Are ESD Chairs Good Enough to Be Used as Primary Means of Personnel Grounding?

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Abstract – Personnel handling ESD sensitive items in seated position are supposed to be grounded via a wrist strap. The paper describes measurement techniques to assess whether grounding personnel via ESD flooring and chair is feasible. Different techniques to measure the body voltage generation and the influence of chair castors are discussed.

I. Introduction

International standards for developing ESD control programs like ANSI/ESD S20.20 [1], IEC 61340-5-1 [2], or JEDEC JESD625B [3] require personnel to be grounded via wrist strap during seated operations. This applies even if footwear/ flooring system is the primary personnel grounding method. The main reason for this requirement is the idea that in seated position it might not be guaranteed that personnel are having their feet down on the floor at all time. This would result in an insufficient grounding and personnel might build up static charges. However, often the use of wrist strap is inconvenient and, therefore, personnel do not use wrist straps consequently.

ANSI/ESD S20.20 and IEC 61340-5-1 allow tailoring statements, defining modifications of requirements if supported by corresponding technically sound data and evaluations. For the problem of grounding personnel via flooring/chair system, measurement methodologies need to be developed which show that people are efficiently grounded. The current ESDA standard on ESD seating, ANSI/ESD STM12.1, covers only the resistive characterization of the seating [4].

As for the grounding of personnel via a footwear/flooring system, characterization of the resistance is not sufficient. The body voltage is the crucial parameter, therefore, the body voltage generation during operation and movement needs to be assessed, too. International standards require body voltage measurements for qualification of a footwear/flooring system [1,2]. This is necessary, as there is no clear and unique correlation between the resistance-to-ground R_g of a person via a footwear/flooring system and the body voltage generation during movement. Figure 1 shows an example of a facility with three different types of flooring and four types of different footwear. Although below the limit of R_g of 1 GΩ, some measured body voltages exceed the limit of 100 V significantly. Obviously, there is only a weak correlation between R_g of the personnel via footwear/flooring system and the body voltage.

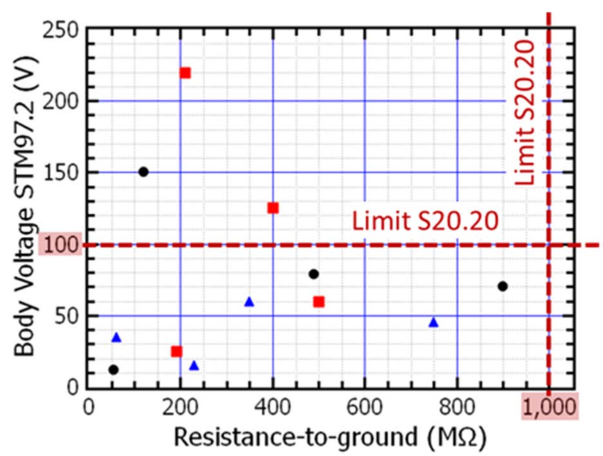

Figure 1: Body voltage of a walking test of a person according to ANSI/ESD STM97.2 with four different ESD shoes on three different floors in one facility.

The paper shows that, amongst many different possibilities, a similar sequence of movements as described in ANSI/ESD STM97.2 [5], the so-called “Chair Walking Test”, can be used to generate static charges on the operator sitting on the chair respectively moving around with the chair.

The Standard Test Method ANSI/ESD STM97.2 allows “a charged plate monitor or equivalent with input resistance of greater than $1.0 \times 10^{14}\,\Omega$ and capacitance less than or equal to 20 pF (…)” to be used for the body voltage measurements. The system time constant shall be not more than 0.2 s. A set-up using a charged plate monitor (CPM) might have different input capacities and response characteristics than set-ups using “equivalent” devices, thus, the resulting voltages might differ. Therefore, a first step in this study was the assessment of different measurement devices.

II. Measurement Techniques

A. Equipment

For measuring the body voltage generation, the following devices have been used:

- Walking test kit (WTK), which is an electrometer measuring the voltage at a hand-held electrode; input capacitance is less than 5 pF.
- Electrostatic voltmeter (ESVM) with a walking-test adaptor (metal hand-held electrode with built-in voltage sensor).
- Three different CPMs with plate capacitances of 20 pF.
- A contact-based high-impedance digital voltmeter (HIDVM) with an input capacitance of less than 0.01 pF.

Resistance-to-ground measurements of seating or a system including a person have been performed using high-ohm meters and a 5-pound electrode or a hand-held electrode, with an upper system limit of at least $2 \times 10^{12}\,\Omega$.

B. Assessment of Body Voltage Measurement Equipment

For body-voltage measurements, the total capacitance plays an important role. The total capacitance of the measurement set-up C_{total} is a sum of the capacitance of the personnel to ground $C_{personnel}$, the capacitance of the wire to ground C_{wire}, and the input capacitance of the measurement device C_{device}:

$$C_{total} = C_{personnel} + C_{wire} + C_{device}$$

The measured voltage at the series of capacitances is $V = q/C_{total}$ with the charge q which is built-up during the movement of the personnel and which is nearly independent of the measurement set-up.

The authors of [6] discuss the influence of the wire and compare a CPM and an ESVM. Therefore, it does not come as a surprise that a walking test according to ANSI/ESD STM97.2 yields significantly different body voltages for the different recording devices (Figure 2).

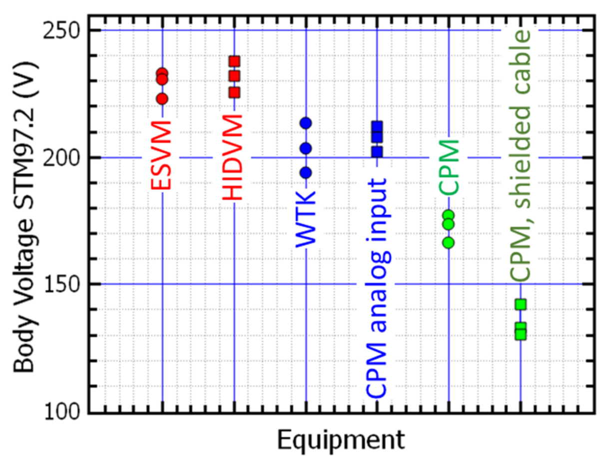

Figure 2: Body voltage of three trials of a walking test according to ANSI/ESD STM97.2 with ESD shoes on a plastic foil.

The ESVM, the HIDVM, and the analog input of the CPM (without charged plate) do not have any significant input capacitance, so $C_{device} \approx 0$. ESVM and HIDVM measure the voltage directly at the hand-held electrode, so also $C_{wire} \approx 0$. With the operator’s capacitance on the thin plastic foil of 130 pF and an average voltage built-up of 230 V for the measurement apparatuses with negligible input capacitance and no additional capacitance of the wire, the static charge build up per step q of the walking pattern is approx. $q = C \times V = 30$ nC.

Using the WTK, the 3 m long wire from the hand-held electrode to the recording device adds approx. 20 pF capacitance, the CPM adds another 20 pF, and the shielded cable even adds 70 pF. Table 1 summarizes the measurements of the voltages and the deviation from the “real” walking test voltage measured by an ESVM or a HIDVM.

The calculated ratio of the body voltages matches the experimental results fairly well.

Table 1: Compilation of different measurement set-ups and measured body voltage of a walking test according to ANSI/ESD STM97.2

	ESVM	HIDVM	WTK	CPM, analog input	CPM	CPM, shielded cable
$C_{personnel}$	130 pF					
C_{wire}	0	0	20 pF	20 pF	20 pF	70 pF
C_{device}	0	0	0	0	20 pF	20 pF
Voltage	230 V	230 V	205 V	205 V	170 V	135 V
Deviation	*reference*		-11 %	-11 %	-26 %	-41 %

Of course, the capacitances are not the only parameters of the recording devices that influence the body voltage measurements. The responses of the analog output signal to static signals show that some devices have a significant offset, even after a thorough nulling procedure (Figure 3).

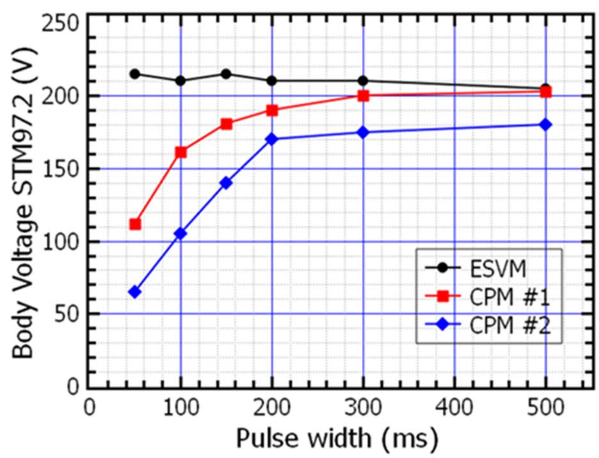

Figure 3: Measured voltage recorded and extracted by analysis software after approx. 25 200 V pulses with different pulse width. According to ANSI/ESD STM97.2, the average of the five highest pulses is taken. The pulse frequency was kept constant at 1 Hz.

The ratio of the measured voltage to the actually applied voltage might vary with increasing voltages. The largest variation was measured for two CPMs, however, the deviation is less than 10 % at 200 V and, thus, still in an acceptable range. Response to a dynamic signal shows much higher deviations. Some devices are too slow to follow pulses with a pulse width of 100 ms or below, resulting in measurement outputs, which are 50 % lower compared to the input signal. The input signal was generated by a high-voltage supply and a relay triggered by an Agilent 8114 pulse source.

Obviously, not all CPMs and other recording devices are suitable for the – although comparably slow – walking test pattern in which typically “two steps per second” are required, resulting in a dynamic pulse width of 100 –200 ms. Static and dynamic verification of the equipment is mandatory for a meaningful assessment.

Most of the experiments in this study have been performed either with an ESVM or with a WTK.

C. Body Voltage Measurements

The body voltage measurements of operator and chair should simulate different scenarios, use case and very unlikely worst case as described in [7].

The most likely scenario can be modeled by personnel moving around with the chair, following a similar walking test pattern as used for standing operations as described in ANSI/ESD STM97.2.

Additionally, two likely worst-case scenarios in seated operations were evaluated.

- Both legs on foot/base, turn chair with body left and right,
- Roll the chair left to right and vice versa (with at least one leg in contact with the floor).

Another unlikely worst-case scenario where the personnel were sliding around on the chair with both feet up in the air was also assessed. This extreme worst-case condition would not happen in reality because it is not very likely that personnel charges up during sliding and simultaneously touches a device or board without touching a table or other (grounded) objects before. The four seated operation scenarios are summarized as shown below:

a) Normal seated operation, with both legs on floor, move the chair around following a defined pattern (“Chair Walking Test”, see Figure 4) – use case. According to ANSI/ESD STM97.2, the average of the five highest values is taken.

b) Both legs on foot/base, turn chair with body left and right – use (worst)-case. The maximum voltage of typically five movements is taken.

c) Roll the chair left to right and vice versa (with at least one leg in contact with the floor – use (worst)-case. The maximum voltage of typically five movements is taken.

d) Roll the chair with both feet up ("Push Test", see Figure 4) – worst case. The average of the five highest values of typically five "pushes" is taken.

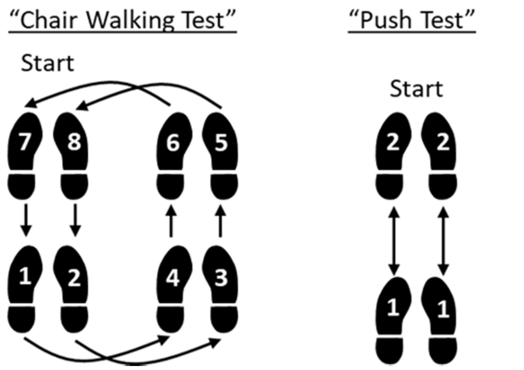

Figure 4: Movement patterns primarily used in the investigations of the paper. Left: "Chair Walking Test" (use case). Right: "Push Test" (extreme worst-case situation).

The tests have been performed on different types of flooring (for example, PVC floor laid in tracks or raised floor) and with different types of chairs from different vendors (but all originally equipped with five plastic castors).

One problem in the past was always that the plastic castors got dirty and scratched resulting in a higher system resistance and also a higher body voltage generation when personnel was rolling around with the chair. Little scratches or small holes in the plastic castors filled up with dirt and dust worsening the problem. Therefore two of the plastic castors have been replaced by metal castors. The reason for replacing only two castors was on one side cost and on the other side a safety issue. At least in Germany, chairs with castors need to stop automatically when a person is standing up from the chair. This is to avoid that the chair rolls away unnoticed and the person falls down when sitting down again. The metal castors used for the evaluation did not have an automatic stop function but the three remaining plastic castors did the job well enough.

To see the influence of the weight of the operator (and the resulting contact pressure on the floor) persons with different weights have performed the experiments.

Most of the measurements have been performed while people have been wearing ESD shoes what is the normal case when working inside an EPA. To see whether the grounding via the chair would also work without ESD shoes body voltage (and system resistance) measurements have been performed with people wearing insulative shoes.

IV. Results

A. General Considerations

As a starting point for the evaluation, some general questions have been investigated. Many people complaint that even new chairs show a bad performance after some month of usage when measuring the resistance to ground. Therefore, experiments should clarify whether the dissipative plastic castors that are typically coming with new chairs are good enough to ground operators via chair and ESD floor (together with ESD shoes).

Before performing the body voltage measurements, the resistance to ground of the floor R_{gfloor} and the system resistance of the operator seated on the chair (R_{gop}) with the feet on the floor have been measured. The same chairs and operators have then been used to measure the body voltage generation using the procedures mentioned in Section III.

As worst-case chair, a normal office chair was used without any ESD protection. All the chairs have been measured first "as found", that means with the original castors attached. After these initial measurements, plastic (dissipative) castors have been exchanged with conductive metal castors and the same measurements have been repeated.

Next to the typical use case in an ESD Protected Area (EPA), where personnel is wearing ESD shoes, a person with isolating shoes was measured.

As one example of the manifold investigations, Table 2 summarizes a worst-case result where the personnel were wearing normal (insulative) shoes and no ESD garments while rolling around with different chairs on a dissipative floor. In this case, charge can only dissipate via the chair and not via the shoes of the personnel.

Table 2: Maximum voltage generated on an operator wearing insulative shoes while sitting on different chairs and performing the described movements a) to d) on an ESD floor.

Type of chair	R_{gop} [Ω]	Max. voltage at case (V)			
		a	b	c	d
Office chair 5 insulative castors	> 10^{12}	1100	1000*	1100	1100
Office chair 3 insulative 2 metallic castors	> 10^{12}	300	300*	300	300
ESD chair A 5 dissipative castors	>2 × 10^8	100	35	80	100
ESD chair A 3 dissipative 2 metallic castors	10^8	50	20	35	50
ESD chair B 5 dissipative castors	3 × 10^{10}	320	100	200	380
ESD chair B 3 dissipative 2 metallic castors	3 × 10^6	80	25	40	100

While using the normal office chair without any ESD properties, the operator is charging to more than 1000 V (as expected), showing that the measurement technique is adequate to assess the performance of the operator grounding system. Just using metal castors instead of plastic castors reduces the maximum generated voltage already to approx. 300 V. The reason for this is that the same amount of charge generated between castors and floor is now transferred to and stored in a bigger capacity (metal castor plus star-shaped metal chair base) which reduces the voltage quite a bit.

While ESD chair A (with blue fabric cover) shows only a small reduction of the charging voltage if two dissipative castors are replaced by metal castors, the much older ESD chair B (with red fabric cover) shows a dramatic improvement, going from a "reject" to a very good chair (see also Figure 5).

It is important to notice that already R_{gop} has decreased by four orders of magnitude (while the operator is wearing insulative shoes!), leading to a significant reduction of the maximum generated body voltage.

Table 2 shows also that scenarios b) (both legs on foot/base, turn chair with body left and right) and c (roll the chair left to right and vice versa (with at least one leg in contact with the floor) generate less body voltage than scenarios a) ("Chair Walking Test") and D ("Push test"). Therefore, in the further investigations the focus was on the Chair Walking Test and the Push Test.

B. Influence of Castor Material

Figure 6 shows the result of an investigation where an "old" ESD chair C fails "as is" the internal specification of $R_{gop} < 1 \times 10^9$ Ω. It fails also the resistance-to-ground criterion of $R_g < 1 \times 10^9$ Ω measured with a 5-pound electrode according to

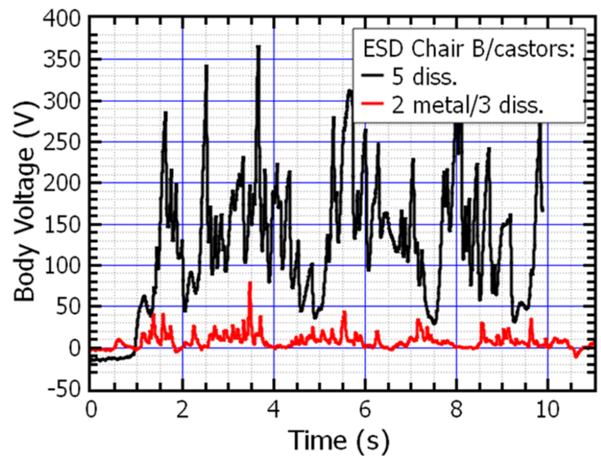

Figure 5: Body voltage generated on an operator while sitting on ESD chair B with five dissipative plastic castors (black) and three dissipative plastic and two metallic castors (red).

[1] and [2]. Root cause analysis showed that the castors of the chair have been significantly worn-out. Cleaning was not effective.

With this chair, two persons with ESD shoes but without any ESD garments performed a "Push Test" and a "Chair Walking Test". The weight of the two persons differs, resulting in a higher system resistance (lighter person, bottom graph of Figure 6) or lower system resistance (heavier person, top graph of Figure 6).

For the original castor configuration with five worn-out dissipative castors, the heavier person passes already the "Chair Walking Test", with a limit for the generated body voltage of 100 V according to ANSI/ESD S20.20. Both persons fail the "Push Test" and the lighter person fails the "Chair Walking Test" slightly. Consistent with the higher resistance-to-ground or system resistance operator/chair of the lighter person, the body voltage test exceeds the ANSI/ESD S20.20 limit, too.

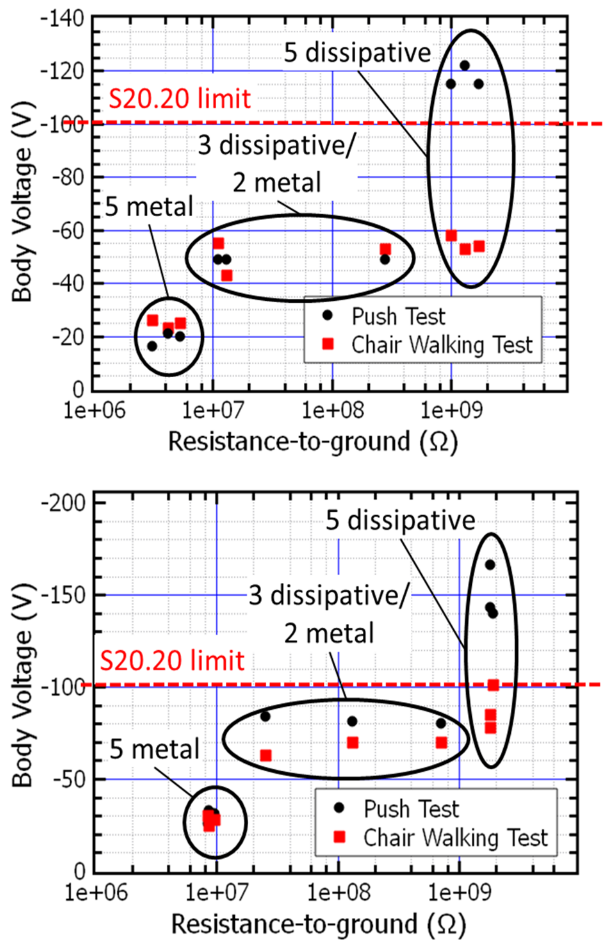

Figure 6: Body voltage generated during a "Push Test" and a "Chair Walking Test" for two persons (top graph: heavier person; bottom: lighter person) and different castor configurations.

Replacing two dissipative castors by metal castors changes the picture completely. Both persons pass the "Chair Walking Test" and the "Push Test" with this modified chair. The system resistance varies from 1×10^7 Ω to 7×10^8 Ω, hence below the limit of 1×10^9 Ω, while the resistance-to-ground of the chair is almost not improved compared to the original configuration with five dissipative plastic castors, and still exceeds the limit of 1×10^9 Ω.

Replacing all dissipative castors by metal castors leads to perfect flooring/castor contacts. For both persons the resistance-to-ground and the system resistance are below 1×10^7 Ω, and the maximum generated body voltage during "Push Test" and "Chair Walking Test" is below 40 V.

In another experiment, a heavy and a light operator performed the body voltage measurements on a raised floor. Since the experiment was performed in a production line, both operators had to wear ESD shoes and ESD garments. Chair D was a brand new chair while chair E was already in use since five years. The body voltage was measured using the walking test kit. The system resistance to ground R_{gop} of the operator was measured with a test voltage of 100 V while the operator had the feet on the star shaped footrest of the chair. Table 3 shows the results.

The chair with five dissipative plastic castors showed a higher resistance to ground R_g when measured with a five-pound probe (one of them even out of spec $> 10^9$ Ω) compared to the same chair with two metallic and three dissipative plastic castors. The same applies for the system resistance to ground R_{gop} of the operator; exchanging two of the five plastic castors with metal castors reduced R_{gop} of the operator (both heavy and light) by at least one order of magnitude. This resulted also in a reduction of the maximum body voltage during the walking chair test from "out of spec" (> 100 V) to a low, uncritical value (< 50 V).

After having assessed the influence of some basic parameters, another round of experiments was performed in a different lab with four different chairs on two different floors (PVC and synthetic rubber) at two different values of the relative humidity (40% and 20%).

Table 3: Maximum voltage generated on a "heavy" and a "light" operator wearing ESD shoes while sitting on different chairs and performing the "walking chair test" on a raised ESD.

Type of Chair	R_g floor (Ω)	R_g chair (Ω)	R_{gop} (Ω)		Max. voltage at "Chair Walking Test" (V)	
			"heavy"	"light"	"heavy"	"light"
ESD chair D - 5 dissipative castors	8×10^6	9.0×10^8	1.4×10^8	3.0×10^8	154	198
ESD chair D - 3 dissipative, 2 metallic castors		1.5×10^7	1.1×10^7	1.2×10^7	35	50
ESD chair E - 5 dissipative castors		1.1×10^9	3.0×10^8	5.4×10^8	164	192
ESD chair E - 3 dissipative, 2 metallic castors		1.7×10^7	6.9×10^6	8.2×10^6	30	29

The chairs shown in Figure 7 have been tested:

A. A chair covered with a light blue fabric with five dissipative plastic castors ($R_{tg} = 9\times10^8\ \Omega$); two plastic castors have been exchanged with metallic castors for some experiments ($R_{tg} = 2.4 \times 10^8\ \Omega$)

B. A chair with a black PU seat and five dissipative plastic castors ($R_{tg} = 7.5 \times 10^8\ \Omega$)

C. A chair covered with a dark blue fabric with two metallic castors and three dissipative plastic castors ($R_{tg} = 5.6 \times 10^8\ \Omega$)

D. A cleanroom chair (black plastic seat with five dissipative plastic castors ($R_{tg} = 5.0 \times 10^8\ \Omega$))

Figure 7: ESD chairs used for "Chair Walking Test" (A to D from left to right)

The following chapters describe the influence of some of the parameters that have been evaluated.

C. Influence of ESD shoes

Typically, people are wearing ESD shoes when working in an EPA equipped with an ESD floor. However, what happens when people are wearing ESD shoes with a high resistance to ground or a heel strap that does not always provide a proper contact to ground in sitting position? To evaluate this, an experiment was performed where the body voltage generation of two operators was compared with ESD shoes and with insulative street shoes.

Figure 8 shows the body voltage generated when two different operators (red = lightweight, black = heavy operator) were performing the "Chair Walking Test" with chair A on a PVC floor. The combination chair A/PVC floor had the highest system resistance of all combinations investigated. As worst-case scenario, the operators were wearing insulative street shoes. This addresses the scenario that an operator is sitting on an ESD chair and wears only heel straps, which might not always make good contact to the ESD floor. The top graph in Figure 8 shows that in this case the operator can easily charge to values that exceed the limit of 100 V. As soon as they wear ESD shoes, the body voltage is reduced to less than 100 V (middle graph). Exchanging two plastic castors with metal castors further reduces the charging to less than 50 V (bottom graph).

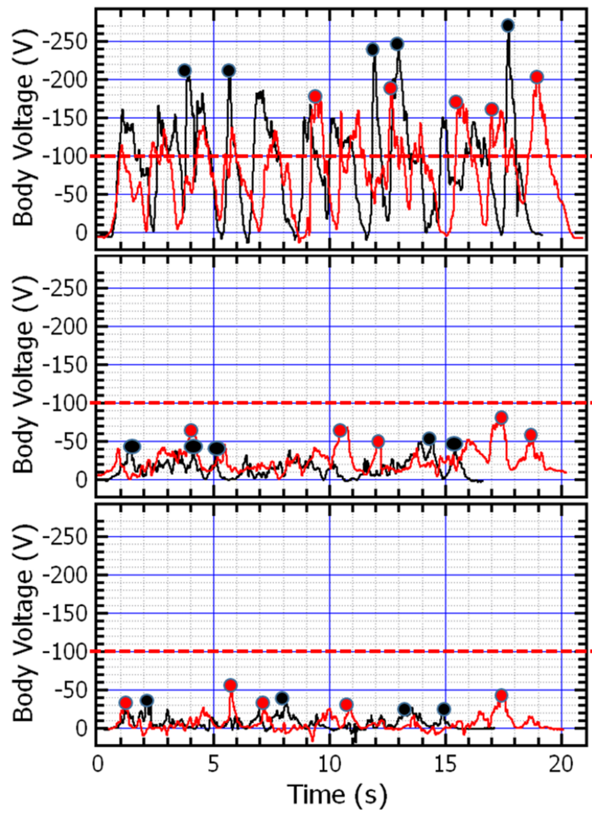

Figure 8: Body voltage generated during "Chair Walking Test" for two persons with a combination of ESD-chair/floor with high resistance-to-ground (~900 MΩ).
Top: Five dissipative plastic castors with street shoes
Middle: Five dissipative plastic castors with ESD shoes
Bottom: Three dissipative plastic plus two metal castors with ESD shoes.

The experiments shows clearly that the grounding of operators via ESD chair and ESD floor works reliably only when ESD shoes are used.

On a chair/floor combination with a lower system resistance of ~100 MΩ, the use of ESD shoes is less important. With this chair/floor combination, all body voltages measured in "Chair Walking Tests" with three different operators and five different shoes (even with insulative street shoes) are below 60 V, with ESD shoes hardly more than 10 V could be observed.

D. Influence of clothes

The material of the garments of the operators is considered as another important parameter affecting the body-voltage generation. In [7], body voltage measurements are summarized that show that wearing insulative Polyester garments do not influence the charge generation compared to cotton garments. However, in the evaluation performed in [7], personnel have been wearing the insulative clothes underneath an ESD coat.

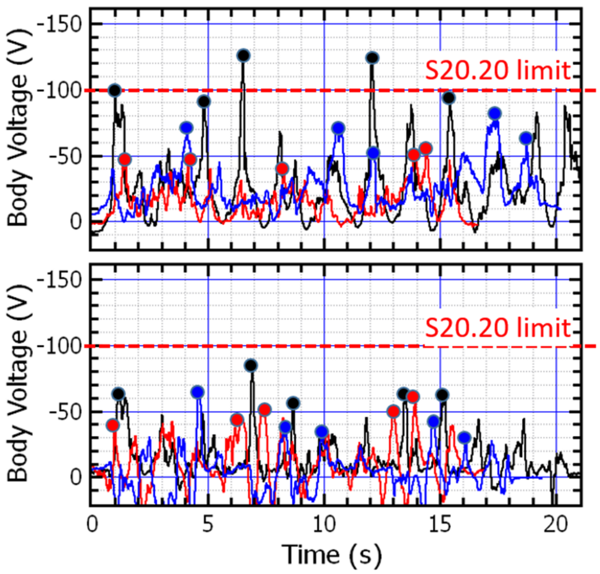

Figure 9: Influence of insulative clothes (top) versus dissipative clothes (bottom)

Since there might have been a contact between the skin of the operator and the ESD coat that would short the influence of the private clothes underneath, new experiments have been performed where the operator was isolated from the ESD chair by a thick insulative foil. The R_{gop} of the operator on the chair to ground with feet up in the air was >1 TΩ. When the feet (with ESD shoes) have been resting on the metal footrest, R_{gop} dropped to 13 MΩ. The body voltage generated in a "Walking Chair Test" was less than 50 V for the operators with good ESD shoes (see red and blue symbols in Figure 9). On the other hand, the operator with a structured shoe sole showed a slightly higher charging with and without an insulative layer on the chair seat. Hence, the private clothes do not significantly influence the body voltage generation during the rolling chair test.

E. Charging on a rubber floor

The same chairs as above have also been used on a synthetic rubber floor. The synthetic rubber floor has a little bit lower R_{tg} (2.5 x 10^7 Ω) when measured with the 5-pound electrode, compared to the PVC floor (9.0 x 10^7 Ω). Another aspect is also that the rubber floor is a bit weaker than the PVC floor, which guarantees a better contact to the castors of the chair. There is a general recommendation from chair manufacturers that a "soft" floor should be used with "hard" castors. Since the castors (plastic and of course metal) on the chairs used have all been hard, there might have been a worse contact between the PVC floor and castors resulting in a higher body voltage generation.

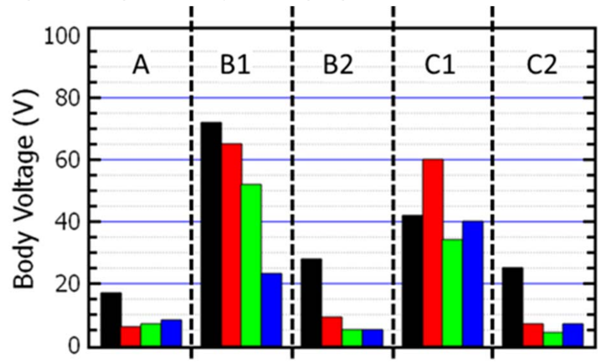

Figure 10: Body voltage generated during a "Chair Walking Test": Three persons (A, B, C) wearing (different) ESD shoes (A, B2, C2) or insulative shoes (B2, C2) on four different ESD chairs (color coded) on a synthetic rubber flooring

Figure 10 shows the result of experiments where the body voltage generated during a "Chair Walking Test" was measured on a synthetic rubber floor. Three different persons (A, B, C) wearing (different) ESD shoes (A = ESD shoes with structured sole, B2 = ESD booties, C2 = ESD sandals) or insulative shoes (B1, C1) performed the tests with the four different ESD chairs described above (Chair A = black; Chair B = red; Chair C = green; Chair D = blue).

As can be clearly seen, all combinations showed a body voltage generation of less than 100 V on the "soft" synthetic rubber floor.

F. Influence of sole structure

In some of the measurements, the body voltage of a person wearing ESD shoes with a roughly structured sole (see Figure 11) was higher than with the shoes having a more homogeneous structure.

Figure 11: ESD shoes with a roughly structured sole

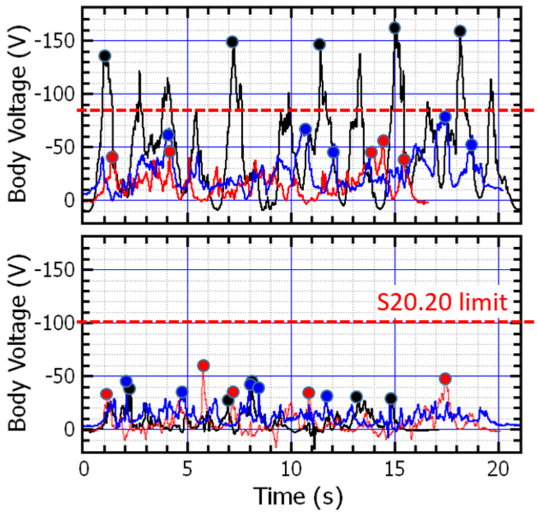

Figure 12: Body voltage on people wearing ESD shoes with roughly structured sole (black), ESD booties (blue), and ESD sandals (red). Top graphs show voltage generated with chair with five dissipative plastic castors, bottom graph shows result when two metallic castors have been added.

With such a structured sole, the contact area between the sole and the floor is smaller and, therefore, the resistance-to-ground is higher, resulting in a higher body voltage. This was not confirmed by a "normal" walking test. However, during the "Chair Walking Test" the operator with the roughly structured sole charged higher when rolling around (black line in Figure 12) compared to the operator with ESD booties or ESD sandals on the same floor/chair combination (red and blue line in Figure 12). Adding two metallic castors to the chair and decreasing the parallel chair-flooring resistance the body voltage generated was decreased to less than 100 V with all shoes.

A. Influence of humidity

Relative humidity (RH) is not required in international standards. Nevertheless, RH is known to have an impact on the body voltage generation. To assess the influence of RH, the body voltage of three different operators wearing the ESD shoes described above on the chair/PVC floor combination with the highest system resistance (with and without two metallic castors) was measured in an air-conditioned lab (38% RH) and inside a "walk-in" climatic chamber at approx. 20% RH. Chair and floor have been conditioned at 12% RH for three days, but when four people walked into the climatic chamber, the humidity increased to ~20%. The shoes used for the experiment have not been pre-conditioned.

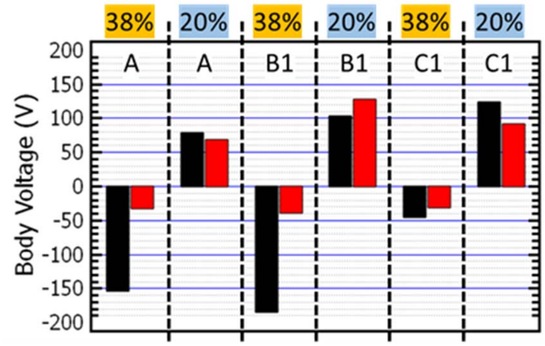

Figure 13: Influence of the rel. humidity on the body voltage generation during a "Chair Walking Test": 3 persons (A, B, C) wearing (different) ESD shoes (A, B1, C1) on an ESD chair with PVC cover with 5 plastic castors (blue) or 3 plastic castors and 2 metal castors (yellow).

Figure 13 shows the result of this experiment. It looks like the charge generation is a little bit higher at low RH (except operator A, but his shoes had a structured sole and the repeatability of the experiments was not so high; so the result might be influenced by this). A remarkable effect is that the polarity of the charge generated is reversed at low RH what cannot be explained so far. It can also be seen that the use of two metal castors reduced the body voltage generation at both RH levels.

B. Body voltage versus R_{tg}

There is an expectation that the body voltage generation is clearly correlated to the system resistance to ground of the operator while sitting on a chair with both feet on the ground. Experiments have shown that when people are grounded using a wrist strap with a resistance to ground such a correlation exists. Unfortunately, the resistance-to-ground during the walking test is not constant due the movement and varying contact area between floor and ground and therefore this correlation is no longer valid.

For the "Rolling Chair Test", the situation is even more complex since we have now the resistance to ground of the operator via shoes in parallel with the resistance to ground of the operator via the chair; and both contact resistances are varying with the movement.

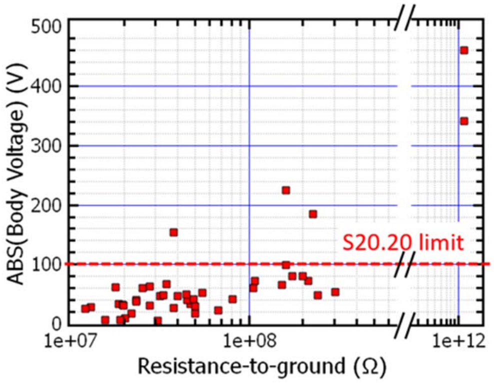

Figure 14: correlation between the resistance to ground of the operator on the chair with both feet on the ground and the absolute value of the body voltage (mean of 5 highest peaks)

Figure 14 shows that only for resistances roughly below 1×10^8 Ω, the body voltage can be expected to be below 100 V. For higher R_{tg} values, it might or might not be below 100 V. Therefore, the "Walking Chair Test" is necessary to verify that grounding the operator via ESD-chair and floor meets the requirements.

V. Summary and Conclusions

Grounding personnel in seated operations via ESD chairs and ESD floor can meet the requirements of international standards for standing operations. That means that the maximum generated body voltage can be limited to far below 100 V, depending on the resistance-to-ground of the chair or the system resistance of the chair/flooring/personnel system. The results of this study with measurements under different scenarios simulating the actual use case as well as a worst-case test confirmed that statement.

The results show that there is no clear correlation between the resistances R_g and R_{gop} and the generated body voltage. Nevertheless, as a first approach, the body voltage limit of 100 V correlates to a resistance of 1×10^8 Ω. If humidity is controlled in the environment, qualification like measurements before using a chair as a primary grounding means for personnel during sitting operations would require both a resistance test and a body voltage test, similar to ANSI/ESD STM 97.1 and 97.2. If there is no humidity control the measurements would have to be done at the lowest expected humidity what makes the whole process more difficult. For compliance verification, a simple resistance measurement could be adequate; however, one has to align carefully the resistance limit in compliance verification with the qualification data (see also Footnote 6 of ANSI/SESD S20.20-2014).

The investigation showed also that possible wear out or contamination of dissipative plastic castors can result in charging voltages >100 V. This behavior can widely be avoided by using at least two metallic castors. Chairs with metallic castors are already used since a long time in some fabs (with humidity control [6,7]) without further problems not fulfilling the R_{tg} or body voltage measurements due to worn out castors.

IV. References

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