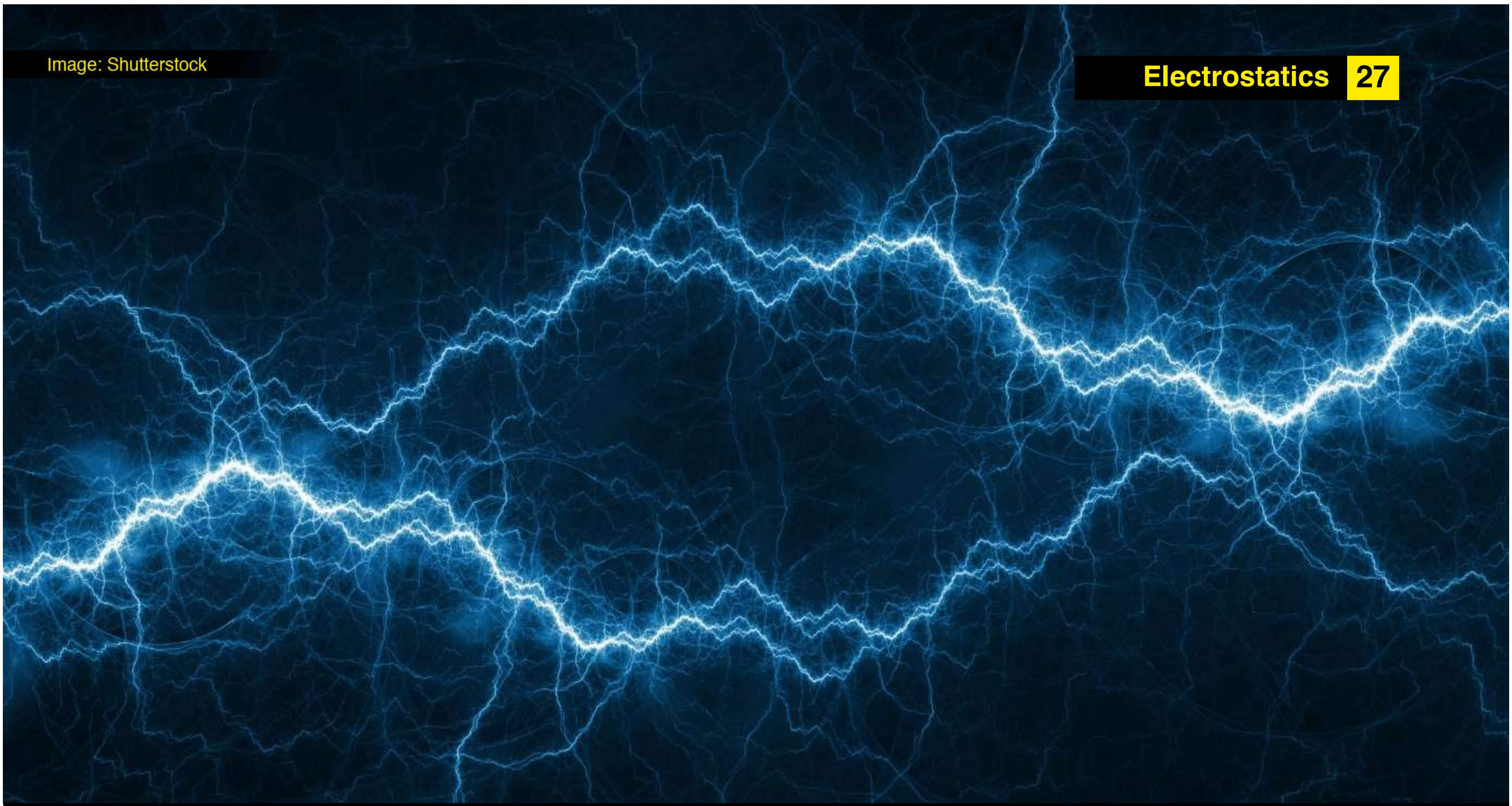

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Earthing conductors for electrostatic hazard avoidance

Electrostatic problems can occur in many different industries, processes and circumstances. The most widely experienced problems are fires and explosions due to ignition of flammable materials, shocks to personnel, disruption (upset) of working electronic systems and damage to unprotected electronic components and assemblies. These issues are caused by electrostatic discharges (ESD).

An important class of ESD is "spark" discharges between conductors at different voltages. Equipotential bonding or earthing is used to prevent the voltage differences greater than 100 V that can lead to ESD occurring. This article focuses on avoiding ignition of materials (such as solvent vapours or dusts) by spark discharges between conductors. It's important to understand that this is not the only way in which ignition by ESD can occur. In many processes "brush" type ESD from insulating materials are also a significant risk for ignition of flammable gases or vapours, and other types such as "propagating brush" discharges can arise in some circumstances[1,2,3].

How static electricity works

Static electricity can arise in a wide range of situations. All materials fundamentally contain electrical charges (negative electrons and positive atomic nuclei) in their atomic structure. In an uncharged material these charges are present in equal numbers and their electrical effects are neutralised. When two material surfaces touch, some charges always move from one material to the other. If the materials are separated, one material is left with a positive charge and the other has an equal negative charge. This is known as triboelectrification[1,2,3]. We say the materials have become charged, although they have just accumulated a very small imbalance in charge due to separation of their natural charges. If repeated contacts are made, then more and more charge can be built up on the material surface as static electricity. Processes that involve more movement or contact typically generate higher electrostatic charge levels.

Like charges repel, and unlike charges attract. So, charges accumulated on one material will repel each other and attract opposite charges on a nearby material. If they are free to move, the charges will attempt to recombine or dissipate to earth. If they succeed, no static electrical effects will be noticed. Electrically conducting materials (conductors) have low or intermediate electrical resistance and allow free charge movement. Examples of conductors found in the workplace are metal parts and equipment, and personnel, and sometimes process materials such as liquids (water, alcohols), or some solids or powders. Materials such as plastics, and some low conductivity process materials such as hydrocarbon solvents, have very high electrical resistance (insulators) and do not allow free movement of charges – they do not conduct electricity. These can act to generate charge and as a block to prevent charge draining away.

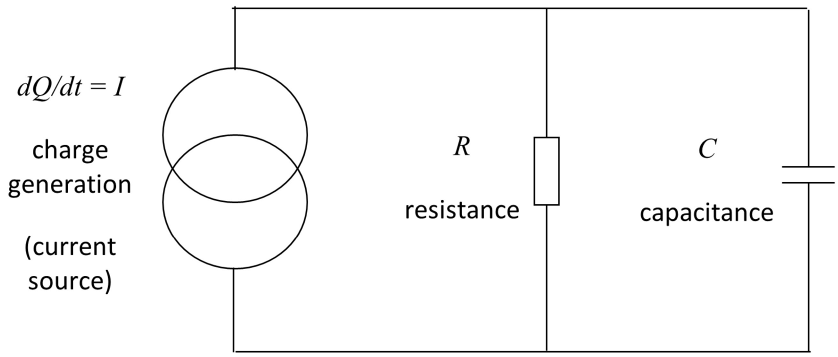

Figure 1: A simple electrical model of electrostatic charge build-up on an item

Personnel are conductors and can form a particular risk. They continually move and generate charge, and can store significant electrostatic charge, before eventually discharging by contact with another conductor causing an ESD. This is why we feel electrostatic shocks in everyday life. We typically wear insulating sole shoes, and walk on an insulating floor, and use furniture made of insulating materials. We get charged by contact between these materials. If we charge to about 2000 V or more, we will get a shock if we touch something metal like a filing cabinet, doorknob, supermarket shelf or car.

Conductors can accumulate charge if they are not provided with a conducting path to earth to allow the charges to dissipate. Such a path is often fortuitously present, but sometimes it must be provided deliberately in the form of a wire to earth. This is known as “grounding” or “earthing” the conductor. The ease with which a conductor can conduct charge is indicated by its resistance or resistivity. A high resistance (low conductivity) material may take seconds, minutes or even hours to allow charge to move and dissipate.

Voltage is in some ways analogous to pressure in a water tank, with charge analogous to the amount of water in the tank. If we continue to pump water into a tank, the pressure may build up until there is the risk of rupture. As charge builds up, the voltage increases and may break down the insulating properties of the surrounding air – an electrostatic discharge (ESD) can occur that could ignite a flammable atmosphere.

An unearthed conductor also poses a hidden risk. “Unearthed” means that it does not have a low enough electrical resistance path to earth to dissipate electrostatic charges. Even if the conductor is not itself charged, it can have a high voltage induced on it by the electrostatic field due to a nearby charged object. No contact is necessary to achieve this high voltage, but the part may easily become the source of an incendive ESD event[1,2,3].

Earthing, grounding and bonding

The main way we prevent conductors having a voltage difference between them is to connect them together electrically. This is known as equipotential bonding, or just bonding. If one of the conductors is earth, then the other is bonded to earth – i.e., “earthed” or “grounded”. In electrostatics work, earthing and grounding are synonymous. Attempting to earth an insulator does not work well of course, because the insulating material has high electrical resistance and does not allow charge to move to the earthing conductor. Nevertheless we may have to provide an earth path for grounding even high resistivity (low conductivity) process materials – but it might take a while for any charge to dissipate.

A simple electrical model of charge build-up in many situations is given in Figure 1. This helps to explain charge build-up, and the maximum resistance allowable in the earth connection. Contact charging (triboelectrification) causes charge generation – in effect a small electrical current source I which is often less than 1 μA. A conductor has an ability to store electrical charge, equivalent to capacitance C in an electrical circuit. The charge also tries to leak away (often to earth) via the resistance of the earth connection R, which can be through a material.

If charge storage (capacitance) is first ignored, the voltage build-up V will be dependent on the charge generation current I and the circuit resistance R alone. By Ohms Law

$$V = IR$$

If, for example, the charge generation current is around 10-9A and the resistance is 109 Ω (1 G Ω), the voltage built up is only 1 V, which we probably wouldn’t notice. But many modern materials have resistance well over 1000 GΩ. If the current is increased to 10 nA and resistance to 1000 GΩ the voltage built up would be 10000 V. Static electricity would probably be observed, and there would be a risk of ESD!

In practice, capacitance and other factors come into play to modify the voltage built up. The stored charge Q in the circuit related to the voltage V

$$CV = Q$$

The capacitance is usually variable. Even if the charge is constant the voltage changes as capacitance varies, usually with changing proximity between the conductor and other things. When the capacitance reduces, the voltage increases. As an example, a person sitting in a car seat has high capacitance with respect to the seat and charges up by contact with the seat. Their body voltage remains small as long as they are close to the seat surface (high capacitance). When they leave the seat the capacitance drops dramatically, increasing their body voltage to several thousand volts. Often, they then turn and touch the car door to close it – and receive a shock! If they discharged to the fuel filler opening, ignition of emerging fuel vapour could occur. So, fuel dispensers are designed to earth the person holding the nozzle.

When charge generation ceases, the remaining accumulated charge decays away over a period of time. If the resistance to ground is high, the charge dissipation is slow, and the accumulated charge and voltage can remain for seconds or longer. In theory the charge or voltage decays to 37 % of its initial value in a time given by the product *RC*. This gives another way of looking at *R*, as it may need to be low enough to lose accumulated charge within a given time.

Earthing (Grounding) in practice

From the previous discussion, we can summarise the following points:

- Earthing, grounding and bonding are used to reduce the voltage differences between conductors to a low level to prevent ESD occurring.
- The static electricity voltage is often produced by small charging current charge flowing through an earth or bonding path (it can also be a result of voltage induction on an unearthed conductor).
- The higher the resistance of the earth or bonding path, the higher the voltage produced by a given charging current, and the longer the charge will be held.
- Voltage changes can also be produced by changing capacitance (charge storage).
- As electrostatic charging current and storage capacitances are often quite small, we can use relatively high resistance for earthing (grounding) and bonding. The resistance of the ground connection can be of the order of MΩ or even GΩ.
- The ground path can often be a material (e.g., tyre and road surface, or static control footwear and flooring) although it can sometimes be a wire.

As an example, a vehicle can be expected to have a capacitance around 1nF. The vehicle can be earthed (grounded) via its tyres in contact with the road surface. The resistance from chassis to ground will be dependent on the resistance of the tyres and road surface. A car will charge up as it rolls on the road surface and lose its charge when it stops. If we wish the charge on the vehicle to be dissipated within one second, a resistance from the vehicle to ground less than 10^9 Ω (1 GΩ) would be required. It is sometimes wise to maintain the characteristic resistance of the floor material to less than 1 GΩ to allow charge dissipation and prevent voltage buildup and retention on the vehicle. Often a value of 100 MΩ or lower is specified in practice.

In processes where flammable solvents are handled, a hazard Zone 0 or Zone 1 can be formed where flammable vapours are likely to be present. Personnel working in such an area must be grounded (earthed), usually through ESD control footwear and flooring, to prevent their charging up and being the source of ESD that might ignite the flammable atmosphere. BS EN 60079-32-1 guidance specifies that personnel working in such areas should be grounded with a resistance from their body to earth less than 100 MΩ.

A fuel delivery lorry and system can be grounded and bonded in various ways, such as a static dissipative road surface – Image: Shutterstock

Grounding (earthing) of personnel is often done via static control footwear and flooring – Image: Shutterstock

In one example, a laboratory was sieving some particulate material out of a solvent based liquid. The solvent used produced a flammable atmosphere. It was a simple manual operation – they simply placed a metal sieve in a polythene funnel over a flask to receive the liquid. Unfortunately, they did not at first realise that the sieving would generate charge on what was now an ungrounded metal sieve. The sieve charged sufficiently to cause a spark to jump to the operator's hand, and the spark caused a flash fire. The solution was simple – a flexible earth wire (such as that used in electronics industry for wrist strap earthing of personnel) was added between the sieve and mains protective earth. The earth wire had resistance of about 1 MΩ, but this was easily low enough to adequately earth the sieve.

A fuel delivery lorry and system can be grounded and bonded in various ways. As the truck approaches the fuel delivery location, it will normally drive onto a static dissipative road surface (e.g., concrete) with resistance less than 100 MΩ that grounds it through its tyres. The metalwork of service station installations is earthed to the electrical installation. Where there are metal-metal earth bonding connections, these should be less than 10 Ω – a higher resistance might indicate corrosion deterioration or other problems. In some parts of the system, earthing must be via a higher resistance of 0.1 – 1 MΩ to prevent creation of an earth loop that could allow high galvanic currents to flow. The hoses used to connect the tanker to the receiving system are normally conductive. This is to allow electrostatic charge generated and conveyed by fuel flow to flow back to the tanker and prevent charge buildup on the vehicle. In some circumstances, earthing of the vehicle using an earth wire can be required before connection of hoses and fuel flow commences.

In processes where flammable solvents are handled, personnel must be grounded (earthed) to prevent their charging up and being a potential ignition source via ESD – Image: Shutterstock

Grounding (earthing) of personnel is often done via static control footwear and flooring. BS EN 60079-32-1[3] recommends that in general for working in flammable atmospheres the resistance from the person's body to ground should be less than 100 MΩ. To this end, the person usually wears static control footwear

with resistance less than 100 MΩ (e.g., "antistatic" footwear according to BS EN ISO 20345[4]) and walks on a static control floor with resistance from surface to earth less than 100 MΩ. Concrete often has suitable resistance range.

How things can go wrong

Unfortunately, few road surfaces are selected with consideration for static electricity or knowledge of their electrical properties, and high electrical resistance materials are often used. For comparison, a road surface of resistance 200 GΩ (e.g., asphalt) would be expected to give a voltage decay time around 200 seconds, with vehicles thus holding their charge for a few minutes. Even worse, epoxy coatings having resistance greater than 1 TΩ (10^{12} Ω) have been used. This has led to drivers experiencing static shocks when stopped and reaching from the charged car to take a ticket at car park entrances.

Effective grounding of personnel via footwear and flooring requires that the footwear makes effective electrical contact with the floor. "Antistatic" footwear according to BS EN ISO 20345 includes a specified minimum resistance that helps protect against electric shock risk if there is a risk of exposed power voltages. The presence of contaminants on the floor or shoe sole can change the contact conditions and can prevent grounding. Conversely, water on the floor, or wet footwear, can reduce the resistance to ground – this can create an electrical shock hazard. The simple act of inserting an insole into the footwear can prevent contact between the person's body and the footwear sole, breaking the ground path. Placing an insulating rubber mat or board on the floor is another way the person can become unearthed.

When working in flammable atmospheres, hand-held metal tools or containers must be earthed to prevent them becoming charged and an ESD source. As the user is normally earthed in this situation, one way of earthing a hand-held item is by contact with the earthed user's hand. If a glove is required, e.g., for chemical protection, this should be static dissipative (less than 100 MΩ) to maintain electrical connection between the hand-held item and the hand. There have been cases in which the wrong type of gloves is used, or incorrectly specified gloves are worn over the correct ones, e.g., for warmth, causing a flash fire incident.

Summary

Earthing (grounding) and bonding are very important in preventing charging of conductors that can lead to ESD that can ignite flammable materials. They are used to reduce the voltage differences between conductors (e.g., metal items or people) to a low level. The static electricity voltage is produced by a small current flowing through an earth or bonding path. As the current is small, the resistance of the grounding or bonding connection can be as high as tens or hundreds of MΩ in many cases. The earth connection path can often be a material (e.g., tyres and road surface, or static control footwear and flooring) although it can sometimes be a wire. The higher the resistance of the earth or bonding path, the higher the voltage produced, and the longer the charge will be held. The earth path can be inadvertently broken by simple change, sometimes made by unwary personnel.

While earthing all conductors is an essential part of static control in processes, sparks from unearthed conductors only form part of the ESD risks. Brush discharges from insulating materials and other ESD sources must always be addressed. ■

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