Research on welding defect examination technique based on phased array ultrasonic for high voltage transformer oil tank welds

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Abstract. Oil tank of high voltage transformer plates. During welding and operation, defects such as incomplete fusion, incomplete penetration, air holes and cracks may be produced which influence the integrity and density of the welds and the whole tank. In order to test the integrity of the shell weld of high-pressure transformer box and ensure no leakage of transformer oil, the phased array testing technology is used to detect the defects of the butt weld of the transformer oil tank. The characteristics of weld defect detection under the condition of incomplete penetration were studied, and the sound beam accessibility, process selection principle and probe selection principle were theoretically analyzed. The test tests were carried out on the artificial samples of the butt weld of the transformer oil tank plate. The results show that the phased array can effectively detect the defects in the weld of transformer tank shell under the condition of incomplete welding, and the imaging results are intuitive and easy to judge, which can effectively evaluate the integrity of transformer tank weld. During the process selection, the probe-wedge combination with appropriate front distance and detection Angle should be selected according to the wall thickness, weld penetration depth and crown width of the transformer oil tank. During defects judgment, the interference of structure echo wave and incomplete penetration area should be considered. The assistant defect positioning analysis based on incomplete penetration is also suggested.

1 Introduction

Oil tank is the main part for ensuring the safety operation of transformer body. The quality of the oil tank weld protects the transformer oil from external pollution and leakage. The oil tank weld is constructed by butt welds with thin thickness steel plates. Significant deformation during the welding process may causes defects such as incomplete fusion, incomplete penetration and air holes influences the integrity and density of the welded joint. The welds subject to the multiple effects of the transformer body, internal transformer oil and operation load, especially the seasonal changes in the northern cold regions form large

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additional stress, which can lead to fatigue cracking or low-temperature cracking during the operation stage. Therefore, the inspection of oil tank weld defects during the manufacturing and operation stages is of great significance for ensuring the safe and efficient operation of transformers [1-5].

Weld defects are generally inspected by non-destructive testing methods. Due to the limitations of testing mechanisms, eddy current [6-9], magnetic particle [10-11], and penetration testing [12] methods can only detect surface or near surface defects and cannot detect internal defects. The most widely used radio graphic testing is limited by the unique structure of transformers and cannot be carried out [13-14]. Therefore, only ultrasonic testing methods can be selected for the welding seams of the transformer shell. For the welds of transformer oil tank, they are generally butt welded or fillet welded by thin-walled steel plates, and the effect of traditional ultrasonic testing method is not obvious. Compared to traditional manual ultrasound, phased array ultrasound testing has the advantage of image visualization. Compared to manual ultrasound testing, the results are more intuitive, and the degree of automation is high, which can improve the defect detection rate.

In this paper, phased array technology to detect the welding seam of the transformer shell in the case of incomplete penetration. Theoretical analysis was conducted on the characteristics and acoustic path diagrams of defect detection in flat butt welds under incomplete penetration. Based on the actual situation, process selection principles and probe selection principles were determined. This method can be used to effectively identify the defects in the welds of the transformer oil tank.

## 2 Weld types of transformer oil tank

The transformer oil tank is welded by plates which includes butt welds. Flat butt weld refers to placing two flat plates in parallel with a reserved welding area in the middle, and connecting the two plates into a whole through welding, as shown in figure1. Common welding structures include I-shaped without grooves, V-shaped with grooves, and X-shaped with grooves. The common welding situations are incomplete penetration and full penetration, as shown in figure2. The butt weld of the flat plate in the transformer oil tank shell is the incomplete penetration weld without groove, as shown in figure3.

![Fig. 1. General flat butt weld structure.](image1)

![Fig. 2. General welding conditions.](image2)
3 Phased array inspection process for transformer oil tank welds

In view of the butt weld structural characteristics on the transformer oil tank, different phased array detection processes are applied for totally scanning detection.

3.1 Scanning method

The commonly used scanning methods for phased arrays are divided into linear scanning and sector scanning. The detection principle of phased array is consistent with conventional ultrasound, which utilizes the reflection and refraction that occur when ultrasound encounters defects during propagation to detect defects.

According to the structural characteristics of the flat butt weld in the transformer oil tank shell, as well as the common defects, including the location of incomplete penetration at the root, incomplete fusion at the groove, air holes, slag inclusion, etc., the flat butt weld should be scanned and tested by sector scanning.

3.2 Detection area

The optimal probe detection position should be selected based on the detection conditions, detection timing, and the structural characteristics of the tested piece, in order to achieve 100% effective detection of the weld area. In order to simultaneously apply to the detection after welding, before delivery and during service, the flat butt weld in the transformer oil tank shell shall be detected from the outside of the shell and the welding crown side.

3.3 Acoustic road-map analysis

Due to the fact that all the welds to be inspected are incomplete welded structures, it is only necessary to ensure a comprehensive inspection of the effective welding area when testing. For flat butt welds, the probe should be placed on the outer welding crown detection surface of the shell, and single sided and double sided detection should be carried out, as shown in figure 4. Select appropriate wedges and sound beam angles to achieve full coverage detection of the welding area of incomplete welds using secondary waves. Using dual sided sector scanning method for detection, different directions and angles of sound beams can be used to scan the welding area to prevent directional defects in the weld area from being missed.
3.4 Probe and process selection principles

The frequency of the probe, the number of chips, the distance between the centers of the chips, and the parameters such as aperture number, sound beam angle, focusing method, and focal position in the detection process focusing rule should be selected according to the detection standards. Some parameters of the probe should be constrained optimization according to some characteristics of the tested object.

For flat butt welds, due to their incomplete penetration structure, the main focus is on detecting the area near the crown side in the wall thickness direction. The detection surface is also the crown side, so a second wave scanning inspection is required. At this point, the leading edge distance, wedge angle, scanning angle, and offset distance of the probe should be determined based on the wall thickness of the test piece, welding crown width, and incomplete penetration height. After these parameters are determined, determine the focusing law parameters. On the premise that the aperture number meets the standard, the sound beam should effectively cover the area to be inspected. Within the effective sound beam range of the wedge, adjust the sound beam angle to cover the overall area to be inspected by the second wave. The focus method should be determined based on the shape characteristics of the area to be inspected or the key focus area, and the focus position should be determined based on the position of the key focus area.

4 Experiment and result analysis

The phased array detection method analyzed above was used to conduct testing on flat plate butt welds to verify the feasibility of the method.

4.1 Test system

The test system for welds detection of transformer oil tank shell includes phased array host, detection probe and test sample. The phased array host adopts the Hanwei HS PA20-E model, and the probe is self-made by Wuhan Zhongke 5L32 linear array probe, with 60° transverse wave wedge for SA30-60S. The shell of the transformer oil tank is generally welded by 11.5mm plate with SMAW and the material is Q235. The test sample is to cut and decompose the welded intact shell into small pieces of flat butt weld samples. A 2mm artificial through hole has been made in the butt weld for calibration. An artificial groove is made from the bottom of the center of the weld with the depth 8mm. The sample diagram is shown in figure5.
Fig. 5. Test sample of transformer oil tank butt weld.

(a) PA image of butt weld joint without artificial defect

(b) PA image of butt weld joint with artificial defect

Fig. 6. Test results of flat butt weld.

4.2 Test results

Using the above detection device, the incomplete flat butt weld has been inspected by using the detection method. The weld was inspected using a sector scanning method on the outer side of Plate B as shown in figure 6. The test results are shown in figure 6.
From figure 6, it can be seen that there are two inherent echo signals and one natural defect signal in the intact incomplete flat butt weld sample. The self contained incomplete penetration echo signal at the root of the weld caused by incomplete penetration and the "self contained incomplete penetration 2 times" echo signal are used respectively. Both are inherent echo signals, and as long as there is incomplete penetration in the sample, the above two echo signals exist and their positions are relatively fixed. The undercut of the opposite welding crown in the figure is true defect signal, which is detected by a small angle second wave located on the extension line of the base metal at the center of the welding crown. The use of two waves can effectively detect defects in the butt weld specimens of incomplete welded flat plates.

The phased array is used to detect the butt weld of the transformer oil tank shell according to the detection method effectively detect the defects in the weld. The image is consistent with the actual structure. During detection, inherent echo signals such as incomplete penetration can be used to assist in identifying the coupling situation and the location of defects.

5 Conclusion

5.1 The phased array is used to detect the incomplete penetration butt weld in the transformer oil tank shell, which can effectively detect the defects in the weld.

5.2 For butt welds, the method of single sided and double sided inspection on the crown side is adopted to adapt to the inspection after welding, before leaving the factory, and during service.

5.3 The artificial calibration sample can simulate typical weld defects such as holes, incomplete penetration and other defects for phased array detection.

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References

4. Liu Jianjun, Jin Yan, Yang Liheng, etc. Study on the fatigue life of welds containing defects in large transformer oil tank [J]. hot working Process, 50, 03 (2021)
5. Hu Anchao, Chen Hongbo, Chen Lunlun, etc. A structural improvement that facilitates automatic welding of transformer oil tank [J]. Modern Manufacturing Technology and Equipment, 282, 05 (2020)


13. Yue Shuangling. Application of non-destructive testing technology in steel structure construction engineering inspection [J]. Stone, 383, 01 (2023)

14. Tao Haibin, Yan Xueqing, Yi Yiping. Application of non-destructive testing of ship welds based on digital radiographic testing [J]. Shipbuilding Technology, 50, 06 (2022)