OBSERVATION OF SILENT DISCHARGE USING PIEZOELECTRIC TRANSFORMER

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Abstract

This paper deals with observation of light emissions around a piezoelectric transformer (PT) in nitrogen. The light emissions associated with \( \lambda \) mode vibration was observed using a single-reflex camera and electric potential distributions on the PT were measured using a probe electrode. Temporal variations in the light emissions around the PT were observed by a CCD camera and variations in potential were measured by an oscilloscope. The results suggest that the intensity distribution of light emission corresponded to potential distribution induced on the surface of the PT.

1. Introduction

Piezoelectric transformers (PTs), which are small and highly efficient devices for energy conversion, are used in the power supply for the backlight of liquid crystal displays (LCDs) and have contributed to the advance of compact information equipment such as mobile computers, mobile phones and car navigation systems [1].

A number of papers have been published on the behavior of PTs in the past [2]. However, the luminous phenomenon of the PT itself has only been observed by Yamagata [3]. In their study, they measured the potential distribution on the surface of the PT with the method proposed by Koga [4] for measuring the potential distribution on the AT-cut crystal slab. Recently, Miyake et al. [5] investigated PTs in order to apply for a plasma source.

The present authors [6],[7] discovered that PTs can be utilized as not only high voltage generation devices but also as discharge exciter. In this case, discharge occurs between the ceramic body of the PT and the earthed stainless steel discharge chamber, so we consider that the discharge is a silent discharge.

In order to investigate the mechanism this phenomenon, the spatial and temporal variation of light emission around the PT was observed, as was the temporal variation of electric potential on the PT surface. From the results, we suggest that light emission around the PT is direct related to the electric field on the PT surface.

2. Experimental setup and method

Figure 1 is a schematic of the experimental setup. The PT was made of PZT(Pb(Zr,Ti)O₃), with a length 60 mm, width 13 mm and thickness 2 mm, as shown in figure 1(a). Primary electrodes P were attached to both sides and half-length of the PT, and secondary electrode S was attached to the top of the PT.

The PT was placed vertically on the base plate at the center of the chamber. A sinusoidal voltage of 12 V and 52.61 kHz was applied to the primary terminal of the PT from the signal generator, resulting in a high potential between the secondary terminal and the discharge chamber due to the elastic vibration of the PT. The resonant frequencies of the PT were 26.62 kHz (1/2 \( \lambda \) mode), 52.22 kHz (\( \lambda \) mode) and 80.27 kHz (3/2 \( \lambda \) mode). Here, resonance occurs when the wavelength of elastic vibration of the PT is equal to the length of the PT, at which vibration displacement is maximum and the highest output voltage is obtained. This is called \( \lambda \)-mode vibration. In this experiment, we used this vibration mode almost exclusively.

The chamber was evacuated by a turbo-molecular pumping system and experiments were carried out in nitrogen at a gas pressure of 0.45 Torr.
The light emission around the PT was captured using a single-reflex camera through the quartz window of the chamber. In order to observe the temporal variations of luminous patterns, a CCD camera was also used in this study. The CCD camera was fitted with a UV lens, capturing short wavelengths up to 200 nm. An image intensifier was used as a high-speed shutter, operated by a gate signal from the signal generator driving the PT. The primary and secondary voltages of the PT and the gate signal voltage were recorded by an oscilloscope. The CCD images were analyzed using a personal computer.

The system for measuring the potential distribution on the PT surface is shown in figure 2. The PT was placed, vertically on an XY stage in the atmospheric pressure. A voltage was applied to the primary terminal, and the potential on the PT surface was measured by a probe electrode 2 mm from the surface. The PT was moved in the x and y direction by the XY stage and a traveling microscope. The potential distribution was measured at 3 V and 12 V, and we confirmed that the distribution is identical in both cases. An electronic voltmeter and oscilloscope were used to record the data. These instruments were controlled by the personal computer.

3. Results and discussions
3.1 Spatial distribution of light emission and potential
3.1.1 Observation of the light emission around the PT

Figure 3(a) shows the front and side photographs of silent discharge in λ-mode. These photographs were taken with a shutter speed of 5 s. The outline of the side view in (a) is shown in (b) in the same figure.
There are 8 regions of luminous parts around the PT. Regions (1),(2) and (3),(4) are observed at a distance from the PT and regions (5),(6) and (7),(8) occur at the PT surface. Regions (1),(2),(5) and (6) are near the top of the secondary terminal, and (3),(4),(7) and (8) are near the primary terminal near the center of the PT.

3.1.2 Measurement of electric potential distribution on PT surface
The measured potential distribution on the PT surface is shown in figure 4. The x and y axes correspond to the width and length of the PT, respectively. Two peaks, at y=5 and 26 mm, can be seen in the potential distribution in λ mode. These peaks can be associated with the upper and lower areas of luminous parts in figure 3(b). The potential distribution is almost symmetrical about the long y axis of the PT.

3.1.3 Comparison between spatial distribution of potential and light emission
Figure 5(a) shows contour diagrams of potential and light emission. There is a clear relationship between the two distributions.

3.2 Temporal variation of light emission and potential
Temporal variations of the potential and the luminous patterns around the PT are measured using the probe electrode connected oscilloscope and the CCD camera.

Shutter speed of the image intensifier is 1 μs and images are integrated 10 times. Figure 6 shows the images of light emission in λ mode vibration. The twelve images (a) to (l) represent one period of primary and secondary voltage corresponding to the time point indicated in (n).

Images (a) to (l) are the luminous patterns for positive secondary voltage. The luminous patterns correspond to (3),(4) and (5),(6) in figure 3(b), that is, removed from the PT at the lower end and close to the PT, at the upper end, respectively. Image (d) exhibits the brightest luminous pattern, corresponding to the time at which the secondary voltage is a maximum. Images (g) to (l) are luminous patterns when the secondary voltage is negative. Image (g) is taken when the secondary voltage is zero, and no luminous pattern is observed at that time. Images (h) to (l) are luminous patterns which appear at the region (1)(2) and (7),(8), that is, at a distance at the upper end of the PT and close to the lower end of the PT. The brightest light emission is observed in image (i), where the secondary voltage is at a negative maximum. The temporal variation in potential at a number of positions along the central axis at x=6 mm is
shown in (n). At the position of $y=20$ mm, the node in the standing wave of $\lambda$-mode PT vibrati

3.3 Comparison between the light emission a

The temporal variation of the light emissi summarized in figure 7.

3.4 Polarity of the induced potential and the

In the previous section, we established that $\gamma$ polarity of potential on the PT surface and the responsible for this phenomenon then appears. However, the source of the initiating electron $e^-$

We conducted an examination of electron em glass plate near the PT during operation are ob: was observed only during previous of negative $\gamma$ fast electrons are emitted from the PT and incid observation will be pursued in future work.

Fig. 6 Temporal variations of light emission and potential distributions
4. Conclusions

Luminous phenomenon of the silent discharge producing the PT was observed optically and electrically, and the causative mechanism was investigated. The results obtained are summarized as follows;

1) Light emission was observed on and around the PT when the surface was at maximum potential. The spatial distribution of light emission was found to correspond to the electric field intensity distribution.

2) In λ-mode vibration, the potential distribution has two peaks of opposite polarity along the length of the PT.

3) The location and intensity of light emissions was found to be directly related to the polarity and phase of the PT surface potential.

References
