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MODERN ELECTROSTATICS FOR HIGH-TECHNOLOGIES

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The study on Electrostatics represents the first scientific interest of human being on electrical phenomena, and it led to enormous progress of electrical and electronic science and engineering up to the current levels. Electrostatics, however, has been long forgotten in the stream of this history as a tribial minor field. Interensting enough, this minor sector has regained recently its new life, in particular in the area of high-technologies, and Electrostatics is going to become one of the most important field in the future of electrical and electronics engineerings.

It is impossible to cover the entire trend of this emerging field in a limited space, so that spot lights shall be focused on several important topics in this paper.

[1] Specific Feature of Electrostatics

Before entering into technical details of applications it might be of reader's interest to give a small look at the uniqueness of Electrostatics which leads to its various modern applications. An evaluation of Maxwell's stress available in an electrostatic field reveals that its maximum value remaind to be only 0.4 gram weight/cm^2 in air, limited by spark, while that in a magnetic field about 4,000 gram weight/cm^2, limited by magnetic saturation of iron core. Evidently, Electrostatics is not suitable for any kind of applications where a large quantity of power conversion is concerned. However, electrostatic force is a surface force, becoming dominant over mass force with the decrease in a linear dimension of the object to be handled down below, say 1 mm. Furtheremore, unlike magnetic field in which only dipoles can be exploited, electrostatic field allows the use of positive or negative monopole charges given to the object, leading to an immense freedom of controlling its force in time and space. Hence, Electrostatics has its unique technical potentials in controlling the movement of small particles, fibers, or thin sheets, all of which have a large surface-to-mass ratio. Among forces available to applications Coulombic force is the most powerful, although image force and gradient force provide unique driving force in several high-tech applications.

A very specific nature of Electrostatics is that it also causes various troubles, hazards and accidents in different forms and fields - particle contamination of semiconductor chips due to electrostatic force, malfunction of computers and failure of the chips due to electrostatic discharge, ignition of inflammables and explosion of fuels due to the discharge, etc. Thus, unlike other fields of engineering, Electrostatic Hazard and Safety represent another large area of importance in Applied Electrostatics.

Like all other engineering fields, Electrostatics requires the committments of various disciplines, but its level of inter-disciplinary nature is much more remarkable. Just in this feature exists the great attractiveness of Electrostatics, too.

[2] Electrostatic Cell Handling and Cell Fusion

Electrostatics is representing an indispensable tool for all of the handling and processing technologies of biological cells, including cell transport, cell separation, cell fusion and DNA-injection into a cell. Using a travelling non-linear electric field cells suspended in liquid can be contactlessly

tranported from one place to any desired place. During this process one kind of cells can be moved into a positive direction of wave motion, while another kind into a negative direction, resulting in the cell separation. Use of a Coulombic force is also possible to separate two different groups of cells, of which one being positively and another negatively charged in the medium. A high-frequency non-uniform field can also separate the cells into positive and negative directions perpendicular to the curved lines of force, depending upond the quantities of the complex dielectric constant of the cells.

For cell fusion two different cells are at first brought into contact within a medium by a high frequency electric field (Pearl-Chain Formation). Then, a short pulse high voltage is applied between two electrode to produce a puncture at the contact point between the two cells so that they merge into one single hybridoma. The use of a fluid-integrated-circuit in combination with ceramic micro-pumps enhances greatly the yield of hybridoma production, and its computer-aided processing.

Injection of DNA can be very easily completed in the suspension of cells in a liquid containing DNA's with the use of electric field.

[3] Electrostatic Means for Production of Super-Clean Air

Super-clean air with the quality level of class 10 to class 0 has now become necessary in the course of drastic increase in integration of the IC-chips beyond 4 to 16 M-bits. Extremely high power rasers requies the ultra-clean gases with class 0 in the pulse gaseous discharge for excting the raser tubes, as the existing of one single particle can trigger a spark at a substantially low field and thereby hindering the production of high-energy photons. Such a high clean level can be only achieved by Electrostatically Augumented Fabric Filtration at an acceptable of power consumtion of the blowers.

Super-clean air is also finding its applications in the bio-engineering areas to avoid the entrace of undesirable microbes into the processing and production areas of the desired species. It also is getting its applications in hospitals to avoid the in-house infections and outdoor emission of dangerous microbes and virus. In particular, there is an increasing concern in the operation rooms and intense care units after cancer operations.

In parallel to the above areas, the clean air in living rooms and offices is also getting an increased concern, and use is being made of various types of electrostatic precipitators.

[4] Electrostatic Means for Production of Composite Materials

Fiber-reinforced metals (FRM) and fiber-reinforced plastics (FRP) are being increasingly used in various fields of engineering as a result of their unique features. Here again, Electrostatics is going to play a major role in their fabrications. For example, ceramic short fibers out of alumina or silicon carbide are suspended in an insulating liquid, and then subject to an electric field, either dc or ac. Fibers immediately form a number of feather-like bridges between two electrodes, and they fall very rapidly to produce a paper-like mat consisting of fibers alligned in one direction. The mat is dried and placed into a form, into which a molton aluminium is injected under pressure. A FRM with uni-directionally orientated ceramic fibers is obtained. It indicates a great increase in its tensile and bending strengths, very low value of the coefficient of thermal expansion in the fiber orientation direction, and a much reduced coefficient of friction in the direction perpendicular to it. Its applications cover a broad area, including engine parts, rocket parts, weapons and other specific areas which require greatly improved characteristics of materials.

[5] Electrostatic Means for Control of Environmental Pollutions

Electrostatics is playing an important role in the control of both particulate and gaseous pollutants.

Electrostatic precipitation has long been a most effective control device for particulates emited from stationary sources including thermal power plants, cement and steel plants, mining furnaces, etc. Particles are charged in corona fields by ion bombardment, and then subjected to a dc electric field to be collected on a plate electrode. The deposit of particles is dislodged from the plate by mechanical rapping to fall into a hopper, while cleaned gas is led to the stacks. It provides an exremely high collection performance beyond 99.0 - 99.9 %, with the outlet mass concentration below 50 - 10 mg/Nm^3.

However, an abnormal discharge called "Back Corona" takes place when a very high resistivity dust has to be collected. Owing to an excessively high voltage drop to develop across the dust deposit, breakdown occurs in the deposit layer to emit copious ions of opposite polarity towards the corona electrode. This greatly decreases the particle charge, and also produces excessive sparking. Pulse energization proved to be a very effective solution to this trouble, and it is now being used increasingly. It also decreases greatly power consumtion of precipitators.

Electrostatic precipitator can also remove carbon soot from diesel engines both in passenger cars and trucks, and also in large scale diesel engines used for Co-Generation. In this particular application in which particles are extremely small in size (0.3 micro-meter in MMD) and conductive, they must be at first electrostatically agglomerated, and then collected on a moving belt to be removed in a space free of gas stream to avoid re-entrainment into gas which occurs at electrode rapping.

It has been discovered recently that intense streamer coronas produced by nanosecond pulse high voltage can produce copious radicals in the flue gas, and thereby oxidize NO, SO2, Hg-vapour, etc. into a form to be easily removed. This process is called "Pulse Corona Induced Plasma Chemical Process (PPCP), and its development is now going on worldwide, as it could provide a very economical means of DeSOx and DeNOx as well as mercury vapour control. It may be possible to complete in one box the control of both gaseous and particulate pollutants in near future.

[6] Other Electrostatic Applications

Electrostatic painting has been widely used in automibile and funiture industries. Liquid paint is sprayed by electrostatic forces, using a rotating disc applied with a high dc voltage. Fine liquid particles, strongly charged with electrostatic induction, are driven to a grounded object by Coulombic force to deposit on its surface to form a paint film. By infra-red or UV irradiation, curing of the paint film is made. For production of a thick coat the electrostatic powder coating is used. Powder paint carried with air is charged by corona or tribo-electrification, and driven to the object surface. By infra-red heating the powder layer is melted to form a continunous coat. This is used primarily for top coating of trucks.

Electrostatic flocking is widely used to produce a velvet-like cloth very economically. Short fibers are charged by corona and sprayed over the moving belt of cloth with adhesive film painted on its surface. Above the belt exists a grid high voltage electrode to produce dc electric field against the grounded electrode underneath the belt. Hence, the charged fibers are alligned in the direction of electric field perpendicular to the belt, and planted on the adhesive film, which then subjects to heat treatment to fix the planted fibers. This technology finds many applications, including the inner coat

of passenger cars. Flocking of carbon fibers has now become possible.

Electrostatic imaging represents the largest market of electrostatic applications, including electrostatic copying, electrostatic raser printing, etc. Basically, it started from Chester Carlson's idea "Combine electrostatics with photo-conductivity". The photo-conductive film is charged by ions from corona discharge in darkness, and it is subjected to optical image to produce an electrostatic latent image on it. Then, color powder called "Toner" charged in a opposite polarity is introduced on it so that the electrostatic latent image is covered with toner film. Then, the toner film is transfered by electrostatic force to a paper, and thermally fixed on it. Charging of toner is made by contact electrification with much larger particles called "Carrier". Toner-Carrier mixture is applied on the latent image so that toner particles attaching on the non-image part are removed back to the carrier particles by electrostatic force. Recently, ferite powder is mixed with the color plastic material to produce the so-called one-element type toner. Toner particles are conveyed by travelling magnetic field in its opposite direction, charged by tribo-electric action, and transfered to the electrostatic latent image.

[7] Electrostatic Hazards and Troubles

Contamination by micro-particles owing to charging of IC-chips and its processing devices and carrier vessels has become one of the most nasty troubles in semiconductor industries, lowering the yield of the products. Various methods of neutralizing such charging have been proposed and marketted, using low-ozone ac corona discharge to provide bi-polar ions. Electrostatic discharge could cause errornous operation of instruments and computer-controllers in the chip-manufacturing processes. The surge voltage in the level of several tens volt may damage the IC-chips.

The same troubles are very common in the high speed jet machines and rockets, as well as helicopters. Discharge shock occurs either by lightning to their body, or charging of the body due to collision with snow or dusts. The charge must be removed by aerosol neutralizers which emit aerosol particles charged with the same polarity as the body through a supersonic nozzle. The ejection of ions is useless, as they are immediately pulled back by a strong local field produced by space charge of ion cloud. Only heavy particles (aerosols) having very low mobility do not produce such difficulty.

[8] Conclusion

State of the art of Modern Electrostatics are described, with its example of applications in the High-Technologies. These examples alone could make it clear that Electrostatics is going to be a very interesting and important emerging field of electrical engineering, on which careful attention must be paied.

Close examination of these examples might raise a question as to the definition of Electrostatics, since all of them are more or less including the movement of charge. A broadened definition is evidently necessary. However, in all of these applications, "Electrostatic Field" is playing a key role.

It is the author's desire that this short paper could provide readers with a rough image of this emerging technology.