Evaluation of performance of footwear and flooring systems in combination with personnel using voltage probability analysis

Jeremy Smallwood1, David E. Swenson2.
1Electrostatic Solutions Ltd, U.K. 2 Affinity Static Control Consulting LLC, U.S.A
jeremys@static-sol.com

Abstract. Evaluation of electrostatic performance of footwear and flooring in combination is necessary in applications such as electrostatic discharge (ESD) control in electronics manufacture, evaluation of equipment for avoidance of factory process electrostatic ignition risks and avoidance of electrostatic shocks to personnel in working environments. Typical standards use a walking test in which the voltage produced on a subject is evaluated by identification and measurement of the magnitude of the 5 highest “peaks” and “valleys” of the recorded voltage waveform. This method does not lend itself to effective analysis of the risk that the voltage will exceed a hazard threshold. This paper shows the advantages of voltage probability analysis and recommends that the method is adopted for use in future standards.

1. Introduction

Evaluation of electrostatic performance of footwear and flooring in combination is necessary in applications such as electrostatic discharge (ESD) control in electronics manufacture [1], evaluation of equipment for avoidance of factory process electrostatic ignition risks and avoidance of electrostatic shocks to personnel in working environments. For this reason, standards such as IEC 61340-4-5 [5] have been developed. These typically use a walking test in which the voltage produced on a subject is measured. Evaluation is typically by manual identification and measurement of the magnitude of the 5 highest “peaks” and “valleys” of the recorded voltage waveform. This method does not lend itself to effective analysis of the risk that the voltage will exceed a hazard threshold, e.g. 100V body voltage for protection of electronic components or 4kV as the threshold of perceptible shocks to personnel. The measurement is typically done on one test subject and floor area only.

The method of voltage probability analysis has several advantages. Firstly, the results may be directly interpreted to find the risk of exceeding any desired hazard threshold voltage. Secondly it can be easily automated using a computer. The results of many measurements (e.g. at different floor positions, or with several subjects or shoe types) may also be combined to give greater confidence in an overall performance of the footwear-flooring system in practice.

As an example the risk of shocks to personnel in an office environment, where a number of subjects wore different shoe types of their choice, is evaluated, based on a sample of subjects selected from that population. Typically in this situation measurements on one person will not be representative of the office population, and measurements of several personnel may be required. In this case...
comparative measurements on different floors led to identification of a particular floor covering as a key source of electrostatic charging and shocks to personnel.

In a second example, voltage probability analysis is used to evaluate the ElectroStatic Discharge (ESD) risk from personnel within and electronics industry ESD Protected Area (EPA).

2. Methodology

The method of measurement of body voltage is well known and hardly needs description here. Various standards have slight variations on the equipment required. Typically the human subject holds a hand-held electrode which is connected to an electrostatic voltmeter. The output of the voltmeter is recorded, for example by a datalogger or digital oscilloscope. In proprietary instruments, these stages may be combined in one unit.

![Diagram of measurement setup]

Figure 1. Typical arrangement for measurement of body voltage.

As an example, we have made measurements of body voltage using an electrostatic voltmeter connected to a software oscilloscope running on a laptop computer. The oscilloscope software recorded a voltage trace as a series of digitised voltage values. These were then saved as a comma separated value (csv) file for processing using a spreadsheet software package. The csv file is presented by the spreadsheet as a table of voltage samples at a series of time intervals, determined by the operator on setting the oscilloscope. This table may be presented conventionally as a graph or subjected to further processing and voltage probability analysis. Each time and value pair represents the body voltage at one sample instant over the trace.

One simple method of analysis is to convert the data to a voltage frequency table as follows. Parallel columns of the spreadsheet may be set up, in which the column value is set to 1 if the voltage lies between set limits (e.g. 0-50V, >50 – 100V, >100 – 150V etc). The number of 1’s in each column is summed to give the number of data samples within that range. Each of these sums may then be divided by the total number of samples to give the frequency with which the voltage appears in each range. These values may then be presented conveniently as a barchart or graph.

If a simpler output evaluation is required, e.g. the percentage of samples which lie above a 100V hazard threshold value, then it is sufficient to set up 1 column ( >100V). The percentage of data samples over that value is easily calculated from the number of 1’s in the column divided by the total number of data samples.

3. Results and discussion

A typical body voltage waveform generated by a walking test over a 20 second period using the above method is shown in Figure 2. Table 1 shows sample data from this (Waveform F data) and 6 other similar waveforms (A, B, C, D, E and G) produced by different subjects walking on the same surface material in an office floor evaluation. The table summarises the number of data points for each waveform in the voltage ranges 0, 0.5, 1, ...,5kV. It can be seen that different personnel (presumably wearing very different shoe types) could produce very different voltage data distributions.

An overall voltage distribution for the population as a whole was produced by summing all the data values for waveforms A-G, as well as the total number of data samples. The frequency of the data in each voltage range was then calculated for the population.
Figure 2. Typical body voltage waveform generated from walking test. This waveform gave Waveform F data shown in Table 1.

| Voltage range (kV) | 0 | 0.5 | 1 | 1.5 | 2 | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 |
|-------------------|---|-----|---|-----|---|-----|---|-----|---|-----|---|
| Sum of samples over all waveforms | 0 | 83 | 251 | 1051 | 3071 | 2291 | 1175 | 397 | 97 | 15 | 0 |
| Total no. of samples | 8431 |
| Frequency of data in voltage ranges (%) | 0% | 1% | 3% | 12% | 36% | 27% | 14% | 5% | 1% | 0% | 0% |

Table 1. Table of data arising from waveforms A, B, C, D, E, F and G from walk tests with seven personnel on the same surface.

Figure 3. Comparison of body voltages experienced in 3 floor areas in an office environment. Figure 3 shows the results of similar measurements made in three floor areas in an office environment compared for body voltage where shocks had often been reported by personnel. The example data given above is for the “Boardroom and offices” areas, obtained using seven walk tests.
with volunteer personnel from the area. The data for the “BC area” and “Reception” were obtained from four walk tests. Some, but not all of the personnel participated in tests for all three areas.

The difference in performance of the three floor coverings can immediately be seen. The purpose of this investigation was to identify floor coverings which may contribute to shocks to personnel, with an estimated threshold of 4kV. It can immediately be seen that the Boardroom and office floor covering are the most likely to contribute to this. Under the ambient relative humidity of 36% r.h. there was already a small chance (circa 1%) that personnel may experience shocks. When humidity is reduced, the probability curve would be expected to move to the right and the frequency of shocks increase. The data shows clearly why personnel who are more sensitive to shocks would expect to feel them with increased frequency.

4. Conclusions
Simple voltage probability analysis gives a useful means of evaluating the performance of personnel in combination with their footwear and floor coverings against a hazard threshold. Furthermore, the results of many tests may easily be combined to give a greater confidence in the performance of a system, especially where many personnel or types of footwear may be present. The analysis process may easily be automated in a spreadsheet or by some other computer based method.

It is recommended that this type of analysis should be adopted by future standards as an option for evaluation of footwear and flooring in combination with personnel.

References
[1] Swenson D.E. Process Monitoring to determine electrostatic risks, J. Phys. Conf. Se. 142 (2008) 012005
[2] British Standards Institute. (2001) Electrostatics - Part 5-1: Protection of electronic devices from electrostatic phenomena - General requirements. BS EN 61340-5-1: 2001. ISBN 0 580 32346 3
[3] ESD Association. (2007). ESD Association Standard for the Development of an Electrostatic Discharge Control Program for – Protection of Electrical and Electronic Parts, Assemblies and Equipment (excluding Electrically Initiated Explosive Devices). ANSI/ESD S20-20-2007. ISBN 1-58537-121-1
[4] ESD Association ESD Association standard test method for the protection of electrostatic discharge susceptible items. Floor materials and footwear – voltage measurement in combination with a person. ANSI/ESD STM97.2-2006
[5] IEC 61340-4-5 Standard test methods for specific applications – Methods for characterizing the electrostatic protection of footwear and flooring in combination with a person