GOOD PRACTICE GUIDE FOR THE
MANUAL ELECTROSTATIC SPRAYING OF PT MATERIALS

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1- INTRODUCTION

The electrostatic spraying (ESS) application of the penetrant materials is derived from that of paints.

Though this technique is not new, some aerospace engineers told us they were concerned because some operators do not use it as it should. This is why they asked us to write a kind of good practice guide on this topic.

2- HISTORICAL REMINDER

In the year 600 BC, Thales of Miletus (625 -547 BV), the famous Greek mathematician and philosopher, discovers the electrification by rubbing a piece of amber with a cat's skin. He explains this phenomenon as a "soul" and "breath" of these items.

In the mid-60s, a new technique was born in the field of the application of paints: electrostatic spraying (ESS).

In the 60s, a somewhat peculiar gun for dry developer application is described in the excellent book titled ''*Principles of penetrants*'' by Carl E. BETZ.

It was a powder gun (see above), fitted with a 1 litre (circa one quart) jar, which was connected to the dry and oil-free compressed air network of the workshop via a pressure-reducing gauge. Air + dry powder were then expelled at a low pressure, in the 100-170 kPa (circa 15-25 psi) range.

The 20 cm (8") long barrel of the gun was made of ebonite. Ebonite is an electrical insulator. When powder goes inside, the friction between powder and ebonite induces electrostatic charges.

This kind of gun has not been marketed for decades. Was it efficient?

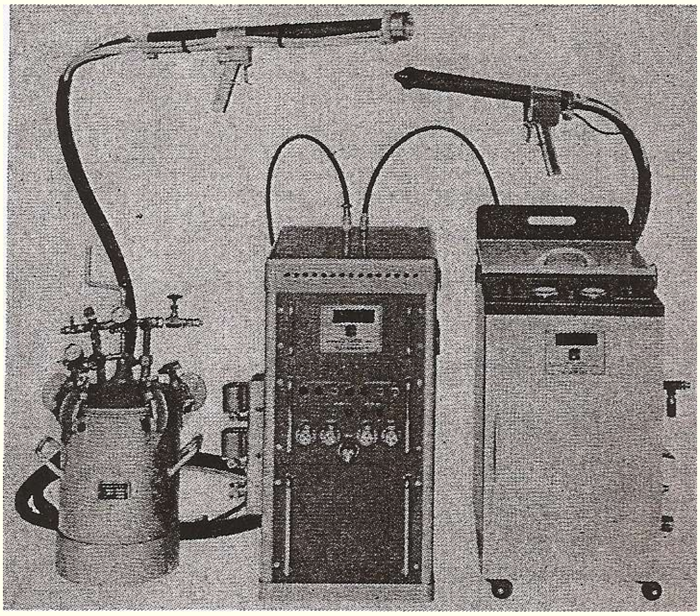
Nevertheless, we think that the spraying came as "blasts" of powder: powder accumulated in the barrel to a point when the pressure so increased that, suddenly, it pushed the "cork." Then the cork was mounting again, and the cycle began again.

In April 1969, the American monthly journal Materials Evaluation published a paper titled

Penetrant Inspection by Electrostatic Spray Method. The author's name is unknown.
This very interesting paper, a landmark, let us know that a manual ESS application installation of both colour contrast and fluorescent penetrant materials had been commissioned in an Aerojet-General plant in Sacramento, California.

1975 was the year when the first electrostatic spraying of penetrant materials occurred in France.
A French PT materials supplier asked the Works Committee Manager of the SNIAS (Société Nationale Industrielle Aérospatiale, now AIRBUS) for performing this test in the Nantes Bouguenais (Western France) plant.

About fifty major members of the French civil and military aerospace industry attended this presentation which made with an ESS equipment manufactured by a British company.
The equipment (see below) comprised: a high-voltage DC generator and two pressurized containers, one for the penetrant and the other one for the developer. The hopper-type pressurized container for the developer was provided with a needle for controlling the powder flow, and a vibro-venturi. Each of these pressurized containers fed a pressurized a spray gun connected to the high-voltage source.



ESS equipment dating back to 1975
ARDROX SPEEDSPRAY®

On the left: the penetrant-application equipment, in the middle: the high-voltage generator, on the right: the developer-application equipment

The penetrant testing process was then widely used in the SNIAS plants: a water-washable fluorescent penetrant and a dry developer.

Thanks to this successful presentation, applying PT materials with an ESS equipment became a standard means, at least for some applications.

Should the spray guns fall down on the floor, spray nozzles and the rotating discs located at their ends were damaged and needed to be replaced. In addition, these spray guns measuring about 50 cm (circa 20 inches) were quite heavy.
Electrostatic spraying was first used in the aerospace industry to inspect structural panels (particularly those of the Concorde supersonic transport aircraft) using a Level 2 water-washable fluorescent penetrant and a dry developer (product family ISO 3452-2 IAa Level2).

In 1978, a manufactured of heavy steel plates looked for improving its procedure for penetrant inspection.
In this context, it launched a feasibility study of the automation of the ESS application of penetrant materials.
This manufacturer wanted to replace the manual application of penetrant materials with ESS guns attached to brackets so that they can make an XY scanning over the steel plates.

These plates were very large stainless steel plates (10 m long, 2.5 m wide and 30 cm thick) (11 x 2.8 yards, 12" thick) for the nuclear industry.

In view to be penetrant tested, the plates were horizontally positioned on the floor, slightly inclined to allow for the liquid flowing. It would have been better to have the plates in the vertical position, to improve the solvent, penetrant and washing-water runoff. However, the Health and Safety Committee of the factory feared that the plates, if accidentally falling, led to severe operators' injuries.

This manufacturer asked the only two experienced French companies to perform a test.

The process used so far was as follows.
Degreasing was carried out with a broom by pouring on the plate surface huge amounts of acetone. The water-washable colour contrast penetrant was spread onto the metal plate also with a broom.
After the required penetration time, the parts were water-washed with a water jet, then, dried with a broom, then with a swab.
Then, the non-aqueous wet developer was applied. As these parts were for the nuclear industry, the penetrant materials had to be halogens-free, which meant that the developer was 2-propanol-based.

However, the 2-propanol is a chemical classified as "highly flammable"; nevertheless, the regulation applicable then did not prevent an ESS application. Nobody was worried by the risks.

The technical manager of one of these two companies carried out a demonstration on December 14, 1978 using an ESS spraying equipment from a French company.

Sometime later, the technical manager of the other company carried out his demonstration with the equipment from the British company referred to above.

Both tests were successful.

The latest point was to combine the system with a robot to move the electrostatic spray guns so as to scan the surface of the metal plates. Unfortunately, then, none of our two companies was on the verge to design PT process lines.

Finally, this manufacturer gave up.

In the mid ‘80s, in France, some new installations have been commissioned:

- PLC-driven PT process lines with the ESS application of three different fluorescent penetrants [a Level 2 water-washable penetrant, two Levels 2 (or 3) and 4 post-emulsifiable fluorescent penetrants] and of the dry developer. Two installations commissioned in two jet engine repair workshops,

- A fully automatic PT process line commissioned in a French flexible manufacturing workshop, which machined turbine disks. The Level 4 post-emulsifiable fluorescent penetrant and the dry developer were applied through an ESS equipment, and the hydrophilic emulsifier (through a pneumatic equipment) using a 7-axis robot,

- PT process lines with ESS application of the hydrophilic emulsifier, for example, in the workshop of a French aerospace equipment manufacturer for the inspection of parts such as aero-engine gearbox housings.

3- CURRENT SITUATION

The current situation, as it exists in France, may be slightly different in other countries.
Nowadays, many aerospace manufacturers and aircraft equipment manufacturers use ESS to apply penetrant materials.
This technique is mainly used on large parts. It is not that interesting for small parts, more efficiently processed by immersion.

However, as a general matter, we think that its use is no longer increasing. It is rarely used outside the aerospace industries. Nevertheless, there are some electrostatic installations in the automotive and energy industries.
The hydrophilic emulsifier is applied by air-assist spray. It is no longer ESS applied.

There are now several suppliers of ESS equipment for paints that have in their respective ranges equipment suitable for PT materials.

There are, at least since 1995, self-sufficient ESS guns for liquid materials that generate their own high voltage through an alternator built in the pistol grip and which is driven by compressed air. The alternator coupled to a cascade assembly generates the internal electrostatic charge. These spray guns allow for avoiding the need for a remote generator in a cabinet and, therefore, make useless for an additional wire along the pipes.

Some automatic process lines exist in which the penetrants are applied by ESS in a tank. An aberration, as the materials are also applied on the walls of the tank. In the end, a mist of material is produced, which could be done far more easily and far cheaper with pneumatic guns. The product consumption is very often above what it should be when using ESS.
Most of the time, ESS is manually performed in booths similar to paint booths.

The other improvements deal mainly with the operators’ safety. A major improvement has been made in the ventilation of booths, now close to that of paint booths. Always think, where feasible, to have the exhaust of the vapour at the BOTTOM, of the booth: vapours of materials are heavier than air, and this prevents any product going to the level of the operators' noses.

4- FUNDAMENTAL PRINCIPLE

The electrostatic spraying principle is based on:

- Providing liquid droplets or solid particles with electrical charges,

- Creating a DC voltage between the part connected to the earth and the end of the spray gun barrel, which generates an electrostatic field.

The technique is based on the following physical phenomenon:
Electrically charged particles of opposite signs are attracted to each other. When these particles are placed in an electric field, they follow the electric force lines.
In practice, this electric field is produced by the electric potential difference between the part connected to the earth, and the spray gun connected to the electrostatic generator. This potential difference can range from 30 kV to 100 kV, depending on the model and applications. The current intensity may range between 50 and 200 µA according to the model. The negative charge of the particles is produced by a rotary atomizer (gun for liquids spray) and by a charged electrode surrounding the spray nozzle (gun for powders spray). This leads to an even coating of the overall surface of the part, regardless of its shape. A single application on the front surface is enough to get, generally, a uniform coating on the back surface, at the same time. However, this depends on several parameters.

Thus, any earthed surface attracts electrically charged liquid droplets and solid particles, when sprayed, which, then, lose their electrical charges.

Benefits of the process:

- PT products which are used are always new, hence, a consistent performance,

- Fewer material's losses: 80 to 90 % of the material goes on to the part surface; a very little quantity of the material goes out into the exhaust ventilations; less penetrant is used per square metre of part, leading to a lower consumption of PT materials and activated carbon for rinsing/washing water treatment,

- Very small quantity of dry developer applied as a very thin film, hence, an excellent sensitivity and an amazing definition of the indications,

- Better coverage: the material goes onto the part surface,

- Fewer liquid droplets or solid particles in the ambient atmosphere, hence, almost no mist (lower air pollution), hence, improved working conditions for the operators,

- Application times saving, especially on large surfaces,

- Better layer evenness on the part surface. The sprayed material is evenly spread over the entire surface of the part and is also applied on the back side thereof, thanks to the by-pass effect, also called wraparound effect, within some limits,

- Etc.

As for material saving, this is true on large part surfaces, but it is less obvious for small ones. In fact, some of the material ESS-applied is lost, as it does not go on the part surface.
It is difficult to measure the savings made thanks to ESS. Some suppliers claim a saving of about 1/6th compared to the air-assist spraying. However, the contexts may be so different.

The wraparound effect of the ESS ensures that large parts generally receive a complete and uniform coverage of penetrant and developer.

However, ESS does not allow for the reducing the penetration time, or for the increasing the detection sensitivity.

Provided that operators understand how to use it the right way, ESS gives very good results with a very low material consumption; this is a very good news for the environment, because a very small quantity of product goes to the atmosphere or drains off from the parts.

5- PT MATERIALS FOR ESS

As a general matter, all the oil-based penetrants may be applied as well the dry developers through equipment that does not require an insulation system.

The water-based penetrant materials such as: the hydrophilic emulsifiers, the water-based penetrants, etc. may be also applied according to this technique if using an appropriate equipment, which requires insulation and an insulated tank for the materials, usually mounted on a carriage fitted with rubber or plastic wheels.

Regarding the non-aqueous wet developer, the ESS application of 1,1,1 –trichloroethane-based ones, therefore, nonflammable, was possible. However, the overall implementation of the Montreal Protocol, on November 30, 2005, banning substances that deplete the ozone layer led to the ban of, among others, the 1,1,1 -trichloroethane.
In most cases, 1,1,1 -trichloroethane was replaced in the non-aqueous wet developers by 2-propanol, the Pensky-Martens close-cup (PMCC) flash point of which is 11.7 °C (circa. 53 °F); this chemical is classified as a highly flammable material. Sometimes, 2-propanol is mixed with propanone, the Abel closed-cup flash point of which is - 18 °C (circa. 0 °F); thus, this developer form is classified as a highly flammable material, and shall not be ESS applied.

As the colour contrast penetrants can be used only with this developer form, the ESS of the PT materials is therefore used, in fact, only for fluorescent penetrant inspection, in conjunction with a dry developer, almost always.

6- SOME FEATURES OF THE PROCESS

The electrostatic equipment shall be used only by trained and qualified personnel knowing perfectly the requirements contained in the instruction manual.

6.1- DIFFERENTS TYPES OF SPRAY GUNS

Each penetrant material requires a suitable spray gun:

- One for each of oil-based penetrant which is used to avoid the penetrant cross-contamination and to avoid a costly cleaning of the pipes and spray guns when changing the penetrant,

- One each for the hydrophilic emulsifier and/or the water-based penetrant,

- One for the dry developer.

The electrical resistance of the spray guns shall be checked every day according to the procedure stated by the supplier.

6.2- SPRAYING PRESSURE

The ESS equipment supplier’s recommendations shall be taken into account, in particular, as regards to the stated maximum working pressure, which shall never be exceeded.
It may occur that the applicable specification states pressures that shall be complied with.
Note here that the pressure has no influence on the process quality. If the pressure is too high, it leads to a material over-consumption. Low pressure has almost no effect, except that the operator will spend more time to apply the material. Thus, there is an optimum pressure, to be defined by tests.

Check manometers every day. Note that the manometer which measures the pressure supplied to push the material may be defined as an "indicator" (the actual pressure value is not very important, but rather a way to ensure that compressed air is flowing), rather than as a meter. This is an important difference from the point of view of Quality Assurance: an indicator does not need to be calibrated, which saves time, money, needs less paper. It is only necessary that the Level III responsible for the plant states it, and it is recommended that an "Indicator" label be affixed on the manometer: this avoids unnecessary questions and discussions during an audit.

If the part has recessed surfaces, blind holes or concave surfaces, they behave as Faraday's cages. The sprayed material does not enter the hole or does not go to the surface. In such conditions, the high voltage shall be switched off (typically a trigger on the spray gun allows for switching from the electrostatic mode to the air-assist mode); the material is applied, thanks to the compressed air which pushes it (when out of blind holes, recessed surfaces or concave surfaces, high voltage is switched on again).

6.3- EARTHING

The equipment, as well the operators in the spraying area or close to, the part(s) to be inspected as well as all the objects in the spraying area shall be earthed according to the equipment supplier's requirements.

The operators shall wear shoes with conductive soles, such as leather, or wear personal grounding straps to avoid the build-up of static electricity charges. Do not wear shoes with non-conductive soles such as rubber or plastic.
This is of paramount importance when using the ESS application of penetrant materials so that the operator is grounded for safety reasons.

Furthermore, the operator shall keep the contact between the hand and the grounded spray gun handle. If the operator should wear gloves, they shall be conductive. If they are non-conductive, the fingers or the palm area of gloves shall be cut off.

The floor of the working area shall be electrically conductive and grounded.

If the equipment is improperly grounded and if the rooms are poor air ventilated, flames or sparks may cause hazardous conditions and result in fire or explosion.

If static sparking occurs or if the operator feels a shock, he shall stop immediately spraying, identify and solve the problem.

6.4- OPERATOR – PARTS/WALLS DISTANCE

The operator should always keep in mind that he, as well as the part, shall be grounded. As the electrostatically-sprayed liquid droplets or solid particles arrive onto the object the closest to the spray gun outlet, connected to ground, the distance between the spray gun nozzle and the part surface shall be less than that between the nozzle and the spray gun operator. Otherwise, the operator will get the sprayed material: it will become quite yellow after the fluorescent penetrant application and all white after the dry developer application. Many operators using ESS spraying for the first time are taken by surprise! A lesson not forgotten for the next applications!
Similarly, the distance between the spray gun nozzle and the part surface shall be less than that between the nozzle of the spray gun and the metal walls; otherwise, the walls will be coated with penetrant or developer.

6.5- COMPRESSED AIR QUALITY

Compressed air cleanliness and dryness shall be checked, which requires a regular purging of oil separators, air filters, etc.

The presence of moisture in compressed air is not well understood by many users. Indeed, any compressed air facility comprises an air dryer just at the compressor outlet.
It is recommended to install an air dryer, just upstream from the point where pressure is released, able to make sure to get at least a - 20 °C (- 4 °F) dew point, if - 40 °C (- 40 °F) is unattainable. The air dryer shall be maintained as per the manufacturer's instructions!

Note: *The dew point is the temperature at which a given quantity of humid air must be cooled, at a constant barometric pressure, for water vapour to condense into water. The condensed water is called dew. The dew point is a saturation temperature.*
*The dew point is closely related to the relative humidity of the air. A high relative humidity means that the dew point is close to the current air temperature. A relative humidity of 100 % means the dew point is equal to the current temperature and the air is saturated with water. When the dew point stays at the same temperature while the air temperature is increasing, that means the relative humidity is decreasing***.**
The compressed air, suddenly loosened from 600 kPa (circa 87 psi), the network pressure, down to about 30 kPa (circa 4.35 psi) to push the developer powder, dramatically cools, resulting in moisture condensation on the powder, among other things, if the air is not dry enough: hence the required dew point, - 20 °C (- 4 °F), and, if possible, - 40 °C (- 40 °F).

6.6- CONTROL OF ELECTROSTATIC EFFICIENCY

Some specifications, such as AIRBUS', state to perform a daily performance control of the coating obtained with the penetrant and developer spray guns.

6.7- EQUIPMENT CLEANING

The cleaning of the equipment shall not be performed when the equipment is switched on. Discharge the system voltage.

Use cleaners as recommended by the equipment supplier.

6.8- MAINTENANCE OF THE SPRAYING EQUIPMENT

The good condition of the spray equipment shall be daily checked. Any worn or damaged parts shall be immediately replaced.

Comply with the equipment supplier's requirements regarding the procedures for the spraying equipment cleaning.

6.9- MAINTENANCE OF THE SPRAY BOOTH

The spray booth should be kept clean and free of waste (papers, rags, etc.).

7- HYGIENE AND SAFETY

The operator shall comply with:

- The applicable regulations regarding safety (fire, electricity, etc.).

- The hygiene and safety rules stated in the relevant material safety data sheets (MSDS), regularly updated by the PT materials supplier.

A particular attention should be paid to protective masks to be worn by operators, and to the good ventilation of the spray booth where penetrant materials are applied to prevent vapours build-up.

The user should refer to the instruction manual of the equipment he uses to ensure compatibility with the material to be sprayed, regarding the minimum flash point and the maximum organic solvent concentration of the material to be sprayed.

In the case of the ESS of water-based penetrants or of the hydrophilic emulsifier, the spray gun should be connected to an electrical insulation system. All the material in the spray gun, the hose and the isolated material supply is under high voltage, which means that the system has more power than a system for oil-based materials.
Furthermore, care should be taken to prevent any risk of shock. When the spray gun applies high voltage to the insulated material, the process is similar to the charging of a capacitor or a battery. The system collects a portion of the energy during spraying and retains some of this energy after the spray gun switch-off. It is unwise to touch the front end of the spray gun until the stored energy is dissipated. The time required to discharge this energy depends on the type of system used. Comply with the material voltage discharge and grounding procedures stated in the instruction manual of the equipment before approaching the front end of the spray gun.

Eliminate all ignition sources such as pilot lights, cigarettes and arcs of static electricity. Do not plug or unplug power cords or turn on and off lights in the spray area.

Only use non-sparking tools to remove paint projections in the booth and on the part hangers.

NOTE

In no way, this guide to good practice replaces the instructions and recommendations set forth by the suppliers in the instruction manuals they provide.
The information above is based on the state of our current knowledge and the result of our long experience. However, your attention is drawn to the fact that this information is provided for guidance only, and it does not constitute, in any case, a specification/recommendation: we cannot be held responsible in any way.

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SOME MISCONCEPTIONS ABOUT THE PENETRANT ELECTROSTATIC SPRAYING

INTRODUCTION

From 1965 [(1)] when electrostatic spraying began to be used for the application of penetrant materials, this application technique has been credited with several benefits.
Some of them were based on misconceptions and we shall mention only two of them.

FIRST MISCONCEPTION: ELECTROSTATIC SPRAYING ALLOWS FOR THE LOWERING OF THE PENETRATION TIME

This assertion had been launched on the assumption that the penetrant droplets negatively charged when in contact with the gun electrode are attracted by the grounded surface of the part, due to the electrostatic field that exists between the gun electrode and the part surface. Their speed, as well as their kinetic energy, increases when approaching the part surface. Hence, the result was a supposedly faster penetration of the penetrant into the discontinuities.

It was a misconception.
Indeed, the penetrant droplets reaching the surface of the part lose anyway their electric charge: the penetrant, whatever its application technique, enters the discontinuities only by capillarity.

SECOND MISCONCEPTION: ELECTROSTATIC SPRAYING ALLOWS FOR THE INCREASING OF THE SENSITIVITY OF DETECTION

Another benefit that electrostatic spraying was accredited with is that for the application of a thinner penetrant layer onto the surface of the part to be inspected that any other application technique. Thus, the penetrant consumption would fall down(2). This is true.

Another assertion is that the penetrant applied as a thin layer, evaporated more easily, this increasing the dye concentration in the discontinuity, so that during the inspection, a very faint indication may become a "less faint" indication and, therefore, be detected with a higher probability of detection (POD).

Obviously, it is nowadays also a misconception.
Indeed, current penetrants have a flashpoint (Pensky-Martens closed cup) above 93 °C (circa 200 °F) and their vapour pressure, extremely low, is about 0.002 kPa (circa 0.00029 psi) at 20 °C (ca 70 °F), 0.009 kPa (circa 0.0013 psi) at 38 °C (100 °F) and 0.022 kPa (circa ca 0.032 psi) at 50 °C (circa 122 °F).
The old penetrants, the flash point of which was about 70 °C (circa 158 °F), had a slightly higher vapour pressure circa 0.035 kPa (ca 0.005 psi) at 20 °C (circa 70 °F).
Therefore, under normal conditions of use, at the usual temperatures between 10 and 50 °C (50 °F and 122 °F), should a low evaporation occur, it would be on the surface and not inside the discontinuities. Therefore, its effect would be very minor especially since the penetration time is generally about from 10 to 60 minutes(3).

CONCLUSION

Any assertion may be misleading. This is a point we should be careful about.
If in doubt, better therefore to ask to a PT expert who will be able to restore the truth, if any, based on the fundamental physical and chemical properties of the penetrant materials.

References

[(1)] Pierre CHEMIN and Patrick DUBOSC, *Penetrant Testing history.*

[(2)] Pierre CHEMIN and Patrick DUBOSC, *He gets a dose of his own medicine!*

[(3)] Patrick DUBOSC and Pierre CHEMIN, *Penetrant application why is it essential to "prevent pooling" and "drain penetrant"?*