"Predicting the voltages that will arise on garment surfaces by tribocharging"

J. N. Chubb (John Chubb Instrumentation,UK)
P. Holdstock (British Textile Technology Group, UK)
M. Dyer (William Barnet and Son Inc, US)

Measurements are reported showing that appreciable surface voltages can arise on inhabited cleanroom garments when these are locally charged by triboelectric rubbing. Surface voltages can be up to 1000V. It is shown that the performance of the variety of inhabited garments relates primarily to the 'capacitance' experienced by charge on the fabric surface - as measured using corona charging on sample areas of the fabric. Resistivity has been shown to be irrelevant.

1. INTRODUCTION

This paper is concerned with the voltages that can arise on the surfaces of garments, in particular cleanroom garments, during work activities. If surface voltages are too high and last too long then there can be risks of damage to nearby sensitive devices. It is therefore important that the choice of fabric and garment construction ensure that the surface voltages of garments as worn remain suitably low.

The present work had two main objectives:

- to establish reliable methods to measure the surface voltages of inhabited cleanroom garments where these experience tribocharging
- to see if these voltages can be predicted from measurements of electrostatic performance features on sample areas of garment fabrics

Electrostatic charges will be separated when surfaces around the work area are rubbed against garment surfaces. This might be a sleeve or body area of a garment. The charge left on the garment will create a local voltage depending on:

- the quantity of charge transferred
- how quickly charge can move away from its source area in comparison to the time of rubbing
- the capacitance experienced by the charge
- whether the rubbed area of the garment has a good linkage path to earth
- whether the person's body inside the garment is bonded to earth

The quantity of charge separated will depend on the garment fabric, the material of the other surface that is rubbed and the mechanical speed and intensity of the rubbing action. From the point of view of comparing garment fabrics and construction it is important to have information on a per unit charge basis. To assess acceptability for particular applications one then also needs information on maximum likely quantities of charge expected in practical activities and voltage levels that are acceptable.

'Apparent surface voltages' may perhaps also arise from charges on clothing between the outer garment and the person's body and on the body itself. The term 'apparent surface voltage' is used because it could be that there is no actual nett electrostatic charge on the outer garment surface, but items nearby experience the influence of electric fields from charges on underlying garment surfaces that are not shielded by the outer garment. Where charge separation occurs by rubbing between the outer garment and the next inner surface this will have little external influence unless the outer garment is loose so that there can be appreciable distances between the separated charges. If the garment is bonded to earth but the person's body is not then there could be a question of shielding of body voltages by the garment material.

2. SURFACE VOLTAGES ON INHABITED GARMENTS

The present studies have aimed to match normal operational experience as far as ia practically commensurate with making good quality electrostatic measurements. A person (operator) has been clothed in a number of cleanroom garments and boots and stood on an earthed metal plate surface. Electrostatic charge has been separated at a local position on the surface of the garment by having a second person (tester) strike this area with the end of a charge neutral Teflon rod (‘scuff’ charging [1]). The area chosen has been the upper arm, as this was convenient for striking, with quick removal of the charging rod, and for surface voltage measurement. Surface voltages were measured by a ‘field mill’ electrostatic fieldmeter (JCI 140). The measurement separation distance was 100mm. This allowed the garment surface to be struck directly in front of the fieldmeter sensing aperture so observations related fairly reliably to the area over which charge was separated. It also gave opportunity for reasonable accuracy of measurement because at 100mm separation a 10% error in distance only gives 5% error in reading. It needs to be noted, of course, that as the area charged is of limited size the reading by the fieldmeter, set up to show the voltage on an extended surface, will be an underestimate of the immediate local voltage. It is however an indication of the influence of the surface charge at a nearby earthed item.

To enable the charge transfer to be measured the metal plate on which the operator stood was insulated from an earthed support plate by localised insulators. The standing plate surface was connected, by coax cable, to a virtual earth charge measurement unit (JCI 178). This kept the metal standing plate at earth potential throughput measurement. Discrete insulators were used to support the standing plate to avoid risks of tribocharging at the support insulation or of signals arising from varying capacitance to nearby charged surfaces.

To enhance confidence in surface voltage measurements, a robust tripod support stand was built that mounted a shaped wooden support on high quality insulation to support the forearm of the operator. The JCI 140 Static Monitor used to measure garment surface voltage was mounted from the top of the tripod stand. This tripod arrangement gave good positional stability of the body and the garment surface relative to JCI 140 for good quality surface voltage measurements.

Measurements of surface and body voltages were recorded on a digital storage oscilloscope (Picoscope ADC-212). To achieve good signal to noise ratio records the charge and surface voltage signals were passed through filter and gain stage units providing –3dB roll-off (70% signal) at 2Hz with a x10 gain.

The garments tested were standard cleanroom coveralls and boots manufactured to a normal commercial design. The garments were laundered 5 cycles to ISO 6330 procedure 5A at 40C, followed by a final low temperature tumble dry. The garments were worn over normal shirt and trousers - as is usual. The following table lists garment details.

Table 1: Test garment construction

	Grid	Thread
A	5mm grid (white)	Core conductor [1]
B	5mm grid (white)	Surface conductor [1]
C	2mm grid (white)	Core conductor [1]
D	2.5mm grid (white)	Surface conductor [2]
E	5mm grid (white)	Core conductor [1]
F	20mm stripe (blue)	Surface conductor [3]
G	7.5mm grid	

1, 2 and 3 are different types of conductive thread

Measurements were made in a controlled environment of 23°C and 40%RH in the test laboratory of British Textile Technology Group (BTTG), Manchester, UK.

The local area electrostatic characteristics of the garment fabrics were measured by corona charge decay (to IEC 61340-2-1) in combination with ‘capacitance loading’ [1] and by surface resistance (to EN 1149-1). These measurements were made in the same environmental conditions at used for the electrostatic performance tests on inhabited garments.

3. RESULTS

An example of the variation with time of surface voltage of an inhabited garment (E) is shown in Figure D1 below (in blue) together with the charge measurement signal (in mauve).

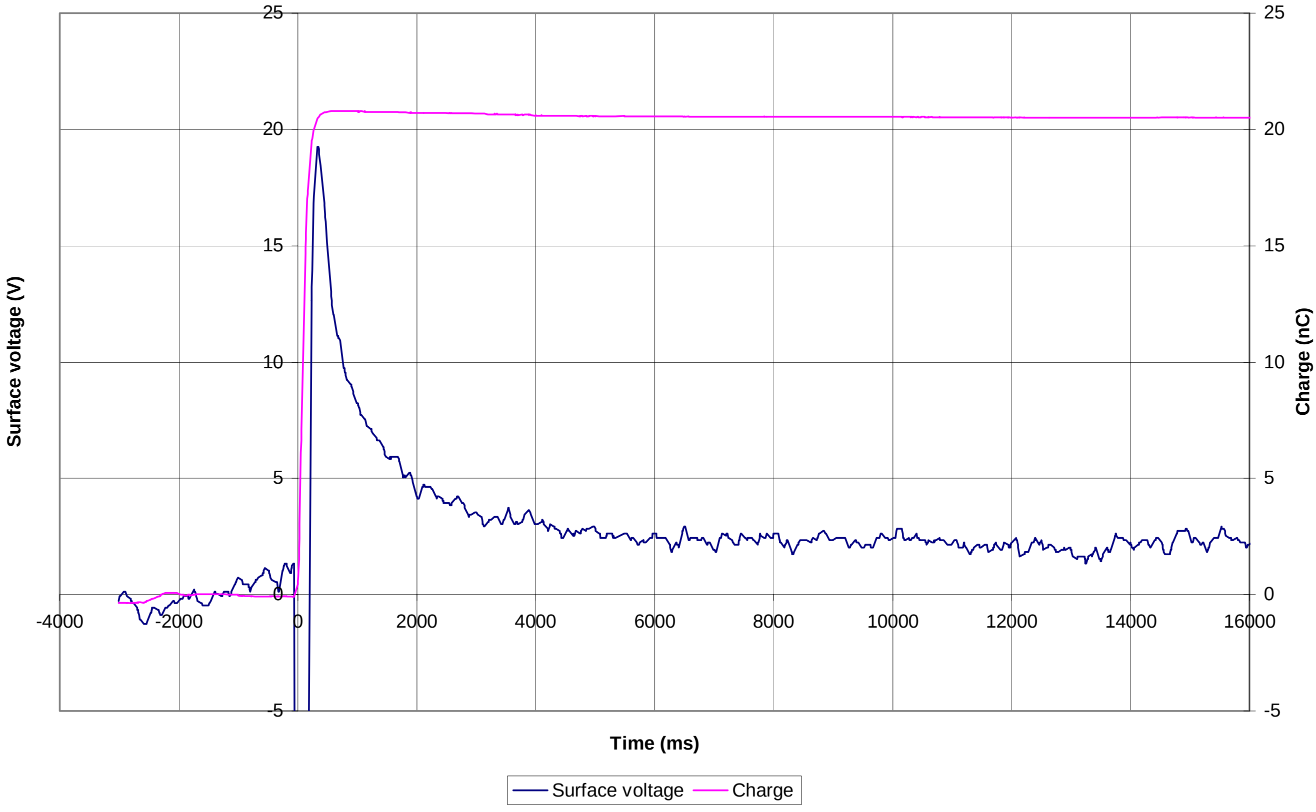

Figure D1: Example of variation of charge and surface voltage signals

The values for the initial peak voltages observed for garments with different fabrics as a function of the quantity of charge transferred are shown in graph in Figure D2 below. This graph shows that quite high surface voltages can arise on certain garments (to over 1000V), while on others surface voltages are no more than 20V. While there is quite a bit of scatter in the present measurements it seems likely that the average or the maximum surface voltage varies in proportion to the quantity of charge. From the point of view of risk it is, of course, the maximum value that may occur that is relevant.

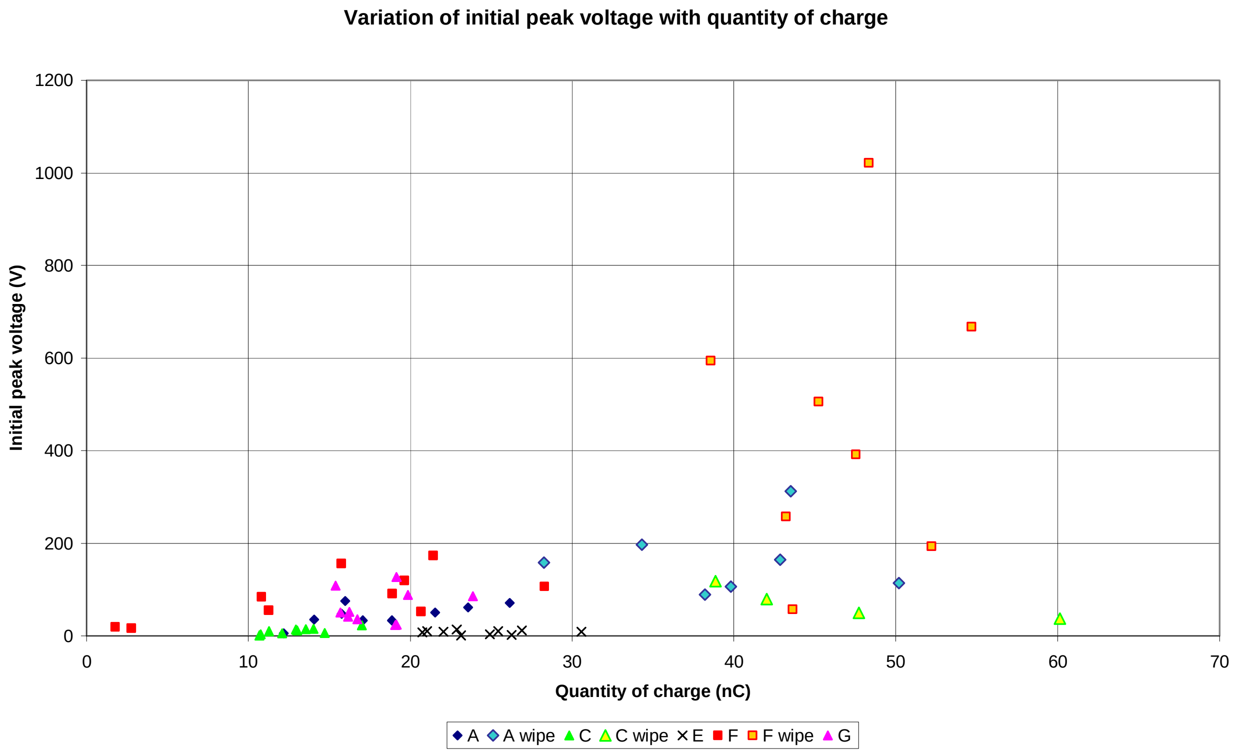

Figure D2: Variation surface voltages with quantity of charge

4. MEASUREMENTS ON FABRICS

The electrostatic characteristics of the fabric of garments have been assessed by measurement of charge decay time and capacitance loading, based on the use of corona charging. The equipment and techniques for these measurements have been described in published papers [1,2]. The essence of the method of assessment is to use a short period of high voltage corona discharge (20ms) to deposit a local patch of electrostatic charge on the material to be tested and to measure the quantity of charge transferred. A fast response electrostatic fieldmeter is used to measure the initial peak surface voltage created by this charge and the decay of this voltage with time. The 'capacitance loading'[1] experienced by the charge on the surface is calculated from the quantity of charge deposited and the initial peak surface voltage created [1,2].

Measurements were made on areas of fabric of the various garments tested above at quantities of charge comparable to those involved in the triboelectric charging. It was found that charge decay times were essentially independent of the quantity of charge transferred. Capacitance loading values did, however, vary with the quantity of charge. The variation was linear and had the form of an intercept at zero charge and a positive slope. (It is observed that materials and fabrics that do not include conductive threads show no significant variation of capacitance loading with quantity of charge. The mechanism responsible for this behaviour with conductive threads is not yet known).

---

[1] 'Capacitance loading' is the relative capacitance experienced by charge on the material compared to that for a similar distribution and quantity of charge on a thin layer of a good dielectric - where the capacitance is essentially that of just the spatial distribution of charge and any influence of proximity of nearby earthy surfaces. The enhanced capacitance to the deposited charge probably arises from coupling of the deposited charge to some structural feature in the material. This might be a relatively conductive layer or pattern of threads or a high dielectric constant feature. Coupling may link to nearby earthy surfaces or just to a larger effective area of material.

Historically, 'resistance' has often been used as a way to assess materials. Measurements of resistance were hence also made on the garments, using standard test method EN 1149-1.

5. COMPARISON OF TEST RESULTS

The results of surface voltage measurements on the various inhabited garments are compared in the histogram in Figure D3, below, with the values of charge decay time, capacitance loading and resistance measured on sample areas of these garments [3]. These results showed that high garment surface voltages related to low values of capacitance loading and low surface voltages to the higher values of capacitance loading. For these garment materials charge decay time was not a limiting or relevant feature. It was very clear that surface 'resistance', was not a relevant feature.

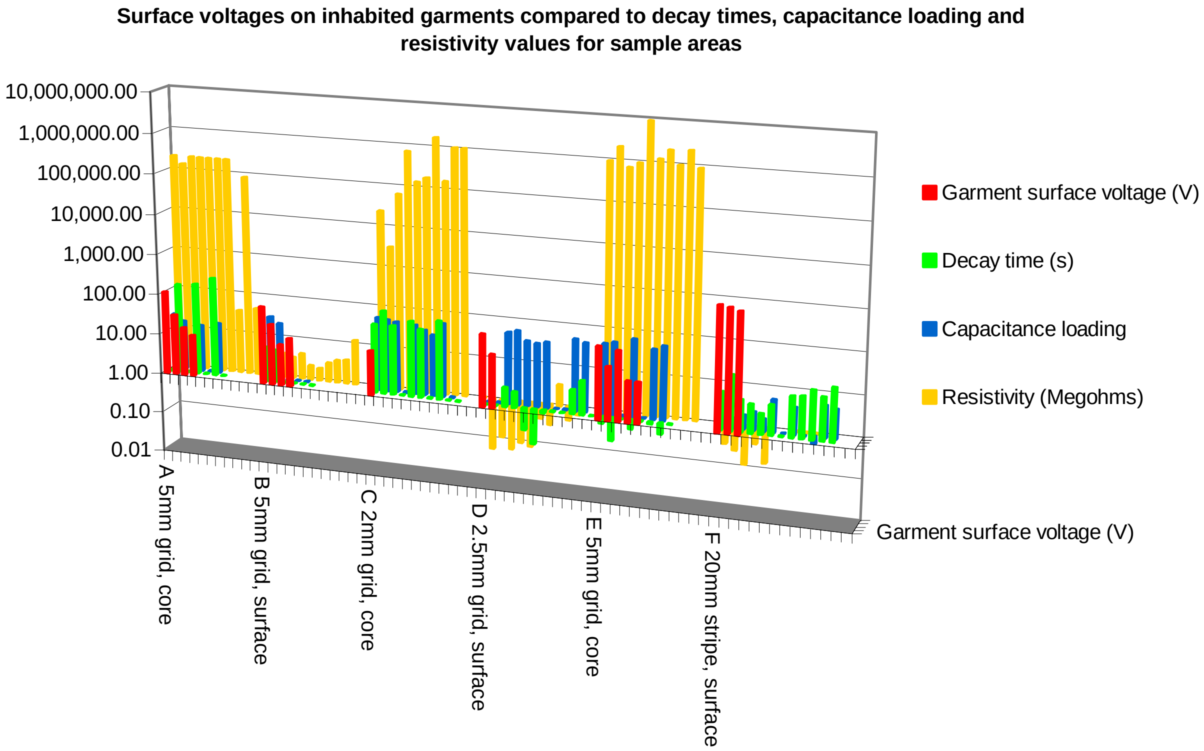

Figure D3: Histogram comparing measurements on various garments

It seemed likely, and plausible, that the maximum voltages on garment surfaces might relate directly to 'capacitance loading' values measured on sample areas. It is observed that for fabrics including conductive threads and with corona charging, capacitance loading values increase with the quantity of charge transferred. A family of curves can then be drawn using these varying values to predict the surface voltages expected as a function of charge quantity. It was clear, however, that this did not match practical experience of surface voltages on inhabited garments. A better match is achieved using the extrapolated values for capacitance loading at zero charge transfer to produce a predicted linear variation of surface voltage with quantity of charge. On this basis the maximum local surface voltage V_g (volts) on an inhabited garment may be predicted from the quantity of charge q (nC) transferred by a rubbing action and the capacitance loading value $CL_{q=0}$ at q=0, as:

$$V_g = f\, q / (CL_{q=0})$$

It seems the factor f may be around 25, possibly a bit larger. The following graph, Figure D4, shows both the experimental observations (as in Figure D2) and the predictions by the above equation using values for $CL_{q=0}$ derived from the capacitance loading measurements made on local sample areas of each of the garments.

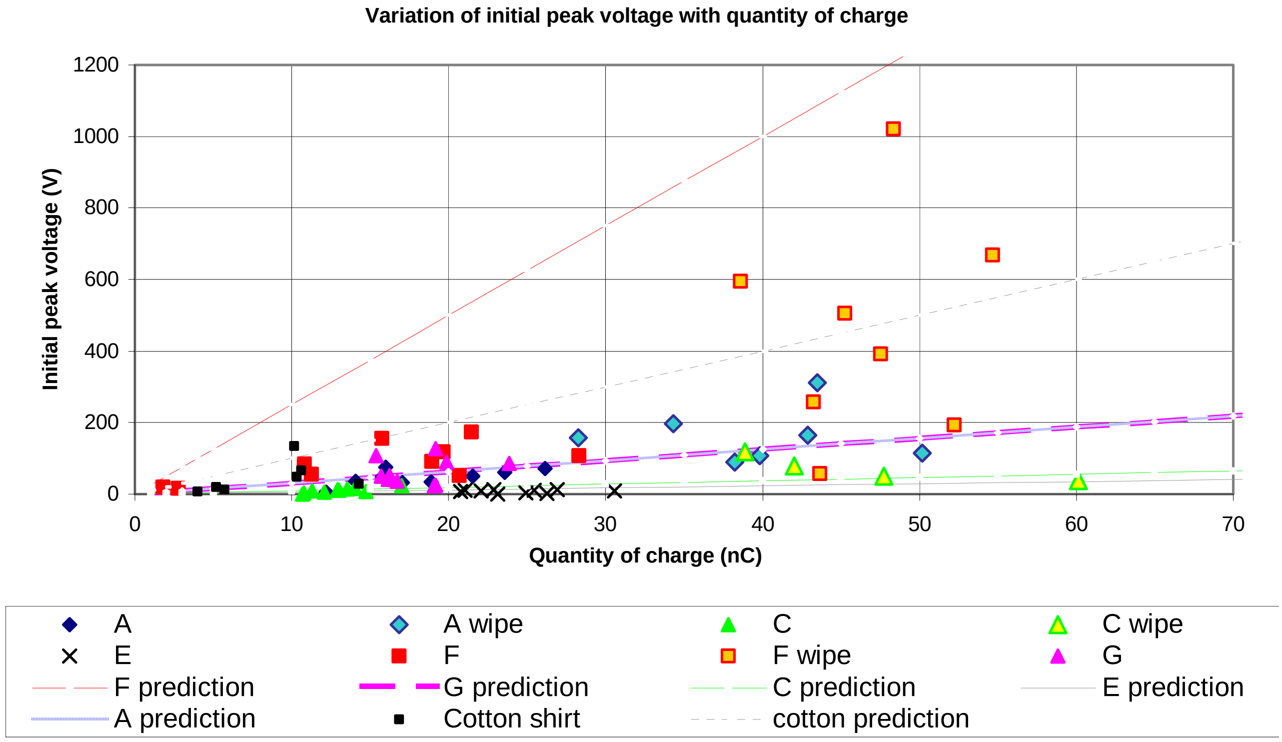

Figure D4: Comparison of garment surface voltage measurements with predictions

6. CONCLUSIONS

The present studies indicate that the surface voltage on an inhabited garment can be predicted from the quantity of charge transferred by a rubbing action and knowledge of the capacitance loading experienced by charge of the surface. Capacitance loading values are measured as a characteristic of the fabric using instrumentation based on corona charging. Thus maximum surface voltages to be predicted from the maximum quantities of charge likely to be transferred at practical rubbing actions.

Further work is being pursued to confirm the present findings with a wider variety of garments and fabric materials and constructions.

The differences in performance for the garments tested related primarily to the capacitance experienced by charge on the fabric surface. It does not relate to surface resistance – and for the present garments does not appear to be related to charge decay times. This is expected as decay times are fairly long.

The present work enhances knowledge on practical electrostatic risks by showing how measurements can be made on cleanroom garments ‘as used’. The results of such work are important as they provide a route for the assessment of fabrics and of garments to achieve target requirements. They also have relevance to the choice of materials to be used for personal protective clothing for work in flammable atmospheres – and may well have wider application.

References

[1] J. N. Chubb *"Measurement of tribo and corona charging features of materials for assessment of risks from static electricity"* Trans IEEE Ind Appl 36 (6) Nov/Dec 2000 p1515

[2] J. N. Chubb *"New approaches for electrostatic testing of materials"* J. Electrostatics 54 March 2002 p233 (ESA Annual meeting, Brock University, Niagara Falls, June 18-21, 2000).

[3] J. N. Chubb, P. Holdstock, M. Dyer *"Can cleanroom garments create electrostatic risks?"* 'Cleanroom Technology' 8 (3) March 2002 p38