6. PRACTICAL ELECTROSTATIC PROBLEMS

6.1 General comments

The preceding Chapters have provided a background of theory, methods for measurements and the levels at which static is likely to cause problems in different situations. It is now time to turn to practical questions:

- how do you find out if it is static causing the problem experienced?
- is static a real risk in particular situations?
- what can be done to overcome/avoid risks?
- how do you know if remedial measures remain effective?

We start by noting the 5 Cs of static electricity:

C1: Characteristics of materials:
- chargeability
- charge decay
- capacitance loading
- resistivity
- dielectric constant
- shielding
- ability to support an incendive electrostatic discharge

C2: Coupling:
- geometry effects
- modelling
- time domain effects
- capacitance

C3: Consequences:
- electric fields
- surface voltages
- stored energy
- electrostatic forces (attraction for dust and debris and thin films)
- ignition capability (metal electrodes/dielectric surfaces)
- EOS/ESD damage risk to semiconductors
- EMC radiation/susceptibility (upset operation of electronic systems)

C4: Countermeasures:
- reduce charging
- promote charge removal
- design to overcome consequences

C5: Constructive use:
- electrostatic forces (electrostatic precipitation, photocopying, paint and crop spraying, particle alignment (e.g. flocking)

6.2 Is 'static' the cause?

The first point to consider in any practical situation are whether there are materials and activities that are likely to give rise to separated charges and what measurements can be made to examine the practical situation. In many cases inspection and experience will provide a very useful starting point. If plastic or artificial fibre materials are present, if materials are dispersed into the air, if sizeable conducting bodies (notably people) may not be electrically well linked to earth – then there could be problems. While it may be feasible to make helpful measurements on materials away from the practical situation it is desirable, and often necessary, to make observations in the real situation. This gives opportunity for unexpected features to show themselves.

The above overview needs to lead to an assessment of the forces, potentials, quantities of charge, available electrostatic energy available in relation to the practical situation and operations. From this the significance of various electrostatic aspects can be assessed and recommendations made on actions to overcome or avoid risks and problems. To this will be added recommendations on future actions to ensure that the remedial actions proposed are checked to ensure they remain effective.

When considering problems with static electricity it is important to remember that electrostatics is only ever a part of the overall 'system'. Electrostatic aspects must be viewed in conjunction with many other practical factors. Thinking of the 'system' is important because not only does it help assessment of the role of static but it also provides the framework for considering alternative ways to tackle problems. Understanding the electrostatic aspects of problems is usually desirable but may not be necessary for achieving a solution. The 'problem' may be an electrostatic problem: but the 'solution' need not depend on electrostatics. For instance: risks of ignition of flammable atmospheres by static discharges might be tackled by avoiding static. Alternatively, risks of ignition might be removed by avoiding the occurrence of a flammable atmosphere. In such situations it is important to recognise that there may be other mechanisms of ignition and to check for these - for example by frictional heating, impact sparks (for example steel and flint) or thermite reactions (involving aluminium or other light alloys with rusty steel).

It is important not to stop thinking of alternatives as soon as one possible cause or one solution of a problem has been identified. There may be several contributory factors and a variety of solutions. All factors need to be recognised and considered in the context of the 'system' - which will include personnel, engineering implementation and economics as well as technical aspects. There are, however, a number of general basic actions that need to be taken for reasons of safety [1,2,3].

6.3 Codes of Practice

A number of Standards relating to the control of static are listed in Chapter 7.6. The main Codes of Practice available that relate to static electricity concern:

- the control of static risks in relation to risks of shock, mechanical handling problems and ignition of flammable gases in petrochemical and processing industries [1,3]

-the control of static risks in the handling of semiconductor devices and microelectronic assemblies [2].

The basic philosophy for the control of static in the above Codes is to provide reliable earth linkage everywhere to everything. This to ensure that any static charges that arise will have opportunity to migrate quickly to earth and not be available for retention on isolated conductors or insulator surfaces. This means visible metal earth bonding straps for all metal plant. With plastics and naturally insulating materials it means avoiding charge retention by, for example, modifying the material by additive or by surface treatment or by an alternative choice of material. Where charge retention cannot be adequately controlled by material selection then local air ionisation may provide a route for charge neutralisation by making the local atmosphere partially conductive.

It may be expected that static could be controlled by appropriate choice of associated materials according to the 'triboelectric series'. This is not in general a practicable or reliable approach to avoid risks or problems – but it may help reduce them. It is easy to show that PTFE rubbed on PTFE gives two highly charged surfaces!

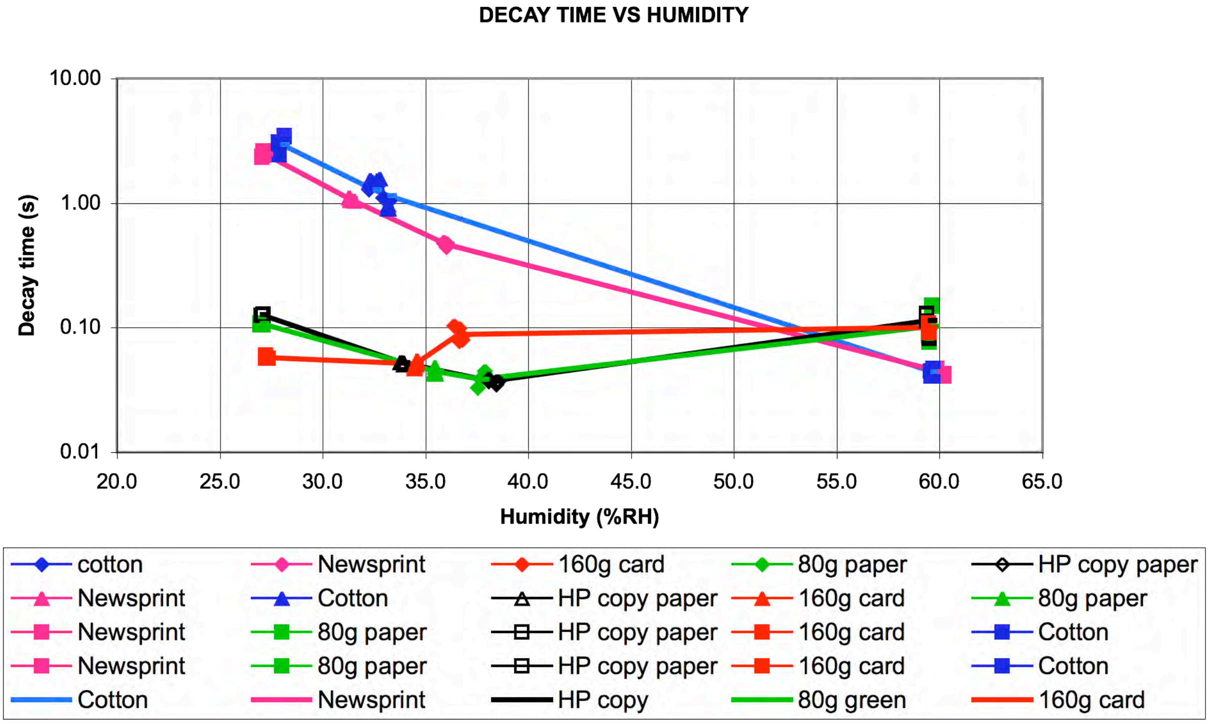
Codes of Practice cover many common practical risk situations very well, but there are a number of problems which are not covered. The following sections provide ideas of some alternative approaches worth consideration.

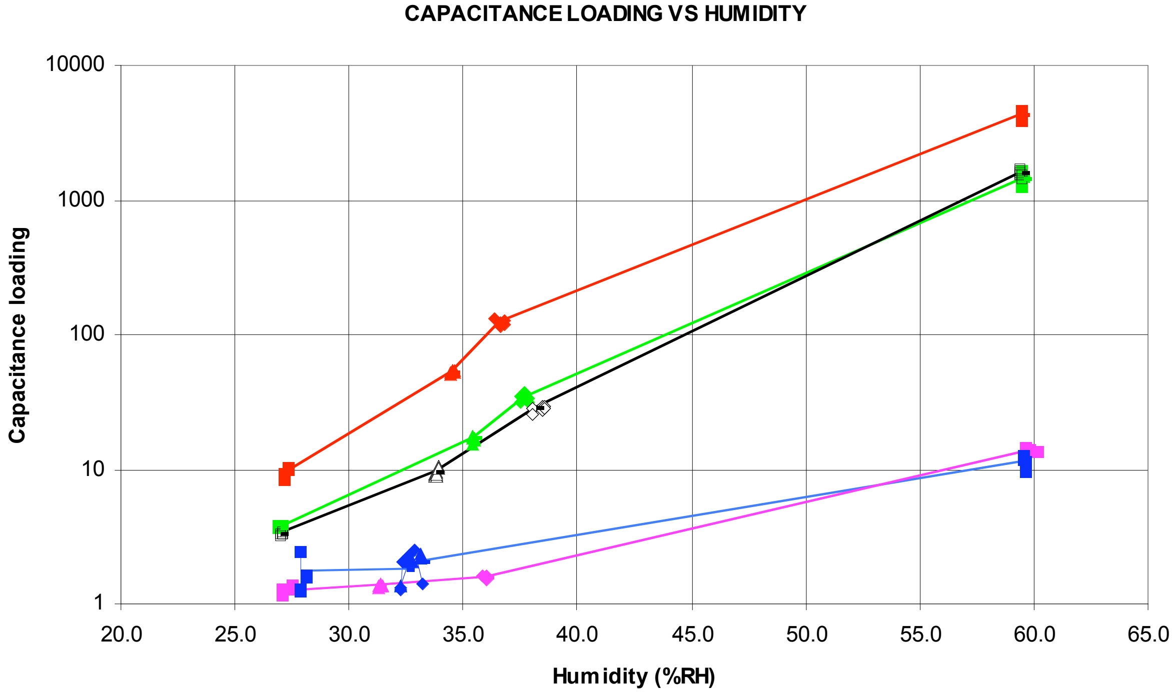
6.4 Characteristics of materials

Resistivity measurements have traditionally been the way used to qualify materials where static electricity is thought likely to causes problems or presents risks. In some situations this measurement can be appropriate (e.g. flooring and footwear) when the need is to drain charge from a conductor in contact (e.g. from the body to the floor). Where problems arise from static charge retained on a material itself then a measurement of resistivity may be quite inappropriate. This is particularly true for inhomogeneous materials. Resistivity indicates the fastest route available for charge migration. The slowest route for charge migration is what is relevant for charge retention. Charge decay measurement is appropriate in such situations. However, it is important that the method of measurement used is suitable and is shown to give results that match the decay of triboelectrically generated charge [4,5] (see also Chapter 3.7). It is to be noted that Federal Test Standard 101C Method 4046 does not achieve this – as noted in Chapter 3.4.3 [4]. To avoid the occurrence of local high voltages and to limit the time they may be present requires the charge decay time to be short compared to the time of mechanical actions responsible for charge separation. Decay times below ½ s have been suggested as suitable but recent studies have indicated that decay times below ¼ are preferable [5]. It is worth noting that decay time must not be too short (probably not less than a few ms), to avoid the possibility of spark discharges directly to the material itself.

Two particular area where the characteristics of materials is important is electrostatic precipitation of airborne particles from flue gases and electrostatic paint spraying. If charge can migrate too quickly through the layer of particles built up on the collection electrodes (as applies with precipitation of, say, carbon black) then the material is not adequately held to the surface by electrostatic forces and fall away prematurely and so are re-entrained within the airflow. If, on the other hand, charge cannot migrate adequately quickly through the layer of particles in relation to the local flow of corona current then a large voltage can build up across the layer. This will reduce the electric field depositing charged particles and may lead to electrical breakdown through the layer. This leads to reduced deposition efficiency – and breakdown causes ‘orange peel’ type non-uniformity in sprayed paint.

A special feature of materials that can limit the influence of retained static charge is the capacitance presented to charge on the surface. If the capacitance is high then the surface voltage likely to arise from the quantities of charge transferred in practical events may be sufficiently low as not to allow risks or problems. Measurement of this capacitance effect requires measurement of the initial peak voltage generated when a measured quantity of charge is deposited on the surface of a material (see Chapter 3.4.5) [6]. The following Figures show examples of how charge decay times and capacitance loading vary with humidity in different ways for a cotton fabric and for paper. Charge decay times for ‘finished’ papers seem fairly constant with humidity, whereas for newsprint and for a cotton fabric they are much longer with lower humidity. The constancy of decay times of ‘finished’ papers may arise because of a near balance between increasing charge mobility and increasing capacitance loading with humidity.





6.5 Investigative procedures

The fieldmeter is the main instrument for investigation of electrostatic questions. These instruments can be used, as explained in Section 3, for measuring the main parameters of interest in electrostatic investigations. The following comments draw attention to a number of points to remember in studies in practical situations.

- <u>Sources of static:</u> A fieldmeter is useful to scan around a work area to identify materials and operations where static charge and surfaces voltages are present. Remember to earth bond the fieldmeter. For induction probe instruments (no rotating chopper) switch on the instrument with the sensing surface well shielded from any sources of charge. A high sensitivity fieldmeter (field mill type) makes it easy to find even low levels of static at a distance. When possible sources have been identified then one can focus in to confirm identification and make quantitative measurement. Beware of influence of other surfaces nearby that may be charged or may be shielding the effects of charge. Where suspect materials are lying on another material, particularly on an earthed surface, it is helpful to lift the material to see whether it is this that is actually charged – and to try rubbing the material to see if it easily becomes charged. Do not scan too quickly when looking for sources of static as the response time of the display may not show observations reliably.

- Body voltage: A fieldmeter in an electrostatic voltmeter configuration provides a useful basis for near zero current drain measurement of voltages. The electrostatic voltmeter can be connected to the person by a trailing lead to, for example a wrist strap. The lead should have good quality insulation. Because body actions involve timescales to below a second it is wise to record observations with a time resolution better than ¼s .
- Charge decay: A simple approach to assess charge dissipation capability of powders is to slide the powder down a chute of the material likely to be relevant on to an earthed metal plate. A sensitive fieldmeter observing the pile of powder will show how strongly the powder is charged and how quickly this charge goes away. If the powder is very dusty then it is wise to shield the sensing aperture of the fieldmeter while sliding the powder. The difficulty with the method is that ii may not be very quantitative for the quantity of charge generated, or the size and form of the pile of powder, etc. This is where more formal instrumentation becomes appropriate (see Section 3.7).
- Flooring: Resistivity is the appropriate way to assess flooring. The overall ability of flooring and footware to control body voltage can be demonstrated by linking the person to a recording electrostatic voltmeter and getting the person to walk, scuff their feet, get up from a chair, etc.
- Garments: The ability of garment fabrics to dissipate static charge and so avoid problems of cling and attraction of atmospheric dust and debris is most simply assessed by charge decay measurements (see Section 3.7). With fabrics for cleanroom garments the inclusion of conductive threads may provide sufficient capacitance to surface charge to enable the material to be suitable to avoid appreciable surface voltages even though the decay time may be long [6].
- Microelectronics: The problem is often the identification of unsuitable materials – and the testing of new prospectively suitable materials. The problem is often that of proximity. If for practical convenience items arrive for assembly in ‘unsuitable’ packaging can one be sure to avoid this packaging coming close to sensitive devices and circuits. Note that devices do not become insensitive to static just because they are on a circuit board – you may have just connected the device to extensive aerials! Note also that solder resist coatings on PCBs can become charged and hold that charge! Where materials cannot be made ‘acceptable’ in themselves or extra measures seem appropriate then air ionisation is a useful additional way to control static.

6.6 System changes

The following notes suggest general ways risks and problems may be reduced or avoided by changes to the ‘system’:

a) Change system design to avoid any significant levels of static arising on isolated conductors - for example earth bonding all metal parts of plant, ensure operators wear conductive footwear and ensure floor free of insulating layers, avoid chance of release of flammable gases and dusts, use of inert gas where flammable materials can be released (but think about asphyxiation risks), change materials so static can leak away easily, on-chip protection against static discharges, make microelectronic systems immune to static discharges.

b) Design to accept consequences - for example explosion venting, explosion suppression, remove personnel from direct line of fire for loading reactors, avoid possible knock-on effects to prevent possible small events becoming major disasters (e.g. think through the 'What if...'

possibilities)

c) Minimise static generation - avoid sliding of materials (webs, powders), avoid stalled rolls, limit speeds (processes, liquid flows), minimise use and areas of insulating material surfaces.

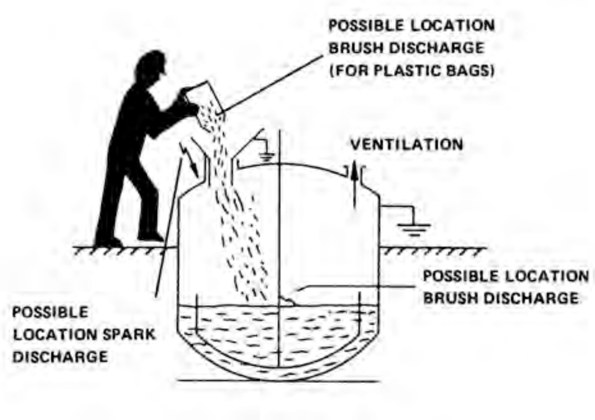
d) Enhance charge leakage - for example by choosing or modifying materials to have good charge decay characteristics. This may require use of humidity control or additives or surface treatments

e) Avoid the presence of the dust or debris that can be attracted to charged surfaces – for example, by a local supply of well filtered air

f) Train staff to increase awareness of risks and benefits of following guidelines and requirements. (See general guidance from Health and Safety Executive [12]).

6.7 Some specific examples

6.7.1 Risks at loading reactors containing flammable solvents:



- opening hatch to over-rich reactor atmosphere will ensure a region within flammable range around hatch
- stirring, or stopping of stirring, can cause generation of high voltages within reactor, on surface of liquid or on any unbonded conductors
- sliding of powders out of packaging, plastic or paper, likely to mean charged powder and charged operator and probably charged packaging. Note that the operator is optimally positioned to receive the full consequences of any explosion.
- incendive discharges can occur if highly charged packaging or charged operator touches reactor hatch opening
- if ignition and explosion occur operator is in prime target position for damage

Remedial approaches: Use of inert gas seems attractive but is not simple. Inerting may be ineffective around open hatch and sizeable quantities of inert gas may be needed if frequent hatch openings occur. There is asphyxiation risk to operators. Best to segregate operator from open hatch using indirect loading via rotary loading valve and have a separate safe route blow off vent if any ignition occurs. If open hatch must still be used then best to use paper not plastic lined sacks, to provide general fresh air movement to clear flammable atmosphere around open hatch and to ensure operator is earthed via footwear and by contact to a support guard rail which he will naturally contact on loading into hatch opening.

6.7.2 In silos and flammable liquid storage tanks:

All debris (in particular any cans that might float in fluid systems) need to be removed before filling vessels.

Carry out dipping and gauging only via a permanently mounted earthed shield tube and use only dissipative dipping or gauging equipment. Avoid direct man lowered sampling cup into vessel - a conducting cup and/or line may collect charge and spark on touching probing aperture, an insulated person may become charged up via the support line and discharge on touching the probing aperture.

6.7.3 Transfer of charged material into vessels/containers

The receiving container must be earth bonded. If the container has an insulating lining and/or the powder may have a long charge decay time then an earthing rod should be placed into powder within the lining. This will provide a resistive path for charge leakage and opportunity for corona charge leakage if surface potentials try to rise to a high level on the powder surface.

6.7.4 FIBCs

If charged powders are collected in fabric storage vessels (e.g. FIBCs) the fabric should be dissipative and preferably have multiple conductive threads woven in. It is not yet clear why certain FIBC materials appear to avoid risks of ignition, even when they are highly charged and not bonded to earth. It is suggested that the inclusion of 'conductive' threads with quite high core resistivity may both limit the area of surface from which electrical discharges can draw charge and also limit the ability to draw charge from neighbouring areas. If metal threads are used then these MUST be reliably bonded to earth.

6.7.5 Fluids

Charge will be retained on fluids collected in vessels with insulating linings, so an earthing route must be provided by an earthing rod or plug of adequate area

6.7.6 Moving webs

Charge on moving webs arising from contact and separation from drive and handling rolls may be neutralised using passive, radioactive or active (corona) charge neutraliser bars. This only neutralises the charge locally. A better solution is to change the characteristics of the material to provide more rapid charge dissipation.

6.7.7 Flooring

Wherever flammable atmosphere may occur conductive/dissipative flooring and conductive footwear should be used to avoid charges on personnel. In many industries flooring may get covered with powders that may be insulating – so other ways of earth bonding are needed (for example an earthed rail against which the operator is likely to lean during operations).

6.7.8 Humidity

It may be possible to use humidity to enhance electrical conductivity of powder products and surfaces - but this may cause problems of adhesion, may be technically unacceptable or may not be successful if product does not adsorb moisture

6.7.9 Aircraft refuelling:

The flow of insulating liquids (for example high quality hydrocarbon fuels) through fine filters can cause strong charging. Charge can accumulate on any unbonded conductors but also on free surface of fuel. Usual to limit maximum flow rates and use antistatic additives where feasible [3]. The rate of charge dissipation in low conductivity fluids collected in large vessels is more important than initial charge density - charge decay time needs to be short compared to filling time.

6.7.10 Carbon dioxide

The release of carbon dioxide causes strong charging when 'snow' is produced [5,6]. This can be a problem in preventative release of fire extinguishing gases [7,8]. Major accidents have been Bitburg and Alva Cape.

6.7.11 Aerosol cans

Aerosol cans may become charged if leakage occurs. If a flammable propellant is used then there cam be a risk of ignition. Lifting a leaking can from earthed surface can increase the risk by decreasing the capacitance and increasing the voltage - and hence the energy.

REFERENCES

[1] *"Code of Practice for Control of undesirable static electricity"*
BS 5958: Part 1:1991

[2] *"Basic specification: Protection of electrostatic sensitive devices. Part 1: General requirements"* EN 100015: 1992

[3] *"Static electricity: Technical and safety aspects"* Shell Safety Committee 1988

[4] J N Chubb *"Comments of methods for charge decay measurement"* J. Electrostatics **62** 2004 p73-80

[5] J N Chubb *"Experimental comparison of the electrostatic performance of materials with tribocharging and with corona charging"* JCI Website at: http://www.jci.co.uk/cache/Tribo-corona-comparison.pdf

[6] J N Chubb *"Test method to assess the electrostatic suitability of materials for retained electrostatic charge"* Document prepared in 2004 for discussion as prospective British Standard. Available at: http://www.jci.co.uk/cache/JCITestMethod.pdf

[7] E. Heidelberg, K. Nabert, G. Schon Arbeitsschutz 11 1958 p 221

[8] G. J. Butterworth *"Electrostatic ignition hazards associated with the preventative release of fire extinguishing fluids"* Electrostatics 1979 Inst Phys Confr Series 48 1979 p161