The Measurement to the Pillar Fillet Weld of the Differential Settlement Spherical Tank by the ACFM

Zemin Wu, Guang Dai, Guoqiang Zhou and Jiancheng Leng
The Northeast Petroleum University, Daqing 163318, China.

Abstract. Present the method that using the ACFM to test the spherical tank which had appeared the differential settlement. First introduced the principle and the system composition of the ACFM, by using which, the pillar fillet weld of the LPG spherical tank had been tested, and then the quantitative evaluation of the weld cracks had been get out. After analyzed deeply, the reliability of the ACFM when testing the pillar fillet weld of the spherical tank had been proved, in additionally, the causes of how the cracks come out had been given, too.

Keywords: Spherical tank; Differential settlement; Pillar fillet weld; Alternating current field measurement.

1. Introduction
The Spherical tank is one of the most common pressure vessel in petroleum and chemical industries, which was mainly used in storing of the material, like LPG and LNG, etc., which included the shells, the supports and the accessories, and the pillars could be fell into pillar type and apron type. At present, most of the spherical tanks use the support type of pillar with equatorial tangent. To the spherical tank with pillar support, the welding connection between the pillar and the shell would support the weight of the whole sphere and the material.

Differential settlement is a common problem to the spherical tank, which should lead the stress unbalance in each pillar of the spherical tank, and could cause additional stress, which would easily cause the crack of the pillar fillet weld to appeared out, and evenly impact the safety in using of the spherical tank [1-3]. As to the special structure style of the pillar fillet weld, normal testing methods would cost much more time, and there might be some chances of mis-detection. Thus, this text used ACFM to do the test, which had many disadvantages like non-contacted measurement, high speed acquisition, high accuracy, qualified and quantified quickly, and the testing result could be shown with computer graphics, which could make a good effect to detect the pillar fillet weld in test.

2. The ACFM Technique
2.1. The Detecting Principle
The ACFM technique was founded and developed on the basis of ACPD, of which, the theoretical basis was the electromagnetic induction principle[4-5], that is to say, when an inductive probe with alternating current approached the work piece, the alternating current would produce a alternating magnetic field
around itself, and according to the test of the intensity variation, people could judge whether there was a crack or not, as shown in the Figure 1 (in which, the X axial was in the direction of the crack, and the Y axial perpendicular to the plane of the crack, and meanwhile, paralleled to the current direction, the Z axial perpendicular to the surface of the conductor, and pointed to outside). When there wasn’t flaw on the surface of the work piece, when the induction density \( B_x \), which paralleled to the surface of the work piece, paralleled to the direction of the X axial, then the induction density \( B_z \), which perpendicular to the surface of the work piece will be zero, and if the flaw existed, with the increasing of the crack’s resistivity index, the current field and the induced magnetic field would be distorted, in which, if the scattered electric streamlines corresponded to the crossing of the \( B_x \), as the magnetic induction intensity, then the depth of the crack could be tested, if the clockwise and anti clockwise electric streamlines respectively corresponded to the positive and negative peak of the \( B_z \), as the magnetic induction intensity, then, the length of the crack could be tested. Thus, according to the variation of two mutually orthogonal magnetics, people could quantitatively check out the size of the flaw.

![Figure 1. The schematic diagram of the ACFM.](image)

2.2. Detecting System

The ACFM testing system included two parts, such as the hardware and the software [6]. The hardware part, is made up of the scanner, the ACFM mainframe, and the computer, etc. as shown in Figure 2, and the scanner drove out the uniform alternating current on the surface of the workpiece, then get the magnetic signal’s changes from the surface of the workpiece in the same time, and analyzed and processed the signal with crack detection analysis software, could intelligently analyzed and identified the crack of the workpiece in testing.

![Figure 2. ACFM testing system](image)

3. The ACFM Testing To the Pillar Fillet Weld

A LPG spherical tank belonged to a petrochemical company was built and went into operation in 2006, whose volume was 2500m³, who had the structure with the pillar of equatorial tangent with 10 pillars. During the regular checking in 2016, the spherical tank was found out that there was a differential settlement problem in the tank, which is, the settling differential value between the adjacent pillars was too big, because of which the standard request of GB12337 was exceeded [7]. Thus, it was very necessary to measure the pillar fillet weld by the ACFM to ensure the spherical tank operate safety.
3.1. The Testing Method
In order to record and issued the report the 10 pillars of the tank was in ordered with number, as the figure 3. In thinking of the working place of the pillar fillet weld area was limited and the length of the weld was long, the testing area was divided into 4 parts (a testing part, b testing part, c testing part and d testing part), the testing could began, as shown in Figure 4.

![Figure 3. The number of the spherical tank’s pillars](image)

![Figure 4. The testing to the pillar fillet weld](image)

According to the structure of the pillar fillet weld area, the pencil-type probe was used, after which was connected with the main engine, the first step was to checkout the equipment and the probe by using the standard testing panel, in order to ensure the ACFM system operate normally to meet the requirements of the detection precision, the curve of the testing signal was shown in figure 5.

![Figure 5. The testing signals of the ACFM’s standard panel](image)

During testing, the probe always moved along with the direction which paralleled with the welded joints, because the scanning speed would affect the strength of the testing signals directly, so the scanning speed should be steady, so the probe should maintain the state to fit into the weld and the weld-toe. The width of the pillar fillet weld was about 40mm, the probe would scan 3 times in the parallel directions to the weld to ensure covering to whole width of the weld. When scanning the sectorial weld, for fear of the missing test caused by fringe effect and the lift-off effect, every part must be scanned overlapped by the length of 50mm. And scanned the transversal crack of the weld in a Z-shape [8], then recorded the marked position in the weld corresponded to the curve peak of Bx, after which, the strike of the crack could be confirmed by connecting the marked positions.

During the testing process, the software could store the signal curve scanned by the probe automatically, and also had the function of replaying, which could be checked and analyzed lately.

3.2. The Testing Result
When testing the 10 pillar fillet welds of the spherical tank with differential settlement by the ACFM, it was found that there was a suspicious crack in the 6th site of the pillar 5# from which, as shown in figure 6.
When quantitatively evaluate to the suspicious crack, after measuring the mark point corresponded to the trough and the crest of the Bz signal according to the original curve, the estimated value of the crack length was get, from which, the system software could compensate to the crack length on the basis of the theoretical model, then size of the crack could be calculated, which was, 13mm long and 2.2mm deep, as shown in figure 7.

![Figure 7. The calculation to the size of the flaw](image)

After the treatment of depainting had been done to the surface of the suspicious cracking area, by using the MPT method, the existence of the crack could be proved, and according to the result of MPT, it was found that, the crack’s length was about 12~13 mm, and after polished and smooth transited to the crack, it was also found that the depth of the crack was about 2~2.5 mm, and the flaw didn’t appear anymore when rechecked.

4. The Cause Analysis of the Crack in Pillar Fillet Weld

4.1. Regarding to the welding material
After looking up the construct data of the spherical tank, it was informed that, the tank was installed not only with the rods Ø3.2 as the backing weld, but also the rods Ø4.0 in other levels whose content of diffusible hydrogen were 6.46ml/100g, which had exceeded the claim in GB12337 as the content should less than or equal to 6ml/100g. If the diffusible hydrogen in the weld was too much would cause hydrogen brittleness and delay cracks, which would cause the low stress crack in the structure.

4.2. Regarding to the quality of the welding process
Because of the structure of the fillet weld of the connection between the pillars and the shell of the spherical tank, affected by which, there must be a V-type groove on the pillar in sideways, which had used on side welding Bothe sides formation technology. This kind of welding process could lead to the non-fusion flaws on the backside, such as, the pore inside the welds and the slag inclusions, etc., which would become to the pillar fillet weld cracks under alternate loading over a long period of time.
4.3. Regarding to the differential settlement

This spherical tank was built on the coastal backfill foundation, which would lead to the differential settlement after a long-time running. During the regular checking in 2016, the value of the differential settlement of the pillars as shown in table 1 (take pillar 1# as the measurement standard), could be 12.6mm in Maximo between two adjacent pillars.

Table 1. The differential settling volume of the pillar

| Number of the pillar | Settlement value (mm) |
|----------------------|-----------------------|
| 1#                   | 0                     |
| 2#                   | -7.2                  |
| 3#                   | -11.8                 |
| 4#                   | -19.7                 |
| 5#                   | -14.0                 |
| 6#                   | -24.6                 |
| 7#                   | -12.0                 |
| 8#                   | -7.6                  |
| 9#                   | -4.9                  |
| 10#                  | -3.2                  |

After setting up the finite element model by using of the ABAQUS software, as shown in Figure 8. According to the working condition of the spherical tank, when applied load to the finite element model, including that, the gravitational load—the gravity of the shell, pillars, pull-rods and the accessories, the gas load—the oil gas, pressure over LPG, the hydraulic load—the gravity action of the LGP to the internal surface of the spherical tank. The boundary condition of the finite element model was the value of the differential settlement. By setting the downward displacement along the axial direction with the bottom of the spherical tank’s pillars to carry out the value of the settlement between the pillars. From the cloud atlas of the stress coming from the pillars and the shell of the tank, as shown in Figure 9 and 10, it could be seen that, when differential settlement appeared, the stress distributed very unevenly on the pillars, that is, the pillars 1#, 3#, 5# and 8# had raised bigger stress and the value of the stress in the fillet weld area connected to the shell was big too, to which, the out load (like wind, snow, etc.) overlaid, the stress would exceed the allowable strength of the material, which would lead the structural damage in parts of the tank.

Figure 8. The finite model of the spherical tank.
5. The conclusion

(1) When measuring the pillar fillet weld of a spherical tank which had differential settlement with the ACFM, the crack had been found out from the testing position in stage d of the pillar 5#, to which, processed the evaluation, the existence of the crack could be varied with MT method.

(2) When the differential settlement appears in the spherical tank, there would be a additional stress produced from the fillet welds between the pillars or between the pillars and the spherical shell, which, is, added the effected of external factors and load conditions, and would produce flaws such as crack easily, which should be the important testing part in NDT.

(3) According to the local testing and application results, it was shown that, to test the pillar fillet weld of the spherical tank by using the ACFM method, can meet the site operation demand such as no need to polish, high testing speed, the quantitative measurement to the flaw, low effect from external force, etc. From those, the ACFM method is proved to be an effective method of testing to pillar fillet welds of the spherical tank.

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