Acoustic Detection of Partial Discharges in Insulation Oil

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Abstract: - In this paper, we performed an insulation diagnosis technique for oil-immersed power transformers by an acoustic detection method. Electrode system such as needle to plane electrode was fabricated to simulate a defect of power transformers. In addition, the frequency spectrum of acoustic signals with partial discharge (PD) in insulating oil was analyzed. From the FFT result, the frequency spectrum of the acoustic signals measured by a wide and a narrow band AE sensors were distributed in the range of 50–170 kHz. Therefore, a narrowband AE sensor with a resonant frequency of 140 kHz is suitable for the diagnosis of oil-immersed power transformers. We could find the position of the PD source with an error margin of 10% in the experiments by calculating the position of the PD occurrence using the time difference of arrival measured by five AE sensors.

Key-Words: - Acoustic detection, Partial discharge, Insulation diagnostic, Frequency component, Positioning

1 Introduction

Research on insulation diagnostic techniques is being actively carried out because of the increasing demand for high quality power, which power facility owes its high voltage and large capacity to. Electrical insulation is an important factor in the performance of power facility; however, the insulation performance of the power facility decreases because of mechanical, thermal, chemical, and electrical stress [1], [2]. As power transformer accidents cause large outage areas and are expensive to repair, on-line monitoring and periodic diagnosis of the stability of the power supply is required [3]–[7].

A recent important technique for insulation diagnosis is the partial discharge (PD) detection method, which can detect insulation deterioration in its early stages because there is a concentrated electric field in the defective area of an insulator i.e., where PD occurs [8]–[10].

PD detection can be divided into two methods: one, electrical, the other, nonelectrical. The electrical method has high sensitivity, which enables precise measurement. However, some of the shortcomings of this method include the fact that it is likely to be affected by electromagnetic noise and its coupling network cannot be installed during operation. The nonelectrical method includes acoustic, optical, and chemical detection. The acoustic detection method is less sensitive than the electrical method [11]. This method, however, is less likely to be affected by electromagnetic noise as it is electrically insulated. Additionally, the acoustic sensor can be installed easily during operation. Locating the defect is possible by measuring the time difference of arrival (TOA) of the acoustic signal using multiple sensors [12].

This paper deals with the application of the acoustic detection method for the insulation diagnostics of oil-immersed power transformers. We simulated partial discharge in insulation oil in order to emulate defects. Moreover, the propagation characteristics of the acoustic signals and 3D positioning of the partial discharge were studied.

2 Experimental Set-up

As shown in Fig. 1, the experimental apparatus for the simulation of oil-immersed transformers was built using a metallic enclosure.

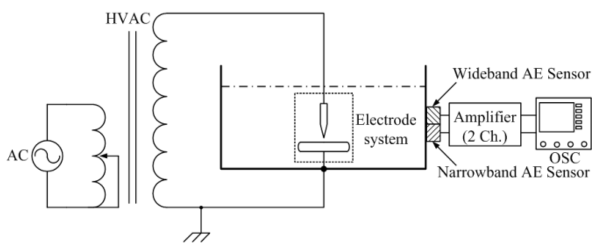


Fig.1 Circuit of the decoupler

We could generate partial discharges (PDs) by increasing the AC voltage from 0 to 50 kV while immersing the electrode system in insulating oil. To detect acoustic signals generated by PDs in insulating oil, a wideband AE sensor, with a frequency range of 100 kHz–1 MHz, and a narrowband AE sensor, with a frequency range of 50 kHz–250 kHz, were used. The two types of AE sensors that measured acoustic signals were installed on the outer surface of the metallic enclosure. As the AE sensor uses a single cable for transmitting both power and signal, we separated the acoustic signal from the DC voltage using a circuit with high-pass filter characteristics [12].

In this paper, we designed the decoupler to separate the acoustic signals from the DC voltage. As shown Fig. 2, acoustic signals over 10 kHz being transmitted from the AE sensor to the DC source are attenuated by more than 200 dB, but are transmitted to the input terminal of the amplifier without attenuation.

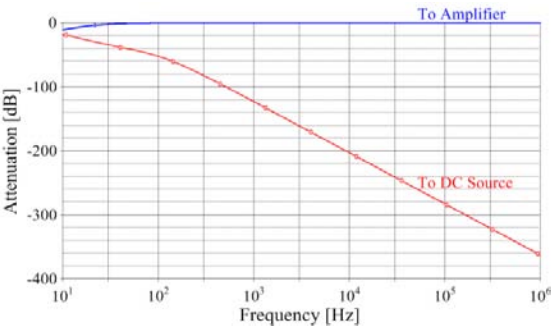


Fig. 2 Frequency response of the decoupler

A needle–plane electrode has been fabricated to simulate the defects that can be generated inside the oil-immersed transformer, as shown in Fig. 3. A plane electrode was made from a tungsten–copper alloy disc 15 mm thickness and 60 mm diameter to avoid electric field concentration; the radius of curvature of the needle electrode was 10 μm. A pressboard of thickness 1.6 mm was inserted between the needle and plane electrode.

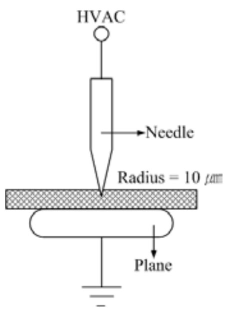
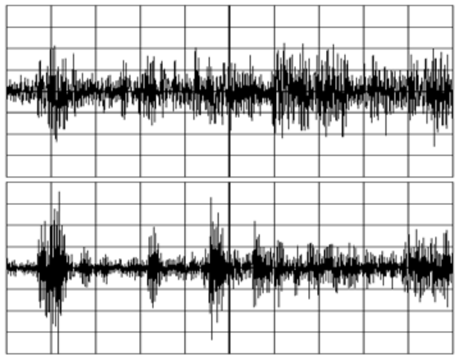


Fig. 3 Needle-plane electrode

3 Measurement and Analysis

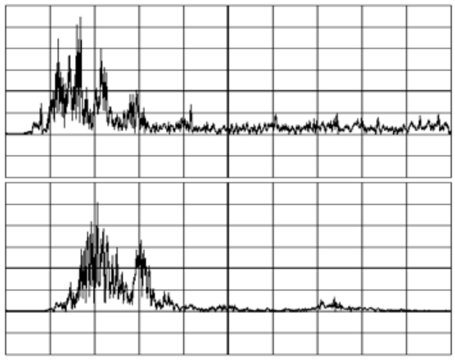
3.1 Frequency Spectrum

The detected acoustic signals and the FFT results generated by needle-plane electrode are presented in Figs. 4 and 5.



Upper: Wideband AE sensor [0.5V/div, 200μs/div]
Lower: Narrowband AE sensor [0.5V/div, 200μs/div]

Fig. 4 Acoustic signal waveform examples



Upper: Wideband AE sensor [20 mV/div, 50 kHz/div]
Lower: Narrowband AE sensor [20 mV/div, 50 kHz/div]

Fig. 5 Frequency spectra of acoustic signals

The frequency ranges of the acoustic signals generated at the needle–plane was in the ranges 50–170 kHz. Therefore, it should be noted that a narrowband AE sensor with a resonant frequency of 140 kHz is suitable for the diagnosis of oil-immersed transformers by acoustic detection.

3.2 Positioning of Partial Discharge

To find the source of the PD of oil-immersed transformers by the acoustic method, three or more AE sensors are required.

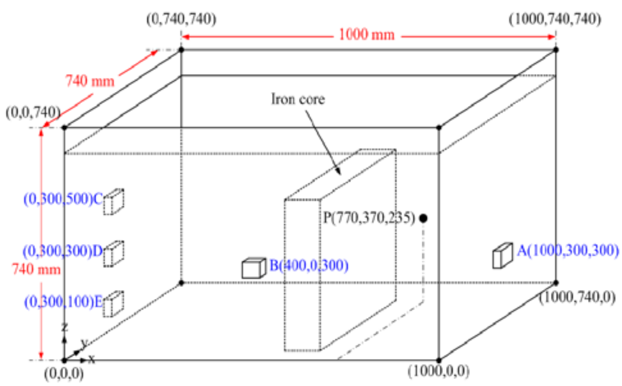


Fig. 6 Configuration of the coordinate system

In this paper, we used five AE sensors to estimate the position in 3-D using the TOA of the acoustic signals. We marked coordinates on the enclosure to calculate the location of the PD occurrence and installed AE sensors, as shown in Fig. 6. Fig. 7 shows the configuration of the experimental setup.

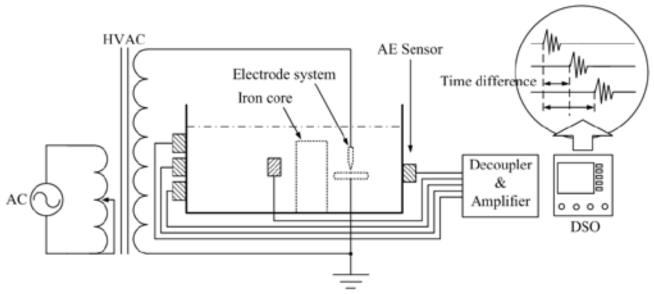
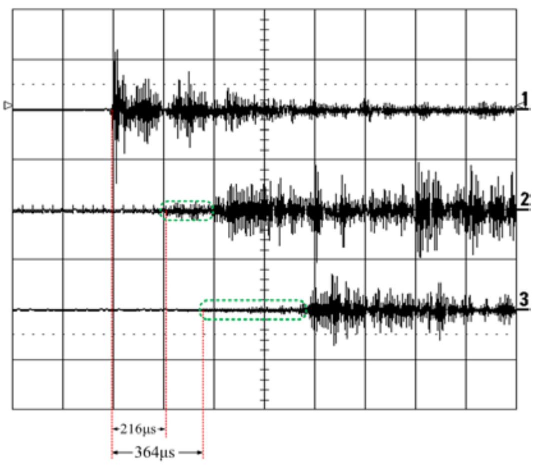
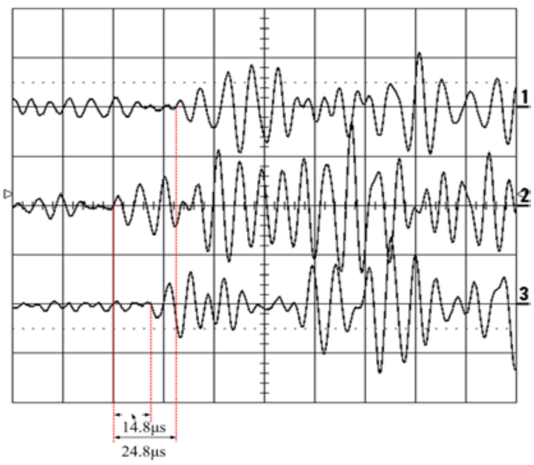


Fig. 7 Configuration of the experimental setup

Acoustic signals detected by each AE sensor are shown in Fig. 8.



(a) Horizontal



(b) Vertical

Fig. 8 Typical waveforms of acoustic signals

The TOA of the AE sensors are listed in Table 1.

Table 1. Time difference of arrival of each AE sensor

Sensor	A-B	A-C	C-D	C-E
Time difference [µs]	216	364	14.8	24.8

The following equations are derived on the basis of the coordinates of the enclosure shown in Fig. 6 and the TOAs.

$$t_{B-A} = \frac{1}{v}\left(\sqrt{(x-400)^2 + y^2} - \sqrt{(x-1000)^2 + (y-300)^2}\right) \quad (1)$$

$$t_{C-A} = \frac{1}{v}\left(\sqrt{x^2 + (y-300)^2} - \sqrt{(x-1000)^2 + (y-300)^2}\right) \quad (2)$$

$$t_{D-C} = \frac{1}{v}\left(\sqrt{x^2 + (z-500)^2} - \sqrt{x^2 + (z-300)^2}\right) \quad (3)$$

$$t_{E-C} = \frac{1}{v}\left(\sqrt{x^2 + (z-500)^2} - \sqrt{x^2 + (z-100)^2}\right) \quad (4)$$

Where,
t_{B-A}: Time difference of AE sensor between A and B [s]
t_{C-A}: Time difference of AE sensor between A and C [s]
t_{D-C}: Time difference of AE sensor between C and D [s]
t_{E-C}: Time difference of AE sensor between C and E [s]
v: Velocity of acoustic signal in insulation oil [m/s]

The propagation velocity of acoustic signals in insulating oil was measured as 1460 m/s, and the coordinates calculated in equations (1)–(4) were x = 778.1 mm, y = 430.4 mm, and z = 256.9 mm. Considering that the coordinates of the position of the electrode in this experiment were x = 770 mm, y = 370 mm, and z = 235 mm, and the dimensions of the metallic enclosure were 1000 × 740 × 740 mm, the positioning error should be within 10%.

4 Conclusion

This paper studied the frequency spectrum of acoustic signals based on the presence of defect, and 3-D positioning of the PD occurrence for use in insulation diagnostics of oil-immersed transformers. When comparing the frequency ranges of acoustic signals measured by wide and narrow band AE sensors we found that the frequency spectrum of the acoustic signals were in the range of 50–170 kHz at needle-plane electrode. Therefore, it was noted that a narrowband AE sensor with a resonant frequency of 140 kHz is suitable for the diagnosis of oil-immersed transformers. We installed five AE sensors to estimate the position of the PD source in a

3-D plane by using the differences in the TOA of the acoustic signals. From the experimental results, we were able to calculate the position of the PD source with an error margin of 10%. The positioning error was due to the nonlinear propagation characteristics of the acoustic signal and the time resolution of the measurement system.

ACKNOWLEDGEMENT

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