

Understanding & Troubleshooting Electroplating Installations: Stray Currents & Bipolar Effects

By N.V. Mandich

To help practicing electroplaters better cope with electroplating problems arising from stray currents and bipolar effects that may occasionally or even perpetually happen in their electroplating lines, I have attempted to analyze the causes of such problems and offer answers in the most practical fashion. Because of the number of possible variables and the complex nature of some electroplating systems, a generalized approach to recognizing and eliminating those problems is presented. For reasons of clarity, no theoretical explanations are presented and the technical language used is simple and straightforward. I will discuss some of the defects arising from stray currents and bi-polar conditions, how to detect them, how plating systems can be engineered to prevent them, and the means for their elimination if they occur.

Probably from the very inception of industrial electroplating, two of the curses to the unsuspecting electroplater have been: (a) ubiquitous stray currents and (b) bipolar effects. They generally appear to originate from electrical grounds and short circuits from improperly insulated tanks, heaters, steam lines, water lines, electrical installations, accumulation of accidentally fallen parts or plating racks on the bottom of the tanks, inactive anodes, and just plain carelessness. They remain with us for lack of understanding of their origin and facilities for their elimination.

Discussions on this subject are very limited and inadequate in the open literature. Notable exceptions are two excellent papers by Guernsey.^{1,2} Published 25 years ago, they may have escaped attention by the current generation of electroplaters. For this reason, and because of the severe effects that elusive stray currents can have on normal electroplating practice, another look at this subject is timely.

Nuts & Bolts: What This Paper Means To You

In 1976, V. E. Guernsey published a couple of fine papers discussing “those elusive little amperes” associated with stray currents. Here, Dr. Mandich takes us on an overdue revisiting of the subject that can plague plating shops mercilessly. Improperly insulated tanks, heaters, steam lines, waterlines, electrical installations, an accumulation of accidentally fallen parts or plating racks on the bottom of the tanks, inactive anodes and just plain carelessness can lead to stray currents. The results are rejects, wasted power, rejects, loss of bath control and more rejects. This paper discusses defects arising from stray currents, and how to detect, prevent and eliminate them.

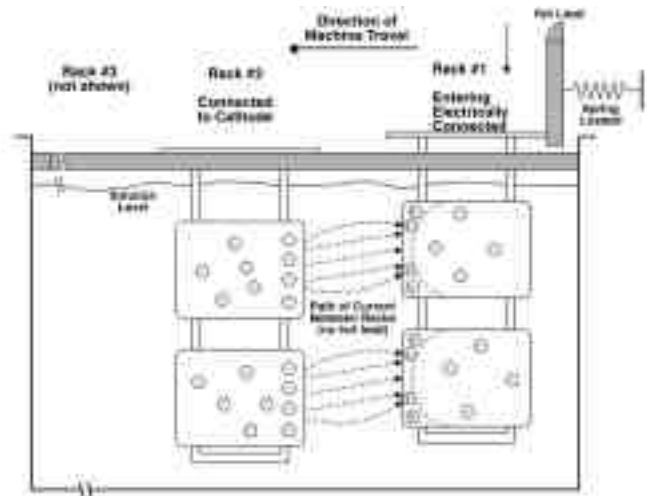


Fig. 1—Bipolar effects.

Stray currents can be depicted³ as “currents through paths other than the intended circuit, such as through heating coils or the tank.” This points out that all current through an electrolyte is intended to pass from one electrode to another without the other haphazard paths, or leaking out from the system altogether. Other than the obvious fact that the desired current distribution is disturbed, there are possible side effects that may, on occasion, be more acute. It is not intended here to elucidate details of the electrochemical actions of stray currents, but rather to infer that, for the greater part, they are related and coupled with insidious bipolar phenomena.

Caused by close racking, anode spacing, auxiliary anodes or accumulation of parts on the bottom of the tank, bipolar effects sometimes may occur in plating tanks. It generally occurs on automatic plating lines used for decorative nickel-chromium systems. The rack that suffers from bipolarity is positive and negative at the same instant, but in different areas.^{1,2} The consequence is a jagged white pattern, called “white wash,” bipolar burn, or false burn. In the most severe cases, the nickel will peel.

If bipolarity exists in the nickel tank, the bipolar burn will be on the lower trailing corner of the rack after chromium plating. If it is occurring in the chromium tank, the burn will be in the lower leading corner of the rack. When plated parts are partially passive in areas other than geometric low current densities, this problem should be addressed and “hot leads” installed. Hot leads coming out of the nickel tank use regular plating voltage. The lead for live entry into the chromium tank should have a separate

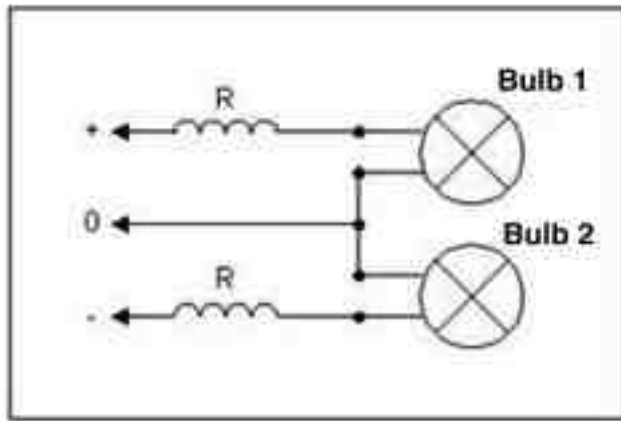


Fig. 2—Stray current indicator lights (SCIL).

power source, supplying about 2.0 to 3.5V, and about 10 to 50 A, depending on the system. Figure 1 illustrates this situation.

Detection of Stray Currents

All stray currents do not necessarily cause visibly detrimental effects. It is sound practice, however, to locate them and eliminate them whenever and wherever they are found.

A highly important addition to any effective plating installation consists of a rather inexpensive, simple, but effective piece of equipment known as “stray current indicator lights” (SCIL). In effect, this simple device is so significant that it should be judged as being as indispensable as the ammeter, and should be mandatory on all plating tanks.

The SCIL is made from easily available components that can be installed by any professional or even amateur electrician. In its simplest form, it can be assembled from two off-the-shelf porcelain wall sockets, two DC light bulbs, and sufficient No.14 wire to make the connections as shown in Fig. 2.

The sockets can be mounted on a small panel, preferably in such a position that they are clearly visible to the plating operator. One pole of each socket is tied together with a short section of wire, which in turn is grounded to the nearest permanent ground (*e.g.*, a water line). A short section of wire is connected to the remaining pole on each socket, with one wire connected to the positive and the other to the negative bus bar. After low-voltage bulbs have been turned into the sockets, the installation of SCIL is complete. Six- or 12-volt bulbs can be used, depending on DC-rated output. It is possible to use an appropriate coil restrictor (R) in series with each bulb to compensate for accidental higher voltage, resulting in a longer bulb life.

Waterproof pigtail sockets can be used, preferably if a portable SCIL is needed. However, a permanent installation is favored on each electrified tank, as it will detect intermittent, reappearing stray currents. These sporadic currents confuse many and try the patience of scores of electroplaters.

The operation of the SCIL is straightforward. If both bulbs glow with the same intensity, there is probably no trouble in the electrical system that will cause plating difficulties. There is an extremely remote chance that both the positive and negative sides of the SCIL circuit would be grounded to exactly the same extent, and in that way cause the bulbs to glow alike. This exact set of circumstances is unlikely, however.

When only one bulb is glowing, it is a warning that one side of the circuit is fully grounded and that plating difficulties may occur. (Of course, if one bulb is burnt out and not replaced, the test is useless). Where both bulbs glow with different intensities, a partial ground on one side of the circuit is indicated, which may also cause

plating difficulties. It should be stressed again that stray currents shown by the SCIL may or may not cause trouble, because many are not necessarily harmful.

As a preventive measure, all quality-conscious platers should suspend plating operations in any tank or system in which the SCIL bulbs do not glow with the same intensity. Realizing that all grounds as shown by the SCIL do not necessarily mean trouble, one should still not take any chances. Simply put, it is difficult to differentiate, quickly and positively, between those that are seemingly harmless and those that are not. The use of SCILs does not in any way eliminate or remove harmful currents. Nor do they point out the exact area where the tank lining has broken down. They are only a practical means for indicating the existence of grounds in a particular current path.

On the return type of automatic plating machines, hoists, or in larger hand-operated tanks, the plating racks can intermittently or even permanently lose contact with the cathode arm and become “dead.” The dead rack can affect the working racks that can be ahead of, behind, or on the same cathode arm. The situation is set for the insidious bipolarity and consequent possible passivation on the working rack as a whole, or at least on a portion of the parts. In many cases, locating the point where current interruption and bipolarity occurs is not obvious and/or simple.

There is a simple, but effective device, however, that I will baptize for this occasion: the dead rack affordable tester (DRAT). It consists of a 12V automotive socket and light bulb. The opposite ends are provided with a sufficient length of No. 14 wire, with standard alligator clips attached on the ends. One end of the DRAT is attached to the carrier arm or cathodic (negative) bus bar, and the other to the plating rack. If the current contact is broken between the rack and the arm, the current that normally travels to the plating rack through the solution to be used for deposition will now travel via the alligator clip contact located on the top of the otherwise dead rack through the DC bulb. Because the other end of the DRAT is connected to the other side of the rack, enough potential difference is made to light the bulb, indicating a dead rack. On the other hand, if the rack is “live” and plating, the anodic current will use, according to Kirchhoff’s Law, the path of least resistance, traveling through the solution to the plating rack, and will be used for electrodeposition without going through the more resistive bulb. Consequently, the bulb will not glow, indicating normal operation.

By following these simple practices, many of the headaches that are usually inherited by unalarmed predecessors are avoided. Knowing that stray currents are an unnecessary evil, and armed with the knowledge of their origin and possible costly consequences, attentive platers should be prepared to contest them at every occurrence.

Of all safeguards that can be recommended for use in the plating room, this plain and undemanding system offers, dollar for dollar, the most protection for the least investment.

Locating Stray Currents

It is a sound and economical practice to eliminate all stray currents, harmful or not, whenever and wherever they are found. The use of SCIL and DRAT does not in any way eradicate potentially harmful stray currents, nor point out the exact area where the tank lining or bus bar insulation has broken down. They are only a practical means for indicating their presence in a particular current path.

Finding the exact area of the troubles may be relatively easy or may include various degrees of difficulties. In some cases, hot areas induced by stray currents may be quickly observed visually and removed quite easily. When these spots are not visible, it becomes necessary to “hunt and try.” Damages to tank linings can be repaired. Worse, the tank itself may be grounded through its

floor supports. These stray currents are almost impossible to find, and it may be necessary to take apart the line, remove the tank, and reinsulate it from the ground up. This condition will rarely occur, however, if the system was properly designed in the beginning.

If the plant floor or pit is kept dry, properly cleaned, and fallen parts are not allowed to accumulate under or between the tanks, one can be reasonably certain that these difficulties cannot appear and reappear. It is still possible for cleaner sludges and other spilled substances to build up on tank-insulating supports and electrically bridge them. Yet, it is quite easy to hose down the floor, pit, and insulators at regular intervals and eliminate these causes.

In addition to effects on current distribution on the plated parts, there is a further danger involving meandering stray currents. After leaking from a non-insulated plating tank, for example, they can find paths to adjacent tanks and through auxiliary equipment such as metal ducts, piping, coils, electrical conduit, etc. Although the voltage driving those currents may be minute, serious acceleration of corrosion may arise in the most unexpected places, often remote from the original source of current.

Where plating lines have not been adequately insulated from the very inception, it can be very difficult to find and remove grounds and stray currents. Nevertheless, some talented electricians can do a good job with a voltmeter and a little common sense.

Prevention of Stray Currents

The first consideration in engineering a new plating line must be given to the drainage and containment pits. Local conditions, such as permanent sewers, headroom and the like, determine how deep a pit can be insulated. Wherever possible and practicable, the drainage or containment pit should be on a lower level than the base on which tanks are to be set. The ideal pit has two levels—a shelf on a higher level for the tanks to rest upon, and a drainage pit at a lower level to collect water from the plating operations. This is, of course, provided the sewer is of sufficient size.

Because the shelf will be wet at all times from drag-out, overflowing rinses, accidental small or large tank leaks, it is beneficial to build supports above the shelf level to act as pillars to support the plating tanks. The pillars may be of several designs, such as narrow supports extending the length or width of the tanks, or a series of small pillars placed in predesigned positions. The supports may be made of reinforced concrete, preferably covered with a chemically resistant organic coating or of acid-proof bricks. The latter is essential with low-pH plating baths, acid-dip tanks and their rinse tanks. The ideal plating tank is, of course, the one lined inside and outside, including the supports.

Pits lined with acid-proof bricks, such as those used in most large pickling units, will obviously out-live an ordinary concrete-lined pit. If the latter type is used, make sure it is thoroughly treated with a resistant coating, particularly in the areas where there is a flow of acid solutions. If circumstances do not permit the use of double-level pits, it is advisable to use the deepest possible single-level pit, and the highest possible pillars.

When the details for the pit have been engineered, concern must be given to the design of a support for the tanks themselves. In new installations where individual tanks are used, it is possible and advisable to weld supporting I-beams, with predetermined spacing, along the bottom of the tanks. This spacing, of course, will correspond to the spacing of the pillars in the pit.

An important factor in eliminating stray currents is the insulator, which will insulate the tanks from the pillars. It must be of sufficient size to protect against high-voltage leaks in AC sources, and must possess sufficient strength to support the weight of the filled tank. A small section of ½-in. solid-lead plate, both under and over the insulator, provides sufficient cushioning to prevent breakage.

Another configuration combines the tank support and the insulator. In this case, the plating tanks sit directly on the built-up support, which is made by clamping the insulators between two heavy steel sections.

When individual tanks are arranged to form a plating line, it is advantageous to insulate all tanks in the line in the same manner. This includes all cleaning, rinsing, acid dipping, and plating tanks. It simplifies engineering all along the line, and eliminates the possibility of stray currents entering the plating circuits from this source.

When engineering automatic or semi-automatic equipment, it is rational to place pillars and insulators under the basic framework supports, thereby insulating the entire plating line. When the plating tanks are insulated in this manner, a safe start has been made. However, the succeeding steps are almost as important.

It is understood that all piping should be engineered so as not to come in contact with any plating tank. Obviously, steam, water, and possibly air lines must be insulated. While there are dielectric insulators for water and steam lines available, ordinary high-pressure steam hose usually will suffice. Manufactured insulators are not only fairly expensive, but after a rather short period of time have a tendency to become limed-up and rendered ineffective. A section of existing pipe can be cut out in all ingoing and return lines, and a section of high-pressure steam hose can be inserted for dielectric insulation.

Bus bars running to or around a plating tank to provide electrical connections, and supported in more than one place on a tank, should be thoroughly insulated with nonconductors, such as PVC, polypropylene, Teflon or Bakelite blocks. In installations such as barrel plating, where motors are fastened to a framework on the side of the tank, it is prudent that the motors be insulated both from the tank itself and from the gears at the universal joint. One item that is repeatedly forgotten is the conduit to the motor, where it is advisable to use the plastic type of conduit for this purpose.

Another step in properly insulating a plating line consists of determining how stray currents can be avoided within tanks that are purposely connected to sources of direct current, such as where the tank itself is used as a cathode in anodic electrocleaning.

It is clearly beneficial to shield heating and cooling coils in preplating or plating solutions. This can be done by the use of proper nonconductive shields. The necessity for this precaution is determined by experience. If the intake and discharge parts of the coil are properly insulated outside the tank, and they are located behind and away from the anodes, there is little need for such additional precautions.

Where continuous filtration or circulation is employed, it is similarly advisable to use chemically resistant hose or plastic piping that will not sag for inlets and outlets. CPVC, PVC, or resistant, rubber-lined steel piping may be used, provided it is insulated from any supports or from pumps and motors.

The life of lined plating tanks can be extended if impact-resistant cushioning for the bottom is used. The cushioned bottom prevents fallen anodes or parts from puncturing the linings, which can result in both stray currents and bipolar current effects. In some installations, acid-proof brick laid in the bottom is sufficient. The bricks need not be sealed, and it is not necessary to remove them each time the solution is batch-filtered. In other installations, resistant plastic sheets have been used to cover the tank bottoms. It is necessary to weight the sheets down to hold them in position, and acid-proof brick may be used for this purpose.

Impediments in Cleaning Operations

A number of cleaning problems are encountered in metal finishing systems where stray currents are present. Experience has shown

that stray currents in alkaline cleaning solutions can harm cleaning effectiveness. In some cases, carbon smuts, polishing compounds, etc., are not readily removed. In others, so-called chemically clean surfaces, as determined by the "water break" method, cannot be easily obtained. Stains of various colors have been known to form on steels cleaned in tanks that are not electrically neutral. Where parts have appeared adequately clean, subsequent plated deposits have been found to be extremely rough, especially after nickel plating, but also after copper, zinc, and cadmium plating. In cleaning and activation prior to chromium plating, it has been noted that stray currents may cause white spots or "rainbow" effects in the chromium deposit.

All of these difficulties lead to poor deposit appearance, and possibly to poor adhesion and corrosion resistance. In addition, they frequently reduce cleaner life and substantially raise cleaning costs. As cleaning solutions age, their soil-removal ability becomes more limited. Many useful old cleaners have been discarded and replaced by new ones, when the removal of stray currents might have allowed extra cleaning life from the old one.

Stray currents in rinse tanks can cause unexpected stains, many of which cannot be removed in subsequent operations. Experience has not shown these stains to be necessarily detrimental, unless they are responsible for unacceptable streaks and patterns that, on occasion, become evident after bright nickel plating. Stray currents can also cause unexpected etching or gassing in acid dips.

Impediments in Plating from Alkaline Baths

Stray currents in alkaline baths of copper, zinc, and cadmium have been known to cause extreme roughness, skip plating, poor adhesion, and blistering.⁴ The latter, in turn, leads to poor corrosion resistance. In one instance, where a copper flash was employed as an undercoat for nickel, the salt spray resistance of the composite coating was increased as much as 24–28 hr, simply by the removal of all stray currents from the copper tank.

In a number of instances, stray currents have had an effect on the color of cyanide copper baths, turning the solution a definite pink color. Once the stray currents were eliminated, the color gradually changed to the natural straw. When pink in color, these baths lost their full ranges of operation, with peeling, blistering, and lack of adhesion evidenced within the copper deposit. Adherent deposits were obtained only by using a minimum temperature of 60°C (140°F), and a free cyanide-to-copper metal ratio of 0.4 to 1. When the electrical problems were eliminated, the full operational range generally associated with alkaline copper baths was restored.

In a second instance, a power generating plant that served trolley cars used for public transportation was located outside a copper plating department.⁵ The DC power was transmitted through third rails centrally grooved in the streets outside the plating department. When the insulation of the tanks from the ground was lost, a litany of weird events occurred within the plating facility. Certain areas of the tanks became anodic, resulting in bipolar effects. Areas of the parts and anodes were de-plating or plating with "burnt" deposits, depending on where they were in the tank. The stray currents were finally traced to leakage of current from the ground. Insulating mats were installed under the tanks, and the tanks themselves were relined. This solved the problem.

Impediments in Nickel Plating

Most stray currents can have a definite negative effect on bright nickel plating solutions. Stray currents, for example, which render immersion-type heating devices anodic, can have a severe effect. Anodic potential that is normally used for the dissolution of the nickel anodes is partially used in this case to react with chloride ions from the solution to form free chlorine. In turn, any liberated

chlorine rapidly breaks down both the wetting agents and the organic brighteners in most of the popular bright baths.

Brighteners and wetting agents can affect semi-bright as well as bright nickel deposition, if they break down. If these breakdown products are allowed to accumulate, strange patterns that are incapable of being removed in subsequent buffing operations may form in the deposits. Bipolar actions can develop in nickel plating tanks that do not necessarily arise from a breakdown in the tank lining. The most common causes are:

1. Anodes accidentally hanging too close to a heating coil.
2. Accidentally dropped parts settling down to the bottom of the tank near the plating load.
3. Anodes temporarily losing contact with the anode rods or becoming positioned behind other bars.

In case #1, a coil or heater block may plate up on one side and de-plate (acting as an anode) on the other. Situations have occurred where a black scum formed on top of a nickel solution, even though no AC or DC stray currents were found. Where this difficulty becomes chronic, a shield of rubber or Bakelite between the coil and the anodes will correct it.

It is possible, albeit costly, to eliminate this type of problem if immersion heaters are replaced by outside heat exchangers. The change can be made quite easily where solutions are already being continuously filtered. Exchangers using nickel tubing for circulation may be procured, or may be constructed in larger, fully equipped plants.

There is always the possibility of deleterious bipolar effects developing between any conducting-type of immersion heater and nearby nickel anodes. Some suppliers of proprietary bright nickel chemistries have wisely made outside heat exchangers mandatory for use with their solutions.

Obviously, the use of outside exchangers is the best means of removing all conducting materials, other than anodes and cathodes, from the plating tank. Clearly, if conducting materials are not present, stray currents from this source are nonexistent and of no effect.

In case #2, parts that have fallen to the bottom of plating tanks become bipolar. They not only alter the current distribution, but may also be a massive source of metallic contamination. When fallen parts are removed, one end will show a large build-up of nickel, and the other end of the part will be eaten away. Fallen parts should be removed as quickly as possible. If not, induced bipolar action usually will cause deposit roughness. Furthermore, the build-up of iron, copper, or zinc in the solution (depending on the basis metal) will cause pitting, lack of ductility, cracking, and so forth.

Finally, in situation #3, some platers, unless they are doing anodizing, have the tendency to relegate anode anomalies to the background.

The bipolarity of anodes is often the consequence of loose contact on anode rods. Sometimes the anodes are just hanging in the solution, becoming accidentally insulated and nonconductive ("dead") by an accumulation of plating salts and/or anode corrosion products. The bipolar action is set between the insulated anode and the anode that is working properly, and causes the non-conducting anode to become cathodic to the rest. This is similar to the "backlash" effect, where the area behind the steel tank, or a lined tank with a broken lining, will plate up, despite the fact that the tank itself may be electrically well-insulated. Even with the proper tank lining, the non-working anode can be plated, causing the familiar anode "treeing."

In one experience, excessive metal losses were found in a gold plating operation. After checking the usual suspects—solu-

tion leaks, wrong current distribution, etc.—and before considering possible theft, the gold loss was traced to several anodes that had an accumulation of precious metal. This phenomenon is a bit unusual because the anodes were made from platinized titanium. Electrically dead anodes were also found responsible for the build-up of a nickel deposit on one side of the anode, to which the anode bag subsequently adhered at points of contact. The other side of the anode de-plated with no serious damage. The only difficulty associated with this case was that the anode bag became ruined and could not be reused.

Impediments in Chromium Plating

In decorative and functional chromium plating, stray current and bipolar effects show up most often as poor current distribution, reduced throwing power, and an effect similar to poor cleaning. If stray currents are present, it may suddenly be necessary to raise the current density above that normally used in order to prevent mis-plated, “mis-chromed” areas (*i.e.*, areas showing a yellowish cast of the underlying nickel). Both of these difficulties may occur on the same piece or on separate pieces on the same rack—pieces that will normally cover well.

White or gray spots may develop with no apparent relation to high- or low-current-density areas. In many cases, this condition has been caused by stray currents in the chromium tank. This same pattern, of course, can be caused by other difficulties, such as poor cleaning, a contaminated acid dip, poor rinsing immediately preceding chromium plating, or a rinse becoming alkaline because of operator neglect. If measures for detecting stray currents are applied and no stray currents are found, then the source of the trouble, in all probability, is coming from something else.

Because of the corrosive nature of hexavalent chromium baths, the use of outside heat exchangers is not widespread. This corrosivity can nevertheless be averted by pumping the solution from the bottom of the tank through a proper heat exchanger, and back into the plating tank at or just below the solution level. By using outside exchangers, all conducting objects from the plating tank are removed, with the obvious exception of the anodes and cathodes. By taking such measures, a vast share of the impediments associated with the presence of stray currents will be removed.

Conclusion

Once a plating line has been properly engineered, built, and installed, it is imperative that it be kept free from stray currents at all times. Cleanliness in the plating room must not be overlooked as an important part in providing trouble-free and profitable plating. Insulated areas, in particular, must be kept clean. In some instances, notably in chromium plating, insulating materials must be replaced at frequent intervals.

No one can feel entirely secure from the negative causes and effects of stray currents. However, by following a well-engineered plan in building the plating plant, as well as proper care in maintaining it, one can readily improve the product, decrease operating costs, and raise the morale of the plating plant personnel.

Detection, location, and prevention of stray currents can be long, costly and frustrating if only trial-and-error methods are used. The shortcut, if any, is an understanding of their origin and their interrelationship with bipolar effects. Practical plating experience, common sense and patience are also good companions. Troubleshooting of incorrect, marginal or defective plating work requires an ordered approach to find the origin of the problem. This approach is invaluable both for the involved plater, inside or outside troubleshooter/problem-solver, and also for teaching plant personnel to solve their own problems in a timely manner. After it is determined where the origin of the problem lies, one can speculate on why it is there and what best set of corrective measures can be contemplated and implemented.⁶

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