Research On Lightning Sparks Discharge and Protection Measures of Large Floating Roof Tank

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Abstract—**In order to avoid and greatly reduce floating roof tank fire accidents caused by lightning, theoretical analysis is carried out on shunts, mechanical seal structure and guide pole spark discharge in the oil and gas space. To study the problem of shunts spark discharge, a 2m diameter tank model was made to carry out simulation lightning experiment of shunts spark discharge. Experimental results show that shunts attached to the tank shell by its own flexibility can generate sparks when the lightning current flow reaches a peak value of about 400 Amperes. If there are gaps between shunts and the tank shell during lightning high voltage stock, potential difference between the roof and shell may breakdown the gaps and cause sparks. Lightning spark discharge on large floating roof tanks is inevitable if shunts are set as an interval of 3m according to the standard. Finally, according to the actual operation of the floating roof tank, some protective measures were put forward, such as removing the shunts, making mechanical seal structure insulating from the tank shell or using soft seal structure, connecting the floating roof and the tank shell by using more equipotential bonding wires, ensure a safe distance for the metal parts in the oil gas space, bonding scraping wax with floating roof, making the guide pole insulating from the floating roof, etc.**

Keywords-floating roof tank; spark discharge; second seal; equipotential bonding; Retractable Grounding Assembly

I. INTRODUCTION

With the increase of crude oil reserve in the world and the scale of tanks enlarging gradually, the risk of lightning on large floating roof tanks increases as well. According to a Swedish review about petroleum storage tank fires which occurred from 1951 to 2003, the number of tank fires reported by worldwide media is in the range of 15 to 20 each year, 31 percent of which is attributed to lightning[1]. Since 2006, 6 large floating roof tanks lightning fire accidents have occurred consecutively in China[2]. Researchers find some common features after analyzing these 6 accidents: the diameter of these tank roofs is 80~100m; all the fires occurred at the seal ring; the tanks are fitted with the primary and secondary seals; the primary seal is mechanical seal, and shunts are installed on the secondary seal; the oil and gas space between the primary and secondary seals is able to reach explosive limits.

II. THEORETICAL ANALYSIS

Because the scale of floating roof is very large and directly exposed to the atmosphere, the risk of direct lightning stroke increases obviously. Floating roof can induce a lot of static charges under the thundercloud. If there is a gap between the seal and the tank shell and the static charges can't discharge quickly during a lightning stroke, a tank fire may take place.

Shunts and the tank shell are connected by flexibility. However, for some reasons, it is difficult to achieve good electrical connection with the tank shell. Heavy components of crude oil, such as wax, tar, paraffin, etc., tend to coat on the inner face of the tank shell, which forms an insulation barrier between the shunts and the tank shell. If the inner face of the tank is painted, this also forms an insulation barrier similarly. Rust Corrosion on the inner face of the shell will create high resistance connection between the shunts and the tank shell. Large tanks are typically out-of-round by several inches. In the dimensions of the tank that are elongated, the shunts may be pulled away from the tank shell. Therefore, if the shunts and accessories are not in perfect contact with the tank shell, bound charge will take place and create an arc between shunts and the tank shell during a lightning stroke, and if a flammable mixture is present at the same time, a tank fire may occur.

The structure of the primary mechanical seal is similar with shunts, which are mainly composed of the metal parts, but these metal parts cannot guarantee a reliable electrical connection. As a result, discharge gaps are formed between active axis position or sealing shoe and the edge of the tank shell[3]. What's more, the roundness of the tank shell will influence the performance of the mechanical seal. All the reasons above can lead to the concentration of the gas and oil in the space between the primary and secondary seal, in which the concentration is high enough to reach explosive limits.

The space between the gauge or guide pole components and the floating roof is easily to form discharge gap, and the oil and gas concentrated here because of leakage can cause tank fires when the tank is struck by lightning.

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III. Experiment Study and Calculation Analysis

A. Experiment study

A floating roof tank model was made and simulation lightning strike experiment on shunts spark discharge was carried out in the laboratory. Experimental tank model is shown in Figure 1. The diameters of the tank and the floating roof are separately 2m and 1.6m. Shunts are elastic stainless steel pieces, which are 1mm thick, 300mm long, and 15mm wide and are connected around the tank shell.

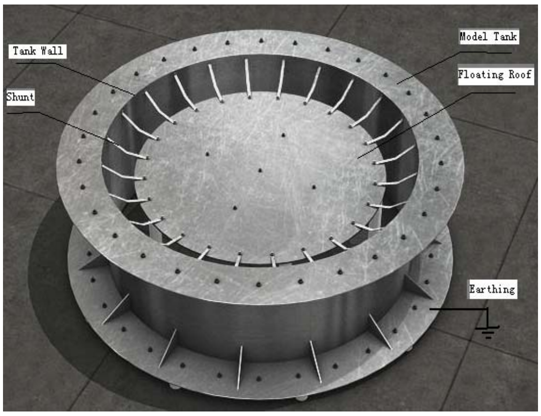

Figure 1. The tank model

1) Shunts sparks discharge experiment

The results of the experiment show that one shunt which was attached to the tank shell by its own flexibility started to generate sparks when 10/350μs or 8/20μs lightning current reached a peak value of about 400 Amperes. As the lightning current enlarges, the spark discharge level of shunts increases. The photo of shunts spark discharge is shown in Figure 2.

Figure 2 The photo of shunts spark discharge

According to NFPA 780，shunts on floating roof tanks are required to be installed above the seal at 3 meter (10 feet) distance around the tank perimeter and the purpose is to provide a conductive path from the floating roof to the tank shell[4]. However, theory and experimental studies have shown that large floating roof tanks spark discharge is inevitable if shunts are set as an interval of 3m according to the standard. The following Table1 lists the initial current value of spark discharge of large floating roof tanks.

TABLE I. THE INITIAL CURRENT VALUE OF SPARK DISCHARGE OF LARGE FLOATING ROOF TANKS

No.	**Volume** （$\times 10^4 m^3$）	**Diameter** （**m**）	**Number of shunts setting interval 3m**	**Tank initial current value of spark discharge** （**kA**）
1	5	60	62	25
2	10	80	83	33
3	15	100	104	42

2) Shunts gap breakdown discharge experiment

If shunts and the tank shell fit bad and form large and small air gaps, potential difference between the floating roof and the tank shell enough to breakdown the gaps and cause to sparks discharge when floating roof tank struck by lightning. The experiment uses the waveform of 1.2/50 μ s impact the floating roof. The experiment result shows it is linear relationship between the gap size and breakdown discharge voltage. Table II lists the initial voltage value of shunts gaps breakdown discharge of large floating roof tanks.

TABLE II. THE VOLTAGE VALUE OF SHUNTS GAPS BREAKDOWN DISCHARGE EXPERIMENT

The size of gaps（mm）	Breakdown discharge voltage（kV）
5.0	12.6
10.0	15.8
15.0	23.2
20.0	26.4
25.0	31.2
30.0	37.9

The experiment result shows that shunts are one of the main ignition sources of floating roof tank lightning fire. According to the standard API RP 545，the contact point of shunts on the tank shell should be submerged at least 0.3m below the surface of the liquid product[5~6]. This approach is difficult to detect and maintain and cannot guarantee a good electrical connection to the tank shell. So we suggest shunts should be removed away.

3) Retractable Grounding Assembly lightning Impedance experiment

Another lightning current discharge method is two static conductive cable next to escalator between the floating roof and the tank shell. After remove away shunts higher potential difference between the floating roof and the thank shell because of the high inductance of the cable as the tank struck by lightning. Symmetrically set more equipotential bonding wires may increase discharge path and reduce potential difference between the floating roof and the tank shell. Retractable Grounding Assembly is a good choice and can achieve the shortest wire connection between the floating roof and tank shell[7]. Retractable Grounding Assembly is shown in figure 3.

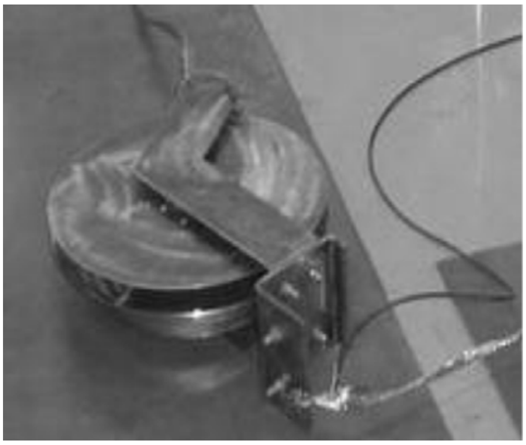

Figure 3 The expriment picture of Retractable Grounding Assembly

The experiment uses the waveform of 10/350μs impact Retractable Grounding Assembly. The cable of Retractable Grounding Assembly stretches out a different length. Experiment result shows that it is a linear relationship between impendence of Retractable Grounding Assembly and the stretched length of the cable. Retractable Grounding Assembly is a good choice and can achieve the shortest wire connection between the floating roof and tank shell[7]. The data of experiment is shown the following figure 4.

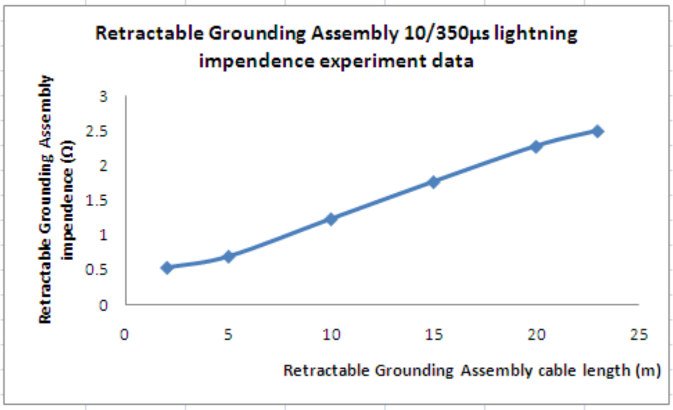

Figure 4 Retractable Grounding Assemble 10/350μs lighting impendence experiment data

B. Calculation analysis

The inductance L of Retractable Grounding Assembly is calculated by the rectangular cross-sectional wire inductance formula(1).

$$L = \frac{\mu_0 l}{2\pi}\left(\ln\frac{2l}{b+c}+\frac{1}{2}\right) \quad (1)$$

Where l is the wire length; b, c is the side length of wire cross-section, c>b.

When the wire of Retractable Grounding Assembly stretches a length of 20m, calculate the inductance L_{20m}=31.7μH.

The potential difference U between the floating roof and the tank shell according to the formula(2).

$$U = R * i(t) + L * \frac{di(t)}{dt} \quad (2)$$

Where R is the wire resistance, i(t) is the current flowing through the wire, di(t)/dt is the lightning current steepness.

Wire resistance can be neglected. Therefore, the above formula(2) can be reduced to the following formula(3)

$$U = L * \frac{di(t)}{dt} \quad (3)$$

When the tank level is lowest, the potential difference is the highest between the floating roof and tank shell as Retractable Grounding Assembly stretches wire length of 20m. For a volume of 10×$10^4$$m^3$ tank, in according with the standard IEC 62305-1 given $di(t)/dt_{max}$=20kA/μs of LPL I class lightning protection level, the highest potential difference is 634kV if one Retractable Grounding Assembly is set. When thirteen Retractable Grounding Assembly are set, the highest potential difference is 45kv and may ensure the size of 36mm gap is not breakdown discharge.

IV. CONCLUSION AND RECOMMENDATION

Shunt and mechanical seal are main ignition sources in the first and second sealing oil and gas space of floating roof tank. Guide pole is another ignition source of floating roof tank fires. In order to avoid the occurrence of spark discharge on shunts, mechanical seal, guide pole, and other facilities in oil and gas space when the floating roof tank is being struck by lightning, several measures were proposed as follows.

All of the following measures are of vital importance to reduce floating roof tank sealing ring fires caused by lightning.

1) shunts should be removed away.
2) Mechanical seal should be electrically insulated from the tank shell. Alternative seal type may be soft seal structure.
3) Ensure a safe distance is greater than 40mm for the metal parts between the floating roof and the tank shell in the first and second sealing oil gas space.
4) More equipotential bonding wires should be symmetrically set around the tank to increase lightning current discharge channels of floating roof and reduce the potential difference between the floating roof and the tank shell. Retractable Grounding Assembly is a good choice.
5) Scraping wax should be equipotential bonding with floating roof. This is another lightning current discharge channel between the floating roof and the tank shell. The connection points are below the surface of liquid product and it's more secure.
6) Guide pole or assemblies that penetrate the floating roof should be electrically insulated from the floating roof by insulation board.

Figure 4 Floating roof tank lighting protection measures

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