Temperature Dependency of Partial Discharge Acoustic Emission Signal in Transformer Oil

Prasanta Kundu, N. K. Kishore and A. K. Sinha

***Abstract*--Partial discharge (PD) produces acoustic pressure wave which propagates from source to sensor and is picked up by the sensors mounted on the transformer tank. In normal operating condition, a transformer operates over a wide range of operating temperatures. This paper investigates the characteristics of frequency spectrum of the partial discharge acoustic emission (PDAE) signal for different operating temperatures. The experimental results are analyzed using FFT. Two parameters namely, peak frequency and median frequency are explored to quantify the frequency spectrum. The results are verified using theoretical analysis and show a good agreement. It is believed that this finding will enhance the understanding of acoustic emission based partial discharge measurement in transformers.**

***Indexing Terms*--Partial Discharge, Acoustic Emission, FFT.**

I. INTRODUCTION

Partial discharge (PD) measurement is a well known diagnostic technique for insulation condition assessment. There are different methods for PD measurement. Acoustic emission (AE) based PD measurement is advantageous for online application and PD source location. PD produces acoustic wave which propagates from source to sensor and is picked up by the sensors mounted on the surface of the apparatus.

Frequency spectrum of PDAE signal is studied at two oil temperatures [6]. Fraction of total energy of frequency domain PDAE signal is calculated and it is shown that the fraction of total energy has very small dependence on the oil temperature [6]. In normal operating condition, a transformer operates over a wide range of operating temperatures. So, PDs also occur at different operating temperatures in transformers. Ref.[6] studied PD at two distinct temperatures only. There are no detailed studies of PDAE signal at various operating temperatures. Hence, PD at various temperatures is required to be studied to draw any meaningful decision based on PDAE measurement. This paper analyzes frequency spectrum of the PDAE signal at various operating temperatures.

Experiments are conducted to obtain the PDAE signal for different transformer oil temperatures. The experimental results are analyzed using FFT analysis. Two parameters, peak frequency (*fp*) and median frequency (*fm*) are calculated to quantify the frequency spectrum results. The results are verified using theoretical analysis.

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II. EXPERIMENTAL DETAILS

Experiments are conducted in the laboratory to measure PDs employing AE techniques. A model transformer tank, built in house, of 60 cm X 60 cm X 60 cm is used for the experiment. The tank thickness used is 5 mm, close to most common transformer tank thickness in practice. It is well known that attenuation of PDAE signal depends on the thickness of the tank wall. For 5 mm tank thickness, the attenuation is uniform (10:1) for the range of frequencies considered in this work [3]. Experiments are conducted at various transformer oil temperatures ranging from room temperature (25ºC for rod-plane electrode system with insulation / 35ºC for plane-plane electrode system with insulation) to 65ºC at a source to sensor distance of 30cm. Experiments are conducted for rod-plane electrode system with insulation and for plane-plane electrode system with insulation on two different days. So, the room temperature is different in the experiment, for the two different electrode systems.

The AE sensor of 150 kHz resonant peak type is mounted on the model transformer tank to pick up the PDAE signal. It is appropriate to mention that though the sensor is 150 kHz resonant peak type, the sensitivity of the sensor upto 500 kHz is good. The sensitivity of the sensor at 150 kHz is -62 db and that at 500 kHz is only -72 db. To create PDs in the laboratory, different types of electrode systems are used. The results of plane-plane electrode system with pressboard insulation and rod-plane electrode system with pressboard insulation are reported here. Fig. 1 shows the schematic diagram of the experimental model. Distance '*x'* indicates the source to sensor distance.

III. RESULTS AND DISCUSSIONS

PDAE signals are recorded during the experiment for further analysis. Sampling frequency of signal recording is kept at 1 MHz to get signal frequency upto 500 kHz. A typical PDAE signal and its frequency spectrum are shown in Fig. 2 and Fig. 3 respectively.

The PDAE signals are analyzed in frequency domain [4,5]. Frequency corresponding to the peak value in the spectrum is defined as peak frequency (*fp*) [4].

Median frequency (*fm*) is defined such that [4]

$$\int_{f_l}^{fm} E(f)df = \int_{fm}^{f_u} E(f)df \qquad (1)$$

Where, $E(f)$ is the value of the AE spectrum at frequency f. f_l is lower frequency of the frequency spectrum and f_u is upper frequency of the frequency spectrum. *fp* and *fm* are calculated for PDAE signals at different transformer oil temperatures.

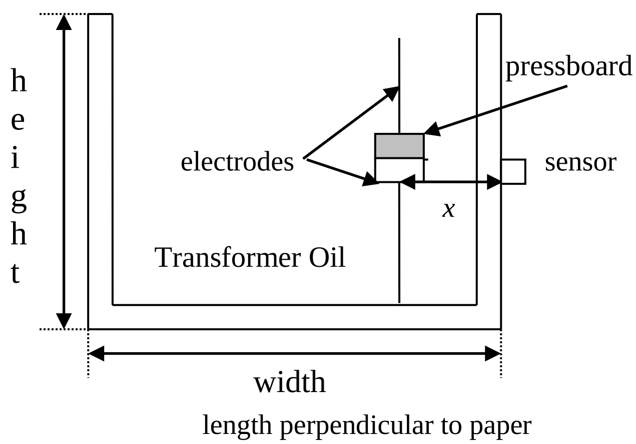

Fig. 1. Schematic diagram of experimental model.

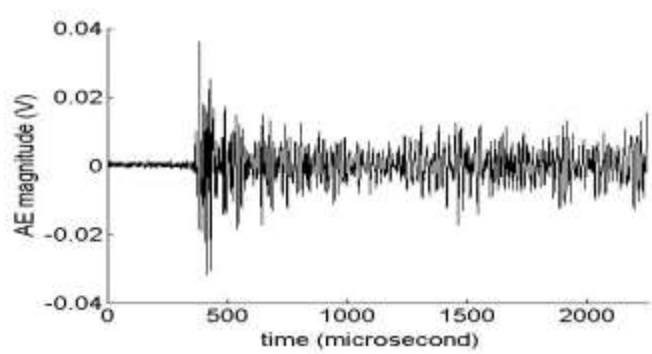

Fig. 2. Typical PDAE signal.

Figs. 4 and 5 show *fp* and *fm* of PDAE signal for different transformer oil temperatures at source to sensor distance of 30 cm for plane-plane electrode system with insulation and for rod-plane electrode system with insulation respectively. Each data-point on the Figs. 4 and 5 indicates data for one observation. It can be observed from Figs. 4 and 5 that ranges of *fp* and *fm* are almost constant for different transformer oil temperatures of measurement for around 100 observations. From Fig. 4 for plane-plane electrode system with insulation, *fm* ranges mostly from 70 kHz to 100 kHz and *fp* ranges mostly from 40 kHz to 60 kHz. From Fig. 5 for rod-plane electrode system with insulation, *fm* ranges mostly from 80 kHz to 110 kHz and *fp* ranges mostly from 40 kHz to 60 kHz. Table 1 shows the summary of experiments conducted and results at constant source to sensor distance and variable temperature.

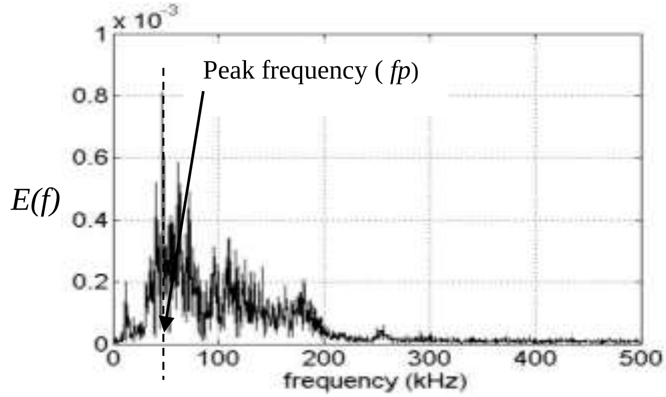

Fig. 3. Frequency spectrum of typical PDAE signal shown in Fig. 2.

Table 1

The summary of experiments conducted and results at constant source to sensor distance with variable temperature

Parameters ↓	Plane-plane electrode system	Rod-plane electrode system
Distance (cm)	30	30
Temperature (°C)	35 - 65	25 - 65
Peak frequency (kHz)	40 - 60	40 - 60
Median frequency (kHz)	70 - 100	80 -110

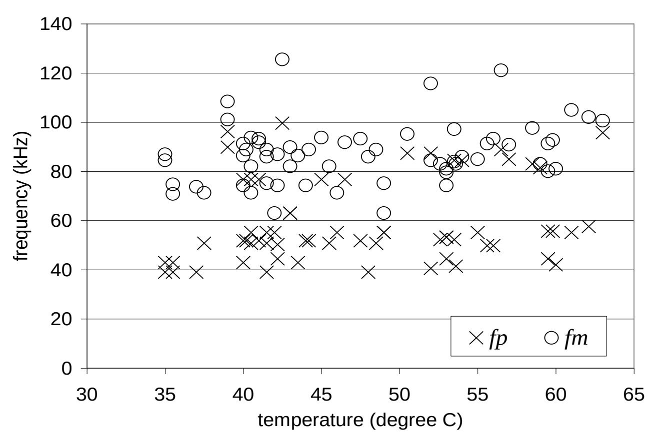

Fig. 4. *fp* and *fm* of PDAE signal for plane-plane electrode system with insulation at different oil temperatures. (source to sensor distance: 30cm). [*fp* : peak frequency; *fm* : median frequency.]

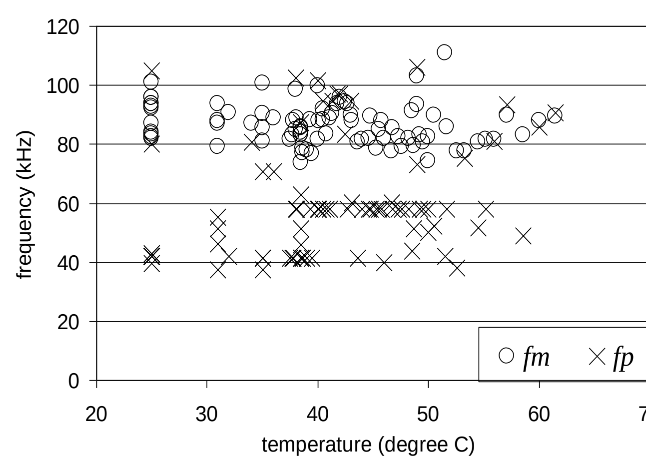

Fig. 5. *fp* and *fm* of PDAE signal for rod-plane electrode system with insulation at different oil temperatures. (source to sensor distance: 30cm).

Figs. 6 and 7 show average value of peak and median frequency of PDAE signal for different transformer oil temperatures at source to sensor distance of 30 cm for plane-plane electrode system with insulation and for rod-plane electrode system with insulation respectively. Average is taken for data from all the observations at a particular temperature. It can be observed from Figs. 6 and 7, that *fp* and *fm* are almost constant with respect to transformer oil temperature. Table 2 shows the mean of *fp*, mean of *fm*, standard deviation of *fp* and standard deviation of *fm* for around 100 observations at different oil temperatures. .

Table 2
Statistical Parameters of *fp* and *fm*
for PDAE signal at different oil temperatures

Electrode systems → / Parameters ↓	Plane-plane electrode system with insulation	Rod-plane electrode system with insulation
Mean of *fp* (kHz)	61	58
Mean of *fm* (kHz)	88	86
Standard deviation of *fp* (kHz)	15	15
Standard deviation of *fm* (kHz)	10	5

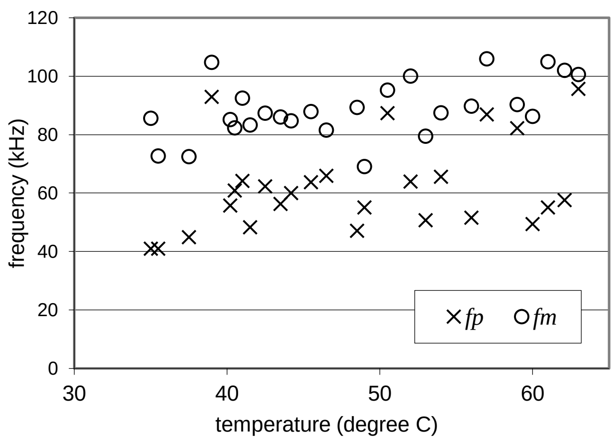

Fig. 6. Average of *fp* and *fm* of PDAE signal for plane-plane electrode system with insulation at different oil temperatures.

IV. THEORETICAL ANALYSIS

The frequency spectrum of PDAE signals are also calculated theoretically using attenuation expression of acoustic wave. The attenuated acoustic wave can be expressed as [6, 7]

$$\xi(x,t) = \xi_0 e^{-\alpha . x} e^{i(\omega . t - k . x)} \quad (2)$$

where, $\xi(x\ ,t)$ is the acoustic pressure at distance x from source at time t , ξ_0 is the static value of ξ, α is attenuation constant given by expression (3) and $\omega = 2\pi . f$, f being frequency (Hz).

$$\alpha = \frac{\omega^2 v}{6c^3} \quad (3)$$

where, v is the kinematic viscosity of oil ($m^2.s^{-1}$), and c is acoustic velocity.

By substituting the expressions of α and ω in (2), equation (4) is obtained.

$$\xi(x,t) = \xi_0 e^{\frac{-2(\pi . f)^2 v}{3c^3} x} e^{i(\omega . t - k . x)} \quad (4)$$

The relationship between viscosity and temperature is expressed by (5) [6].

$$v = \frac{V_0}{1 + aT + bT^2} \quad (5)$$

where, T is the temperature in degree C, V_0 is the kinematic viscosity of transformer oil at 0^oC. The value of V_0 is $6.6X10^{-5}m^2.\ s^{-1}$ for the transformer oil; 'a' and 'b' are 0.097965 and 0.0014588 respectively [6]. By substituting (5) in (4), equation (6) is obtained.

$$\xi(x,t) = \xi_0 e^{\frac{-2(\pi . f)^2 V_0}{3c^3(1+aT+bT^2)} x} e^{i(\omega . t - k . x)} \quad (6)$$

The energy of the acoustic wave is directly proportional to the square of the peak magnitude of acoustic wave and is given by (7)

$$E = \left(\xi_0 e^{\frac{-2(\pi . f)^2 V_0}{3c^3(1+aT+bT^2)} x} \right)^2 \quad (7)$$

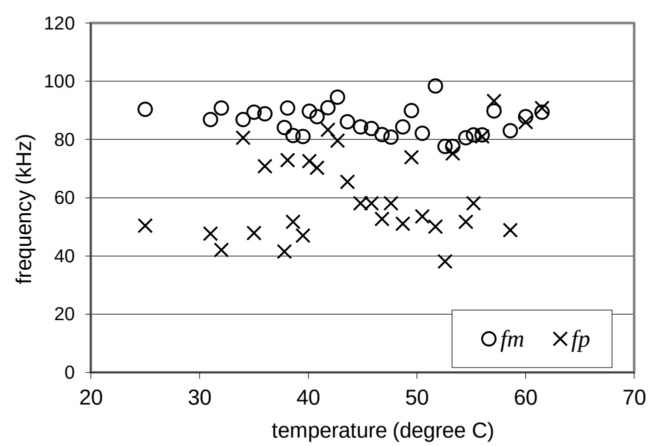

Fig.7. Average of *fp* and *fm* of PDAE signal for rod-plane electrode system with insulation at different oil temperatures.

Using expression (7), frequency spectrum for different transformer oil temperatures is calculated. The magnitude of frequency spectrum of PDAE signal at room temperature (25^oC for rod-plane electrode system with insulation / 35^oC for plane-plane electrode system with insulation) is taken as reference value for the theoretical calculation of frequency spectrum at different transformer oil temperatures. In the calculation of frequency spectrum using expression (7) for different transformer oil temperatures, source to sensor distance '*x'* is kept constant at 30 cm. *fp* and *fm* are calculated for the theoretically calculated frequency spectrum. Figs. 8 and 9 show the theoretically calculated *fp* and *fm* of PDAE signal at different transformer oil temperatures for plane-plane electrode system with insulation and for rod-plane electrode system with insulation respectively. Figs. 8 and 9 show that the value of *fp* and *fm* are constant over the considered transformer oil temperatures. This is in agreement with the experimental finding (Figs. 6 and 7).

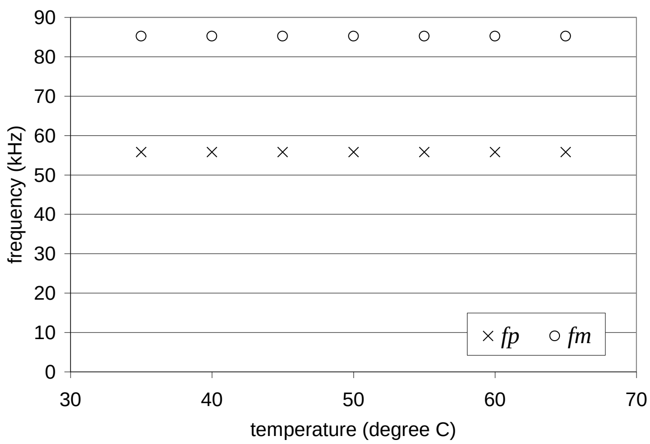

Fig. 8. Theoretically calculated *fp* and *fm* of PDAE signal of plane-plane electrode system for different oil temperature.

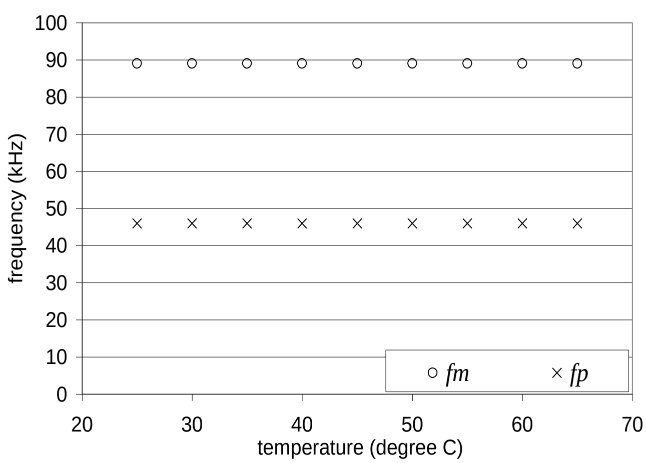

Fig. 9. Theoretically calculated *fp* and *fm* of PDAE signal of rod-plane electrode system for different oil temperature.

V. CONCLUSIONS

The peak and median frequency of PDAE signal are seen to be almost constant at considered transformer oil temperatures. The experimentally and theoretically obtained results are in good agreement. The fraction of total energy over the entire frequency spectrum, is used for analyzing the PDAE signal in [6]. No doubt, this fraction of total energy appears to be dependent on oil temperature, but the difference in the magnitude on increase of oil temperatures is very low and considering that, it is very likely that *fp* and *fm* may remain constant over the range of oil temperatures. Hence, effect of oil temperature on *fp* and *fm* of PDAE signals, is agreeing with the ref. [6].This study signifies that the frequency spectrum characteristics are unaffected within practical operating temperatures of a transformer. Hence, PD classification based on PDAE signal will not be influenced by operating temperature in an actual transformer.

VI. ACKNOWLEDGMENT

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