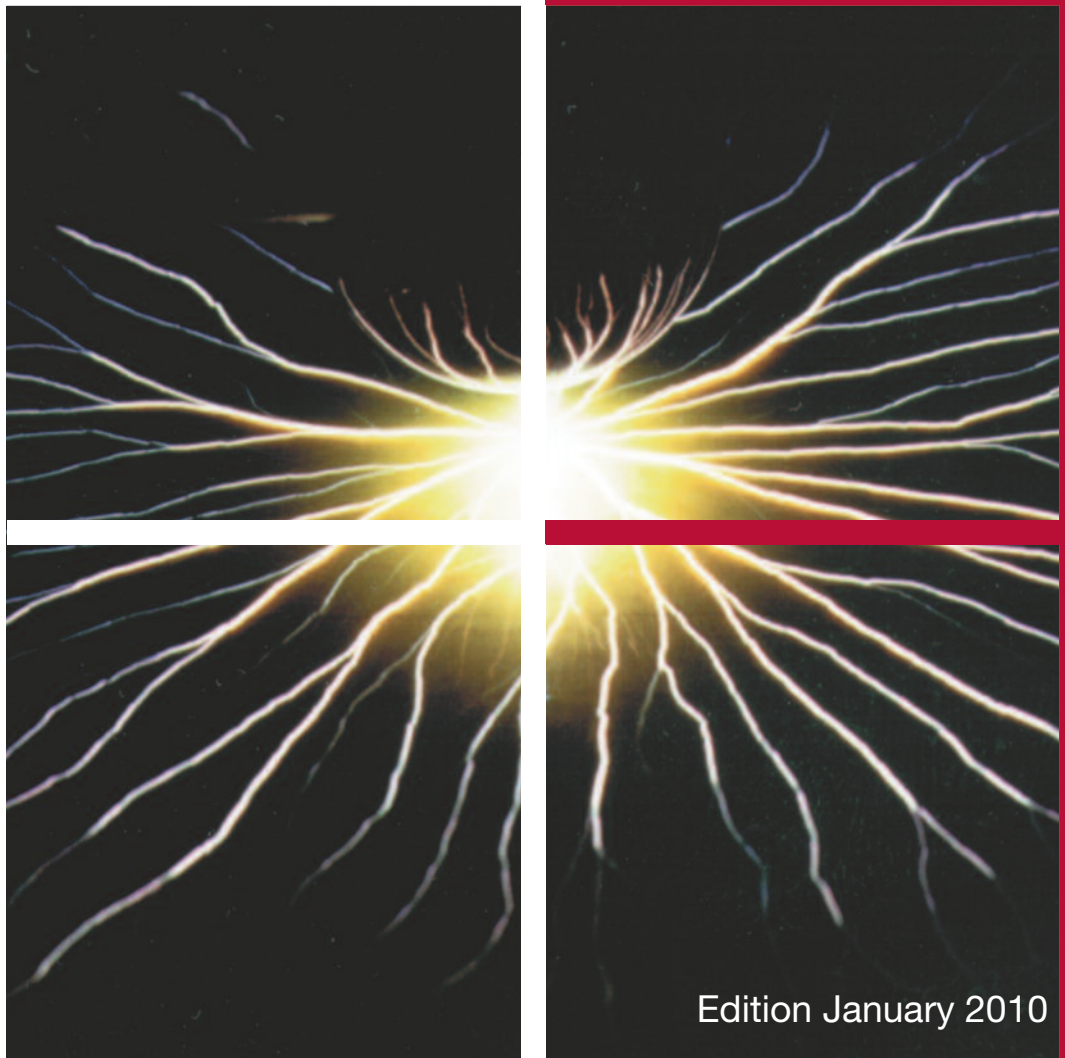




**Ignition Hazards Caused  
by Electrostatic Charges  
in Industrial Processes**



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## 1 Introduction

### 1.1 *Explosion hazards in industrial processes*

Processes in many different industries produce or process combustible and explosive substances, or use them as auxiliaries. These include flammable gases, vapours, liquids, aerosols, dusts and their mixtures. When mixed with air, these substances can form a potentially explosive atmosphere. All that is needed to trigger an explosion is an effective ignition source. The physical laws governing the sequence of events leading up to and occurring during explosions are described in detail in the literature [1-3].

Protective measures against explosions come under two headings: preventive and constructive precautions. Preventive precautions are designed to prevent explosions from occurring in the first place, while constructive precautions aim to reduce the effects of explosions to an acceptable level.

Among the measures taken to prevent explosions from occurring, the "exclusion of effective ignition sources" is accorded very high priority. On the one hand, it is employed in combination with other preventive measures and in particular with constructive measures taken to minimize explosion effects. Even if a plant, say, is sufficiently protected by explosion pressure relief or explosion suppression, a serious effort is made nonetheless to exclude effective ignition sources in the interest of ensuring plant availability. On the other hand, the exclusion of effective ignition sources is the most important precaution of all for most operations involving the "open" emptying, filling or transfer of combustible liquids or bulk solids.

Wherever the exclusion of effective ignition sources is applied as a precaution, a detailed risk analysis must be carried out to compare the ignition sensitivity of the potentially explosive atmospheres that may occur with the incendivity of the possible ignition sources. Considering the great variety of industrial processes and the atmospheres in which they take place, all sorts of ignition sources can occur. The technical literature lists 13 different types of possible ignition sources. In this connection, it is extremely important to assess electrostatic charges properly with regard to incendivity. Unlike many other sources of ignition, electrostatic discharges occur not only as a result of deviations or faulty operations, but frequently under normal operating conditions as well.

### 1.2 *Electrostatic charge as ignition source*

In many industrial processes, electrostatic charges are quite common. They can cause breakdowns, damage, fires and explosions. The crucial factor in evaluating the hazards of electrostatic charges is the probability that a potentially explosive atmosphere and a dangerously high charge will occur at the same time and place.

This probability is highest, of course, where the handling of a given product can result in both a dangerously high charge and formation of a potentially explosive atmosphere. In particular, this can occur during the handling of nonconductive, combustible liquids such as hydrocarbons or other non-polar solvents or of nonconductive, combustible bulk solids. But even conductive substances can accumulate dangerously high charges if they are being processed in nonconductive equipment. Dangerously high charges can also occur in nonconductive installations themselves or

in conductive installations that are not earthed. Examples of fires and explosions caused by static electricity as ignition source range from the filling of a plastic bucket with toluene to the pneumatic filling of a large storage silo with a combustible bulk solid. Accidents also occur during the filling of solvent-moist products into dryers, the emptying of centrifuges, and the dumping of combustible bulk solids out of flexible intermediate bulk containers (FIBCs). The ignition hazards caused by electrostatic charges are the subject of many text books, guidelines and special literature, e.g. references [4-11, 15].

## 2. Creation of electrostatic charges

An electrostatic charge occurs whenever two surfaces are separated, where at least one of them is highly electrically insulating. When two surfaces come into contact, a redistribution of charge carriers takes place. If the subsequent mechanical separation takes place fast enough in relation to the mobility of the charge carriers, the two surfaces will be left with the redistributed (opposing) charges after separation. Because all transport functions and most of the physical operations in industry involve separation processes, electrostatic charge is quite an ordinary phenomenon – depending, of course, on electrical conductivities. This applies to both solids and liquids. The examples described in the following are intended to illustrate the foregoing (see Fig. 1).

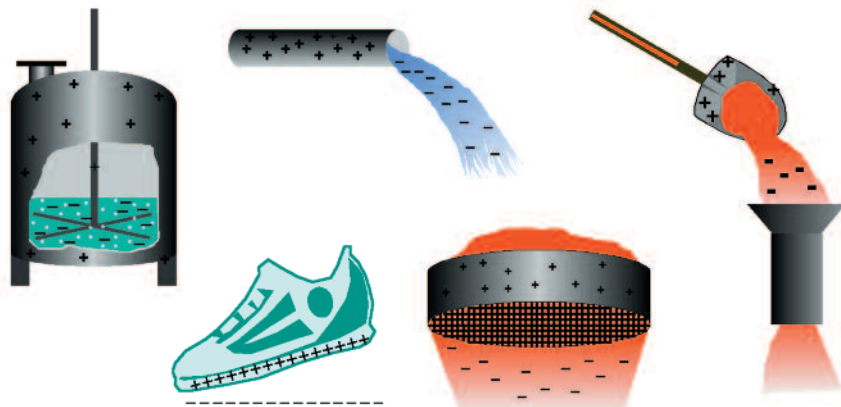


Figure 1: Typical examples of electrostatic charging

Anyone can become charged merely by walking across the room, provided either the carpet or their shoes are nonconductive. When a powder is dumped out of a sack or conveyed through a pipe, the powder and the sack or pipe can become charged. Similarly, when powder is sifted or fed through a funnel, the powder and the sieve or funnel will probably be charged. When a liquid flows through a pipe or a hose, both the liquid and the pipe or hose can become charged. The charging tendency is sharply increased in pipes that contain filters. Liquids are also charged during stirring, spraying and atomization. If the liquid in question is a multiphase mixture that contains (for example) suspended solid particles or droplets of an immiscible liquid, the charging tendency will probably increase by several orders of magnitude. High charges are also observed on transmission belts and conveyor belts and during the unwinding of paper or plastic film webs.

As these practical examples show, most charges accumulate during separation processes between products and equipment parts. The charge level depends partly on the product's properties, but to a far greater extent on the kind of operation being carried out.

### 3. Systematic procedure for evaluating ignition hazards created by electrostatic charges

If electrostatic charges are actually going to cause ignition in practical situations, the same sequence of physical events must always take place. These events are shown in the diagram in Figure 1. Although the diagram may seem quite simple at first glance, it is not always easy to pinpoint just where and when each step will take place in a given process. Certain steps take place simultaneously at different locations. For instance, the amount of charge accumulated is determined by the equilibrium reached between the charge separation rate and the charge dissipation rate.

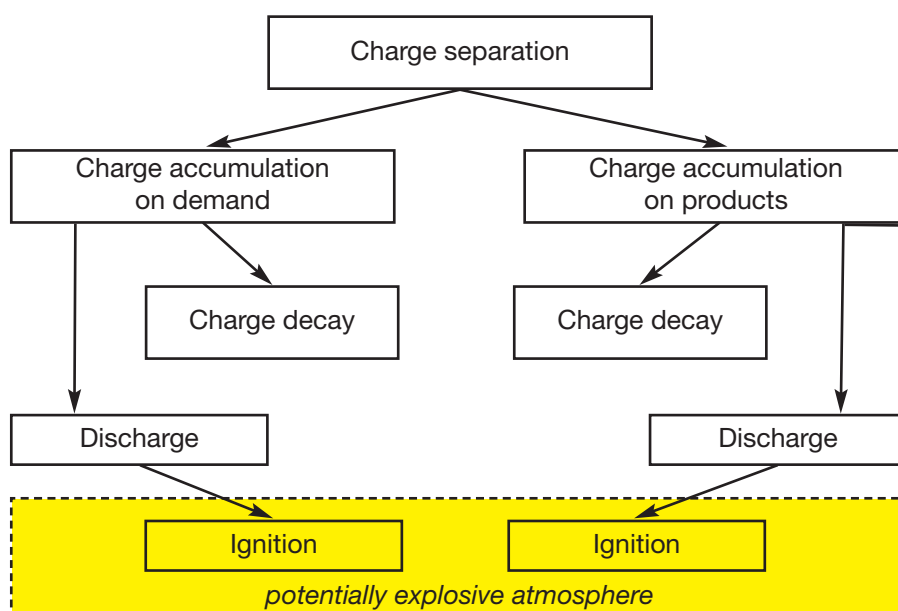


Figure 2: Schematic diagram of the electrostatic steps leading up to ignition of a potentially explosive atmosphere.

Whenever two surfaces come into contact, charge carriers can be exchanged on the surface provided the material combination and surface qualities are conducive to this. This charge interchange, which is described in solid-state physics in terms of the work required to extract the electrons from the two surfaces, results in the buildup of a contact potential. Strictly speaking, these concepts are defined for crystalline solids only, but they can also be applied analogously to amorphous structures like polymers. If the mechanical separation process following contact is fast enough compared with the mobility of the charge carriers on the surfaces, the latter will remain charged after separation.

The result of this sequence of events is a charge separation, i.e. a separation of positive and negative charge carriers (see Fig. 3). This process is normally referred to as "charging". In actual practice, it means that charging must always be expected in cases where two surfaces are separated from one another, provided at least one of them is electrically insu-

lating. Hence charge separation is always determined by the process itself and is measurable in terms of the charging current, which can be calculated as the product of the specific product charge and the mass flow.

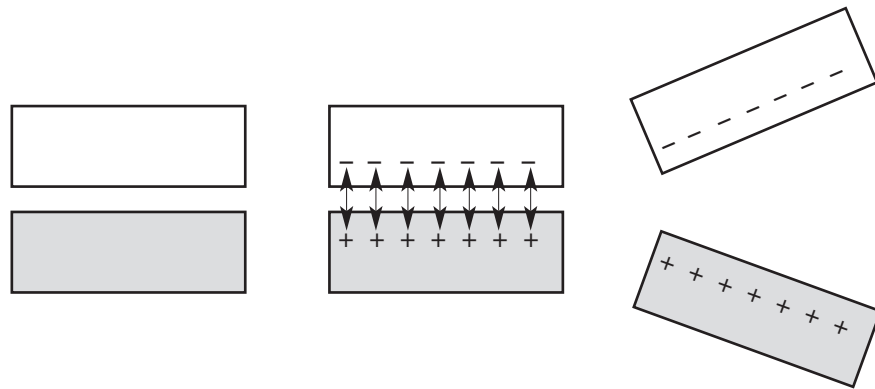


Figure 3: Charge caused by the separation of two surfaces

Surface contact with subsequent separation occurs frequently in industrial processes, and so do scraping and rubbing movements between poorly conducting surfaces. Examples in the broadest sense are the flow or filtration of non-conducting liquids, the movement of bulk solids in grinding, mixing or sifting operations, the pneumatic conveying of bulk solids, persons walking or vehicles running over insulating flooring materials, and the passage of transmission belts or conveyors over drive pulleys and idling rollers. Electrostatic charges are practically unavoidable in these and similar processes. It is important to remember that, in all such cases, both surfaces are charged after they are separated. Where products are handled or processed, both the product and the processing equipment become charged – as shown in Figure 2. This fact must be kept in mind whenever one tries to assess the dangers caused by electrostatic charges.

Besides separation charging (also referred to as "triboelectricity"), there are other charging mechanisms (see Fig. 4). One example is electrostatic induction. Charging by electrostatic induction takes place when an electrically conductive surface is exposed to an electric field that itself has been created by an accumulated charge. Another way a surface can be charged is by "spraying" charges onto it. The preconditions for this are charges in the form of ions or electrons that are created by ionization of the air (or another gas) and then follow the path of the electric field and are deposited on the surface in question.

Charge separation alone does not necessarily create a dangerous situation. The crucial variable is the size of the accumulated charge. This is determined by the charge separation rate (charging current) and the charge dissipation rate (discharge current). In actual practice, charges can accumulate on conductors that are insulated electrically from earth, on insulating surfaces, or on insulating products such as insulating liquids (hydrocarbons) or plastic powders. The rate of charge dissipation is a function of the total earth leakage resistance, which in turn depends on the different specific resistances of the equipment materials and the geometric arrangement.

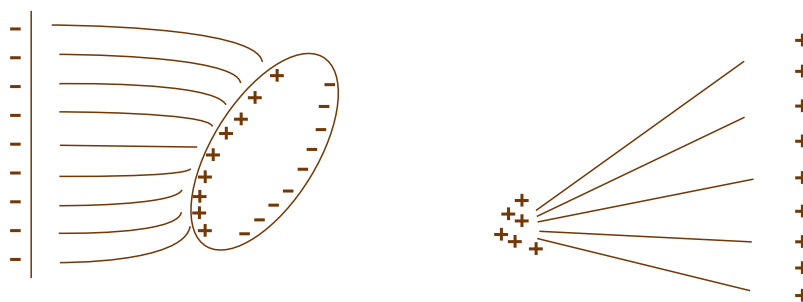


Figure 4: Charging by electrostatic induction and by the spraying of charges

Charge dissipation can occur even if the earth leakage resistance is relatively high. The electric currents produced by actual separation processes are very small. Typical amperages are around  $10^{-6}$  A or less. Under extreme conditions (high separation speeds) amperages as high as  $10^{-4}$  A can occur. For such low currents, charge dissipation to earth through a resistance of  $10^6$  to  $10^8$  ohms is sufficient to prevent dangerously high charges (charge accumulation). It should be borne in mind, however, that the use of highly insulating plastics such as polyethylene, polypropylene, etc., or of non-polar liquids such as kerosene, petrol, hexane, toluene, etc., yields earth leakage resistances much higher than those mentioned above.

In cases where the accumulated charge keeps on increasing, the assumed electric field can rise to the disruptive field strength level in air. This disruptive field strength is also referred to as the "dielectric strength" of air. Under normal conditions, it is approx. 3 MV/m. When this limit is reached, a "discharge" can occur. Part or all of the entire energy stored in the accumulated charge can be released in such a discharge. It produces a hot, high-energy discharge channel that may be capable of igniting an existing potentially explosive atmosphere.

The incendivity of the discharge (i.e. the amount of energy released) and the sensitivity of the existing potentially explosive atmosphere, as characterized by its minimum ignition energy, determine whether ignition occurs or not.

The physical variables that describe and influence the electrostatic steps illustrated diagrammatically in Figure 2 are sketched in the same schematic fashion in Figure 5. The operation being carried out determines the separation process and therefore the intensity of the charging current. The various resistance levels of the equipment components and products and the electrical connection to earth determine whether the charges can be safely dissipated to earth or will keep on accumulating. The assessment of the occurrence and the incendivity of discharges in all kinds of practical situations is the most important – and also the most difficult – step in analyzing the hazards created by electrostatic charges. Because it is next to impossible to assess the occurrence and incendivity of discharges in industrial environments based on the laws of plasma physics, a purely phenomenological approach is normally taken.

Besides the charge level, the occurrence of discharges depends on the electrical properties and spatial arrangement of the charged objects. These variables determine the nature of the discharge and therefore the amount of energy released and its incendivity. Whether ignition takes

place depends on the comparison between the minimum ignition energy of the potentially explosive atmosphere and the incendivity of the discharge.

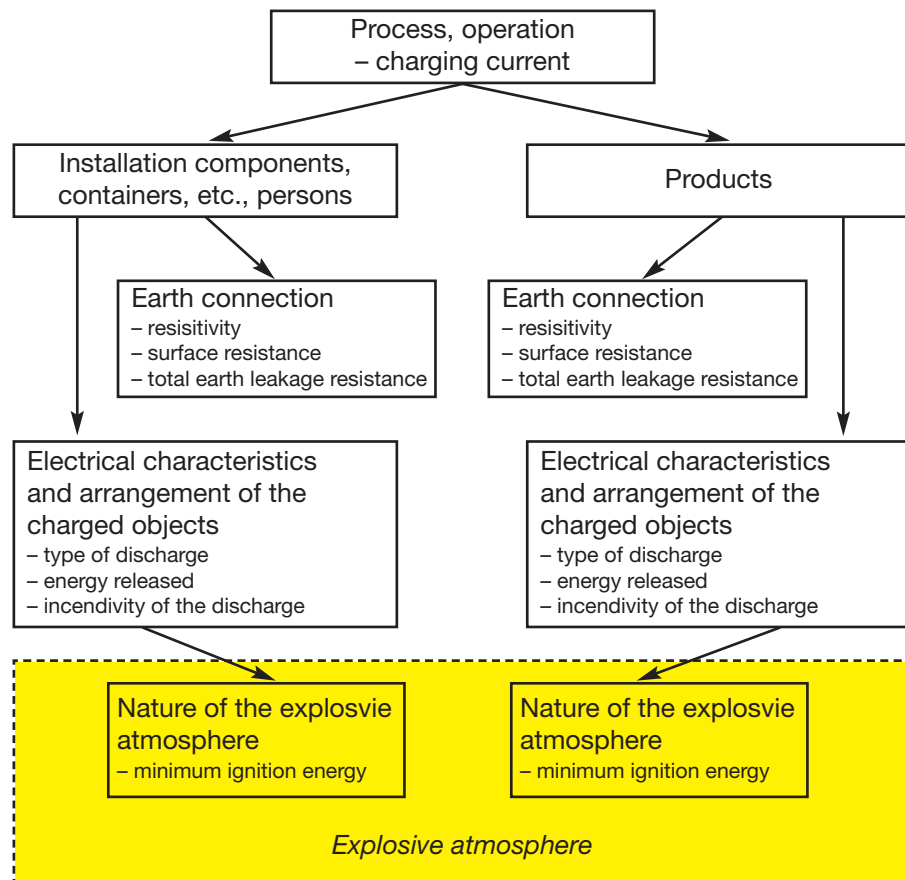


Figure 5: Schematic diagram of the variables that govern the electrostatic steps shown in Figure 2

#### 4. Discharges – occurrence and incendivity

##### 4.1 Discharges emanating from insulated conductors

###### 4.1.1 Spark discharges

Because of the increased use of insulating plastics in the fabrication of apparatus and equipment, the danger that essentially conductive components will be electrically insulated from earth is clearly on the increase. The charging of insulated, conductive parts is responsible for most of the ignitions of potentially explosive atmospheres by static electricity in industry today. Typical examples are:

- metal flange on a glass pipe
- conductive flexible intermediate bulk container (FIBC) suspended on insulating hangers
- person insulated from earth by insulating shoes and/or insulating floors

In all of these examples, a so-called spark discharge can occur as soon as the insulated conductor becomes charged. The spark discharge occurs whenever its potential rises to the point where the dielectric strength of the air is reached across a suitable sparking gap to an earthed object. The energy  $W$  of such a spark discharge can be calculated with the formula

$$W = \frac{1}{2} CU^2 \quad (1)$$

where  $C$  represents the capacitance of the insulated, conductive object and  $U$  its potential. The ignition danger is assessed by comparing the energy obtained with formula (1) with the minimum ignition energy of the potentially explosive atmosphere present. The minimum ignition energy governing here is that measured without any additional inductance in the discharge circuit. Essentially, flammable gases, vapours and dusts can be ignited by spark discharges. Consequently, the precautions described in the following must be applied wherever potentially explosive atmospheres comprising such substances might occur.

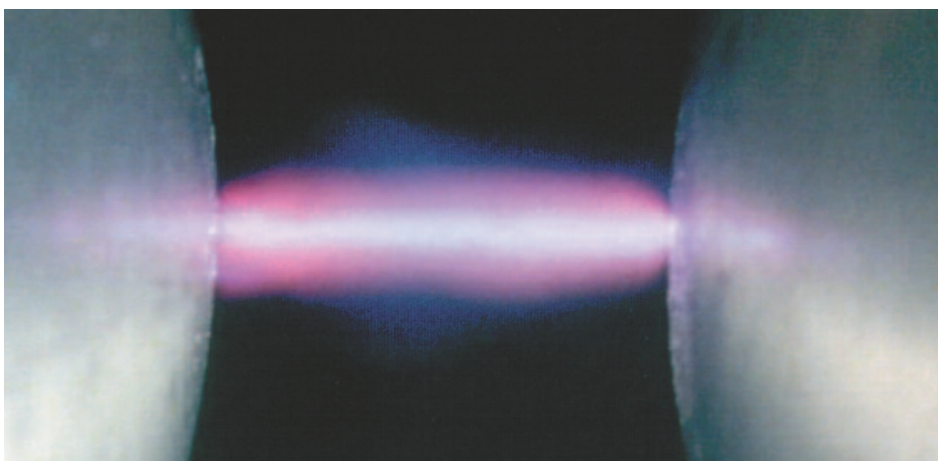


Figure 6 : Spark discharge

Photo: D. Settele, Mannheim

#### 4.1.2 Precautions against the occurrence of spark discharges

Theoretically, spark discharges can be prevented simply by earthing all conductive parts. Experience has shown, however, that it is not always so easy to do so securely in practice. In particular, movable objects would always have to be earthed anew by personnel. Then there are installations made up of both conducting and non-conducting parts where there is a strong likelihood of conducting parts being installed so they are insulated. For this reason, thorough training of plant personnel and the exclusive use of conductive materials in the fabrication of equipment are important precautions to take against the occurrence of spark discharges.

From the electrostatic standpoint, earth leakage resistances of  $10^6$  ohms for equipment and  $10^8$  ohms for persons are adequate for avoiding spark discharges. In actual plant environments, however, it usually makes sense to specify much lower earth leakage resistances than  $10^6$  ohms wherever metallic contacts are used for earthing. But if under these conditions the earth leakage resistance is found to be substantially higher than  $10^6$  ohms, the earthing connection is defective and can easily exceed the limit of  $10^6$  ohms at any time.

#### 4.2 *Discharges emanating from insulating surfaces, insulating liquids and insulating bulk solids*

Where charges are restricted to nonconductive surfaces, they cannot be dissipated in the form of a single spark discharge. The mobility of the charges along the surface is far too small in comparison with the discharge time of a spark discharge. Under these circumstances, however, there are three other types of discharge that might take place. Their occurrence depends on the geometric arrangement of the charges and their surroundings.

#### 4.2.1 Brush and corona discharges

If charges of one polarity are distributed on the surface of an insulator, so-called corona or brush discharges can occur as soon as the surface of an earthed electrode – such as a person's finger – nears the surface. In this case the electric field strength on the electrode surface is raised so much that the dielectric strength of air (approx. 3 MV/m under normal conditions) is reached. Whether a corona or a brush discharge occurs depends on a number of factors, such as the electrode's radius of curvature, the speed at which the electrode approaches, and the polarity of the surface charges. But it can usually be assumed that corona discharges will occur only if the electrode's radius of curvature is less than 0.5 mm. For radii greater than 5 mm, the probability that brush discharges will occur is very great. For hazard assessment, the worst-case scenario of a brush discharge – which are much more incendive – should always be assumed.

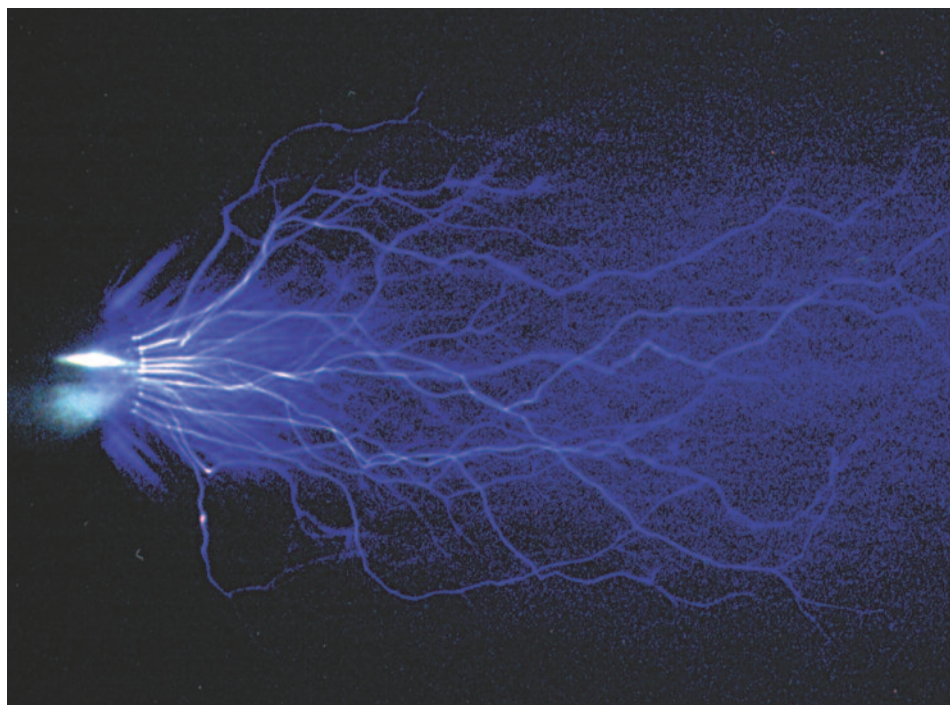


Figure 7: Brush discharge

Photo: D. Settele, Mannheim

But brush discharges do not occur only in connection with highly charged insulating surfaces of plastics. Indeed, they must be expected whenever an earthed, conductive electrode enters a high-strength electric field. The electric field may be created by a highly charged insulating liquid or suspension, a mist, a pile of insulating bulk solids, or a dust cloud.

The characteristic properties and incendivity of brush discharges have been studied by many authors [9, 16]. The figures stated in the literature for the equivalent energy of brush discharges, which were determined with explosive gas/air mixtures, are on the order of a few millijoules. The incendivity of brush discharges depends on the electrode's radius of curvature, the polarity of the electric field, and – if the electric field emanates from a charged plastics surface – the surface charge density and size of the charged surface area.

Based on the empirically determined figures for the equivalent energy of brush discharges, it must be assumed that most potentially explosive gas/air mixtures, solvent-vapour/air mixtures and hybrid mixtures can be ignited by brush discharges. Even though the minimum ignition energy of

certain dusts is less than a few millijoules, no ignitions of dust clouds by brush discharges have ever been reported. On the basis of the present state of knowledge, therefore, brush discharges are very unlikely to ignite pure dust clouds containing no flammable gases or vapours. It follows that efforts should be taken to exclude brush discharges wherever potentially explosive gas/air or vapour/air mixtures can occur.

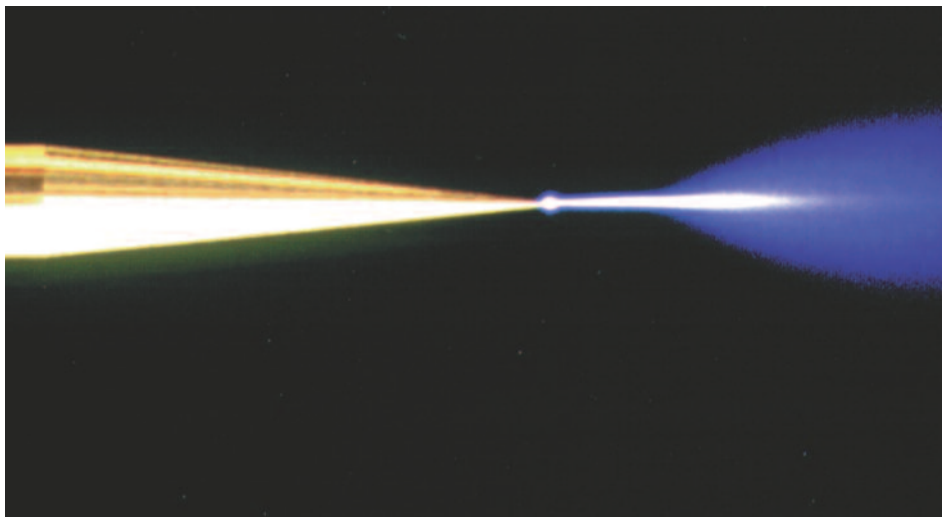


Figure 8: Corona discharge

Photo: D. Settele, Mannheim

#### 4.2.2 Preventive measures against brush and corona discharges

Brush and corona discharges emanating from apparatus, hardware, containers and packing materials can be excluded by using conductive materials or by restricting the size of chargeable surfaces. The term "antistatic" is often used in this connection. In the German literature, the precisely defined property "unchargeable" is the nearest equivalent to "antistatic". A surface is considered unchargeable if its surface resistance measured under standard atmospheric conditions is less than  $10^9$  ohms. No brush discharges are expected under these conditions. Besides surface resistance, the charge decay time is also used to characterize the discharge behaviour of surfaces.

The inclusion of "antistatic" additives in polymers is a frequently used method of improving the charge dissipation behaviour of chargeable surfaces. These additives make it possible to lower the surface resistance to levels within the band mentioned above. One trouble with this method, though, is that the effectiveness of the antistatic additives depends heavily on the relative humidity of the ambient air; another is that the antistatic agents tend to be absorbed by substances in contact with the treated surfaces.

The volume conductivity of polymers can be increased by several orders of magnitude by including carbon powder in the compound in the right quantity, fineness and dispersion. Plastics thus modified are regarded as conductive from the electrostatic standpoint and have to be earthed in practice.

Because of the electrostatic induction effect, chargeable surfaces that are backed by a conductive, earthed layer (as in the case of metal surfaces coated with an insulator) will not emit any brush discharges. The same applies to walls of insulating material, provided at least one side has been rendered unchargeable, i.e. antistatic. But brush discharges can only be

ruled out with certainty in these cases if the layer or wall thickness does not exceed precisely defined limits and the conductive (i.e. unchargeable) surface cannot peel away from the rest of the lamination.

#### 4.2.3 Propagating brush discharges

If the charges are not arranged in the form of a single charged layer of one polarity but as a double layer of charges of opposite polarity on the opposing surfaces of an insulating sheet, propagating brush discharges can occur. They are caused by an electrical short circuit between the two oppositely charged surfaces of the sheet. Such short circuits can be caused either by the approach of two electrically connected electrodes to the respective surfaces or by electric or mechanical perforation of insulating sheet. The discharge pattern is always the same: many discharge channels propagate outward along the surface from the short-circuit point like the spokes of a wheel. Though they all come together in a bright central discharge channel – between the approaching electrodes in the case of an external short circuit or through the perforated sheet – the resulting brush discharge emanates from the entire surface of the sheet on both sides.

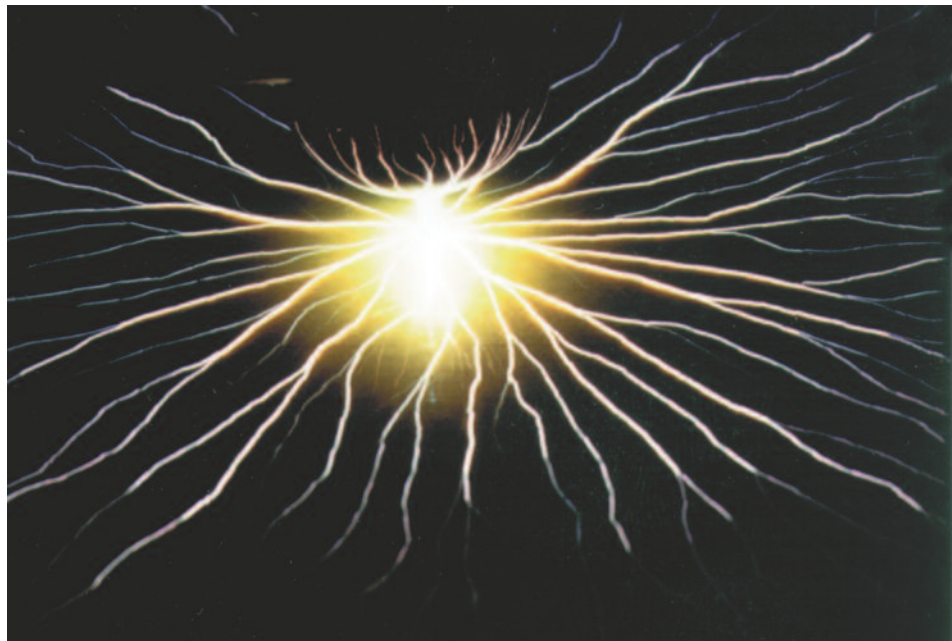


Photo: D. Settele, Mannheim

Figure 9: Propagating brush discharge

For a long time it was assumed that these discharges occurred only if one side of the sheet was in solid contact with an earthed metal surface. The idea was that the other charged layer of opposite polarity was created automatically by electrostatically induced charges. But by "spraying" on the second charge layer with corona discharges, it is easy to demonstrate that an earthed metal surface is not absolutely essential to formation of the two charged layers. If the insulating wall of a drum or container becomes highly charged on the inside, the electric field will normally be directed outward through the wall toward earth. It can trigger external corona discharges that result in the outer wall becoming charged with opposite polarity. This sort of charging mechanism can be observed, for example, during the filling of an insulating container with highly charged, insulating bulk solids.

On the basis of practical experience and the results of empirical studies, it can be assumed that the kind of high surface charge densities required to trigger propagating brush discharges cannot be caused by manual separation processes such as the wiping of insulating surfaces or the dumping of powder out of a plastic sack. Such high surface charge densities can be built up only by the extremely rapid separation processes occurring, for example, in the pneumatic transport of bulk solids through insulating pipes or through conductive pipes with an insulating internal coating of high dielectric strength.

The energy released by propagating brush discharges is normally sufficient to ignite potentially explosive gas/air, solvent-vapour/air, and dust/air mixtures. Persons may suffer serious shock if, for example, they initiate a propagating brush discharge by inadvertently touching a highly charged surface. Efforts must be taken to exclude this kind of discharge wherever potentially explosive gas, vapour or dust atmospheres can form.

#### 4.2.4 Preventive measures against propagating brush discharges

Propagating brush discharges are excluded by using conductive materials or using insulating materials of low dielectric strength at all locations where high surface charge densities might occur. Wherever an insulating wall or coating reduces the puncture voltage to less than 4 kV, no propagating brush discharges can occur.

#### 4.2.5 Cone discharges

Besides spark discharges emanating from charged, conductive product and brush or corona discharges emanating from charged, insulating product, there is another type, the so-called cone discharge. These discharges are observed in connection with charged and highly insulating bulk solids filled into silos and containers. They occur in the form of discharge channels directed radially outward, or in special cases right through the cone of material. Cone discharges can ignite potentially explosive gas, vapour or dust atmospheres. Their incendivity (equivalent ignition energy) increases with rising silo diameter and with increasing particle size of the bulk material in which the cone discharge occurs [12-14].

#### 4.2.6 Preventive measures against cone discharges

Prevention of the accumulation of high charge levels in bulk solids filled into containers is the only dependable measure against the occurrence of cone discharges. At volume resistivities of the bulk solids up to about  $10^{10}$  ohms·m, the use of conductive, earthed silos ensures sufficiently rapid charge dissipation. For higher volume resistivities, the accumulation of dangerously high charges cannot be excluded for certain filling methods and filling rates. Because there is usually no practical way to raise the conductivity of the bulk material, it is necessary to resort to other explosion protection measures in cases where cone discharges cannot be reliably excluded and the expected equivalent energy is equal to or greater than the minimum ignition energy of the product being processed. One is the exclusion of potentially explosive atmospheres (e.g. by excluding flammable gases, vapours and fine dust, or by reducing the oxygen level), and another is the application of constructive explosion protection.

#### 4.2.7 Lightning-like discharges

Before anything was known about cone discharges, charged dust clouds were regarded as the major electrostatic hazard in silos and containers. This speculation stemmed from the observation of lightning bolts in dust and ash clouds during volcanic eruptions. More recently, systematic investigations in a 60 m<sup>3</sup> bunker led to the conclusion – which is supported by practical experience to date – that the occurrence of lightning-like discharges is very unlikely in commercial-scale industrial installations.

### 5. Directive 94/9/EC and electrostatic ignition hazards

European Directive 94/9/EC, also known as ATEX 95 [17], stipulates in detail that equipment and protective systems used for their intended purposes in potentially explosive areas are not allowed to constitute an ignition hazard. This also applies expressly to nonelectrical equipment (Appendix II Section 1.0.1). It follows that these pieces of equipment and protective systems are not allowed to present an ignition hazard as a result of electrostatic discharges. This particular aspect is addressed in Appendix II Section 1. In detail, the requirements cover:

- Avoidance of ignition sources in general (Sections 1.0.1 and 1.0.2)
- Selection of appropriate material (Sections 1.1.1 and 1.1.3)
- Operating principle and design (Section 1.2.1)
- Possible sources of ignition (Section 1.3), in particular electrostatic charge (Section 1.3.2)

It is stipulated further that no ignition hazards should arise, either, in the event of malfunctions or as a result of ageing.

The requirements stipulated in ATEX 95a for avoiding ignition hazards as a result of electrostatic charges on equipment and protective systems deal primarily with excluding spark and brush discharges. As explained in sections 4.1.2 and 4.2.2 of this article, spark discharges are excluded by earthing all conductive parts and incendive brush discharges are excluded by

- increasing the surface conductivity of insulating surfaces
- restricting the size of insulating surfaces
- limiting the layer thickness of insulating coatings

The relevant requirements are summarized in Table 1. Thin insulating coatings on conductive, earthed surfaces are admissible in all zones, provided the thickness does not exceed 2.0 mm or 0.2 mm in the cases of gases or vapours of Groups IIA and IIB or IIC respectively [11, 17, 18, 19].

## 6. Risk assessment and the exclusion of static electricity in the harmonized standards

As already noted in section 3 "Systematic procedure for evaluating ignition hazards created by electrostatic charges", assessment of the occurrence and incendivity of discharges in all sorts of actual situations is the most important and also the most difficult step in analyzing hazards created by electrostatic charges. For this reason, Table 1 recapitulates the incendivities of the various types of discharge occurring in practice. By now, sufficient experience and knowledge have been accumulated to make such assessments in cases where the necessary underlying data are available. The data required for a reliable analysis are exact knowledge of the properties of the potentially explosive mixture that may be present, the resistances or conductivities of the substances, apparatus, packing materials and personal equipment in use, volumes and geometric arrangement of the installations and technical devices, and precise knowledge of the existing earth leakage and equipotential bonding conditions.

Type of discharge	Incendivity Gases, vapours		Dust
	MZE < 0.025 mJ	MZE > 0.025 mJ	
Spark discharge	+	+	+
Needle-point discharge	+	-	-
Brush discharge	+	+	-
Propagating brush discharge	+	+	+
Cone discharge	+	+	+
Lightning-like discharge	+	+	+

Table 1: Incendivities of the different discharge types

### 6.1 Fundamentals and methodology of explosion protection EN 1127-1:2008 (Sections 5.3.7 and 6.4.4) [3]

#### 6.1.1 Risk assessment

Incendive discharges of static electricity can occur under certain conditions. For example, discharges from charged conductive parts installed so as to be insulated can easily result in incendive sparks. Charged parts of nonconductive materials, such as most plastics and certain other materials, can produce brush discharges. In some cases involving rapid separation (such as transmission belts, film webs passing over rollers) or combinations of conductive and nonconductive materials, propagating brush discharges are possible as well. Other possible types of discharges include cone discharges (in bulk solids) and lightning-like discharges.

Brush discharges can ignite practically any kind of potentially explosive gas or vapour atmosphere. Based on the current state of knowledge, brush discharges are not capable of igniting potentially explosive dust/air mixtures even not those with extremely low minimum ignition energy levels [16]. Sparks, propagating brush discharges, cone discharges and lightning-like discharges with sufficiently high energies can ignite any kind of potentially explosive atmosphere.

#### 6.1.2 Preventive measures against ignition hazards caused by static electricity

Wherever static electricity hazards are found to exist, installations, pro-

protective systems and components must satisfy the following requirements for the different categories:

#### 6.1.2.1 All categories

The most important protective measure is to connect and earth all conductive parts that might become dangerously charged. However, if non-conductive parts and materials are present, this is not enough. In such cases, dangerous charging of nonconductive parts and substances (including solids, liquids and dusts) has to be excluded. Information pertaining to this must be included in the respective instruction manuals.

#### 6.1.2.2 Category 1

Incendive discharges even have to be excluded in the event of infrequently occurring malfunctions.

#### 6.1.2.3 Category 2

Incendive discharges must be excluded during normal operation of the installations, including servicing and cleaning, as well as during relatively common malfunctions.

#### 6.1.2.4 Category 3

Preventive measures other than earthing are usually only required in cases where incendive discharges occur frequently (insufficiently conductive transmission belts, for instance).

### 6.2 Requirements for electrical equipment in Group II (IEC/EN 60079-0) [18]

In the new 2007 version of IEC/EN 60079-0 the requirements for electrical equipment of the Equipment Protection Levels Ga, Gb and Gc have been combined for all types of protection.

#### 6.2.1 Protective measures

The electrical equipment shall be built in such a way that ignition hazards caused by electrostatic charges are excluded during normal use, servicing and cleaning. This requirement shall be fulfilled by means of one of the following measures:

- a) by appropriate selection of the material to ensure that the surface resistance of the enclosure, measured according to the method specified described in the standard, does not exceed  $10^9$  ohms at  $(23 \pm 2)$  °C and  $(50 \pm 5)$  % relative humidity,
- b) or by limiting the surface area of non-metallic enclosure part

EPL	Max. permissible surface area [mm <sup>2</sup> ]		
	IIA	IIB	IIC
Ga	5000	2500	400
Gb	10000	10000	2000
Gc	10000	10000	2000

Table 2: max. permissible surface surface area

The values stated above for the maximum permissible surface area may be exceeded by the factor 4 if the non-metallic enclosure parts are enclosed by a conductive, earthed frame.

Alternatively, the surfaces of elongated parts with non-metallic surfaces, such as pipes or ropes, need not be taken into consideration if the diameter or the width does not exceed the values laid down in the table. Electric cables are excluded from this requirement.

EPL	Max. permissible diameter or width [mm]		
	IIA	IIB	IIC
Ga	3	3	1
Gb	30	30	20
Gc	30	30	20

Table 3: max. permissible diameter

- c) by the limitation of a non-metallic layer that is bonded to a conductive, earthed surface (for example, foils on operator panels or keyboards).

EPL	Max. permissible thickness [mm]		
	IIA	IIB	IIC
Ga	2	2	0.2
Gb	2	2	0.2
Gc	2	2	0.2

Table 4: max permissible thickness

- d) by the limitation of the charge transfer or by the inability to store a hazardous charge in accordance with the method specified in the standard.

If the ignition hazard cannot be excluded by the appropriate design of the equipment, a warning sign must be affixed drawing attention to the safety precautions to be taken in the plant

### 6.3 Requirements for electrical equipment in Group III (IEC/EN 60079-0) [18]

The new Equipment Group III for dusts was also introduced in the new 2007 version of IEC 60079-0. The requirements apply to the Equipment Protection Levels Da, Db and Dc.

#### 6.3.1 Protective measures

The electrical equipment shall be built in such a way that ignition hazards caused by propagating brush discharges are excluded during normal use, servicing and cleaning. This requirement shall be fulfilled by means of one of the following measures:

- by appropriate selection of the material to ensure that the surface resistance of the enclosure, measured according to the method specified described in the standard, does not exceed  $10^9$  ohms at  $(23 \pm 2) ^\circ\text{C}$  and  $(50 \pm 5) \%$  relative humidity;
- a breakdown voltage  $\leq 4$  kV (measured through the thickness of the insulating material according to the method specified in EN 60243-1);
- layer thickness of external insulations on metal parts  $\geq 8$  mm. (In the case of an external plastic layer measuring 8mm or more in thickness on metal parts such as detector probes or similar installation parts, propagating brush discharges are not to be expected. The amount

of wear to be expected during normal operation shall be taken into account during the determination and evaluation of the minimum layer thickness of the insulator.);

- d) by limitation of the charge transfer in accordance with the method specified in the standard.

#### 6.4 *Requirements for electrical installations in explosive atmospheres (EN/IEC 60079-14) [19]*

The requirements according to IEC/EN 60079-0 have been taken over in the new installation standard. During installation, auxiliary parts such as plastic plates and pipes are used for fixing electrical apparatus. The requirements for apparatus shall also apply to the auxiliary parts.

#### 6.5 *Non-electrical equipment for use in explosive atmospheres (EN 13463-1) [20]*

Enclosures of Category 1 and Category 2 equipment shall be designed in such a way that the danger of ignition is excluded during normal operation, servicing and cleaning. This requirement shall be met by applying one of the following measures:

- a) by the appropriate selection of the material to ensure that the surface resistance of the enclosure, measured according to the method specified in the standard, does not exceed  $10^9$  ohms at  $(23 \pm 2)$  °C and  $(50 \pm 5)$  % relative humidity;
- b) by the size, shape and arrangement or other protective measures, so that the occurrence of such hazardous electrostatic charges is avoided. In the case of equipment in the Category 2G, this requirement can be fulfilled by carrying out the test according to EN 13463-1, Appendix C, provided that no propagating brush discharges can occur (propagating brush discharges are considered to be effective ignition sources for gas, vapour, mist and dust/air mixtures. Propagating brush discharges can occur after the high charging of non-conductive layers or coatings on metallic surfaces and, in the case of equipment in Groups I and II, they can be prevented by ensuring a breakdown voltage of the layers of less than 4 kV. In the case of apparatus in Group II D, which may only be used in dust atmospheres with a minimum ignition energy of more than 3 mJ (measured with a capacitive discharge), incendive electrostatic discharges, including propagating brush discharges, can also be prevented by ensuring that the thickness of the non-conductive layers is more than 10 mm);
- c) or by limiting the projected surface areas in any direction of non-conductive parts of equipment that can become electrostatically charged, provided that no propagating brush discharges can occur.

Category	Permissible surface area in cm <sup>2</sup> <sup>1</sup>			
	Dust <sup>2</sup>	IIA	IIB	IIC
1	250	50	25	4
2	500	100	100	20
3	no limits <sup>3</sup>	no limits <sup>3</sup>	no limits <sup>3</sup>	no limits <sup>3</sup>

<sup>1</sup> The unit of measurement cm<sup>2</sup> is not a standard ISO unit. Note: in all IEC standards the units of measurement have been converted to mm<sup>2</sup> according to ISO.

<sup>2</sup> As brush discharges are not capable of igniting the dusts, the limiting values in this table in accordance with EN 13463-1 for chargeable surfaces do not make any sense.

<sup>3</sup> In the case of Category 3 it shall be noted that, in the event of the occurrence of incendive discharges during operation, special measures shall be taken. Unfortunately, the same philosophy as in the IEC/EN standards 60079-0 was not applied in the standard EN 13463-1 for non-electrical equipment. In the IEC standards the maximum permissible values also have to be observed for Category 3 (Equipment Protection Levels 3G and 3D). These requirements can be relaxed provided that suitable proof is provided.

Table 5: Permissible surface areas for non-conductive parts of equipment

If the flat plastic surfaces exposed to rubbing are enclosed by a conductive, earthed frame, these values can be multiplied by a factor of 4. In the case of Category 3, it shall be noted that, in the event of the occurrence of incendive discharges during operation, special measures shall be taken. Unfortunately, the same philosophy as in the IEC standards was not applied in the EN standards for non-electrical equipment. In the IEC standards the maximum permissible values also have to be observed for Category 3 (Equipment Protection Levels 3G and 3D). These requirements can be relaxed provided that suitable proof is provided.

Further information on this subject is provided in CENELEC Technical Report RO44-001 "Safety of machinery – guidance and recommendations for the avoidance of hazards due to static electricity" [11].

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