FIELD TEST ON A TRANSFORMER FOR PARTIAL DISCHARGE LOCATION BY UWB-RF METHOD

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Abstract: Locating Partial Discharge (PD) sources accurately in power transformers is of great importance for maintenance scheduling, maintenance efficiency and even operational risk analysis. A new method based on the differences between propagation times of Radio Frequency (RF) signals was proposed initially in 2003, since then this method has attracted much attention due to its high sensitivity and noise-immunity and constant improvements on this method have been conducted by the researchers. This paper described the in-field verification work in China, an Ultra Wide Band (UWB, 1-5GHz) RF PD location system was developed and applied in PD location experiments on a 220kV power transformer. The experiment result shows that the RF location method has a high precision, the locating errors are less than 30cm for the partial discharge sources occurred in internal or external winding, which meets the needs of the practical use.

1 INTRODUCTION

Locating PD source accurately in power transformer is tremendously important for scheduling and starting maintenance/repair actions cost and time efficiently or to perform a risk analysis[1]. PD source location technology has become research hotspot, and several methods such as Acoustic and electrical method have been developed and employed in field test for about 30 years[2,3]. However, the practical effects of these methods are not satisfactory due to their own defects. Acoustic method can't locate the PD sources lying in the coil due to its low sensitivity[4], the electrical method is difficult to be put into practice because of the complicated propagation characteristics of the transformer windings[5]. PD source location based on detecting EM wave in RF band radiated by PD source is considered as an attractive technology due to its high sensitivity and noise-immune characters. Currently, most of the research focus on the propagation characteristic[6,7], delay time measurement[8] and the selection of wave velocity[9], and constant improvements in these areas have been obtained by the researchers. However, RF location method is still in the stage of laboratory research. The field experiment is requisite for its final purpose of practical use. This paper described the in-field verification work in China, an Ultra Wide Band (UWB, 1-5GHz) RF PD location system was developed and applied in PD location experiments on a 220kV power transformer.

2 TRANSFORMER UNDER TEST AND PARTIAL DISCHARGE MODEL

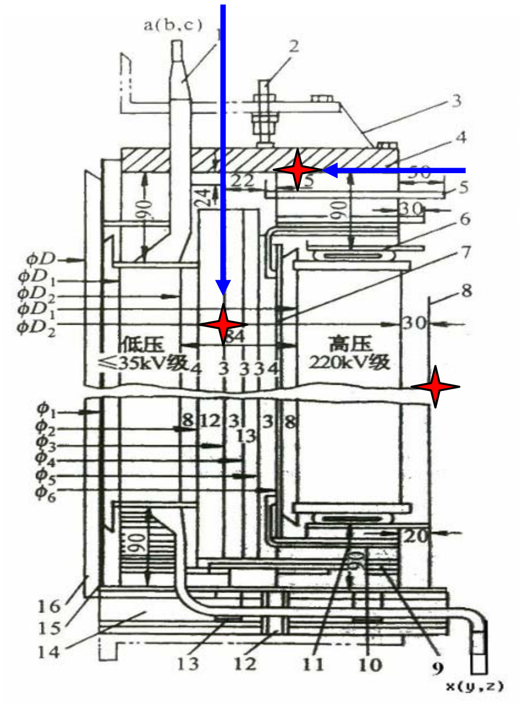
2.1 Structure of the transformer under test

The transformer under test is a three-phase two-winding transformer, the rated operating voltage is 220KV, rated capacity is 120MVA, which is shown in Figure 1(a).The structure of the transformer is the bell structure, its tank is divided into two sections, the lower section connects with the body of transformer as a whole, the part on the inner surface of the tank which is opposite the site of the coils hangs magnetic shield.

The main insulation structure of the transformer is shown in Figure 1(b). The structure of high and low voltage winding is compact, the distance between the cakes is 3-5mm. The radial thickness of the high voltage winding is 130mm, while the thickness of low voltage winding is 113mm. The main insulation structure between the high and low voltage winding is multi-insulating paper tube and thin paper tube of small oil gap, small oil gaps. The distance between the paper tubes is short; while the structure between the low voltage and the ground core is layer paper tube and thick paper tube of double oil gap, and large oil gap structure. The oil gap is relatively wide.

To fully examine the application of the RF locating technology, the partial discharge faults will be set in the three typical parts: between the high and low voltage winding, on the bottom of the winding, and on the high voltage leads, as shown in Figure 1(b).

(a) The transformer under test



(b)The major insulation structure of 220KV two-winding transformer

The attachment of the winding of transformer: 1-Lead of LV winding; 2-stud; 3-case contact; 4-textile board; 5-bond terminal; 6-static board; 7-insulating paper cylinder; 8-screen; 9-bond terminal; 10-square ring; 11-bond terminal; 12-phenolic paper cylinder; 13-Yoke cushion block; 14-bond terminal; 15-nsulating paper cylinder of LV winding; 16-horizontal sheeting

PD model installationsite

Fig. 1 The transformer under test and the location of the PD model

2.2 Partial discharge models

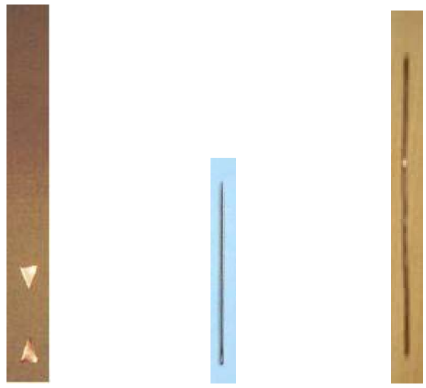
The common partial discharge types in the transformer are: surface discharge, the impurities discharge or bad contact discharge, the metal tip discharge and so on.

(1) Surface partial discharge model

The triangular thin copper plate is attached to the surface of a thin pressboard which is 10mm width, as shown in Figure 2(a). This model will be arranged in the winding overhang. When a certain voltage is exerted to the transformer, the copper will induce a certain voltage, then discharge will be generated along the surface of the pressboard because of the high local field on the contact site of metal tip and the pressboard.

(2) The impurities discharge or bad contact discharge model

The 30mm long needle is bonded to the top of the insulation board, then the needle is inserted to the winding inside through the insulation board and



(a) (b) (c)

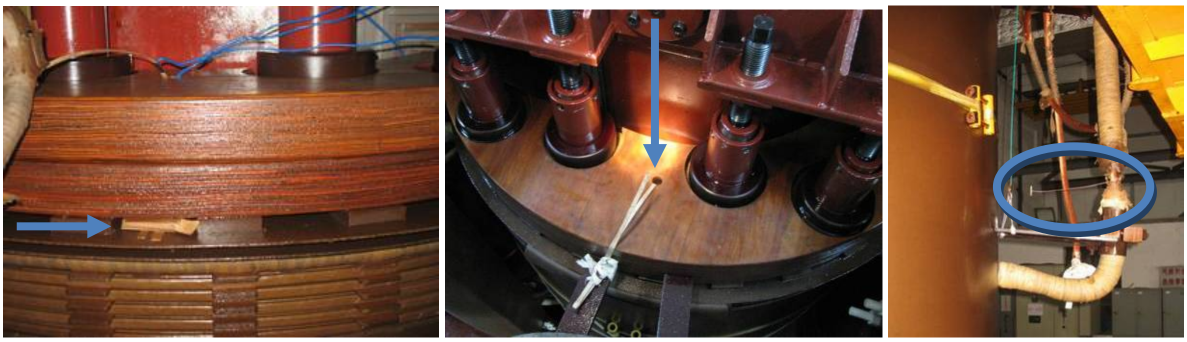
(a)Surface partial discharge model
(b)Floating pinpoint model
(c)metal-tipped model

Fig. 2 PD models

fixed, as shown in Figure 2(b). This model is arranged between the high and low voltage winding. When a certain voltage is exerted to the transformer, the needle will induce a certain voltage, and the local field on the metal tip is so high that the partial discharge is generated.

(3) The metal tip discharge model

The bare copper wire which is about 100mm long is welded to the lead wire of high voltage winding, as shown in Figure 2(c) and Figure 3(c).When a

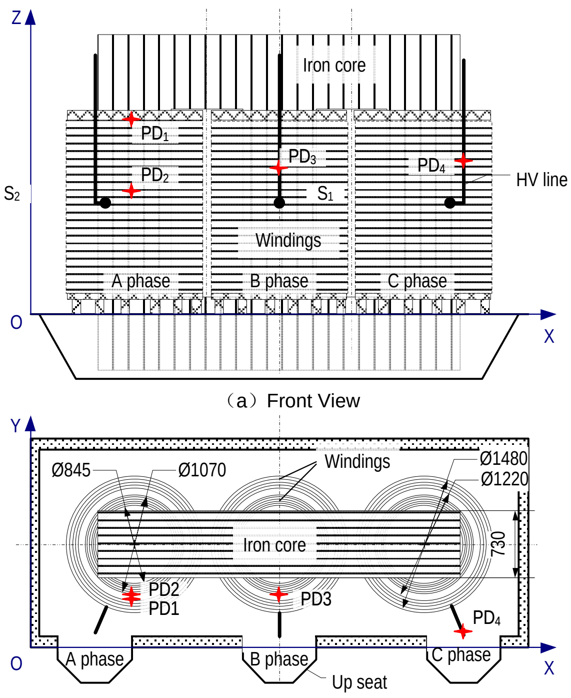


(a) (b) (c)

(a)Surface PD model in the winding overhang
(b)Floating PD model between HV windings and LV windings
(c) pinpoint model welded to the lead wire of high voltage winding
Fig. 3 The location of the PD model in the transformer

certain voltage is exerted to the transformer, the copper will induce a certain voltage, and the local field on the metal tip is so high that the partial discharge is generated.

With the point on the tank which is near to the high-voltage side and A phase as the origin, we established a three-dimensional Cartesian coordinate system, as shown in Figure 4. The coordinates of sensors and the discharge models were measured. As shown in Table 1.



（a）Front View

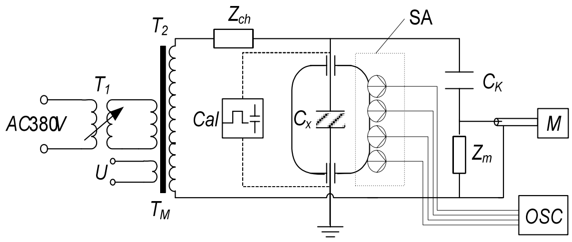
（b）Vertical View

Fig. 4. PD models put into the transformer

3 TEST METHOD AND MEASURING DEVICES

3.1 Experimental schematic

As illustrated in Figure 5. Test Power Supply is 50Hz AC high voltage power supply. The mode of connection of inducing pressurizing and the stepwise pressurizing were adopted. At the same time we used the traditional PD detector to monitor the discharge status. Then the RF signals were detected using devices when the PD signals are founded. We used the high voltage tube as a coupling capacitor, and connected the test resistance to the conducing wire of the end shield of the casing, which is the traditional pulse current detecting method.

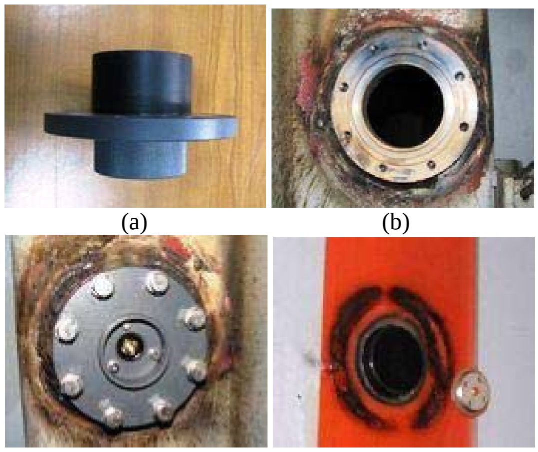


T_1：Booster； T_2：Non-corona test transformer；TM：Measuring winding；Z_{ch}：Blocking impedance；C_X：Test product；C_K：Coupling capacitor；Z_m：resistance detection；M：DST-4 PD detector；C_{al}：Calibration square wave generator；SA：RF sensor array； OSC：oscillograph

Fig. 5 Experimental schematic

3.2 Ultra-wideband radio frequency detecting device

Measuring device consisted of two arrays including two sets of four RF sensors which were installed in the high and low voltage side, power amplifier, high-speed 4-channel digital signal acquisition and so on. Its analog bandwidth is 1-5GHz, single-



(a) (b) (c) (d)

(a) RF sensor
(b) Portiforium
(c) External view of mounted RF sensor
(d) Inside view of mounted RF sensor

Fig. 6 RF Sensors and their installation

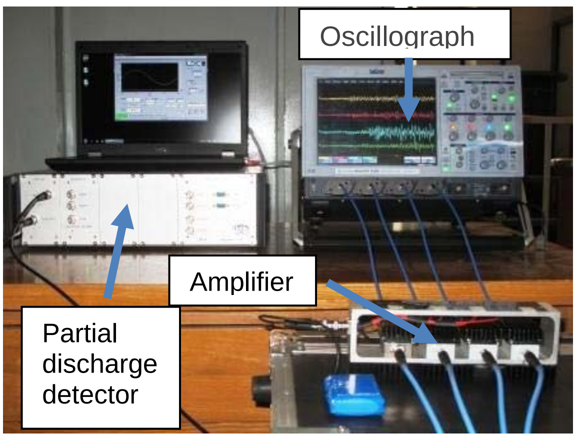


Fig. 7 Detecting devices

channel sampling rate is 20GS/s, delay time measurement accuracy is less than 0.2ns.

RF sensor (Fig.6) is optimal equiangular spiral antenna. It has a high gain within 1-5GHz ultra-wideband. And half-power beam width is up to 120 degrees. The sensors were embedded into the transformer through drilling. What should be noted is that the receiving surface of the sensor should be not less than the inner surface of the magnetic shielding, otherwise the RF signals will be blocked, which can reduce the accuracy of reading the delay time.

The gain of the PA within 1-5GHz is 20dB. We use Lecory8620A which is high-speed four-channel digital oscilloscope as the signal acquisition unit, its analog bandwidth is 0-6GHz, four-channel sampling rate is 20GS/s.

Partial discharge detector, amplifier and digital oscilloscope are shown in Figure 7.

4 EXPERIMENT AND DATA ANALYSIS

In each experiment, the voltage was increased gradually. The test voltage and the apparent discharge magnitude were recorded at the time when the partial discharge signals were detected by the partial discharge detector, and began to detected and store the signals, at least 100 waveforms were stored each time. The date analysis was carried out after the experiment. Firstly, waveforms easy to read were selected. Then the reaching time of the waveform could be got one by one. After that, the average value of the delay time could be calculated. Based on the delay time, we could get the location result. At last, the positional effectiveness was evaluated by the location error.

Take the location experiment for the surface discharge on the bottom of A phase winding as an example.

(1) When the test voltage reached to 19.4KV, the apparent discharge magnitude fluctuated between 500 and 1000pc.

(2) The RF signals detected are shown in Figure 8. It can be seen that: The peak-to-peak value of the RF signals of the four channels counting down is: 4V, 3V, 0.9V, 0.5V, while the background noise is less than 10mv which mostly come from the oscilloscope. So, the SNR of the signal was very high. The pulse width of the first wave was about 0.3ns, so it was very easy to read the starting time.

(3) Read the delay time value of 100 waveforms and the averaging result was: (-5.12,-2.01,5.33); Compared with the theoretical value (-4.81,-1.83,5.24), the delay time error was: (-0.31,-0.18,0.09). So it can be seen that the absolute value of the maximal error was less than 0.5ns.

(4) The locating result was (118,20,208) using the mesh search algorithm. Compared with the real PD coordinate (112,52,216), the locating error was just 21cm, which was less than 30cm and can meet the needs of onsite requirements.

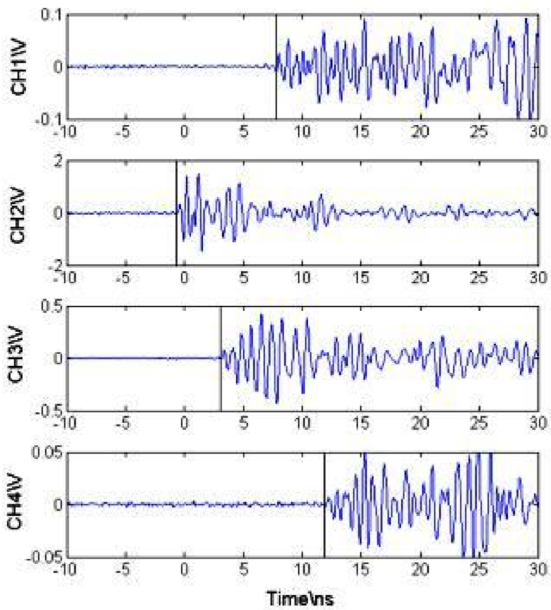


Fig. 8 The detected RF signals

Table1 The date of measured time-delay and calculated PD location

NO.		1	2	3	4
Position		The bottom of the winding of A phase	Between the high and low voltage winding of A phase	Between the high and low voltage winding of B phase	On the high voltage leads of C phase
Type of the PD		Surface model	Floating model	Floating model	Pinpoint model
Real coordinate		(112,52,216)	(112,56,130)	(275,55,130)	(461,36,148)
Academic delay time		-4.81,-1.83,5.24	-8.58,-4.67,4.12	4.45,0.59,4.05	12.44,7.08,-1.18
Mean value of measured delay time		-5.12,-2.01,5.33	-9.07,-4.88,4.02	4.05,0.40,4.10	12.96,7.55,-1.44
Error of the delay time		-0.31,-0.18,0.09	-0.49,-0.21,-0.10	-0.40,-0.19,0.05	0.52,0.47,0.26
Location result	coordinate	(112,20,212)	(108,56,124)	(270,58,132)	(481,20,158)
	Error	21	7.2	6.2	27.5

Annotation：The unit of the delay time and the error is ns; the unit of the location result and the error is cm.

The locating experiment and result of other three models are shown in Table 1. So it can be seen that:

(1) RF detection method is sensitive, it can detect the partial discharge of 200pC or above to achieve the locating.

It should be noted that this experiment focused on the effectiveness of the RF location method on the partial discharge occurred in the deep winding. It can be seen from Table 1: The RF location method can locate the partial discharge of 500pC or above inside the winding.

(2) In the RF location method, the measured delay time error is extremely small, generally less than 0.5ns according to the rectilinear propagation theory. In other words, winding has little effect on the RF signal propagation time.

(3) RF location method has a high precision, the locating error is less than 30cm for the partial discharge of winding inside and outside, which meets the needs of the practical use.

(4) It can be seen from the locating result that the error of y direction is the main reason for the locating error. This may be related to the sensor layout and still needs further study and solution.

5 CONCLUSION AND OUTLOOK

This paper developed ultra-wideband radio frequency locating device based on the accumulation of a large number of studies. To test the feasibility of locating method and devices, an experiment was carried out in the real 220KV transformer. The results show that: (1) The RF location method can detect and locate the partial discharge of 500pC or above inside the winding. (2) Winding has little effect on the RF signal propagation time measurement. Generally speaking, the measured delay time error is less than 0.5ns. (3) RF location method has a high precision, the locating error is less than 30cm for the partial discharge occurred in winding inside and outside, which meets the needs of the practical use.

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