.2/50 μs impulse voltage test of shunt spark discharge, which provide the theoretical and experimental basis for the lightning protection design of the tank.

2. Risk analysis of the shunt

To make the floating roof move up and down, there is 200–300 mm gap between floating roof and tank shell. And in order to reduce the evaporation of the oil through the gap, the gap between floating roof and tank shell is equipped with both primary and secondary seals [2]. The shunts equipped on
secondary seals are bonded to tank shell by own elasticity (Figure 1) or extrusion of rubber scraper (Figure 2), which are not reliable electrical connections [3]. But it is difficult to ensure the perfect connection between shunt and tank shell in actual operation because of the following three main reasons.

- The geometry size of tank can be changed because of influence of climate and temperature in actual operation and the floating roof will move up and down with elevation and subsidence of oil level. All of these factors will cause drift of floating roof, which would cause the air gap between shunt and tank shell (Figure 3).
- Aging and deformation, which cause the air gap between shunt and tank shell, could occur on rubber scraper because of insolation, wind and rain erosion, sulfidation of vapor, etc. (Figure 4).
- Crude oil contains much sticky wax, which is easy to curdle on the tank shell. This will make the shunts electrically insulate from the tank shell.

Therefore, it is difficult to ensure the perfect connection between shunt and tank shell by own elasticity or extrusion of rubber scraper in actual operation. It is easy to form air gap between shunt and tank shell. In this case, if an air-gap spark occurs in a location with a small gap where the lightning creates a voltage large enough to cause electrical breakdown of the air or vapor/air mixture in the gap, it is easy to cause fire disaster [4].

![Figure 1. Shunt is bonded to tank shell by own elasticity.](image1)

![Figure 2. Shunt is bonded to tank shell by extrusion of rubber scraper.](image2)

![Figure 3. The air gap between shunt and tank shell.](image3)

![Figure 4. Aging and deformation of rubber scraper.](image4)
3. Theoretical calculation for spark discharge of the shunt

The breakdown voltage of spark discharge between shunt and tank shell can be calculated by gas discharge theory. There are two basic theories used to explaining the breakdown in gases. The two theories are popularly known as the Townsend theory and the streamer theory. Townsend theory is valid at low gas pressures and for small gap and the streamer theory developed in the contrary cases. According to the Townsend theory, the current that flows in a uniform field is expressed as follows [5]:

\[ i = i_0 e^{\alpha \gamma} \left[ 1 - \gamma (e^{\alpha d} - 1) \right] \tag{1} \]

where \( \alpha \) and \( \gamma \) are the Townsend’s primary and secondary coefficient [6], respectively, and \( i_0 \) is the primary current, and \( d \) is gap distance between shunt and the tank shell.

The medium between shunt and tank shell is air, so relationship between \( \alpha \) and electric field intensity \( E \) can be expressed as follows:

\[ \alpha = A p e^{-B p/E} \tag{2} \]

Where \( p = 760 \) Torr for 1 atm, \( A = 8 \) cm\(^{-1}\) Torr\(^{-1}\), \( B = 247 \) cm\(^{-1}\) Torr\(^{-1}\).

According to Paschen’s law, the breakdown criterion of air-gap between shunt and tank shell should satisfy the following equation [6-7]:

\[ 1 - \gamma (e^{\alpha d} - 1) = 0 \tag{3} \]

4. Spark discharge experiment of the shunt

4.1. Experimental waveform and environment

1.2/50 \( \mu \)s impulse voltage wave (Figure 4) is used to carry out spark discharge experiment. Wave head time of 1.2/50 \( \mu \)s impulse voltage wave generated in the lab is 1.2 \( \mu \)s \( \pm \) 30\% and semi-peak time is 50 \( \mu \)s \( \pm \) 20\%.

![Figure 4. 1.2/50 \( \mu \)s impulse voltage wave.](image)

During the experiment, air conditioner and dehumidifier are used to maintain stable lab environment. Temperature is 20–25 °C, relative humidity is 55%–60%, and atmospheric pressure is 101.8 kPa.

4.2. Experimental scheme

Figure 5 shows the setup for spark discharge of single shunt. Floating roof is insulated from the tank bottom by insulated material. Shunt is electrically bonded to floating roof through the bolt. 1.2/50 \( \mu \)s impulse voltage wave generated by impulse voltage generator is applied to the tank floating roof
bonded to shunt. The breakdown voltage between shunt and the tank shell is measured by a Tektronix DPO4104 oscilloscope. The spark discharge process of the shunt is recorded by a high-speed camera.

**Figure 5.** Schematic diagram of the spark discharge experimental.

### 5. Results and discussion

Figure 6 shows the spark discharge process recorded by the high-speed camera. Table 1 lists spark discharge breakdown voltage for the different gap distances. Table 1 shows that the smaller the gap, the smaller the breakdown voltage. The results indicate that the spark discharge in the small gap is easier to occur than in the big gap. When d is equal to 0.1 cm, the average breakdown voltage is only 5280 V. So spark discharge is easy to occur, when lightning stroke occurs on the tank. Therefore, we should try to avoid forming small gap between shunt and the tank shell and usually check and repair the shunts.

**Figure 6.** Spark discharge process recorded by the high-speed camera.

| Times | d=0.1 cm | d=0.2 cm | d=0.3 cm | d=0.5 cm | d=0.8 cm |
|-------|----------|----------|----------|----------|----------|
| 1     | 5439     | 8210     | 10227    | 13500    | 14500    |
| 2     | 5300     | 8190     | 10100    | 12900    | 15680    |
| 3     | 5100     | 7980     | 11600    | 12080    | 13500    |
| Average | 5280   | 8127     | 10642    | 12827    | 14560    |
Figure 8 shows the breakdown voltage as a function of gap distance. The air breakdown voltages calculated by Eq. (2) and Eq. (3) are compared with the corresponding experimental values in figure 1. The experimental data agree well with theoretical data for the air gap d=0.1 cm, 0.2 cm, 0.3 cm. But with an increase of air gap, the deviations between experimental data and theoretical data are increases correspondingly and experimental data are smaller than theoretical data. The reason of deviations is that Townsend theory is valid for small gap. Calculations and experiments indicate that the spark discharge breakdown voltage of small air gap for the shunt can be calculated by Townsend theory. The results are beneficial to the safe designs of tank, which can avoid lightning stroke spark discharge.

![Figure 8. Theoretical and experimental air breakdown voltages.](image)

6. Suggestions
In the actual operation, it is difficult to ensure reliable connection between shunt and tank shell and easy to form small air gap, because the tank is affected by the movement of the floating roof, mechanical stress, aging, oil, metal corrosion and other factors. In this case, the tank is struck by lightning, it would be easy to cause spark discharge. The following measures are recommended to avoid shunt causing the spark discharge.

- Detect oil-gas concentration around the shunt regularly.
- Strengthen the secondary sealing effect, replace the secondary seal of aging timely scraper, and control oil-gas concentration around the secondary seal.
- Cancel the shunt and install reliable electrical connection between floating roof and the tank shell if possible. The risk factors of the spark discharge will be eliminated virtually.

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