

Electrical Characteristics of the Oscillatory Toner Sensor for Measuring the Charge-to-Mass Ratio (q/m)

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Abstract

We will present here more details of the electrical characteristics of q/m toner sensor on the basis of the technique developed in references [1] and [2].

At first, toner particles are placed on the lower side of the parallel electrodes with piezoelectric element. Next, the piezoelectric element is driven by the rectangular pulse. Consequently, the dumped oscillation in the form of the sinusoidal waveform can be caused on the lower electrode. We can obtain some information for electrical states of the toner particles whether they can be lifted up from the center of the gap between two electrodes toward the upper one or not, from the first half period of the dumped oscillation waveform.

By analyzing this waveform, we can obtain the value of charge-to-mass ratio (q/m) of toner particles.

Introduction

We have already presented the method for measuring charge Σq and mass Σm value of toner particles[3,4] and the observation of the movement of toner particles between parallel electrodes[2]. By the experiment shown in reference [2], we found that the movement of toner particles near the center of the gap between two electrodes depends on only the relationship between the Coulomb force and the gravity one.

In this paper, the electrical characteristics of the q/m toner sensor on the basis of the approach shown in references [1] and [2] will be presented in more detail.

Theory

Figure 1 illustrates a model for the movement of toner particles between parallel electrodes. Lots of negatively charged toner particles are placed on the inner surface of the lower electrode constructed by the piezoelectric element[5]. After that, the piezoelectric one is driven by the rectangular pulse shown in Figure 3.

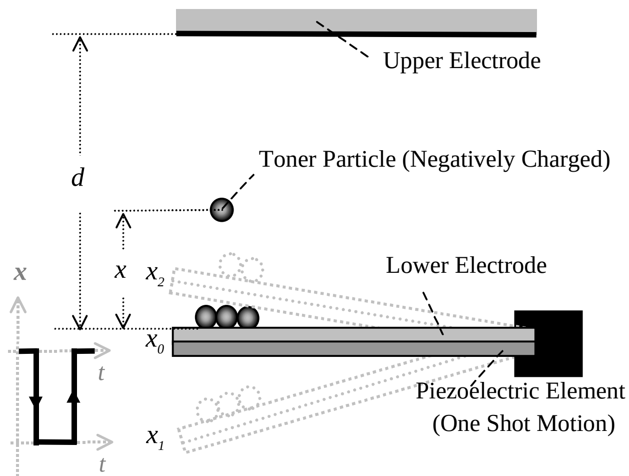


Figure 1. Movement of toner particles between parallel electrodes.

Then, the voltage V_u induced on the upper electrode may be expressed as follows:

$$V_u = \frac{q}{4\pi\varepsilon_0 d} \cdot \frac{1}{(1 - x/d)} \quad (1)$$

where

q: charge of a toner particle
d: distance between two electrodes (500μm)
x: distance between the center of the toner particle and the inner surface of the lower electrode
ε_0: permittivity of the gap space

Toner particles are adhered on the inner surface of lower electrode by adhesive forces. At the initial point x_0 (x = 0), the voltage V_i induced on the upper electrode may be described as follows:

$$V_i = \frac{\sum q}{4\pi\varepsilon_0 d} \quad (2)$$

Let us consider the case that the piezoelectric element is driven by the rectangular pulse. At the leading edge A of the pulse waveform shown in Figure 3, the piezoelectric one is swung by the dumped oscillation toward the next steady point x_1 of the negative direction shown in Figure1. At the trailing edge B in Figure 3, the piezoelectric one has the accelerated by the dumped oscillation toward the opposite terminal point x_2 of the positive direction shown in Figure 1. Consequently, thousands of toner particles may be thrown up to the center of two electrodes. The dumped oscillation x on the basis of the initial point x_0 may be described as follows:

$$x = (x_2 - x_0) \cdot e^{-\alpha t} \sin\omega t \qquad (3)$$

where

ω : proper angular frequency of the piezoelectric element

α : dumping coefficient

By substituting Equation (3) into Equation (1), $(1 - x/d)^{-1}$ is approximated as follows:

$$\begin{aligned}(1 - x/d)^{-1} &= [\,1 - (x_2 - x_0)/d \cdot e^{-\alpha t} \sin\omega t\,]^{-1} \\ &= [\,1 - G \cdot e^{-\alpha t} \sin\omega t\,]^{-1} \quad ((x_2 - x_0)/d = G) \qquad (4) \\ &\cong 1 + G \cdot e^{-\alpha t} \sin\omega t\end{aligned}$$

From Equations (1) and (4), the signal voltage V_d of the dumped oscillation induced on the upper electrode generated by charged toner particles on the lower one is expressed in following form:

$$V_d = \frac{\sum q}{4\pi\varepsilon_0 d} \cdot \left(1 + G \cdot e^{-\alpha t} \sin\omega t\right) \qquad (5)$$

Therefore, the output signal voltage V_o obtained by the differential amplifier may be expressed in the following equation:

$$\begin{aligned}V_o = V_d - V_i &= \frac{\sum q}{4\pi\varepsilon_0 d} \cdot \left(1 + G \cdot e^{-\alpha t} \sin\omega t\right) - \frac{\sum q}{4\pi\varepsilon_0 d} \\ &= \frac{\sum q}{4\pi\varepsilon_0 d} \cdot G \cdot e^{-\alpha t} \sin\omega t \qquad (6)\end{aligned}$$

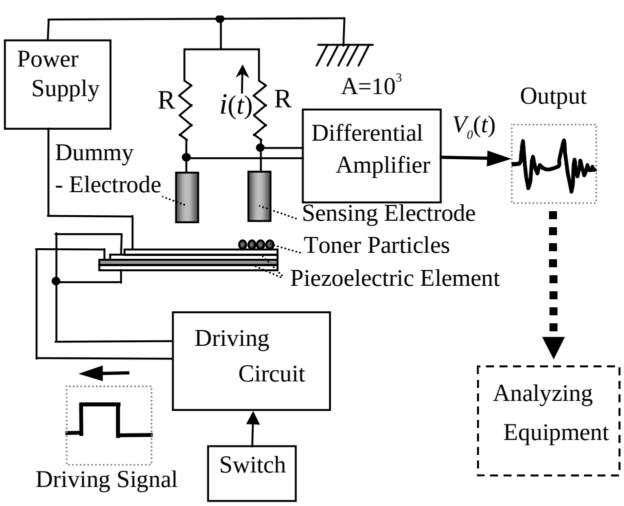


Figure 2. Schematic configuration of the oscillatory toner sensing system.

Experimental System

Figure 2 shows the schematic configuration of the oscillatory toner sensing system. The gap space between two electrodes is 500µm. By pushing the switch-button for operating the driving circuit of the piezoelectric element, a rectangular pulse is given to the piezoelectric element in the lower electrode.

Then, toner particles may be vertically thrown up to the center of the gap between two electrodes. After that, It depends on the voltage applied across two electrodes whether the toner particles move toward the upper one or not. Consequently, the induced voltage $i(t) \cdot R$ is generated across the sensing resister R and is amplified by the differential amplifier. The value of output signal $V_o(t)$ is recorded into the analyzing equipment.

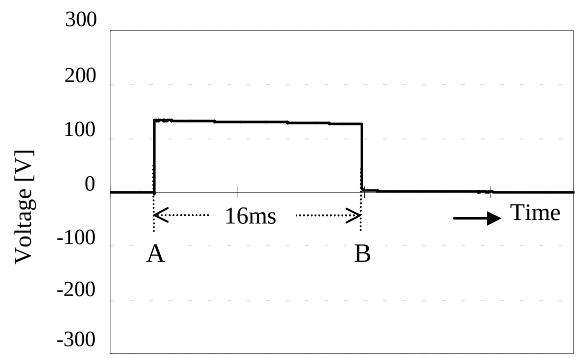


Figure 3. Rectangular pulse for driving the piezoelectric element.

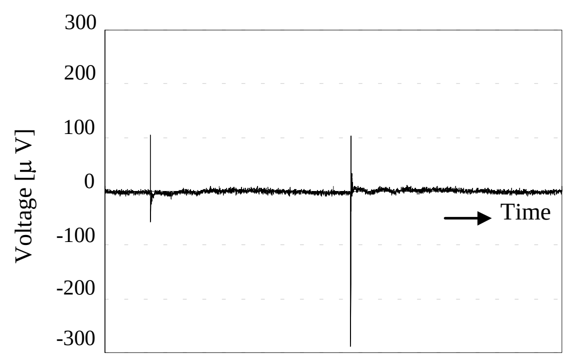


Figure 4. Output signal voltage waveform without toner particles.

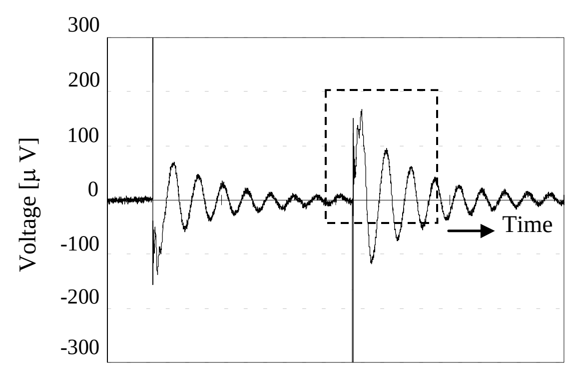
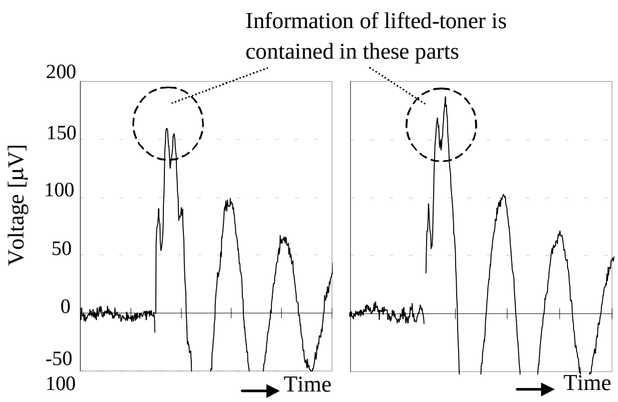


Figure 5. Output signal voltage waveform with toner particles.

Results

The voltage waveform for driving the piezoelectric element is a rectangular pulse having 16ms times duration stepped from zero to 140V amplitude as shown in Figure 3. Figure 4 shows the output signal voltage waveform without toner particles on the lower electrode. In this situation, we can observe that the output signal voltage obtained from the differential amplifier is approximately zero. In the situation that toner particles is placed on the lower one, the output signal voltage waveform $V_0(t)$ of two dumped sinusoidal oscillations in Figure 5 can be observed.

Figure 6 magnifies the output voltage waveform in the square of dashed line shown in Figure 5. In the circle of dashed line shown in Figure 6, first half period of the dumped oscillation contains some of information for electrical states of the toner particles whether they are lifted up from the center of the gap between two electrodes toward the upper one or not.



(a). Voltage Applied Across the Electrodes is 0V.
(b). Voltage Applied Across the Electrodes is 1V.

Figure 6. Magnification of output voltage waveforms obtained from sensing amplifier.

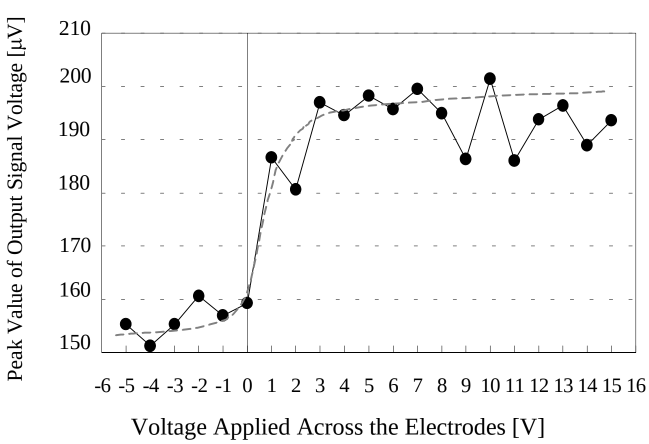


Figure 7. Voltage applied across the electrodes versus peak value of output voltage.

Figure 7 shows the relationship between the voltage applied across parallel electrodes and the peak value of output signal voltage from the sensing amplifier.

In the case that the value of the voltage applied across two electrodes is changed from 0V to 1V, the peak value of output signal voltage of the sensing amplifier is rapidly changed from 159µV to 187µV. In this experiment, we have used the toner particles that the mean value of q/m is approximately 20µC/g. From our method in references [3] and [4], the value of q/m is obtained by the following equation:

$$\frac{q}{m} = \frac{gd}{V_e} \tag{7}$$

where

q: charge of a toner particle m: mass of a toner particle
g: acceleration of the gravity force ($9.8 m/s^2$)
d: distance between two electrodes (500µm)
V_e: voltage applied across the electrodes

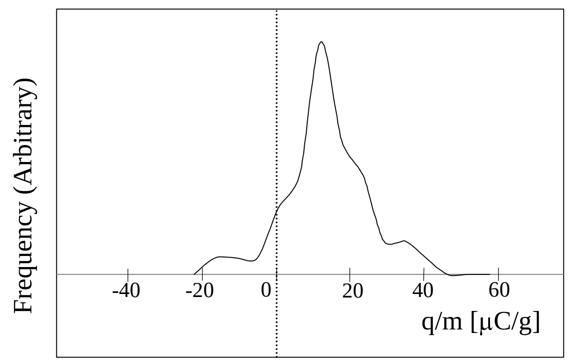


Figure 8. Distribution of the value of the charge-to-mass ratio (q/m).

Therefore, in the case that voltage V_e applied across the electrodes may have the value of more than 0.245V, most of toner particles thrown to the vicinity of the center of parallel electrodes must be lifted up to the upper one. Consequently, we can observe that no toner particles are lifted in the case shown in Figure 6-(a) and some of toner particles are lifted in the case shown in Figure 6-(b). Using these electrical characteristics represented dashed line in Figure 7, we can obtain the value of charge-to-mass ratio (q/m) of toner particles as shown in Figure 8.

Conclusion

In this experiment, we can get some information for electrical states of the toner particles whether the toner particles can be lifted up from the center of the gap between two electrodes toward the upper one or not, from the first half period of the dumped oscillation waveform. By analyzing this waveform, we can obtain the value of charge-to-mass ratio (q/m) of toner particles.

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Biography

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He received a B.E. degree in Electrical Engineering from Kinki University, Osaka, Japan, in 1964 and a Dr. of Eng. degree from Osaka University in 1972, respectively. He was a Research Associate of Electronics Engineering at Osaka, University from 1964 to 1973 and an Associate Professor of Electronics Engineering of Fukui University from 1973 to 1976. Since 1976, he has been a Professor at Fukui University. He has published Image Processing, Sensor and Signal Processing. He is a senior member of the IEEE.

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