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ELECTROSTATIC DUST PRECIPITATION

By

Huang Liu, Hua You-nian

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ELECTROSTATIC DUST PRECIPITATION

by Huang Liu, Hua You-nian
(Peking Univ. of Industry, Physics Group)

Foreword

Under the guidance of Chairman Mao's revolutionary course, our Socialist enterprises are rapidly developing. However, the industrial progress also brings up the problems of how to treat the "three wastes" and protect the environment.

In Capitalism countries, the Capitalists totally ignore the health of the mass people only to make enormous profits. They are not concerned with the air being polluted and the water contaminated. Ignoring the fact that millions of labor workers die from professional diseases due to the pollution, they are still enjoying the summer vacation in their seashore resorts.

Before the liberation, the Chinese working class was under oppression, and numerous people died from professional diseases such as the silicon-lung, etc. Since the liberation, the party and the people's government have been much concerned with the people's health, and much efforts have been made to fight against the "three wastes" pollution. In these measures, one of the very powerful techniques to eliminate the smoke and dust is to use the method of electrostatic dust precipitation (EDP). This advanced technique has been extensively employed since it is featured by a high precipitation efficiency, low power, and a wide range of applications. Given below is an introduction of this technique.

I. Smog and dust in the air

All of us are familiar with the smoke, dust and fog in our daily life, yet it is necessary for us to have an in-depth study to know how to get rid of them.

From a physical chemistry point of view, any system with solid diffused in a gas is called smoke; while with liquid diffused in a gas is called fog. In short, any diffused system with gas as a medium is called "gaseous solution". Since, in general, the air is the most frequently studied medium, it is also called an "air solution". When the air is mixed with small carbon particles (with diameter of 12-50 μ) ~~in the air~~, ~~we have~~ a grey or black smoke is formed; when small dirt particles or cement powder (with diameter of 4-300 u) diffuse in the air, we have a dust. The mixture of air and small water vapor particles (with diameter of 0.25 u) ~~and air~~ is called fog.

The specific gravities of all these solid or liquid substance are heavier than that of the air. However, since these small particles can absorb a lot of air molecules, their structure becomes very porous, and the measured densities are much smaller than their actual intrinsic values. For this reason, these particles can float in the air and do not precipitate. The down fall velocities of these particles can be analyzed by Stoke's Law. The friction(resistance) of a spherical particle moving in a fluid(liquid or gas) with a velocity u is given by

$$F_{friction} = f \cdot u = 6\pi\eta r u,$$

where f is the friction coefficient, η the fluid's viscosity, and r the particle's radius. The friction experienced by a particle dropping freely in the air is nothing but the buoyancy force exerted by the fluid.

Since ,F_b,

$$F_b = (M - M_0)g = (\rho - \rho_0)Vg = \frac{4}{3}\pi r^3(\rho - \rho_0)g.$$

by equating $F_b = F_f$ we obtain

$$6\pi\eta r u = \frac{4}{3}\pi r^3(\rho - \rho_0)g,$$

$$u = \frac{2r^2(\rho - \rho_0)g}{9\eta}.$$

From this, we see that as r becomes smaller and ρ approaching ρ_0, the falling speed u becomes very small.* In addition, due to the random collisions of air molecules in Brown motion, air turbulance, density distribution vs height, and the electrostatic force (which will be discussed later), the gaseous system reaches a dynamic ~~stability~~ equilibrium and no precipitation can be easily achieved.

From an electrostatic point of view, due to the air motion the dust particles collide with the air

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* ρ_0 not defined in the original .

molecules ~~in air motion~~ and become charged. Also, due to the radiation of radioactive materials, x rays, ultra-violet and cosmic rays, the gas can also become ionized. All the liquid and solid particles formed around an ion are charged. Particles of the same kind carry the same type of charges, and they repel each other. Because of this, the smog or dust particles do not precipitate. Moreover, the charged particles at a lower altitude tend to keep the charged particles at a higher altitude from falling down because of the electrostatic force. In other words The density distribution of the charged particles results in an upward E field, which prevents the charged particles from falling down. Large amount of dust or smog in the air will create serious health hazards, and cause ill effects on crops. It will also give damaging impacts on meteorology and navigation. The pollution is a waste of the industry. For some production processes it is a necessity to have the dust precipitated. For instance, in the gas production a lot of tar exist in the gas, which will eventually clog the pipe lines and stagnate the machines if they are not removed. Also in the production of powder materials such as cane sugar, starch and sulfur, combustion, and even explosion can be triggered due to the strong reaction of the small particles with the oxygen in the air, because the particle-s have large intrinsic chemical energy and large contact surface for reaction. Factories and warehouses of these materials should also have dust precipitaion facilities. As for those factories that are involved with toxic gases (such as organic solvent benzene, acetone, etc) and those that are related to the poisonous substance (such as mercury, lead, arsenic berillium, etc.)

with the worker's health being measures should be taken to eliminate the smoke, dust and fog of these materials.

There are many ways to filter out these particles, such as using water spray, activated carbons, bubble materials, blankets and paper pulps, etc. The particles can also be separated by centrifugal method. However, these techniques are limited by the types of smog and the size of the particles. The EDP technique, on the other hand, can be used to collect all kinds of dust and smog particles with radii ranging from 0.1 μ to 100 μ, and a density ranging from 0.5 gm/m^3 to 50 gm/m^3. This technique is more advanced; and the operation is simpler. A filtering efficiency of 99.9 % can be achieved. A combination of this EDP technique and other schemes would give a even higher efficiency.

II. Principles of EDP

1. Charge interaction

It has been experimentally shown that there is an interaction force between two charges. Charges of the like repel each other; while the opposite charges attract. For two point charges, the force is proportional to the product of the charges, and inversely proportional to the square of the distance. Mathematically it is given by

$$F = \frac{q_1 q_2}{r^2} .$$

From this we see that the larger the product of the charges and smaller the distance, the stronger the force becomes. When a particle carries a net charge (unequal amount of positive and negative charges) it is called a charged particle. Due to the charge interaction, charged particles also exert forces on each other.

2. Effects of E field on charge

Around a charged particle, there exists an electric field, and the interaction between charged particles is realized through the electric fields. The force experienced by a charged particle in an E field is proportional to the field strength, E, and the charge, q, it carries, i.e.

$$\vec{F} = q \cdot \vec{E}$$

Therefore, to increase the force on a charged particle, two approaches are usually employed; i.e. either to increase the E field, or the amount of charge on the particle.

3. Motion of charged particle in a uniform E field

An electric field of constant strength everywhere is called a uniform field. For example, as shown in Fig. 1, the E field inside two parallel plates which are oppositely charged can be viewed as a uniform field. The direction of the field is indicated by the arrows, directing from the positive plate to the negative plate . The direction of the force acting on a positive charge is in the same direction as the field; while that for a negative charge is reverse. The field strength is proportional to the applied voltage, but inversely proportional to the separation of the electrodes, ℓ,

$$E = \frac{U}{l} .$$

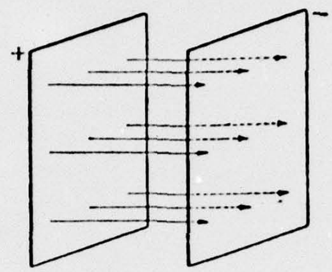


Fig. 1 Uniform field in parallel plates.

Thus the force on a charged particle is given by

$$|\vec{F}| = |q \cdot \vec{E}| = q \cdot \frac{U}{l} .$$

If the mass of the charged particle is m, the acceleration is

$$a = \frac{F}{m} = \frac{q}{m} E = \frac{qU}{ml} ,$$

which is proportional to the charge and voltage but inversely proportional to the separation of the plates.

4. Motion of a charged particle in a non-uniform E field

In a non-uniform field the strength of the field varies from point to point. It could have any distribution. A frequently encountered non-uniform field is the one that is produced by a long wire and a coaxial cylinder oppositely charged. Shown in Fig. 2a is the field frequently used for filtering the tar. Another common field configuration is produced by a plate with a parallel wire at a distance away and oppositely charged.

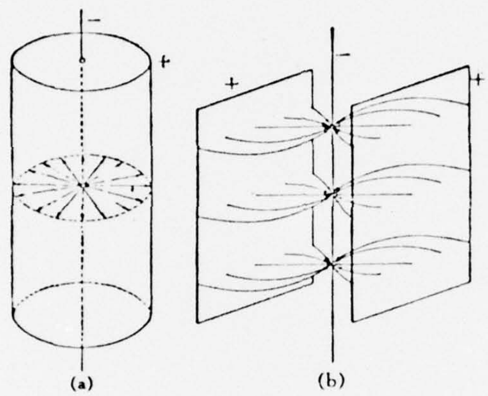


Fig 2 Non-uniform E fields.

At any point in a non-uniform field, these is a direction and a magnitude associated with the field vector, except that they vary from point to point. Thus the force on a point charge also varies from point to point. In the cylindrical case, the field is radially symmetric. The strength can be approximately calculated by Gauss' law. Assume that the height of the cylinder is h, and the distance from the obervation point to the axis is r. If λ is the uniform line charge density, then, by symmetry, the total flux through the cylindrical surface at radius r is $2\pi r h D$, and the total charge enclosed by the cylinder is λh. By Gauss' law and neglecting some secondary effects, we obtain

$$2\pi r h D = \lambda h,$$

$$D = \frac{\lambda}{2\pi r}.$$

$$E = \frac{\lambda}{2\pi \varepsilon r}.$$

It can be seen that the E field decays as $\frac{1}{r}$. For a capacitor of such form, the total charge it can store is $Q = C(U_R - U_0)$, where c is the capacitance, and $U_R - U_0$ is the voltage applied. From the relationship of E field and potential gradient we get

$$E = -\frac{dU}{dr}.$$

$$dU = -E \cdot dr = -\frac{\lambda}{2\pi\varepsilon r} dr,$$

Integrating both sides gives

$$\int_{U_0}^{U_R} dU = -\frac{\lambda}{2\pi\varepsilon} \int_{R_0}^{R} \frac{dr}{r},$$

$$U_R - U_0 = -\frac{\lambda}{2\pi\varepsilon} (\ln R - \ln R_0),$$

$$\lambda = -\frac{2\pi\varepsilon}{\ln\left(\frac{R}{R_0}\right)} (U_R - U_0),$$

$$E = \frac{\lambda}{2\pi\varepsilon r} = -\frac{U_R - U_0}{r(\ln R - \ln R_0)}.$$

Thus in this case the field strength is proportional to the applied voltage and inversely proportional to the distance from the axis.

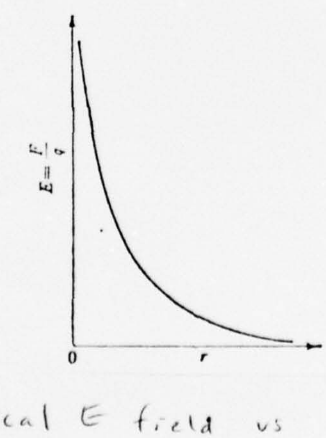
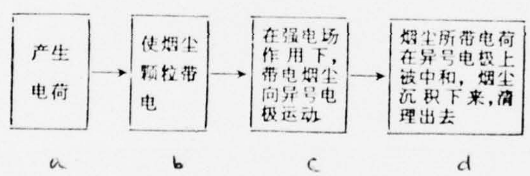


Fig.3 Cylindrical E field vs distance r.

When the center conductor is charged negatively and the outer cylinder charged positively, a positively charged particle will move toward the center and the force increases as it goes inward. Conversely a negatively charged particle wil move radially outward and the force is getting weaker and weaker spatially.

Since in general the particles in air more or less carry some charges. When an electric field is applied, they will, from the foregoing analysis, move toward and precipitate on the oppositely charged electrodes. However, under normal conditions, the particles carry very little charge, and sometimes they are even neutral. In this case schemes have to be devised to make the particles carry more charge for precipitation. This is the basic principle of EDP, and the process can be illustrated by the following block diagram.



a. charge source

b. dust particles become charged

c. particles move toward the oppositely charged electrode.

d. charges carried by the particles get neutralized and the particles precipitate on the electrodes.

III. Gas discharge and the motion of charged dust particles

How to make particles in a gas carry a lot of charges? Under normal conditions, the natural ionization agents (such as UV, X rays, cosmic rays, and high temperature flames) are far from adequate to do the job. However, we know that a strong E field can induce a gas discharge, in which a lot of charges are generated. The charges so produced are used to make the smoke and dust particles charged by attachment.

Normally a gas is not a conducting medium, since most of the gas molecules are neutral particles. However when the gas becomes ionized by some agents, it begins to conduct. In parallel with the process of ionization, there is also a charge recombination taking place at the same time. These two processes reach a dynamic equilibrium; that is, the number of particles being ionized is equal to that recombine. If no external voltage is applied there will be no net current flowing. However when an electric field is applied, the positive ions will move toward the negative plate and the negative ions (the molecules attached with electrons) will move toward the positive plate. A current is therefore flowing and a gas discharge established. The relationship between the discharge current and the applied voltage is shown in Fig. 4. When the voltage is small, the electrons and

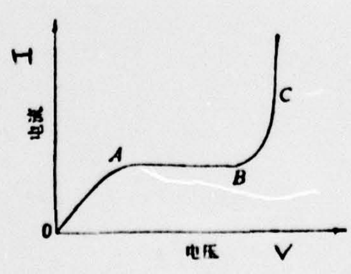


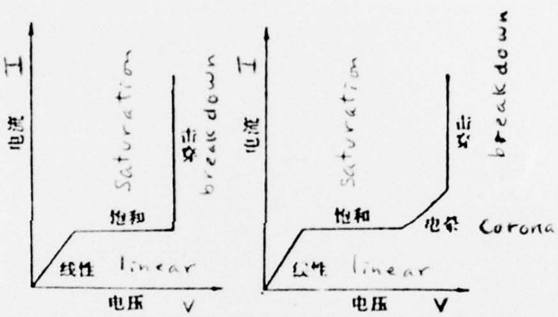
Fig. 4 I-V characteristics of a corona discharge.

~~and~~ the ions move very slowly, and only a few charged particles can reach the electrodes before they get recombined. At this stage the current is very small. As we increase the voltage, the velocities of the electrons and ions become larger, and more of them can reach the surface of the electrodes. In this case the recombination rate decreases and the current correspondingly increases. This is indicated by the OA portion ~~on~~ of the curve shown in Fig. 4.

If we continue to increase the voltage making the E field sufficiently large, all the electrons and ions will be accelerated to the electrodes. However, after a certain point further increase of voltage does not draw more current. This constant current is called saturation current, which is determined by the total number of the electrons and ions available generated by the ionization agents, and it is independent of the applied voltage. This is represented by the AB portion on the curve.

If we keep on increasing the voltage, the kinetic energy of the charged particles is further enhancedd When the particles have gained enough energy, they can ionize the neutral molecules by collisions. The new ions will then be accelerated by the field, and will in turn ionize other molecules. Thus the number of ions quickly multiplies, and the current rapidly goes up. This corresponds to the BC portion of the curve. This process is called collision ionization. At this point the discharge can be maintained by itself even without external ionization agents. This kind of discharge is called self-sustained discharge. Contrast to this is the non-self-sustained discharge.

In a uniform field, collision ionization can produce much more electrons and ions than in a non-uniform field, since the ionization process is taking place simultaneously everywhere in a uniform field. As a result, the whole region begin to conduct and the current instantaneously goes up. This results in a break down forming an arc discharge in the gas. The V-I characteristics of this case is shown in Fig. 5(a).



(a) In uniform field (b). In non-uniform field

Fig. 5 Gas discharge in different fields.

It can be seen that the variation of current from the saturation region to the collision ionization is very sharp.

In a non-uniform field, however, the process of gas discharge is quite different. The break down phenomena takes place in a more gradual fashion. This is shown in Fig. 5(b).

In a non-uniform field, as we raise the voltage the ionization will first take place in the vicinity of the electrodes, where the E field is most intense. When the voltage is further increased, the gas around the surface of the electrodes will begin to break down; while the gas outside the layer surfaces no break down yet, since the E field decays very fast with the distance away from the electrodes. Thus no collision ionization takes place further out. In the breakdown region, the electrons in a molecule are being excited to the higher energy states from the low energy levels. As they jump down to the stable low energy states from the unstable high energy states, the energy is released in the form of light. Therefore in the vicinity of the electrodes a ring of light can be observed. In the mean while, heat is being generated, which results in local gas expansion, causing hissing, vibration and noises. This phenomena is called corona discharge, and the region is called corona region. In the cylindrical case, a sheath of corona will form around the center electeode, causing some hissing and minor arcing. It is this plasma region that provides a charge source for the dust and smoke particles to become charged. Therefore, corona discharge is a sifnificant part of the EDP process.

To achieve a better precipitation, it is essential to generate a lot of charges in the corona region. Usually, in a non-uniform field, only one of the two electrodes will be surrounded by a corona sheath. In a cylindrical field the corona occurs at the center conductor. If the electrode is positively biased, it will be a positive corona. Conversely it is a negative corona. The higher the voltage we apply, the larger the corona region we can get.

Corona discharge can only be generated when the voltage is high enough, to cause collision ionization. This threshold voltage is called critical voltage, which is determined by the size of the electrodes, gas temperature, pressure, humidity, etc. In a corona discharge, initially only hissing can be heard, and no obvious light is observed until more voltage is applied. When the corona electrode is negatively biased, the corona cloud is cylindrical in shape as shown in Fig. 6(a), and the color is blue-violet. When the corona electrode is positively biased,

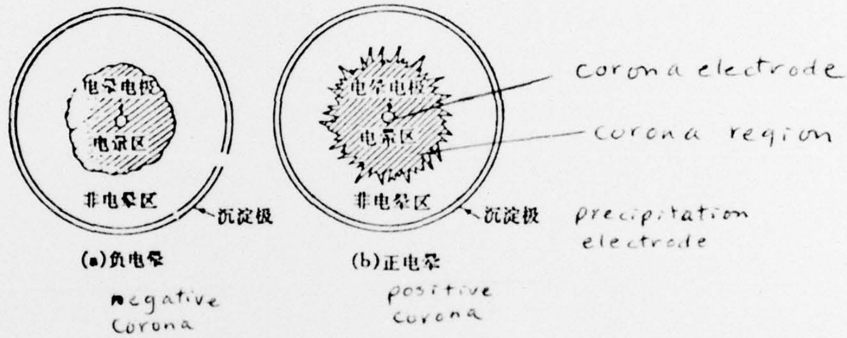


Fig. 6 Corona discharge

the corona cloud appears saw-tooth shaped as shown in Fig. 6b with a color close to violet. In EDP operation, a lot of charges are attached onto the dust particles which are subsequently swept to and collected by the oppositely charged plates under the action of E field.

An increase of voltage will make the corona region bigger and produce more charges. Further increase of voltage, however, will induce sparks between the electeodes, resulting in spark discharge. Since the instantaneous spark current is extremely large, the voltage will redistributes itself in such a way that the voltage drop across the gap and the discharge extinguishes. The open circuit will make the voltage go up again and the process of sparking may repeat. Thus the spark discharge is not a continuous process, but rather intermittenly. For this reason, it is also called flash discharge.

When the gap distance between the electrodes is very small and the the power of the line source or the discharge capacitor is large enough to cause ion bombarment on the corona electrode, secondary electron emission from the incandescent electrode will be resulted. Now the collision ionization in the gas is primarily caused by the thermal electrons and not simply by the ions. This makes the current go up many times and an arc discharge is formed.

Flashes and arc discharges are the two phenomena that are likely to occur in the EDP operation and must be eliminated.

The two non-uniform fields previously described are commonly used for filtering in EDP. The voltage is maintained in the range of corona discharge. Sometimes it is kept just below the voltage of spark discharge to give enough charges for attachment and yet prevent a complete breakdown from happening. This is called flash operation.

In general a negative corona provides a better precipitation effects than a positive corona; mainly due to the following three reasons:

1. In a negative corona, as the positive ions move toward the corona electrode, they not only ionize the gas but also bombard the corona electrode and liberate a lot of electrons. In the case of positive corona, however, the

corona electrode does not emit electrons. Thus for the same voltage, a negative corona gives better results.

2. A negative ion moves faster than a positive ion in the same E field*. Thus in a negative corona, the negative ions move to the positive plate and precipitate faster, and ionize the gas more efficiently. For example, in an E field of 1 v/cm, the velocity of the negative ion is 2.1 cm/sec, while for the positive ion it is 1.4 cm/sec.

3. The initial voltage for a negative corona is lower than that for a positive corona. The breakdown voltage for the negative corona, however, is higher. Thereforee a larger range of working voltage is available for a negative corona, and it can be run at a higher voltage to achieve better corona effects.

In order to make the smaller dust particles ($\leq 10\,\mu$) carry more charges, it is necessary to have a higher charge density and a larger charge mobility. This makes it desirable to have a corona current as large as possible. For the larger dust particles ($\geq 10\,\mu$) the charge to mass ratio is smaller, since the surface to mass ratio is smaller. In order to have more force acting on these particles, we have to raise the field strength. In summary, the velocity of the dust particle is proportional to the charge it carries and the external field strength, but inversely proportional to the mass.

IV. Generation of high DC voltage

There are many ways to generate high electrostatic

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* No clear explanation on the difference of mobility is given, in the original.

voltage. For instance, we can use induction generator, induction coil, small Van De Graaff machine, etc. However, the power so generated is very small. For general purposes, we can make use of EM oscillation to induce high frequency high voltage, and then retify the output by a doubler to gain DC high voltage. For high power applications, however, high voltage derives from city source through high voltage step-up transformers. The rectified output is used to simulate the electrostatic high voltage. Rectification can be achieved by using mechanical rectifiers, H.V. rectifier tubes and H.V. Si rectifiers. Among them, using the H.V. avalanche Si rectifier is more advanced. Regulation is accomplished by using regulation transformers, magnetic amplifiers, and the most up-dated SCR's.

Some time ago, due to necessity, we worked with the technicians in Peking's Second General Machine to modify five junked mechanical rectifiers into automatic SCR rectification devices, which have multipurpose protection channels and are able to automatically track the flash voltage. During one year's continuous production operation, they perform very well.

In this modification project, we strictly follow the principle of self-support, more repair and making use of surplus and junk. We utilized the original 18 kvA, 72 kv, 200 mA H.V. transformer (Xmer), and modified the regulator into reactor(?). We used the old control shafts, meters, components, and only one extra pair of SCR for anti-parallel AC regulation; we used 24 H.V. Si rectifiers to achieve the bridge rectification. We also modified a safety Xmer into a control Xmer; a linear Xmer into a pulse Xmer. Furthermore, we used thirty some crystal tubes to design an automatic control circuit. This has accomplished the goals of automatic control and self protection. The system includes the following channels:

1. Current stabilization and current limiter

In the EDP operation, it stabilizes the current and makes the current independent of the variation of the E field. It also keeps the current under a given value.

2. Overcurrent protection and delayed circuit breaker

When something wrong happens in the E field (e.g. leakage due to cracks in the H.V magnetic bottle; short-circuit of the corona electrode), which results in a current surge, the system can automatically lower the voltage to block the SCR's. If the fault is not removed within 4 secs, the delayed circuit breaker will trip to prevent the SCR's and H.V. Si rectifiers from being damaged.

3. Over-voltage and open circuit protection

When the voltage suddenly goes up due to an open circuit of the E field or other reasons, it will activate the monostable protection device to lower the voltage and then cut off the power supply.

4. Flash or arc protection channel

When spark discharges take place, the monostable activator will, according to the magnitude and frequency of the sparks, lower the voltage to quench the sparks.

After that, the voltage is slowly brought up again. If serious sparking persists, the monostable device will force the voltage to drop to zero and block the SCR's until the arcing is over.

5. Automatic flash voltage tracking channel

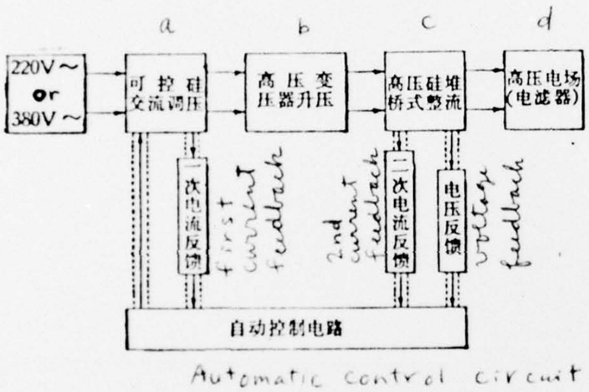
To increase the precipitaion efficiency, maximum ion density and field strength are needed. Thus it is required to operate the filter at a higher voltage but not too high to have an arc over and short circuit. For this reason, the operation point has to be automatically adjusted to provide a critical voltage close to but not above the spark voltage, so that maximum dust precipitation efficiency and safety can be achieved.

6. Soft starting and braking devices

To ensure the safety and convenience of production, we employ the soft starting and braking devices. Once we push the soft starting button, a capacitor is ~~being~~ charged up so that the voltage can slowly go up to the given level. Similarly, to shut-off the machine, we simply push another button to have the voltage slowly drop to zero and then automatically shut off, the power.

To meet the requirements of inductive loading in the operation and the waveform symmetry in the regulation process, we use oscillation input, slope shase shift, pulse controlled trigger circuitry to make sure that the

SCR's can be reliably triggered under different loading and phase angle conditions. Also, the waveform is kept symmetric with respect to the zero line so that the DC component and higher order harmonics can be eliminated. This way the machine can continuously run at the rating of 70 kv, 200 mA day and night. In this case, the transformer temperature increase is 20°C. The system is shown with block diagrams in Fig. 7 and Fig. 8.



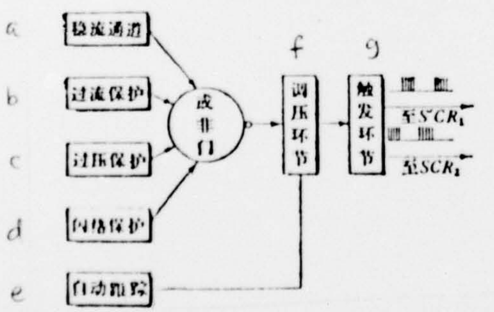
a. SCR AC voltage regulation

b. H.V. step up transformation

c. HV Si pile bridge rectification

d. H.V. E field; filter.

Fig. 7 EPP System block diagram.



a. Stabilization channel

b. Over current protection

c. Over voltage protection

d. flash protection

e. Automatic tracking

f. voltage regulation ring

g. Trigger ring

Fig. 8 Control circuit block diagram.

We also worked with the technicians of related factories to produce the KGGJ-1A/40 kv SCR automatic H.V. rectifier device, which is being used in the Dagong oil field to achieve better results on the automization of petroleum dehydration project. The device now is under mass production.

V. Other applications of the EDP principle

Currently the EDP technique can be applied to the following areas: air purification for auditoriums, conference rooms, residence, powder manufactories, shipboard engine rooms, precision shops, labs, clean rooms, etc. Also it can be used for pollution control; such as treating the toxic gases, auto exhausts, cement dust, Al oxide powder, and other chemical exhausts. Other than these it can also be utilized in the following areas:

1. Electrostatic tar removal

The impurities such as tar, asphalt, etc., in the coal gas can be removed to clear the pipelines. The purification efficiency can be as high as 99%.

2. Petroleum dehydration

The water content in the crude oil existing in a milky form can be separated for the convenience of transport, extraction and export. The water content in the electrostatically dehydrated crude oil is less than 0.02%, which exceeds the export standard.

3. Electrostatic paint spray

By using the effects of static field, paint particles can be vaporized and uniformly coated onto the surface of the processed components. This technique not only upgrades the quality of the spray, but also prevents the toxic vapors of benzene, acetone, etc. from escaping into the air, and conserves the raw materials.

4. Elec-trostatic lamination and alignment of wood fibers

In the production of fiber boards and pressed boards, strong electrostatic field can be used to polarize the fibers and the wood chips; to li up the material in different direction so that the strength of the woodboards can be greatly enhanced. Sometimes the strength so achieved is stronger than that of the woodboard and pressed laminate boards. These products are as good as the plastic material in many aspects. For lumber industry, this technique can minimize the wood-chip dust. It can also be applied to manufacture laminated products with layers of different sizes of fibers. It can produce very high quality decoration boards with a very fine surface.

5. Electrostatic separation

Electrostatic techniques can be employed to separate particles, according to their sizes, masses, water content, and qualities, into differnt categories. For example, it can be applied to classify ores, wood fibers, tea leaves and tea petioles. This technique is also extended to other applications such as electrostatic sand blasting, coating, combing, velvet implanting, etc. We believe that in the height of learning the theories of proletarian monopoly and carrying out the Socialism, the ancient static electricity can definitely contribute in many ways to the construction of the Socialist enterprises.

—end—

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