ELECTRICAL OVERSTRESS/ ELECTROSTATIC DISCHARGE SYMPOSIUM PROCEEDINGS

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Measurements of Body Impedance for ESD

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Abstract High voltage, short duration electrostatic discharge (ESD) measurements of human body impedance have been accomplished for different paths through the body. Skin contact impedance and internal body impedance between various locations on the body were examined. Voltages from 1000 to 5000V were applied and the peak currents is 2.0 to 10A. The current waveform has time constant from 0.25 to 1.25μs. The short time constant is consistent with safety requirements. The body impedance between the palm of the hand and the sole of the feet was found to be about 520 to 550Ω.

I. Introduction

Human body impedance is important in determining allowable safe voltage levels for exposure to the body. Body impedance for transient high voltage currents is significantly different from body impedance measured using steady state currents from low voltage ac. or dc. Sources. A low voltage impedance model of the body can help illustrate the difference between transient impedance and steady state ac. impedance. Fig.1 depicts a simplified electrical model suggested by Biegelmeier and Rotter [1], Edelberg [2], and Tregear [3].

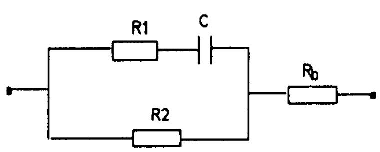

Fig.1 Simplified impedance model of body

This is a low voltage linear model (component values do not change with voltage or time). The steady state impedance of Fig.1 is given by Eq.1:

$$Z_L = R_B + \frac{R_2 (R_1 + 1/j\omega C)}{R_1 + R_2 + 1/j\omega C} \qquad (1)$$

The skin impedance is determined by contact area and type of contact. The skin impedance is represented by the circuit components R_1, R_2 and C_1 shown in Fig.1. The internal impedance is determined by the path through the body. The internal impedance is represented by R_B in Fig.1. Total impedance is the sum of the skin impedance and the internal body impedance.

For transient current, the capacitor C_1 is initially uncharged and the circuit initially behaves as if the capacitor were a low impedance conductor. Thus the initial body impedance, Z_i should be given by Eq.2:

$$Z_i = R_B + \frac{R_2 R_1}{R_2 + R_1} \qquad (2)$$

For high voltage discharge we have found the electrical model given in Fig.1 to be inadequate. The skin impedance is very low and do not determined by the type of contact.

II. Method of Measurement

The body impedance was measured using high voltage capacitor discharge to the subject.Fig.2 contains a diagram of the measurement schematic. E is a high voltage source.

Measurement of current was done using a Philips

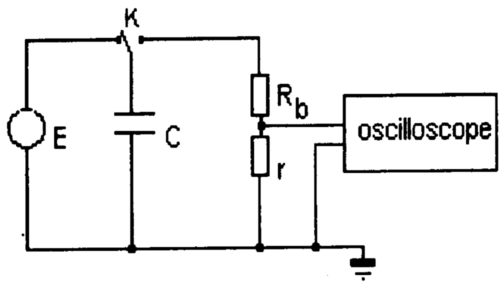

Fig.2 Body impedance measurement

PM3320A oscilloscope. r is 1Ω ,R_B is body impedance. The subject's bare feet were placed on a flat copper sheet (257 by 30 cm), which is the ground electrode. The cylinder used for a grasping hand contact was 3.5cm in diameter and 10 cm long. Three separate impedance paths were measured: left hand to both feet , right hand to both feet , right hand to left hand. In the case of hand to hand measurements, the ground conductor is another 3.5cm diameter cylinder. Skin was either dry (nothing was placed on the skin) or wet. Discharge circuit is a RLC series circuit, the current is given in Eq.3:

$$i=\frac{U}{Rd}\{\exp[-(1+d)Rt/2L]-\exp[-(1-d)Rt/2L\} \quad (3)$$

Where U is the initial voltage of the capacitor, R is the total resistance of the circuit, t is the time, and $d=\sqrt{1-4L/R^2C}$, C is the capacitance of the capacitor, L is the inductance of the circuit. the peak current I_p is given in Eq.4 :

$$i_p=\frac{U}{Rd}[(\frac{1-d}{1+d})^{\frac{1+d}{2d}}-(\frac{1-d}{1+d})^{\frac{1-d}{2d}}] \quad (4)$$

The body resistance can be computed according to Eq.4. the inductance L in our circuit is 2.7μH, capacitance of the capacitor is 500pF, U is from 1000 to 5000V.

III. Result and Conclusions

Fig.3 gives a typical waveform of the discharge current. The voltage of the capacitor is 2500V. The path of the current is from right hand to left hand. Values of the mean and standard deviation of body impedance measurements for four adult males are given in Table 1.

Generalizing from the Table 1, the hand to hand current path appeared to have greater impedance than that of the hand to feet current path. The differences between impedance using large area dry contact and large area wet contact were small.

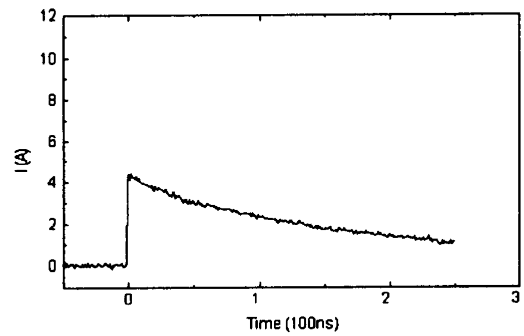

Fig.3 Typical waveform of the discharge current

Table 1. Body Impedance(Ω)

path	state	mean	deviation
left hand/both feet	dry	520	19
	wet	516	13
right hand/both feet	dry	525	20
	wet	510	26
right hand/left hand	dry	530	28
	wet	523	17

The internal body impedance determines the minimum impedance in the cases where the skin is broken or damaged. To estimate the internal body impedance, the skin impedance can be subtracted from the total body impedance. The skin impedance for large area contacts was estimated by placing electrodes(about 10cm^2 each)close together on the body. The measured wet impedance varied from 50 to 75Ω when the electrode is between the top and bottom of the feet. For simplicity, the internal body impedance for hand to feet or hand to hand pathways can be estimated from Table 1 by subtracting 63Ω (approximate average for the wet skin impedance). From the body impedance (wet contact). This result is in a range of internal body impedance of about 460Ω. Thus we find for high voltage capacitor discharge the total impedance is dominated by the internal body component, and the skin impedance makes a relatively minor contribution. This may seem surprising, but remember this result is for high voltage, short duration transient shock.

The current flow, and hence the impedance, would normally be different for someone wearing shoes. The impedance between hands and bare feet determines the minimal impedance one might experience when the shoes were wet or broken.

IV. References

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