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Electrostatically Induced Voltage in Two Metal Cases When a Charged Object Moves Away From and Passes by Cases

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Abstract

Electronic device may malfunction owing to electrostatically induced voltages. Malfunctions or failures can occur because of induced voltages in the range of 10 V. Charged human bodies can occasionally reach as high as 10 kV in offices. When such an object moves near the metal housing of electronic device, a high induced voltage can occasionally be generated in the case. In experiments, the induced voltages in two metal cases are measured using two spark gaps and two electromagnetic wave sensors when the charged object moves away from the metal case and passes by another case. The results will be helpful in the consideration of preventive measures for electronic device.

Keywords: Moving charged object; Two partly opened metal cases; Electrostatically induced voltage; Spark gap

Introduction

Electrostatics has various useful applications such as in copying machines and dust collectors, among others. However, this phenomenon can occasionally lead to malfunction or failure [1-21] of electronic device, such as A4-size laptop computers, among others. A malfunction or failure of an electronic device can occur due to the generation of an electrostatically induced voltage in the metal case or housing of the device. This voltage is generated when a charged object, such as the human body, moves in the vicinity of the metal case.

When an individual moves in a room with air-conditioner, their object is electrostatically charged [22]. Their voltage can occasionally exceed 10 kV. Electronic components that are used in electronic device tend to malfunction at 10 V or less. Thus, the malfunctioning voltage of electronic device is 0.1% of the voltage of a charged human body. If the relationship between the induced voltage in a metal case and the voltage of a charged human body is established, then the electrostatic problem of electronic device malfunction or failure can be considered in terms of the induced voltage from a charged human body. This consideration is helpful in the design of electronic device that is less susceptible to possible malfunction or failure.

Studies have also been performed on a related topic when a charged object, such as a human body, moved near a metal case. The results were as follows:

The results for a charged object approaching and passing near the front of a metal case

a1) When one of the two pieces of conductors is grounded in a metal case of an electronic device, the induced voltage between a conductor of floating potential and a grounded conductor is higher than that between two conductors of floating potential [23].

a2) The induced voltage generated in a metal case decreases linearly, with an increase in the logarithmic distance between a charged object and the front of the case.

a3) When the area of a conductor of floating potential contained in a metal case increases, the induced voltage increases [24].

a4) The induced voltage generated in a metal case is 30% of the voltage of a charged object, when the charged object moves near it [25].

a5) When a charged object passes the front of a metal case, the voltage polarity of the induced voltages generated in the case is changed by the occurrence of a discharge in this object [26].

a6) The value of the induced voltage generated in a grounded metal case is independent of its volume, when its depth is changed [27].

a7) The induced voltage generated in a metal case increases, when the size of its opening increases [28].

a8) The induced voltage of an ungrounded metal case is 56-78% of the voltage of a moving charged object, when the charged object moves near it, with the distance of 1 cm between the object and the case [29].

a9) The induced voltages generated in two metal cases are 43% of a moving charged object, when the charged object passes near the front of two cases. The voltage polarity of the induced voltages generated changes, when a spark discharge occurs in the cases. The value of the induced voltages is independent of the distance between them.

The results when a charged object moves away from a metal case

b1) The induced voltage of an ungrounded metal case, when a charged object moves away from the metal case, is greater than that recorded when the charged object approaches the case [30].

b2) When the surface area of the front panel of an ungrounded metal case increases, the induced voltage and electric charge also increase [31].

b3) The induced voltage generated in a metal case attains inverse polarity against the voltage of a charged object, when the charged object moves away from the front of the metal case. Its value is −0.42 times that of the voltage of the charged object [32].

b4) The induced voltage of an ungrounded metal case increases when the depth of a metal case decreases. The induced voltage of the metal case, such as an A4 size laptop computer, attains inverse polarity against the voltage of a charged object. Its value is −3.73 times (approximately −4 times) larger than the voltage of the charged object. This value implies that the induced voltage generated in an ungrounded metal case, like an A4 size laptop computer, is 4 times the voltage of a charged object although the voltage polarity of the induced voltage is different from that of the charged object.

In this paper, the experimental results of the aforementioned investigation have been presented. The induced voltages generated in two metal cases are measured using the spark gap of an induction instrument and the EMI locator of an electromagnetic wave sensor, when a charged object moves away from a metal case and passes near the front of another metal case. Each of the metal cases has an opening at the front. The experimental results show that the induced voltage in a metal case has an inverse polarity against a charged object, when this object moves away from the metal case. The induced voltage in another metal case has the same polarity as that of the charged object, when the charged object passes near the front of the other metal case. The voltage polarity in two metal cases does not change even if the distance between two metal cases increases. The voltage of a charged object, in which a spark discharge occurs and an EMI locator sounds an alarm tone for each metal case, is independent of the distance between two metal cases. The percentage of the induced voltage in each metal case is 52% of the inverse polarity for the first metal case and 45% of the same polarity for the other metal case, against the voltage of a charged object. The absolute induced voltage generated in a metal case when the charged object moves away is larger than the induced voltage in the other metal case when the charged object passes near its front, although the voltage polarity of the induced voltage is different. The results will assist in the consideration of the arrangement of electronic components such that electrostatic malfunction or failure of the device can be prevented.

Experimental Setup

Figure 1 shows the experimental setup. The experimental setup consisted of a charged object and two metal cases in which each induction instrument was contained, in addition to the measuring devices.

A charged object modeled as a walking charged human body was placed on an automatic transporting stage and connected to a high-voltage power supply. Initially, the back of the charged object corresponded to the right-side edge of the metallic plate (ungrounded) on the left-side of induction instrument A in the metal case A (Figure 2). The distance between the charged object and the front of the two metal cases was 1 cm. The charged object moved away from metal case A at an average velocity of 0.4 m/s. After the charged object moved away from the ungrounded metallic plate of induction instrument A, it passed near the front of metal case B. Possible distance moved was 1.85 m from the starting position of the charged object and its dimensions were 0.55 m in width, 0.2 m in depth, and 1.8 m in height.

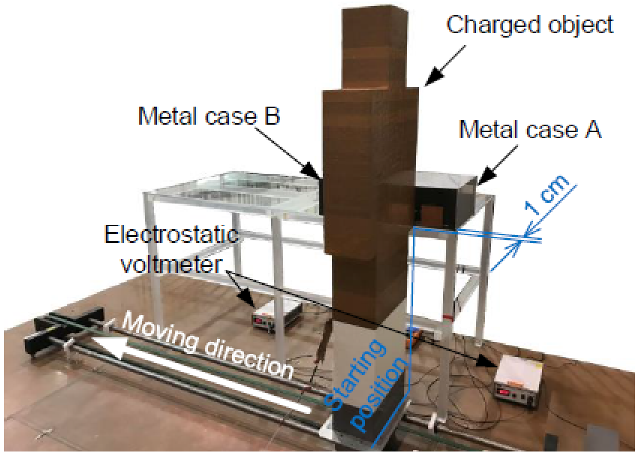

Figure 1: Experimental setup.

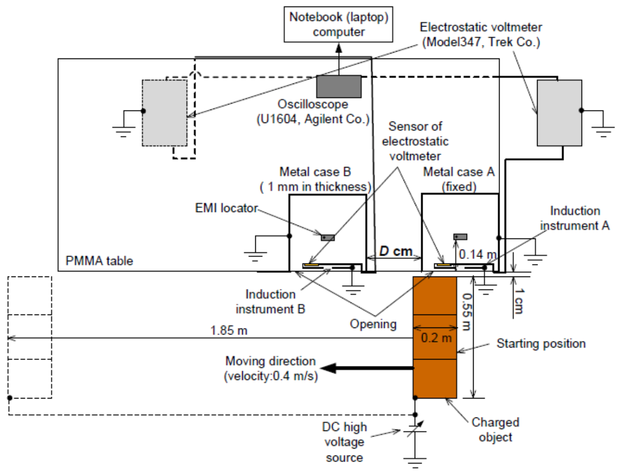

Figure 2: Schematic of experimental setup.

Two metal cases were placed on an acrylic table at a height of 1 m. Each metal case had an opening at its front and they were grounded. The front of metal case A and metal case B corresponded to the front of the acrylic table. The right-side line of the former corresponded to the right-side of the acrylic table. The right-side of metal case B was parallel to the left-side of metal case A. Each induction instrument was placed on the base, at a depth of 1 cm from the front of each metal case (Figure 2). Each EMI locator of the electromagnetic wave sensor was placed on the base at a depth of 0.14 m from the front of each metal case. The center of the EMI locator (Sanki Co., ES-100V) and the induction instrument corresponded to the center of each metal case. The dimensions of the two metal cases were 0.2 m in height, 0.35 m in width, and 0.4 m in depth.

Figures 2 and 3 show the induction instrument contained in the two metal cases. The induction instruments comprise of a spark gap [32] and two metallic plates, in addition to acrylic frames (Figure 3). The electrode on the left-side of the spark gap was connected to the metallic plate on the left-side of the induction instrument. The electrode on the right-side of the spark gap was connected to the metallic plate on the right-side of the induction instrument. In the case of each instrument, the metallic plate on the right-side was grounded. The gap length of the spark gap of each induction instrument of the two metal cases was 30 μm. This distance was adjusted using a micrometer head which accompanied the electrode on the right-side of the induction instrument. The averaged sparking voltage values of the five measurements were 365 V for induction instrument A in metal case A, and 445 V for induction instrument B in metal case B. The area of each metallic plate of the induction instrument was 100 cm^2, and the thickness was 0.1 mm.

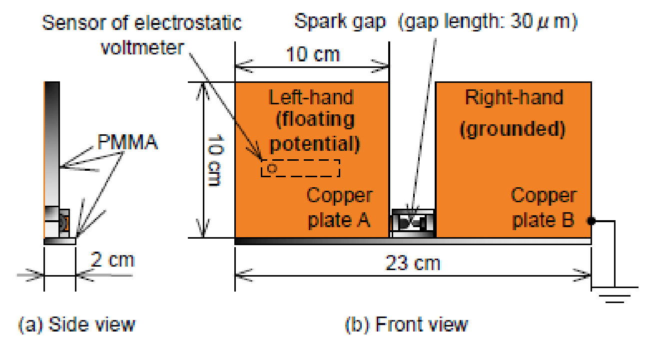

Figure 3: Schematic of induction instrument A or induction instrument B.

A probe (sensor) for the two electrostatic voltmeters in the two metal cases was placed on the back of each metallic plate on the left-side of the two induction instruments. The distance between the metallic plate on the left side and the sensor for the two electrostatic voltmeters was 2 mm. The models of the electrostatic voltmeters used were Model 347 of Trek Co. They were connected to an oscilloscope (U1604 of Agilent Co.) and a laptop computer. The induced voltages generated in each metallic plate on the left-side of the two induction instruments were recorded using PC Link software. Two electrostatic voltmeters and an oscilloscope were placed on the grounded plane in the experimental room.

Experimental Methods

Experiments were performed as follows:

(1) A charged object was arranged in front of the metallic plate on the left-side of the induction instrument A in metal case A, at a given distance, D, between the two metal cases (Figure 2).

(2) The voltage of the charged object was adjusted to a specific voltage.

(3) The voltage of each metallic plate on the left-side of the two induction instruments was checked and set at 0 V.

(4) The charged object moved away from metal case A and passed near the front of metal case B with a constant velocity.

(5) The voltage of the charged object was measured to determine whether the EMI locator sounded an alarm when the charged object at a specified voltage moved away from metal case A and passed near the front of metal case B.

(6) If the EMI locator did not sound an alarm tone, the voltage of the charged object was increased. If the EMI locator sounded an alarm tone, the voltage of the charged object was decreased.

Thus, the minimum (threshold) voltage of a charged object, which caused the EMI locator to sound an alarm, was measured by the repetition of steps (1)-(6).

The distance, D, between the two metal cases was changed from 2 cm to 100 cm. Three measurements were performed at the given distance, D. The experiments were performed in experimental room conditions of 24°C and 46-53% relative humidity (R.H).

Experimental Results

Induced voltages generated in metal cases when charged object moved

Figure 4 shows the induced voltage generated in each metallic plate on the left side of the floating potential of induction instruments for the two metal cases when a charged object of −600 V moved away from metal case A, and passed near the front of metal case B at a distance, D, of 2 cm. The induced voltage generated in the metallic plate on the left side of the induction instrument A in metal case A increased as the charged object moved away from it. The value of the peak induced voltage was 388 V at 2.88 s, and the electrostatic energy was 0.8 μJ. This was because the electric charge of an ungrounded metallic plate of the induction instrument A in metal case A was approximately 4 nC when a charged object moved away from case A. The peak induced voltage was −0.65 times that of the voltage of the charged object, because the voltage polarity of the induced voltage generated in the metallic plate on the left-side of the induction instrument A was different from that of the charged object. The charged object moved through a distance of 1.15 m for 2.88 s. In this case, the induced voltage generated in the metallic plate on the left side of the induction instrument A in metal case A maintained a constant voltage of 384 V, after the charged object moved away from case A.

The induced voltage generated in the metallic plate on the left side of the induction instrument B in metal case B decreased when a charged object of −600 V passed near the front of this case at a distance, D, of 2 cm, as shown in Figure 4. When the charged object faced the metallic plate on the left-side of the induction instrument B, the induced voltage generated in the case B was −280 V, was 0.47 times that of the voltage of the charged object, and increased after the charged object passed near the front of case B.

Figure 5 shows the induced voltage generated in each metallic plate on the left-side of the floating potential of induction instruments of the two metal cases, when a charged object of −600 V moved away from metal case A and passed near metal case B at a distance, D, of 100 cm. The induced voltage generated in the metallic plate on the left-side of the induction instrument A in metal case A increased as the charged object moved away from case A. A value of 376 V was obtained for the peak induced voltage at 3.00 s. This value was −0.63 times that of the voltage of the charged object. The charged object moved through a distance of 1.2 m at the time of peak induced voltage. The induced voltage generated in the metallic plate on the left-side of the induction instrument A in metal case A maintained a constant voltage of 376 V, after the charged object moved away from the case.

Induced voltage generated in the metallic plate on the left-side of the induction instrument B in metal case B decreased when a charged object of −600 V passed near the front of the case at a distance, D, of 100 cm, as shown in Figure 5. When the charged object faced the metallic plate on the left-side of the induction instrument B in metal case B, the induced voltage generated in the case was −284 V, was 0.47 times that of the voltage of the charged object, and increased after the charged object passed near the front of case B.

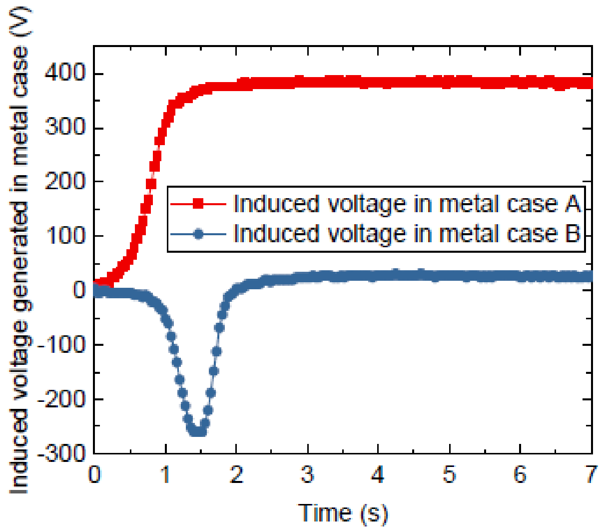

Figure 4: Induced voltage in two metal cases for a moving charged object of −600 V and distance D of 2 cm.

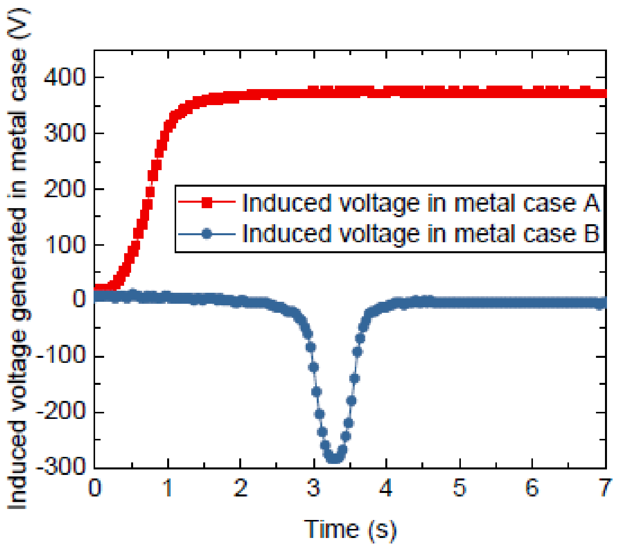

Figure 5: Induced voltage in two metal cases for a moving charged object of −600 V and distance D of 100 cm.

Minimum voltage of charged object

Figure 6 shows the minimum voltage of a moving charged object when the EMI locator sounded an alarm tone, due to the occurrence of an electrical discharge in the spark gap of the induction instrument A in metal case A. In the figure, the relationship between the averaged minimum (threshold) voltage of the charged object and the distance, D, between the two metal cases was plotted. The minimum voltage of the charged object was −700 V at a distance, D, of 2 cm. The minimum voltage of the charged object increased to −750 V at a distance, D, of 100 cm. It was noted that the minimum voltage of the charged object was 1.9 times higher than that of the sparking voltage (365 V) of induction instrument A.

Figure 7 shows the change in the induced voltage generated in the induction instrument A in metal case A, when the EMI locator sounded an alarm tone due to the occurrence of an electrical discharge in the spark gap of induction instrument A. The result of the induced voltage was measured at a distance, D, of 2 cm. The change in the induced voltage generated in an ungrounded metallic plate of induction instrument A occurred when a charged object of −700 V moved away from the metal case A, and passed near the front of metal case B. This change occurred when an electrical discharge occurred in the spark gap of induction instrument A in case A.

Figure 8 shows the minimum voltage of a moving charged object when the EMI locator sounded an alarm tone due to the occurrence of an electrical discharge in the spark gap of induction instrument B in metal case B. The minimum voltage of the charged object was −1000 V at a distance, D, of 2 cm and it remained at a constant until a distance, D, of 100 cm. This voltage was 2.2 times higher than that of the sparking voltage (445 V) of induction instrument B in metal case B.

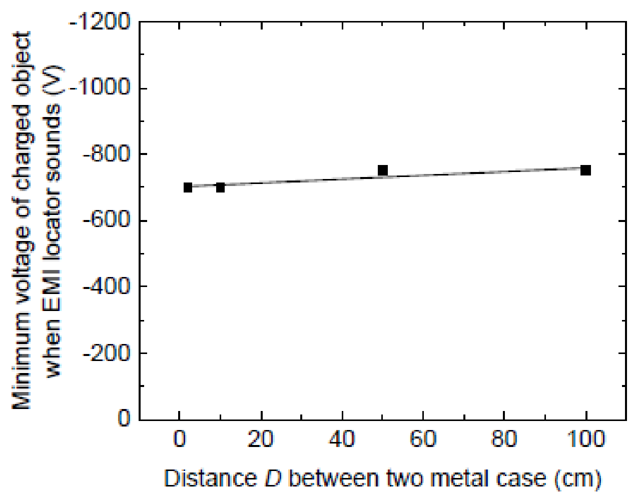

Figure 6: Minimum (threshold) voltage of charged object when spark discharge occurs in metal case A.

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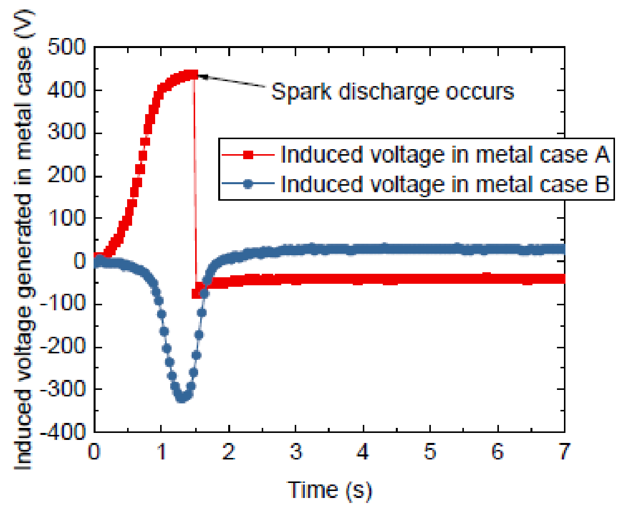

Figure 7: Change of induced voltage generated in metal case A when EMI locator sounds an alarm tone for charged object of −700 V and distance D of 2 cm.

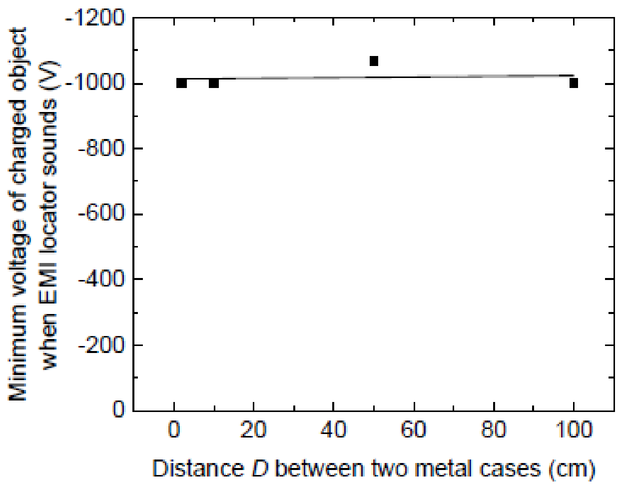

Figure 8: Minimum (threshold) voltage of charged object when spark discharge occurs in metal case B.

Figure 9 shows the change in induced voltage generated in the ungrounded metallic plate of induction instrument B in metal case B, when the EMI locator sounded an alarm tone due to the occurrence of an electrical discharge in its spark gap. The change in the induced voltage generated in the ungrounded metallic plate of induction instrument B occurred when a charged object of −1000 V moved away from metal case A and passed near the front of metal case B. The result was measured at a distance, D, of 2 cm. It was noted that the voltage polarity of the induced voltage generated in the ungrounded metallic plate of induction instrument B changed from negative to positive, due to the occurrence of an electrical discharge in the spark gap of induction instrument B, when a charged object of −1000 V passed near the front of metal case B.

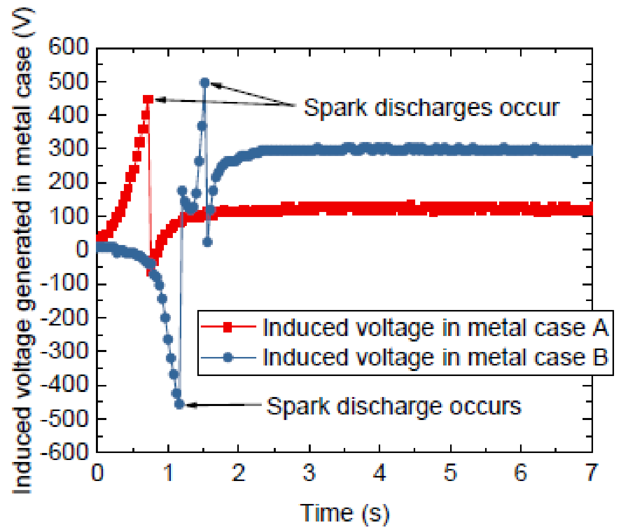

Figure 9: Change of induced voltage generated in metal case B when EMI locator sounds an alarm tone for charged object of −1000 V and distance D of 2 cm.

Discussion and Conclusion

When a charged object of negative voltage polarity moved away from metal case A and passed near the front of metal case B, an induced voltage of positive voltage polarity was generated on the ungrounded metallic plate of induction instrument A and induced voltage of negative voltage polarity was generated in the ungrounded metallic plate of induction instrument B. The reason that the voltage polarity of the induced voltage generated in the metal case A was different from that of the voltage polarity of the induced voltage generated in metal case B has been explained below.

Consider that the negative charges on an ungrounded metallic plate of induction instrument A were discharged upon contact with a grounded rod, before the charged object moved away from case A. The transfer of negative charges through contact occurred because the voltage polarity of the charged object was negative and the positive charges on the metallic plate of induction instrument A were restricted by the electric field strength from the charged object.

When a charged object of negative voltage polarity moved away from metal case A, the positive charges, restricted by the electric field strength from the charged object, appeared on the ungrounded metallic plate of induction instrument A. The induced voltage generated in the ungrounded metallic plate of induction instrument A increased based on the equation q=cv, due to the appearance of positive charges.

When a charged object passed near the front of metal case B, the induced voltage generated in the ungrounded metallic plate of induction instrument B decreased. An induced voltage of negative polarity was generated in metal case B because the induced voltage was generated by the principle of a voltage divider from the voltage of a charged object.

Figure 10 shows the relationship between the ratio of the induced voltage generated in the ungrounded metallic plate of each induction instrument for both the metal cases to the voltage of the charged object and the distance, D, between the two metal cases. This relationship was obtained from the measured results using the induction instrument and EMI locator. The value of the induced voltage generated in metal case A was −0.52 times that of the voltage of the charged object at the distance, D, of 2 cm. When the distance D increased to 100 cm, the value of the induced voltage generated in the metal case A was −0.49 times that of the voltage of the charged object. On the other hand, the value of the induced voltage generated in the metal case B was 0.45 times that of the voltage of the charged object at a distance, D, of 2 cm and its ratio to the distance, D, of 100 cm was maintained at a constant value of 0.45 times. The absolute induced voltage in metal case A when a charged object moved away from it was higher than the induced voltage in metal case B when a charged object passed near its front, although the voltage polarity of the induced voltages was different.

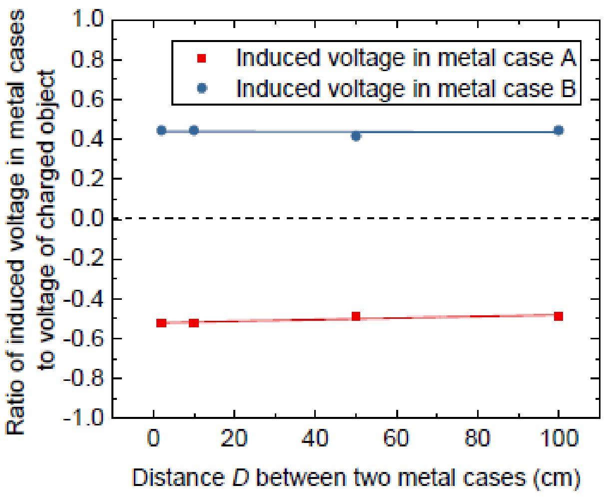

Figure 10: Ratio of induced voltage generated in two metal cases to voltage of moving charged object.

The movement of a charged object could cause malfunction or failure of electronic device. This was caused by the occurrence of induced voltages generated inside the metal cases or housing of electronic device. Thus, experimental evaluation of a charged object moving away from a metal case and passing near another metal case, in a real world environment, was required.

The present study reported on the results of experiments involving induced voltages generated in two metal cases when a charged object moved away from a metal case and passed near another metal case. The results indicated that the induced voltage generated in a metal case increased when a charged object of negative voltage polarity moved away from it. On the other hand, the induced voltage generated in another metal case decreased, when a charged object of negative voltage polarity passed near it. The induced voltages generated in the two metal cases were expressed by eqns. (1) and (2).

The induced voltage generated in a metal case when a charged object moved away from the metal case was given by:

$$V_A = -0.51V_{CB} \quad (1)$$

The induced voltage generated in a metal case when a charged object passed near its front was given by

$$V_B = 0.45V_{CB} \quad (2)$$

where VA and VB denoted induced voltages generated in two metal cases, and VCB denoted the voltage of a charged object (Figure 2).

The absolute value of the induced voltage generated in a metal case when the charged object moved away from the metal case was 112% of the induced voltage when the charged object passed by the front of another metal case. The induced voltages generated in two metal cases, obtained using eqns. (1) and (2), when a charged object moved away from a metal case and passed near the front of another metal case could be estimated. For example, an induced voltage of −510 V was generated in a metal case when a charged object, such as a charged human body of 1000 V, moved away from the metal case. An induced voltage of 450 V was generated in another metal case when the charged object of 1000 V moved near its front. The results of this study would be useful in the prevention of malfunction and failure of electronic device and are also helpful with respect to emerging technologies [33-44].

The change in the induced voltages generated in two metal cases could be theoretically considered as follows. The experimental setup arrangement was a three-body problem [45] of the charged object and floating electrodes in grounded metal cases. The following notations were used. Body 1 represented the charged object at the given voltage. Body 2 represented the metallic plate on the left-side of a floating potential of induction instrument A. Body 3 represented the metallic plate on the left-side of a floating potential of induction instrument B. The three-body problem could be obtained using the following equations.

$$Q_1 = c_{11}V_1 + c_{12}V_2 + c_{13}V_3 \quad (3)$$

$$Q_2 = c_{12}V_1 + c_{22}V_2 + c_{23}V_3 \quad (4)$$

$$Q_3 = c_{13}V_1 + c_{23}V_2 + c_{33}V_3 \quad (5)$$

where cii denoted a coefficient of self-capacitance of positive quantity and cij denoted a coefficient of mutual capacitance.

The experimental result that a spark discharge did not occur in the spark gap of each induction instrument in two metal cases is considered (Figures 4 and 5). When Q2 was assumed to be a positive value and Q3 was equal to zero, eqns. (6) and (7) were obtained from eqns. (4) and (5).

It could be said that the voltage polarity of V2 became positive, if the voltage polarity of V1 and V3 was negative, and the charge of Q2 was a positive value because the system capacitance was altered by the movement of the charged object of body 1.

$$V_2 = \frac{Q_2}{c_{22}} - \frac{c_{12}}{c_{22}}V_1 - \frac{c_{23}}{c_{22}}V_3 = \frac{Q_2}{c_{22}} + \left|\frac{c_{12}}{c_{22}}\right|V_1 + \left|\frac{c_{23}}{c_{22}}\right|V_3 \quad (6)$$

It could be assumed that the voltage polarity of V3 became negative, if the voltage polarity of V1 was negative and $\left|\frac{c_{23}}{c_{33}}\right|V_2$ could be ignored. $V_3 = -\frac{c_{13}}{c_{33}}V_1 - \frac{c_{23}}{c_{33}}V_2 = \left|\frac{c_{13}}{c_{33}}\right|V_1 + \left|\frac{c_{23}}{c_{33}}\right|V_2$ (7)

Consider the experimental result that a spark discharge occurred in the spark gap of induction instrument A (Figure 7). The voltage of V2 showed the voltage ending of a negative value (Figure 7). The reason was that a micro-discharge occurred in induction instrument A when the EMI locator could sense the occurrence of the micro-discharge. When a spark discharge occurred in the spark gap of induction instrument A, body 2 charged the value of Q2. As a result, eqn. (6) was obtained from eqn. (4). It could be assumed that the voltage polarity of V2 became negative, if the voltage polarity of V1 and V3 was negative, and the charge of Q2 was a negative value.

The experimental result where a spark discharge occurred in the spark gap of induction instruments A and B was considered. When it was assumed that Q2 and Q3 were positive values, eqns. (6) and (8) were obtained from eqns. (4) and (5).

The voltage of V3 showed the voltage ending of a positive value (Figure 9). It could be assumed that the voltage polarity of V3 became positive if the voltage polarity of V2 and the charge of Q3 were a positive value.

$$V_3 = \frac{Q_3}{c_{33}} - \frac{c_{13}}{c_{33}}V_1 - \frac{c_{23}}{c_{33}}V_2 = \frac{Q_3}{c_{33}} + \left|\frac{c_{13}}{c_{33}}\right|V_1 + \left|\frac{c_{23}}{c_{33}}\right|V_2 \quad (8)$$

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