4. ASSESSMENT OF SIGNIFICANCE OF STATIC

4.1 Introduction

There are many operations in industry where it is likely that static electricity will arise. The two main questions which need to be considered are:

- under what conditions can static cause problems in particular situations?
- what measures can be taken to reduce the risk or severity of problems?

The first question, considered in this section, concerns levels (charge densities, electric fields, surface voltages) at which static is likely to cause problems. The second question, about remedial measures, is considered in Section 5.

The main categories of problem with static electricity are:

- risks of ignition of flammable gases
- shocks to personnel
- attraction of dust and debris
- cling of thin films
- damage to semiconductor devices
- upset of operation of microelectronic systems

4.2 Ignition of flammable atmospheres

The risk associated with static in flammable atmospheres is primarily related to the energy which can be released in a spark discharge between conducting surfaces [1]:

- hydrogen/air	0.02 mJ
- common hydrocarbon vapour/air mixtures	0.2mJ
- powders	1mJ upwards

The electrostatic energy available from a charged capacitor with a direct spark discharge is:

$$U = \frac{1}{2} C V^2$$

In some situations, for example discharges from people, not all the available energy will be released in the discharge gap [2].

Incendive static discharges can also occur when a blunt earthed projection (radius of curvature around 12 mm) comes up to a charged insulating surface - for example a charged film [3]. If the charged surface is freely supported than it seems the surface voltage needs to be above 20-30kV and the quantity of charge transferred in the discharge more than 100nC [3]. Negative polarity surface charges are appreciably more incendive than positive [4]. If the charged film lies on an earthed backing then incendive discharges, which propagate over large areas of the film (propagating brush discharges), can occur if the surface voltage is greater than about +4kV [4].

A localised high voltage discharge will occur at a fine tip at high voltage where the electric field locally exceeds the breakdown strength of air, but the electric field over the remaining gap is too low (below around 200kV m^{-1}) for the discharge to propagate across the whole gap as a spark type discharge. Such ‘corona’ discharges are considered to be non-incendive, and offer the useful possibility of safely removing charge from charged conductors and insulators even in flammable atmospheres - and so acting to reduce risks. If the discharge occurs at the end of a rather blunt projection (for instance around 12mm radius of curvature) then a 'brush' type discharge can occur. For this to be incendive it seems the potential of the projection needs to be over about 65kV [5]. While the energy dissipated in a spark type discharge can be calculated ($U = \frac{1}{2} C V^2$) it has so far not proved directly feasible to make comparable calculations to predict the incendivity of corona and brush discharges.

Ignition risk mechanisms can be quite subtle. For example, the dipping of a silo or fuel storage tank with a conducting cord could create a risk if the cord and/or the operator were not earthed. Charge could be induced on the cord by space charge in the vessel with risk of discharge to the edge of the sampling aperture. In the operation of large crude oil tankers high pressure water jets are used to clean tank walls during the ballast voyage. The water mist is charged and because of the large size of the tanks space potentials up to 30-40kV can arise [6]. If tanks are not inerted there is a risk that slugs of washing water can acquire sufficient charge (and thereby electrostatic energy) from the high electric fields at tank structure edges that incendive sparks can occur when the slugs reach other parts of the tank structure [7].

Ignition risks can arise from the strong charging which occurs when condensing gases impact on nozzle surfaces: for instance in the release of carbon dioxide [8,9]. Major ignition events have occurred with the use of carbon dioxide for inerting in situations where flammable gases are present (Alva Cape, Bitburg) [8].

4.3 Shock risks

If a person becomes charged, for example by walking across a nylon carpet, a shock is likely to be felt on touching an earthed conductor if the body potential is above a few kV.

Discharge energy (mJ)	Equivalent body voltage (kV)	Response:
1	3.6	perceptible sensation
10	11.5	definite shock
100	36.5	unpleasant shock
1,000		severe shock, muscular contraction
10,000		possibly lethal shock

Maximum body voltages by walking on carpets etc in dry atmospheres are in the range 20-30kV. Body voltages up to 20kV can occur at getting out of a car. Much higher voltages, and hence discharge energies, can arise electrostatically at, for example, reel up of charged webs (e.g. paper) and by hovering helicopters. Shock risks can arise by direct discharge from the highly charged surface or indirectly by induction charging in the high field with the shock at subsequent earth contact.

Electrostatic shocks are unlikely to be lethal. They may be surprising, or unpleasant. The real risk is from the annoyance and the consequence of the surprise reactions.

4.4 Attraction of dust, debris and thin films

When thin films become highly charged, for example by passing over rolls at speed or by peeling off a surface, there will be a force of attraction to any nearby earthed surface (image force) and there will be attraction of airborne dust and debris particles, which are usually charged to some extent. These forces cause problems in the handling of charged thin films. The attraction of airborne particles may degrade the product and/or spoil product appearance (cosmetic).

A sheet of thin film with nett surface charge density σ (C m^{-2}) near an earthed plane surface experiences an attractive force F_e:

$$F_e = \sigma E = \sigma^2 / 2 \varepsilon_o$$

The gravitational force on a thin film per unit area of density (ρ) and thickness (t), with g = 9.81N/kg, is:

$$F_g = \rho t g = 9.81 \rho t$$

Cling will occur if electrostatic forces exceed gravitational forces. This occurs, for example, for a 20µ film when surface charge density exceeds about 2 µC m^{-2} and the electric field at the nearby earthed surface is over about 300 kV m^{-1}.

4.5 Damage to semiconductor devices

The operation, or reliability, of semiconductor devices can be prejudiced if direct electrostatic discharges are communicated to connecting leads or if connections are exposed to high electric fields. Discharges may destroy or thin on-chip connections. The voltages created from high electric fields may breakdown fine chip insulating layers.

The susceptibility of devices varies greatly and techniques are improving to provide on-chip protection. On the other hand device geometries are getting finer and the 'real estate' needed for protection is non-trivial.

Risks are generally thought of in terms of a 'human body model'. The general feeling seems to be that in work areas where semiconductor devices and assemblies are handled electrostatic voltages should be less than 100V. For work with MR head components it seems that voltages should be down below 20V. A 'charged device model' is more appropriate when devices, which have become charged by sliding over a surface or by induction in nearby electric fields, contact earth or a large high conductivity surface. In this situation it seems the threshold voltage for damage may be around 25% of the corresponding 'human body model' value.

4.6 Upset operation of microelectronic systems

Electrostatic discharges involve current flows up to a few amperes and changes in local electric fields with frequency components over a very wide range - up to a GHz. If such signals couple into the circuits of microelectronic systems it is not surprising that operations and data structures may be upset. A major part of the European EMC directive concerns achieving demonstrated immunity of equipment to signals over a wide frequency range. IEC 801.2 involves testing of equipment with a source of high voltage sparks that, of course, may penetrate case apertures and couple directly to circuitry. Equipment operation should be immune to discharges up to about 20kV - which is a sensible maximum value likely to be reached by people working in environments where static is not controlled.

As reliance on microelectronic systems becomes greater, as complexity increases and the range of applications widens, it will be increasingly important to avoid any risk of operational upset.

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