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Partial Discharge Signal Detection by Piezoelectric Ceramic Sensor and The Signal Processing

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Abstract. Partial discharge (PD) in an insulator or on surface of defective conductor emits acoustic wave transmitting through an air or an insulator. The acoustic wave between 20 kHz and several hundred of kHz can be detected by piezoelectric ceramic sensor that converts the acoustic wave into an electrical signal. Piezoelectric ceramic sensor has either the wide resonant band or the local resonant band depending on the ceramic material or the various combinations of each different component in the manufacturing process. This paper presents the piezoelectric ceramic sensor with 0.95 PZT–0.05 PMNS that yields the piezoelectric properties of high k_p, high Q_m . It has the frequency characteristics of local resonant band, such that it can be applied to PD detection. We have demonstrated the properties of the proposed piezoelectric ceramic sensor by comparing with the conventional electrical PD detector. Quantitative analysis is accomplished by comparing the ψ-q_{max} from a PD detector and the ψ-v_{max} from the proposed sensor while ψ-n distributions are the same for both the conventional phase-resolved PD analysis method and the proposed one.

Keywords: partial discharge, piezoelectric sensor, PZT

1. Introduction

In the situation of running many high voltage equipments, PD as a pre-breakdown phenomenon is a good alarm signal before the actual breakdown which evokes a huge accident with lights, heat, sound wave, electromagnetic wave and electrical pulses [1]. Light, heat and electrical wave detectors have been employed in many other studies as the good sensors, which are affected by other noisy sources such as the arc in welding and in switching of power contactor, etc., while the ultrasonic sensor is not. The interference in PD by other electrical and mechanical sources of neighborhood can be ignored in the frequency over 30 kHz. Conventionally, the ultrasonic sensor is called the acoustic emission (AE) sensor [2, 3]. Several researches have suggested that the AE sensor in the range between 30kHz and 300 kHz is very effective to detect PD without any interferences [4].

In this paper, we not only applied the piezoelectric ceramic sensor as an AE sensor that has the resonance frequency at 50 kHz, but also showed the electrical and dielectric properties of the proposed piezoelectric ceramics. And also, we investigated the PD phenomena generated from the three-different electrode structure so as to simulate the real PD sources and consisted the signal conditioning circuit suitable for AE sensor. The ψ-v_{max} and ψ-n distributions are proposed to compare with the results of electrical PD detector used as the phase-resolved partial discharge (PRPD) analysis, such as ψ-q_{max} and ψ-n distributions.

2. Experimental

2.1. Specimens

Lead zirconate-titanate (PZT) ceramics are used extensively for piezoelectric devices and are promising

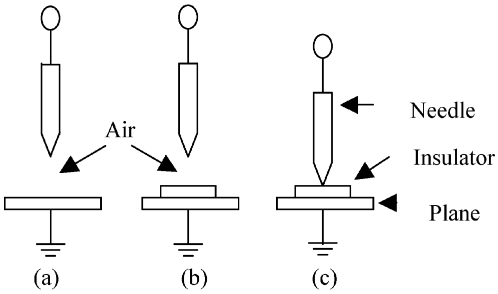


Fig. 1. Electrode structures.

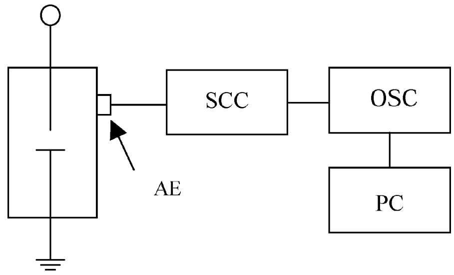


Fig. 2. Experimental setup.

materials for electronic sensors or devices. These applications require the very precisely controlled piezoelectric and dielectric properties. Especially, the piezoelectric ceramic for high power piezoelectric devices is desirable to possess higher Q_m, higher k_p, higher d_{33} and lower $\tan\delta$. The composition developed for the AE sensor is the ternary system of 0.95PZT-0.05PMNS that has Curie temperature $T_c = 350$. The several characteristics of the ceramic and manufacturing methods are presented in Ref. 5.

Thus, we applied the piezoelectric AE sensor to detect the PD phenomenon and analyzed the signal characteristics in the case of three-electrode structures (needle-plane, air gap, surface) as shown in Fig. 1.

The needle is separated 15 mm from a plane and 13mm from the polymer sheet (thickness : 2 mm) of the low density polyethylene (LDPE) as shown in Fig. 1(a) and (b) respectively. Figure 1(c) is the case that the tip of needle is located on the polymer sheet to detect the surface discharge.

2.2. Experimental Setup

Figure 2 illustrates the experimental setup for detecting and processing of the PD produced from the three electrode structures in the normal air condition.

The system shown in Fig. 2 is configured with the device under the test(DUT), a signal conditioning circuit, a digital storage oscilloscope, and a computer. Signal conditioning circuit consists of a band-pass filter (30 kHz–70 kHz) which excludes the electromagnetic interference existing in the range of high frequency above 70 kHz or other sound in the range of low frequency below 30 kHz [6], an amplifier and an envelope circuit. The filtered and amplified signals from signal conditioning circuit (SCC) are transferred to digital storage oscilloscope (Tektronix, 2 GHz) and the stored data go into the personal computer for data processing and for configuring ψ-q_{max} (Phase angle-maximum PD magnitude), ψ-v_{max} (Phase angle-maximum output voltage of the sensor) and ψ-n(Phase angle-repetition rates of PD) and time domain distributions.

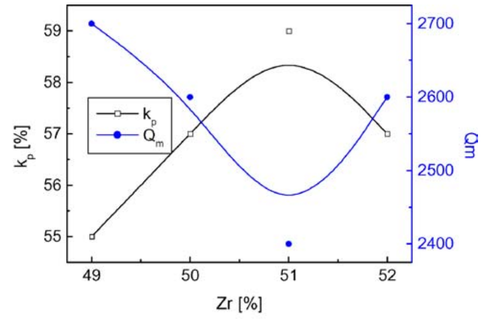
3. Results and Discussions

3.1. Characteristics of the Sensor and its Responses

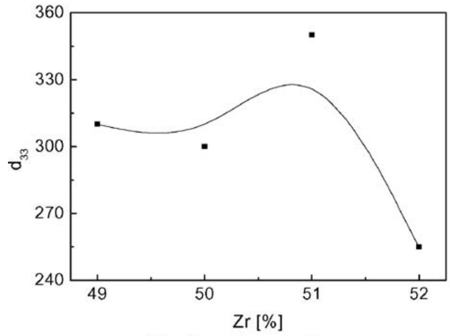
Using this piezoelectric ceramic sensor of 0.95PZT–0.05PMNS, we made the AE sensor of disk type (diameter: 12 mm, thickness: 6 mm) converting the mechanical vibration into electrical signal and investigated the capability of detecting the acoustic wave that are in pulse shape. The mechanical pressure operating to the surface of piezoelectric ceramic disk which is very simple structure cause the potential difference cross the both surfaces by the displacement of perovskite structure. In relation to material properties of AE sensor, electromechanical coupling factor k_p, mechanical quality factor Q_m and piezoelectric strain constant d_{33} of piezoelectric ceramic are

Table 1. Piezoelectric properties of disk type ceramic sensor.

k_p (%)	Q_m	d_{33}
59	2400	350



(a) k_p and Q_m depending on Zr



(b) d_{33} depending on Zr

Fig. 3. Piezoelectric properties of PZT-PMNS ceramic.

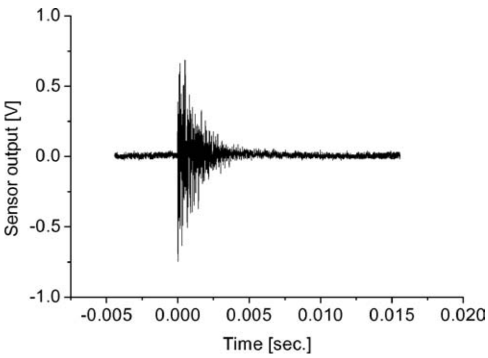


Fig. 4. Output waveform of disk type AE sensor.

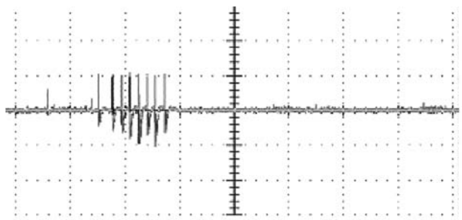
investigated. Figure 3(a) and (b) show the physical characteristics depending on composition ratios of Zr. The highest k_p and lowest Q_m and highest d_{33} exist in Zr of 51%. And their values are described in Table 1. The manufactured AE sensor was tested by the free-drop impact test of iron ball (100 g) as a mechanical impulse vibration and the results are shown in Fig. 4.

AE sensor is equivalent to the series or parallel resonant circuit with resistance (R), inductance (L) and capacitance (C) in electric components. When the mechanical impulse is applied into AE sensor, electrical output of AE sensor shows damped vibrating waveforms. But the frequency band of the detected signal is wide because of the effect of noises and low power frequency.

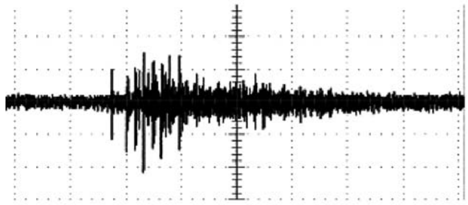
We used ten specimens of AE sensor manufactured in the same process with the same material. The test results yielded almost the same frequency band with the center frequency 50 kHz and the similar sensitivity(0.7–0.8 V/N).

3.2. *Sensor Output and Signal Conditioning*

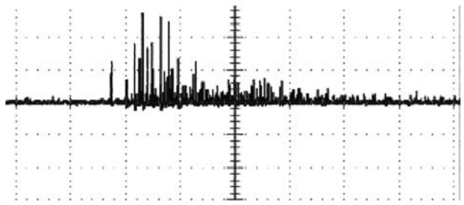
Figure 5(a) shows the pulse train measured by the conventional PD detector (AVO Biddle) which exists in positive half cycle (0°–180°). Figure 5(b) and (c) show the pulse train measured by the AE sensor.



(a) Signal of PD detector (Biddle): 10V/div, 2ms/div



(b) Filtered and amplified AE signal: 1V/div, 2ms/div



(c) Enveloped AE signal with low time constant: 1V/div, 2ms/div

Fig. 5. PD detector signal and AE signals.

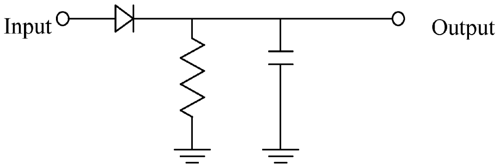


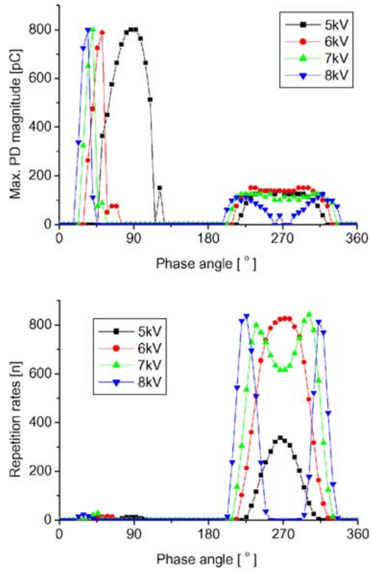
Fig. 6. Envelope circuit (R=13 [MΩ], C=3 [pF]).

Figure 5(b) and (c) illustrate the filtered and amplified waveforms through the signal conditioning circuits respectively where most noises are successively eliminated and suppressed. But the piezoelectric AE signals in Fig. 5(b) are consisted of both the positive and the negative components, which are different from the signals of Fig. 5(a), due to the mechanical vibration and the reflected signal. As shown in Fig. 5(b), the filtered and amplified signal is the pulse waveforms that have positive and negative amplitudes, which becomes Fig. 5(c) when we consider only the positive components.

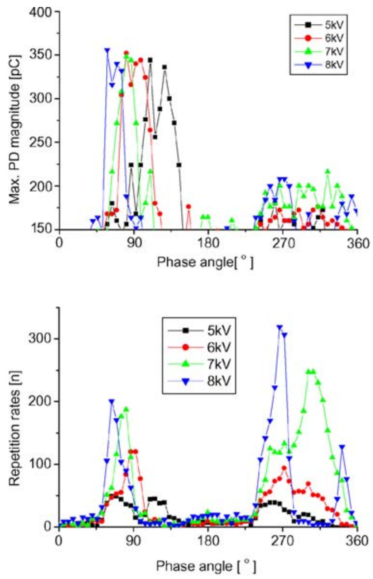
To avoid the complexity of signal processing and to simplify the data acquisition, the enveloping circuit in Fig. 6 is used, which cuts off the negative pulse signals and makes the envelope of positive pulses eventually. The time constant of the envelope circuit varies with the resistance (R) and capacitance (C). We have been fixed to be 39μs ($\tau = \mathrm{RC}$) to make the enveloped AE signal to coincide with the conventional PD detector. This enveloping process of AE signal makes it convenient to configure the distributions, ψ-$v_{\max}$ and ψ-n.

3.3. *Comparing AE Sensor Signal with PD Detector Signal*

Figures 7–9 show the comparisons between the AE signals and the conventional PD detector obtained from three-electrode structures respectively. These distributions are measured and preprocessed during 100 cycles of applied voltage. In both the needle-plane and the surface electrode structures, the distributions of signals from the PD detector and the piezoelectric AE sensor result to be similar because the signals have enough applicability for statistical signal processing [7, 8] to detect pre-breakdown phenomena excepting ψ-n distributions.



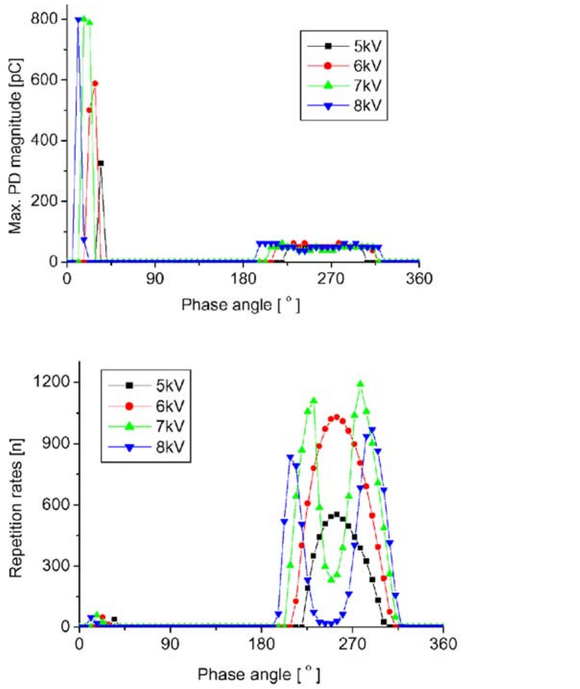
(a) ψ–$q_{\max}$ and ψ-n distributions of signals from a conventional PD detector



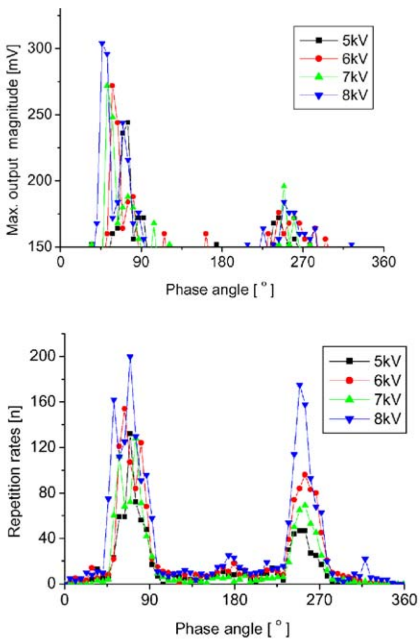
(b) ψ-$v_{\max}$ and ψ-n distributions of signals from AE sensor

Fig. 7. Comparison of signals between AE sensor and PD detector in Needle-Plane electrode structure.

In the air gap electrode structure, the slight difference in the ψ-$q(v)_{\max}$ and ψ-n exists both the proposed sensor and the conventional PD detector.

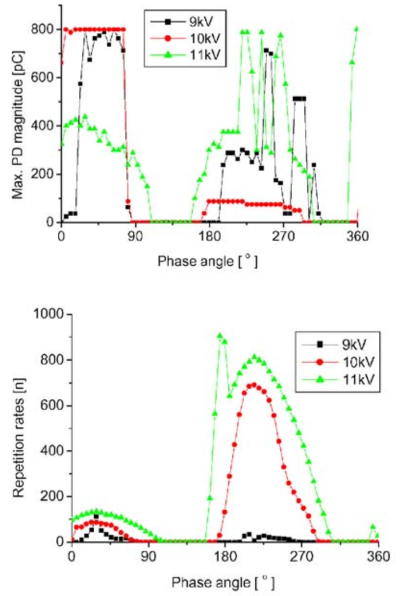


(a) ψ-q_{max} and ψ-n distributions of signals from conventional PD detector

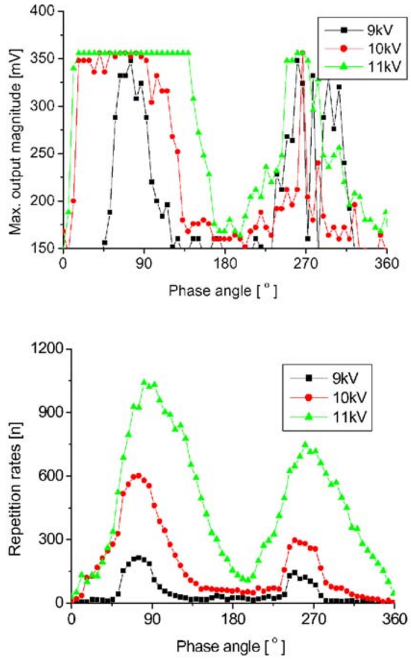


(b) ψ-v_{max} and ψ-n distributions of signals from AE sensor

Fig. 8. Comparison of signals between AE sensor and PD detector in Air gapped electrode structure.



(a) ψ-q_{max} and ψ-n distributions of signals from conventional PD detector



(b) ψ-v_{max} and ψ-n distributions of signals from AE sensor

Fig. 9. Comparison of signals between AE sensor and PD detector in Surface structure.

4. Conclusions

The piezoelectric ceramic sensor of 0.95PZT-0.05PMNS is developed where the piezoelectric and dielectric properties are $k_p = 59\%$, $d_{33} = 350$pC/N, $Q_m = 2400$ and Curie temperature $T_c = 350°$C. The proposed sensor of disk type is used for the AE sensor to detect PD phenomenon with the center frequency of 50 kHz. Also, the signal conditioning circuit is constructed to process the signal from AE sensor, which can do noise suppression and signal amplification. The ψ-$q(v)_{max}$ and ψ-n distributions of the signal of 100 periods, the enveloped signal of the detected signals, are compared with the ones of the conventional PD detector. The results from the sensor are enough to detect pre-breakdown phenomena excepting only the case of air gap electrode structure. However, the proposed AE sensor is still effective to detect PD signal in the various applications.

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