Validity of measurement and calculation on electrostatically induced voltage of ungrounded metal box generated by moving charged body

Norimitsu Ichikawa and Isaku Yamakawa
Dept. of Electrical Engineering
Kogakuin University
phone: (+81) 42-628-4692
e-mail: ichikawa@cc.kogakuin.ac.jp

***Abstract*—When a charged body passes by in front of an ungrounded metal box, which is a floating potential, such as the box of electronic equipment, an electrostatically induced voltage is generated. The induced voltage causes a malfunction and failure of the equipment. The calculation of the induced voltage is not so easy by the numerical simulation since there is a leakage of charges in a real situation. In general, capacitance obtained by a multibody problem is used for calculating the induced voltage. However, the calculation becomes difficult as a number of body increases. In this study, the results of the measured induced voltage are compared with those calculated by two measuring methods of capacitances when a charged body passes by in front of the box. The results will be helpful to estimate the possibility of the malfunction and failure by the induced voltage.**

I. Introduction

An electrostatically induced voltage of an ungrounded metal box causes a malfunction and a failure of electronic equipment [1-3]. The induced voltage is generated when a charged body exists and moves near the metal box [4-7]. The measurement of the induced voltage is difficult because of a leakage of charges in an atmospheric condition. We have ever measured the induced voltage generated between two conductors in a grounded and ungrounded metal case using a noncontact measuring system and compare the measured result with the calculated one. In the calculation of the induced voltage, the measured capacitances between bodies are used. The results show that values of the measured induced voltage is smaller than those of the calculated one.

A calculation of the induced voltage using a multibody [8] becomes difficult as a number of body increases. The consideration of the induced voltages, when a charged body passed by near an ungrounded metal box, has never carried out though some study of this topic has been reported.

The consideration between the measured induced voltage and the calculated induced voltages by means of two methods has carried out. In the calculation of induced voltages, the capacitances of body-to-body (two bodies of floating potential) and body-to-ground are used. The results of the consideration show on the whole, a trend of the induced voltage calculated by capacitances of body-to-body is almost similar to that by body-to-ground. A percentage of the induced voltage of an ungrounded metal box to the voltage of charged body is 56% for the measurement and 69%-78% for the calculation at the distance *L* of 10 mm between a charged body and an ungrounded metal case. The percentage deceases to the voltage of 25% for the experiment and 32%-34% for the calculation at the distance *L* of 200 mm. A human body is electrified up to 10 kV or more in a room condition with air conditioner. Thus, the induced voltage generated of the ungrounded metal case becomes a source of malfunction and failure of electric and electronic equipment. The results will help us to estimate the induced voltage by a measurement and calculations of body-to-body and body-to-ground.

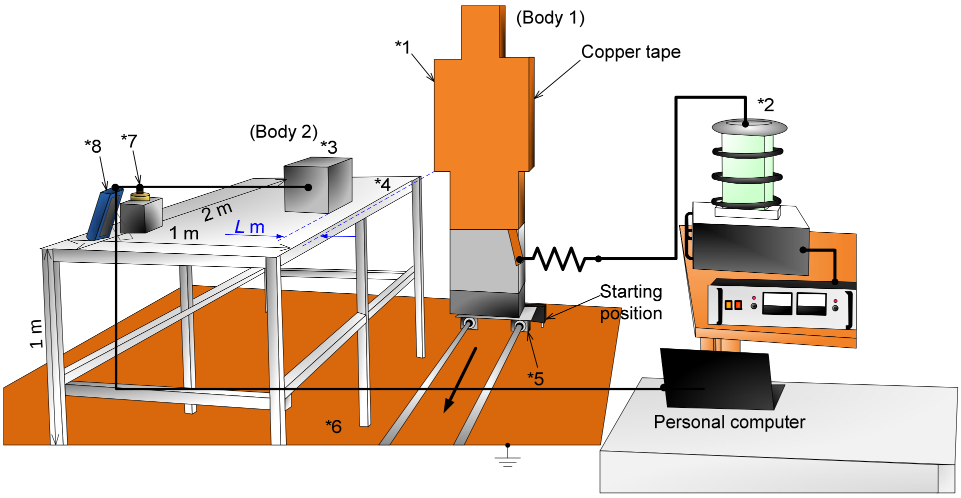
II. EXPERIMENTAL SETUP AND PROCEDURE

A. Measurement of induced voltage generated of ungrounded metal box

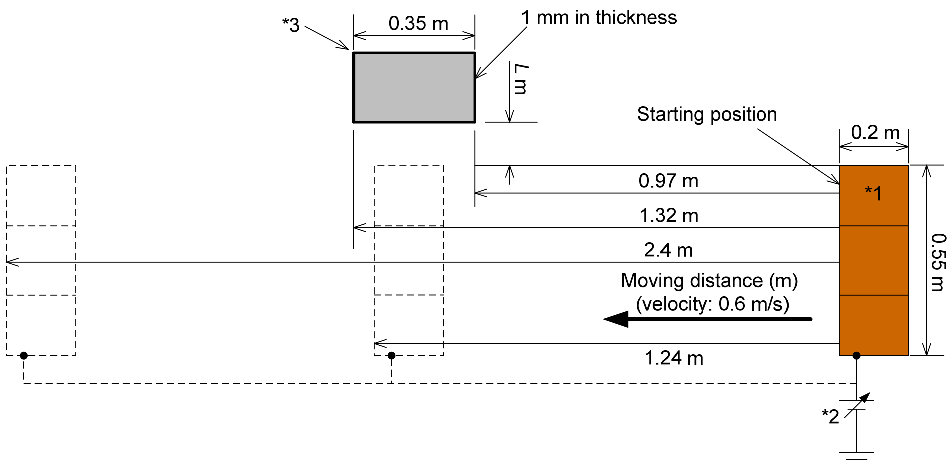
Fig. 1 shows the experimental setup for measuring induced voltage when a charged body passes by near an ungrounded metal box. The setup consists of a charged body like a charged human body, a metal box, a DC high voltage power supply, an electrostatic measuring devices. A body like a human body is moved automatically. The body is connected to the DC high voltage power supply by a high voltage cable. The body is named as a “charged body” and is moved with a speed of approximately 0.6 m/s. The dimensions of the charged body are 1.8 m in height, 0.35 m in width, and 0.2 m in depth. The charged body represents a moving human body which is electrified electrostatically.

An ungrounded metal box is put on a PMMA table of 1 m in height. The metal box is connected to an electrostatic measuring device of 711, 3M Co. for measuring the induced voltage. The electrostatic measuring device is accompanied with an oscilloscope of U1604A, Agilent Co. and a personal computer. The metal box represents an ungrounded metal box of electronic equipment. A front panel of the metal box is parallel to the surface of the charged body. The dimensions of the metal box are 0.2 m in height, 0.35 m in width, and 0.2 m in depth.

In experiments, the distance *L* between a charged body and an ungrounded metal box is changed. The room condition is a temperature of 14℃ and 70% RH.



(a) 3D view



(b) Top view

Fig. 1. Arrangement of experimental setup. The distance *L* denotes the distance between the charged body (object) and the front of metal box.*1: charged body, *2: DC high voltage power supply (0-50 kV), *3: metal box, *4: acrylic table (PMMA), *5: automatically transporting stage, *6: grounded copper plane, *7: electrostatic measuring device (711, 3M Co.), *8: oscilloscope (U1604A, Agilent Co.).

B. Calculation of induced voltage generated of ungrounded metal box

Fig. 2 shows the measured capacitances of body-to-body when a charged body moves. The capacitance measurement of body-to-body is measured by the use of LCR meter of ZM2353, NF Co. In the figure, the capacitance of C_1 represents a capacitance between a charged body and a metal box. The capacitance of C_2 represents a capacitance between the metal box and a grounded plane of floating potential. The induced voltage using capacitances of body-to-body is calculated by *eq*. (1).

$$V_b = \frac{C_1}{C_1+C_2} V_a \quad (1)$$

where C_1: capacitance between charged body and metal box (F), C_2: capacitance between metal box and grounded plane of floating potential (F), V_b: induced voltage of metal box (V), V_a: voltage of charged body (V).

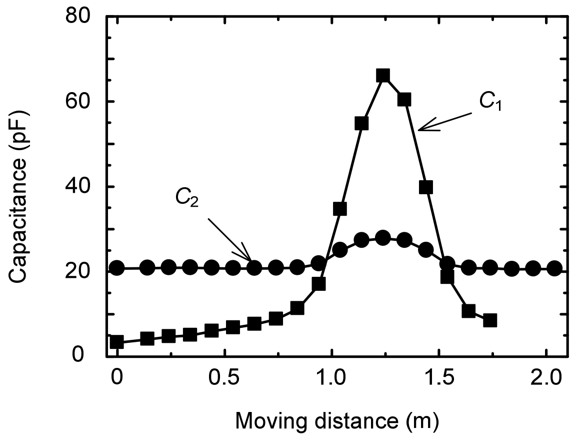


Fig. 2. Measured capacitances of C_1 and C_2 for body-to-body at the distance L of 10 mm

Fig. 3 shows the measured capacitances of body-to-ground when a charged body moves. The capacitance measurement of body-to-ground is measured by the use of C meter (As-911) of NF Co. The averaged value and the standard deviation of 5 measurements are expressed in the figure. In the figure, the capacitance of C_{m1} represents a capacitance (C_{12}+C_{10}) between a charged body and a grounded plane connected to a ground terminal. The capacitance of C_{m2} represents a capacitance (C_{12}+C_{20}) between a metal box and the grounded plane. The capacitance of C_{m3} represents a capacitance (C_{10}+C_{20}) between a charged body accompanied with a metal box by a wire and the grounded plane. The capacitance of C_{12} represents a capacitance between a charged body and a metal box. The capacitance of C_{20} represents a capacitance between the metal box and the grounded plane. The induced voltage using capacitances of body-to-ground is calculated by *eq*. (2).

$$V_b = \frac{C_{12}}{C_{12}+C_{20}} V_a \quad (2)$$

where $C_{12} = \frac{C_{m1}+C_{m2}-C_{m3}}{2}$,

$C_{20} = C_{m2} - \frac{C_{m1}+C_{m2}-C_{m3}}{2}$.

C_{m1}: capacitance (C_{12}+C_{10}) between charged body and grounded plane (F),
C_{m2}: capacitance (C_{12}+C_{20}) between metal box and grounded plane (F), C_{m3}: capacitance (C_{10}+C_{20}) between charged body accompanied with metal box by wire and grounded

plane (V).

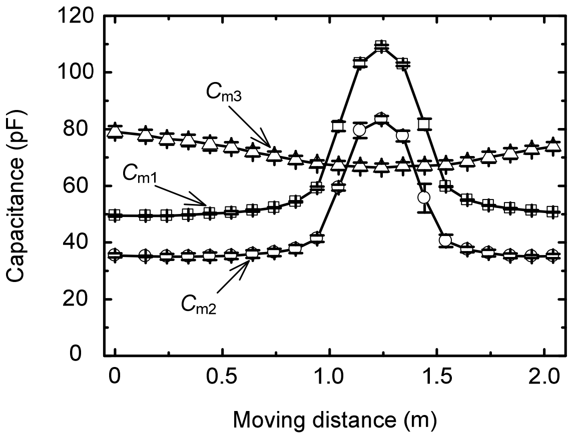


Fig. 3. Measured capacitances of C_{m1}, C_{m2}, and C_{m3} for body-to-ground at the distance L of 10 mm.

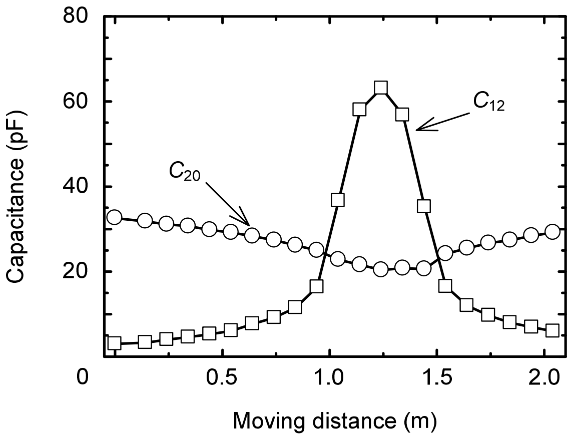


Fig. 4. Calculated capacitances of C_{12} and C_{20} for body-to-ground at the distance L of 10 mm.

III. Induced Voltage Generated of Ungrounded Metal Box

A. Measured induced voltage of ungrounded metal box

Fig. 5 shows an example for the measured induced voltage of an ungrounded metal box while a charged body of 1 kV passes by the front of the metal box at the distance L of 10 mm. The induced voltage increases as the charged body approaches to the metal box. The induced voltage has a peak value of 690 V when the charged body reaches to the front of the metal box. The induced voltage decreases as the charged body separates from the metal box. The peak value of the induced voltage at given distance *L* is shown in Fig. 6.

Fig. 6 shows the measured induced voltage at the distance *L* when a charged body passes by the front of a metal box. The averaged value of 5 measurements and the standard deviation are expressed in the figure. The induced voltage decreases as the distance *L* increases. The induced voltage at the distance *L* of 200 mm is 45 % of that at *L*: 10 mm.

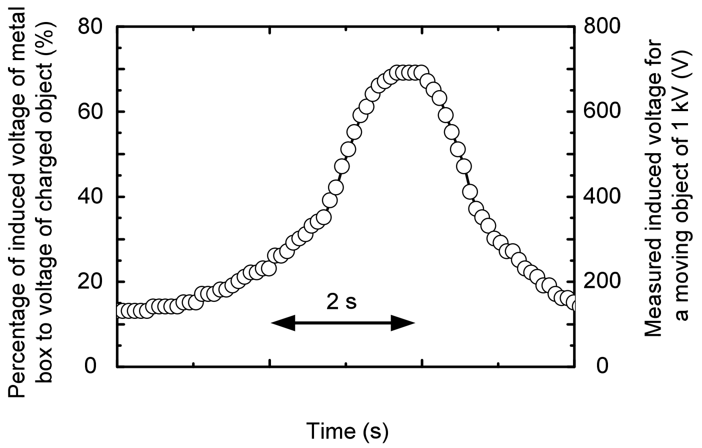


Fig. 5. Measured induced voltage when a charged body of 1 kV moves at the distance *L* of 10 mm.

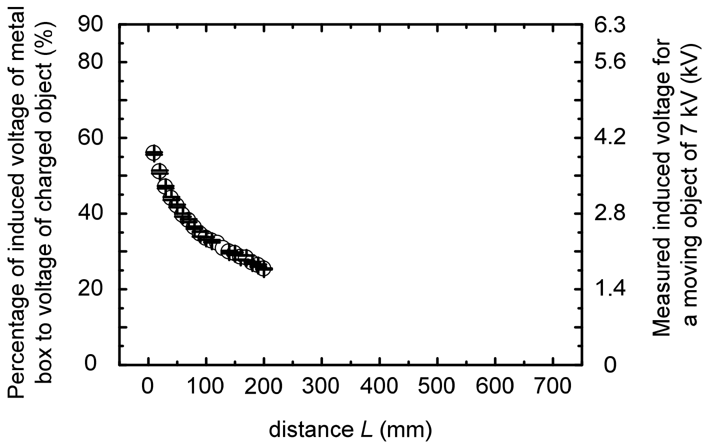


Fig. 6. Percentage of the induced voltage of an ungrounded metal box to the voltage of charged body and measured induced voltage when a charged body of 7 kV moves at the distance *L*.

B. Calculated induced voltage of ungrounded metal box

Fig. 7 shows a percentage of the induced voltage of an ungrounded metal box to the voltage of charged body while a charged body passes by the metal box at the distance *L* of 10 mm. In the figure, the percentages calculated by the measured capacitances C_1 and C_2 of body-to-body are compared with those of capacitances C_{12} and C_{20} by C_{m1}, C_{m2}, and C_{m3} of body-to-ground. The results show a peak value of the percentage calculated by capacitances C_1 and C_2 is 8% smaller than that by C_{12} and C_{20}. The peak value of the percentage is 70% for body-to-body and 76 % for body-to-ground. The characteristics of peak values at given distance *L* is shown in Fig. 8.

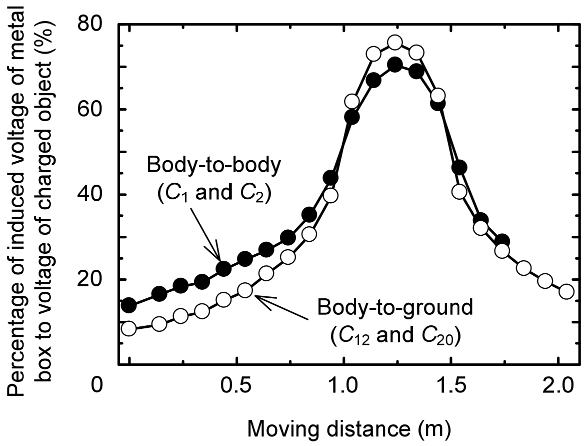


Fig. 7. Percentage of the induced voltage of an ungrounded metal box to the voltage of charged body at the distance *L* of 10 mm.

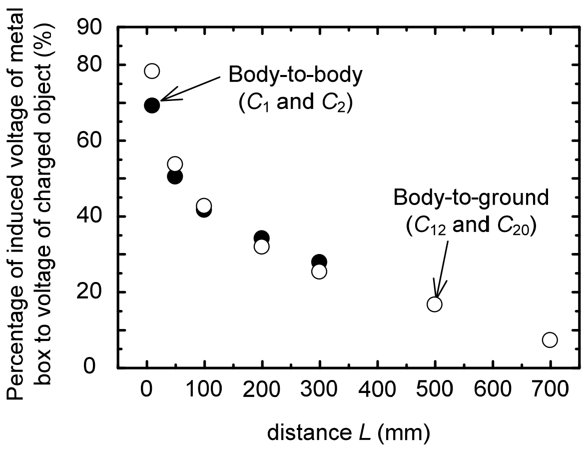


Fig. 8. Percentage of the induced voltage of an ungrounded metal box to the voltage of charged body at the distance *L*.

Fig. 8 shows a percentage of the induced voltage of an ungrounded metal box to the voltage of charged body at the distance *L* when a charged body passes by the front of the metal box. The induced voltage decreases as the distance *L* increases. The decrease of the percentage calculated by capacitances of body-to-body shows the similar trend to that by body-to-ground but the value at the distance *L* of 10 mm.

IV. Discussions

The induced voltage generated of an ungrounded metal box causes a malfunction and failure of electronic equipment when a charged body like a charged human body passes by near the equipment.

The calculated induced voltages by the measured capacitances of C_1 and C_2 (body-to-body) are almost similar to those by C_{12} and C_{20} of C_{m1}, C_{m2}, and C_{m3} (body-to-ground) but the induced voltage at the distance *L* of 10 mm. The difference between the induced voltage by body-to-body and body-to-ground becomes small as the distance between a charged body and an ungrounded metal box increases. The reason is the capacitance of C_{20} is smaller than that of C_2 at the distance *L* of 10 mm.

The measured induced voltage is approximately 76% of the calculated one. The difference between the measured and calculated results is caused by the leakage of charges.

V. Conclusion

The induced voltage generated of an ungrounded metal box is measured by an electrostatic measuring device and calculated by the measured capacitances of body-to-body and body-to-ground when a charged body passes by near the metal box. The results shows the percentages of the induced voltage of the metal box to the voltage of charged body are 56% for the measurement and 69%-78% for the calculations at the distance *L* of 10 mm between a charged body and the metal box. The calculated induced voltage by measured capacitances of body-to-body approaches that by the capacitances of body-to-ground as the distance between a charged body and a metal box increases. The induced voltage becomes large since a human body is often electrified up to 10 kV or more in a room. The results will help us to estimate the induced voltage of a metal box by a measurement and calculations.

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