More of Those Elusive Little Amperes–PART II

by V.E. Guernsey & J. Guernsey

This paper is an update of an earlier paper submitted and published by AESF in 1976. Additional information has been added and clarified for better understanding, some information has been removed and some has been left unchanged. This is a practical article for platers illustrating and defining bipolar current, bipolar problems, live lead systems for bright nickel and chromium, stray current identification, its measurement and various uses of a volt-ohm-milliammeter (VOM) in electroplating. Servicing tips and corrective measures are also included.

Bipolar Problems in a Hoist Line

Bipolar currents in a hoist line, automatic or hand operated, are rare. In general, more problems originate because of a non-insulated hook or improper current initiation in the chromium tank or stray currents.

Bipolar problems, if they are to occur, will normally be confined to a multiple-bay nickel or chromium tank, and are generally a result of voltage differences on anode bars due to plugged anode bags, low anode area and or feedback from a high voltage point (due to conditions listed above) and, of course, breaks in the tank lining. These can provide a current path from anode to disconnected cathode and thence to ground through the lining break or to another set of anodes.

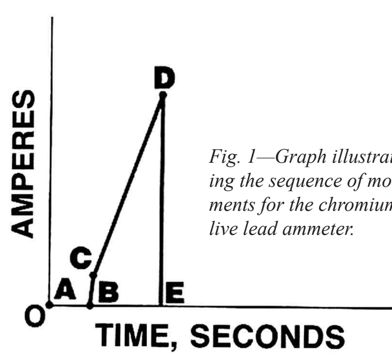


Fig. 1—Graph illustrating the sequence of movements for the chromium live lead ammeter.

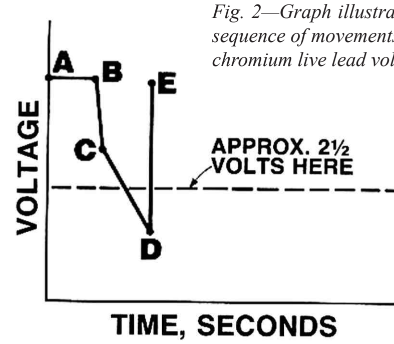


Fig. 2—Graph illustrating the sequence of movements for the chromium live lead voltmeter.

Any single bay tank in a hoist system should be considered reasonably clear of bipolar problems. Whether clear of stray currents - possibly not. There could, of course, be exceptions since no one has yet experienced all the problems that have occurred, or are about to occur, in electroplating. Later on in this article, we will discuss stray currents and their characteristics.

A final note concerning hoist lines. The multifunction rectifier described previously can also be used on a hoist line. Normal operation would be as follows:

1. Enter chromium solution, no live lead.
2. Upon set down, apply about 2 to 2.5V, either pre-set or with timers and relays.
3. Ramp or slope up to strike voltages, 5 to 10 sec.
4. Strike for 5 to 10 sec.
5. Ramp down to plating current density.

Again, excellent activation and coverage are the main features of this procedure.

Live Lead Problems: Nickel–Full Automatic

In the first part of this paper we discussed some of the service problems related to live leads in both nickel and chromium hand lines. Some of those would also apply to full automatics. Among the first prerequisites for automatics are an ammeter and a voltmeter in the live lead circuit, otherwise the chances of resolving a problem in this area are more challenging. In addition, they provide the visual means of establishing operating limits.

Probably one of the most common problems is a make-and-break contact of the live lead as the rack moves out of

Nuts & Bolts: What This Paper Means to You

In 1976, V.E. Guernsey published a widely read and widely cited article, that is still talked about on the Internet, entitled "Those Elusive Little Amperes," covering that vital subject, stray currents, something that had been given little attention [*Plating & Surface Finishing*, **63**, 38 (February 1976) and **63**, 44 (March 1976)]. Twenty-eight years have passed and the subject is no less important. Now a family enterprise, this article is the second and final part of an update on the subject. Let us hope that less than 28 years will pass until the next update.

***Technical Editor*'s note**: *This is the second and concluding part of the article published last month (June 2004).*

the nickel. If you will observe the ammeter, it will instantaneously drop to zero and then quickly rise again. The reaction time of the analog meter is almost always fast enough to indicate this break in current flow. When this happens, look for loose connections in the flexible cable circuitry or worn insulation causing a short or ground to the framework. Grounded arms or pushers should also be considered along with dirty rack and carrier hooks. If the machine has a vertical slide bar, the problem could be the result of excess clearance between the shoe and the slide bar caused by uneven spring pressure or a dry bar. Slide bars should be lightly greased each morning to prevent chattering and current interruptions. Slide bars and shoes occasionally need adjusting to provide uniform pressure and distance.

When any of the above situations exist, the false burn will be inconsistent and seemingly will have no pattern for occurrence since the loss of contact may be accidental or incidental, depending upon the physical condition which caused it. The authors have had occasions when it was necessary to constantly watch the ammeter and voltmeter for 1.5 to 2 hr to resolve this type of problem, mainly because its occurrence was averaging one out of every 20 to 40 racks.

If the automatic is of the type where the rack moves into the last station, and immediately exits, then opportunities for bipolarity are minimal. If the duration of time in the exit station is the same as the previous stations then a full complement of anodes along with a live lead is necessary to provide the proper plating current density. Otherwise, dummying can occur as well as the problems related to dummying described earlier.

Live Lead Problems: Chromium–Full Automatic

Before we consider how to service these alleged monsters, we should look at the exact manner in which they perform their necessary function. We can best show this by a time-voltage and time-current graph. These must be considered separately since they react in opposition, as a result of decreasing resistance as the rack enters deeper into the chromium solution.

Again, it is necessary to remember that we cannot enter the chromium bath with full tank voltage on the live lead. There is a rather narrow usable range of voltage and amperage. Within these narrow limits, good work can be obtained. First, let's take the ammeter readings as shown in the graph of Fig. 1.

From point A to point B is, of course, the transfer time of the machine, and the ammeter would read zero. From B to C there is a small, quick rise as the tip of the rack enters the solution. This will be in the order of about 1 to 5A depending upon rack size and voltage.

From C to D, there is a sharp progressive rise in the amperage that will also be shown on the live lead ammeter. This is normal when you consider that, as the rack enters the solution, it presents more and more submerged area and thus lower and lower resistance, and therefore increasing amperage during its entry.

At point D the rack sets down and contacts the main rectifier and, for all intents and purposes, the live lead amperage drops to zero as shown at point E.

Now let's look at a graphic illustration of the voltmeter connected to the live lead circuit on a chromium tank. (Fig. 2)

From A to B is, of course, again the transfer time while the rack is in the air prior to entering the chromium. The voltage is high and indicates the unloaded voltage of the rectifier. No amperage is involved at this point. From B to C there is an initial sharp drop in voltage as the tip of the rack enters the solution. From C to D, there is a sharp progressive drop in voltage consistent with the immersed rack area. D to E, of course, indicates a sharp rise that occurs as soon as the rack sets down and contact is made with the main rectifier.

Note that between points C and D, a value of 2.5V is given. This figure is normally set by watching the voltmeter on the live lead and adjusting to this value when the rack is immersed about halfway. Larger racks and cathode areas will use higher voltages and vice versa. The value that is ultimately selected will be where good work is obtained, and will be a function of several physical conditions that, if changed, may necessitate a change in entrance (live lead) voltage values. Some of these conditions are as follows:

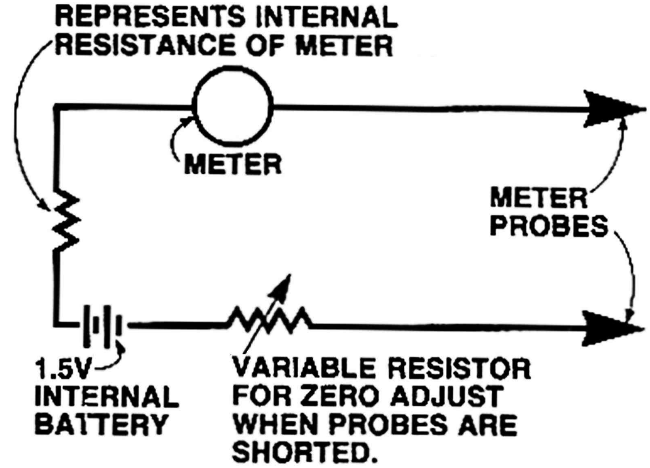


Fig. 3—Simplified illustration of ohmmeter circuit.

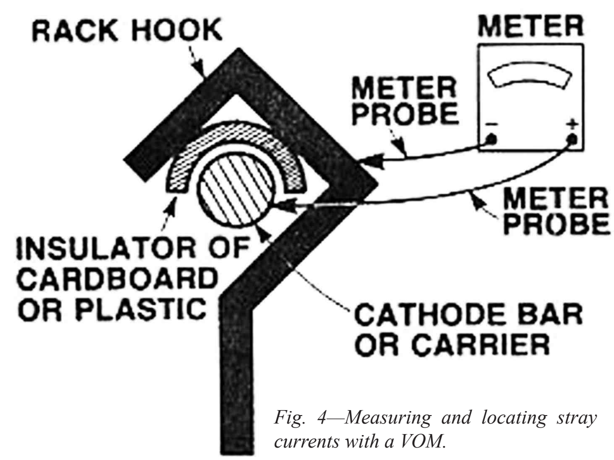
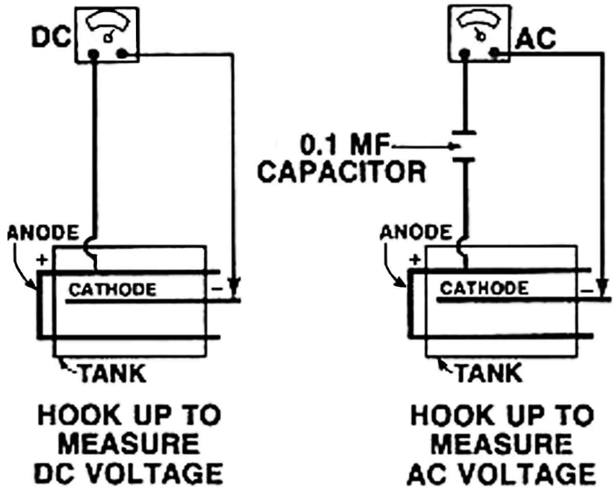


Fig. 4—Measuring and locating stray currents with a VOM.

1. Temperature (Higher bath temperatures require higher entrance voltages.)
2. Type of bath (conventional or proprietary)
3. Ratio of chromic acid to sulfate (Higher than normal ratios require higher entrance voltages.)
4. Concentration of proprietary catalyst
5. Size of racks
6. Concentration of chromic acid
7. Metallic impurities (Making no other changes, they generally result in the use of higher entrance voltages.)
8. Ripple

There are four important things to remember:

1. Voltmeters and ammeters are an absolute necessity on live leads. Otherwise servicing is impossible and proper adjustments for optimum results cannot be obtained.
2. Never assume that the live leads are functioning properly just because the meter pointers move. There is an approved manner of working that has just been described by simple time graphs, so take 5 min of your time and check their operation. They



$$\frac{\text{AC VOLTAGE}}{\text{DC VOLTAGE}} \times 100 = \text{\% RIPPLE}$$

Fig. 5—Measurement of DC and AC voltage in preparation for estimating percent ripple.

should parallel the graphs as outlined above with only minor deviations, depending on the equipment design.

3. As the rack bottoms out in the chromium tank, it should immediately contact the main rectifier. Long delays after set down very often cause streaky chromium deposits, as described earlier in the first part of this paper.
4. Just because you have operated satisfactorily using 2.5V for a period of time doesn't mean this will continue forever. Quite frequently, new values must be established as bath parameters change. Some of these parameters were listed earlier for your convenience and consideration.

Other problems associated with live leads are listed below:

1. Too low a live lead voltage - One might ask too low a voltage for what? Well, too low a voltage for the bath parameters that have been established as normal for your operation.
2. Should the voltage be too low on entering the chromium, a chromate film may form on the work and the result, when we try to plate over this, is a white streaking. This may occur in the low or medium current density areas and, under unusual circumstances, can also appear as a false burn. Where it occurs will depend upon the amperage involved, the time, the nickel activity and the condition of the chromium bath.
3. Heavily scaled anodes in the first station may also cause this white streaking. The voltage may well be normal, but the scaled anodes sharply reduce the plating current in the first station. The result is staining or streaking visible after chromium. The cure, of course, is cleaning these anodes with an approved anode cleaner since brushing is not too effective in removing thick adherent scale that so effectively acts as an insulator. If you doubt this, give a scaled anode a whack with a hammer and note the character and thickness of the scale that falls off, and be sure to wear your safety glasses. Where light scale on the anode is involved they can sometimes be brushed. Just remember to keep the anodes wet when brushing, as the dry dust from the anodes is hazardous.
4. Too high or too low live entry voltage (as discussed earlier).
5. Intermittent contact while the rack is descending into the chromium - This can be caused by dirty rack hooks, faulty contact on the live lead or ungreased rails or slide bars. The usual result is a so-called double contact burn. Watch the ammeter and voltmeter. They will indicate this intermittent contact.

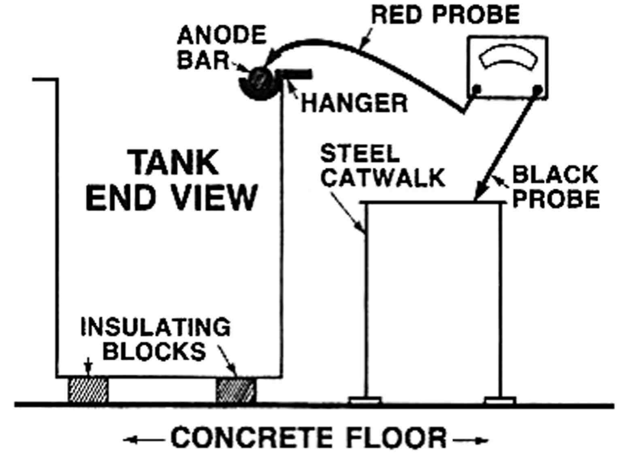


Fig. 6—Illustrating a common mistake in locating short-circuits.

These are the more common problems associated with this circuitry. There are many others that are variations or combinations of these and are better left for another time.

Other Bipolar Problems

In addition to the problems already discussed, another that occurs in nickel tanks results in poor adhesion from nickel-to-nickel. Should a rack or part lose contact during the course of nickel plating, some portion of the outer extremity will be subjected to bipolarity and passivation. When the rack finally makes contact again, fresh nickel is plated over the passivated area and poor adhesion occurs. This usually occurs as a result of dirty hooks, dry rails or poor racking techniques on light parts.

Plating on tank walls, heating coils or through a break in a tank lining are examples of other types of bipolar problems and stray currents. The possible division of current makes for some interesting conversation. Parts on the bottom of a tank can also become bipolar and as a result feed excessive current to the bottom parts on a rack. This can be disastrous when it occurs in the first station of a chromium tank. Not only will it cause false burn or burning, but since a portion of the fallen part is anodic, it will be dissolved electrochemically in the bath.

Occasionally you may see the old familiar art of using a bipolar auxiliary anode. When used properly they can be fairly effective. The use is usually limited to specialized plating jobs and rarely finds use in heavy production. There is quite a bit of known art on the subject, but very little has been committed to paper.

Introduction to the Volt-Ohm-Milliammeter (VOM)

We promised to discuss stray currents; ripple and the use of a VOM to troubleshoot electrical plating problems. It is only fitting that we delay this until we can investigate and understand just how a VOM works when used as a milliammeter, an ohmmeter or a voltmeter. Otherwise, its use in troubleshooting will have little meaning.

By way of general explanation, and before we consider its use, the volt-ohm-milliammeter (VOM) is a very common instrument used in electrical work, which you no doubt have seen your plant electrician use many times. It is readily available from your local electronics supply house, and comes in many different sizes and brand names, either digital or analog. By understanding basically how a VOM functions, you can think your way through a related electrical problem, disregarding those results that have no meaning, while collecting and evaluating those which are relevant to the problem. Space does not permit a long discourse on the use of a VOM. It must be assumed that you are sufficiently acquainted with the instrument to make measurements and have read the instruction manual. If not, it would be wise to contact your plant electrician for further help in understanding the VOM.

First and foremost, a VOM (volt-ohm-milliammeter) sees only one thing, namely current, and is actuated by one thing, current. This current is, admittedly, small, on the order of microamperes (µA). For example, consider an inexpensive analog VOM having a 20,000 Ω/V sensitivity (This is sometimes shown on the meter face.). Using the basic Ohm's Law, E = IR, where R = 20,000 Ω and E = 1.0V, I = 0.000050A or 50 µA for full-scale meter deflection. In other words, whether using this meter for measuring amperes, volts or ohms, it really is registering only micro-amperes calibrated in the above electrical terms and in accordance with Ohm's law (E = IR) where E = Voltage (V), I = current (A) and R = resistance (Ω). When measuring AC voltage, it is rectified to DC inside the meter and then translated into an AC voltage reading. In the case of the analog meter a special scale is used for AC readings. Digital meters have higher internal resistance and are more accurate and easier to use than the analog meter. The science of the two is similar and the information given above applies just as well to digital as it does analog meters.

If you should have occasion to look inside a VOM, the most you will see are resistors and multiple station function switches. These are 1% precision resistors and changing, say from one voltage to another, essentially switches in another set of resistors that are some multiple of the previous setting. This allows measurements of low to high readings, in terms of volts, ohms or milliamperes, depending upon the setting of the function switch.

For example, in measuring DC voltages, if we set the range switch at $3.0V_{DC}$, then any DC voltage-producing device, when attaining $3.0V_{DC}$ will show full-scale deflection on the meter face and the meter will be carrying exactly 50 µA. Now let's set the range switch at $300V_{DC}$. On attaining a reading of $300V_{DC}$, the meter will still be carrying only 50 µA at full-scale deflection. Higher quality meters, digital or analog, will have a higher ohm/volt sensitivity. This same situation holds true when measuring ohms or amperes on this instrument. For those of you who are interested in pursuing this subject further, your city library has books available that can expand upon this subject as far as you wish to go.

There are some general rules to be followed when using a VOM and most of these will be incorporated in the owner's manual. You should familiarize yourself with these before attempting to use this instrument.

If you suspect that high voltage could be present in a circuit that you intend to work with, always go to the highest voltage setting and then start reducing the setting until you reach the proper range, for safety's sake and to prevent meter burn out. Higher priced VOMs will have fuse protection.

In making ammeter readings, start with the highest setting and lightly touch or tap the probe to complete the circuit, thus making certain you are not beyond the meter range. Failure to do this could result in your hooking into a high voltage circuit and burning out the ammeter section or the meter itself.

Ohmmeter Section

Ohmmeter readings are not valid when external voltage of any kind is present. The prerequisite to an ohmmeter reading is a voltmeter reading. Not only is this necessary to prevent meter burn out, but any stray voltage will cause the meter to deviate above or below the correct reading. Properly performed, after any ohmmeter reading, the meter probes should be reversed. If the reading is the same, then the value is correct. Figure 3 illustrates this point.

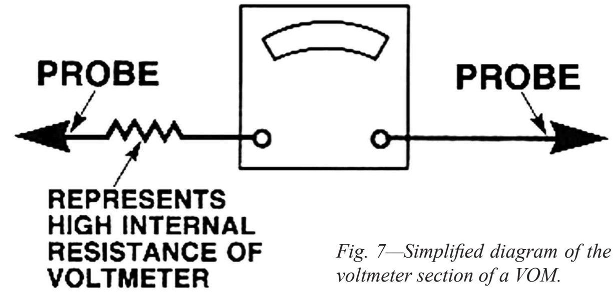


Fig. 7—Simplified diagram of the voltmeter section of a VOM.

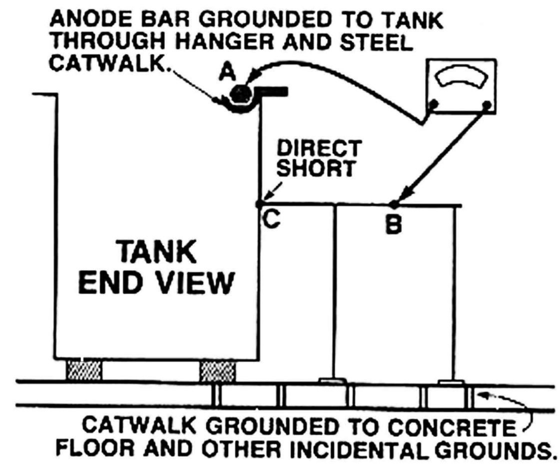


Fig. 8—Illustrating the detection of a short circuit by voltage measurements.

The ohmmeter section then is a micro-ammeter in series with a battery inside the case, a series of fixed resistors and a variable resistor for bringing the meter to zero before making a measurement.

Just to give you some idea of the effect of stray voltage, let's take an actual example. The ohmmeter was set at zero by shorting the probes and adjusting the variable resistor (Fig. 3). A resistance of 5Ω was inserted between the probes and with the needle pointing at 5Ω, an aiding voltage of +0.5V was added to the 1.5V battery inside the meter. The needle immediately moved to zero resistance or dead short. Then a negative 0.5V was impressed across the 1.5V battery and the needle jumped to 17Ω. From this you can see why a stray voltage would result in an inaccurate ohmmeter reading. A resistance of 5Ω is made to look like zero resistance in one case and 17Ω in another. This shift from 5Ω to zero and then to 17Ω may not seem like much until considered in terms of Ohm's law where E = IR.

To illustrate the effect of 5Ω of resistance, let us relate it to the operation of an $8V_{DC}$, 8000A rectifier and assume it to be operating at full voltage and amperage. Under these circumstances, R = E/I = 8/8000 or R = 0.001Ω. This would be the total resistance of the rectifier, bus bar and tank circuit. Now let us insert a 0.01Ω resistance in series with one of the bus bars, and the output of this same rectifier suddenly drops to 800A. Using Ohm's law, 8/0.01 = 800A.

So, remember that it is critically important to take an ohmmeter reading, and then reverse the leads. If the readings are equal, the value as shown is correct. If the readings are not equal, then external voltage may present and the ohmmeter readings cannot be considered useful.

Stray Current Source, Identification & Measurement

With this explanation still fresh, let's continue on with stray currents and their measurement and identification by a VOM.

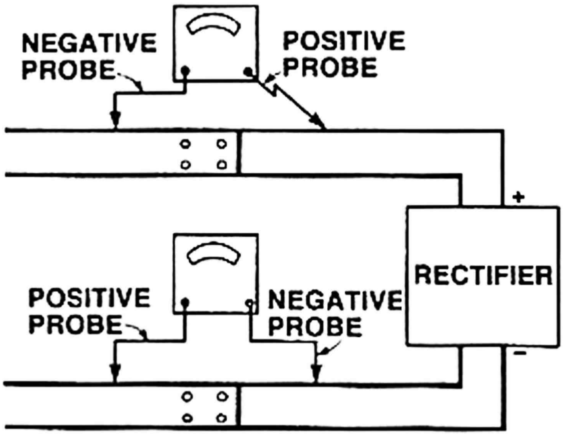


Fig. 9—Locating oxidized or loose connections using the low voltage DC section of the VOM.

An over-simplified and realistic definition of a stray current is a current in a place it should not be, doing something we do not want it to do. Of course this definition could also be aptly applied to a bipolar current. One method of differentiating between the two lies in the manner in which the current enters or exits the rack, whichever you prefer. In general, current, which enters a rack through the hook from an external source and exits via the medium of the solution to a normal or abnormal ground, would be termed a stray current. Conversely, current from the rectifier which enters via the anode, passes through an intermediate carrier such as a disconnected rack, break in the tank lining, part at the bottom of the tank, and exits by way of a live rack, would be termed a bipolar current.

If we carry this definition further, we enter into those parallel areas where a simple definition defines a basic principle, but must be expanded to explain the overlapping gray areas. For example, other intermediate (bipolar) carriers such as heating and cooling coils, can also be classified as bipolar since some object of metal is included in the current path and again the current exits via a live rack. Realistically, there are cases where a combined stray current and bipolar current form a division of current and that we will leave for the reader to isolate and define. With levity, one might say that when either becomes the cause of rejects, the best definition is "nuisance."

Secondly, and also a bit simplified, a stray current has to have an origin. It is not always possible to ascertain its source, but we can, in most cases, break the circuit and destroy its effect.

Normally, for a stray current to be harmful, it must be of such a polarity as to make the work positive or anodic, and it must be of sufficient intensity to pass an unspecified threshold value. This unspecified value would be one which causes rejected or scrap parts. For stray currents to exist, we must also have a conductor that could be in the form of:

1. Metal pipes
2. Uninsulated metal heating and cooling coils
3. Uninsulated hooks on a hoist line
4. Grounded superstructures or arms on automatic plating equipment
5. Current feedback from a rectifier to an accidental ground

Last, but not least, we must have a conductive solution. In all the above situations, if the tank contained plain water, it would effectively break the circuit in any low voltage DC stray current situation. High voltage stray currents are an exception, and can be readily identified momentarily after your hair stands on end. We can therefore state that stray currents need a conductive solution and a lead-in metal conductor.

It should not be forgotten that tanks, after an acid, a cleaner or a dragout recovery tank, may have enough salts to be conductive as well.

It will be characteristic of a stray current problem that both voltage and amperage will be present and both should be measured and considered. If only voltage is present, and the amperage is zero, as shown by an ammeter measurement in series with the suspected circuit, then you can normally discard that section as being troublefree. However, if voltage is present it might be wise to keep it in mind for the future since wherever voltage is present, it is a potential breeder of amperage. So, if you think you have a stray current problem, look for these electrical and physical conditions.

As a means of better understanding, let's take an actual example of a stray current problem between nickel and chromium on a return type automatic with which one of the authors was personally involved. The problem had been going on for about a week and appeared as a chromium whitewash or false burn. The tank sequence was as follows:

1. Nickel plating tank
2. Dragout recovery - lined tank
3. Water rinse - steel unlined tank
4. Alkaline activator (cathodic 4V) - steel unlined tank
5. Water rinse - steel unlined tank
6. Water rinse - steel unlined tank
7. Chromic acid activator, 22.5 g/L (3 oz/gal), proprietary chromium plating salts - Koroseal® lined tank
8. Chromium plating tank

This was a double-row machine and the occurrence was on the lower trailing corner of the rack, and only the longer racks were picking up this false burn. This immediately suggested a bipolar problem originating in the nickel. Live leads were operating properly, no parts on the bottom of the tank. Anode bags were in good condition, and adequate anode area was present. The nickel tank was ruled out. Voltage measurements were run on all tanks between nickel and chromium by attaching the voltmeter to the rack or arm and thence to the tank or the piping extending into the tank.

The rack and carrier in the nickel dragout tank had 5V positive in relation to a steel pipe touching the outside of this tank. However, the piping from the elbow into the solution was plastic. There was a possibility of a large break in the tank lining, shorted pusher or arm. But the milliammeter check read zero. Thus there was no problem here for the moment.

In order to run an ammeter check for stray current in the auxiliary tanks, an insulator was placed between the rack hook and the arm or carrier. Insert the VOM, previously set to milliamperes, observing the polarity and normal meter precautions. (Fig. 4). We followed the same procedure on all auxiliary tanks that indicated voltage and had conductive solutions with no results until we came to the pre-chromium dip containing 15 g/L (2 oz/gal) CrO_3. Here we measured a positive 2.5V from the rack to a badly corroded steel water pipe with no insulator.

Next, an insulator of cardboard was inserted between the rack hook and the carrier and the meter indicated 0.5A with the rack negative. Substitution of a plastic pipe for the steel pipe solved the problem. The rack was negative to the meter only during this isolation. On removing the insulator and placing the rack back on the carrier, that entire section again was positive to the negative water pipe.

In retrospect, this tank was originally an air agitated running rinse tank, changed over to a pre-chromium dip some six months before with no problem. In some manner not known, the circuit was completed the week previous and trouble occurred. The position of the false burn on the racks was a result of the steel pipe being positioned under the trailing corner of the rack and causing rejects only on longer racks since they were much closer to the pipe. Why smaller racks were not affected on the front is not known, but it could have been due to the heavy rust and corrosion on the vertical section of the steel pipe.

Approximating Ripple Voltage Using a VOM

Some 43 years ago, one of the authors happened to be looking over the shoulder of a radio serviceman watching him use a VOM to measure ripple in the power section of a radio set. With his help, and some experimentation, we were able to come up with some standard procedures and rules for estimating ripple voltage in a faulty plating rectifier. It has been of enormous help throughout the years in quickly deciding whether excess ripple from a faulty rectifier was a factor or not. Whenever the meter indicated possible ripple problems, then an oscilloscope was used to confirm the results.

The test using a VOM takes about a minute and is performed in the following manner. First, place a load in the tank and raise to the normal plating amperage. Set the meter within the proper range and measure the DC tank voltage (Fig. 5). Record this value. Then set the meter to the lowest AC range. Place a 0.1 μF capacitor in series with one of the leads and reconnect to the anode and cathode at the tank. Most, but not all, digital VOM's have an internal capacitor in which case the external capacitor is not required, check the schematic diagram in the manual that came with your meter. Record the AC voltage. The purpose of the capacitor is to block out completely any DC voltage, thus allowing the meter to record only the AC or ripple portion. The voltage rating of the capacitor is unimportant and can be any value that exceeds the DC tank voltage. The capacitor can be hooked into either meter probe by attaching alligator clips to the leads on the capacitor. In most cases, it is good procedure to leave the voltmeter hooked up in the AC mode (Fig. 5) and raise and lower the voltage and current on the rectifier, observing the results. For example, a tap switch rectifier might have a bad tap in one or more positions only and it could be located by this method and a correction made. The ripple voltage can then be calculated by the formula given in the figure.

There are some ground rules that should accompany this discussion:

1. All voltage readings should be taken at the tank, and not near the rectifier, since the transformer can induce extra voltage into some meters.
2. Once they are clipped into place for the AC measurement, do not touch the bare metal of the clips or probes, since the lighting system can induce additional voltage into the meter through your body, causing a high AC reading.
3. This is only an approximation, and the AC reading you obtain will depend upon the symmetry of the ripple waveform.
4. Suspect situations should be resolved by use of an oscilloscope.

The extent of harm that ripple can cause is related to several conditions, listed below:

1. Magnitude of the ripple voltage expressed as a percentage
2. Type of bath - Baths containing fluorides are more tolerant than conventional chromium solutions.
3. The symmetry of the waveform - For example, is it smooth or does the waveform have sharp spikes? As an example of high ripple and good symmetrical waveform, three-phase half-wave rectifiers were used in the past on chromium baths with reasonable results. Theoretically this amounts to 18% ripple. However, it should be noted that in those instances where the three-phase half-wave rectifier was replaced by a three-phase full-wave unit, the coverage increased and the bright plate range was improved.
4. Length of dwell time at the lower voltages where the per cent of ripple is quite often the highest (with some types of rectifiers).
5. Temperature of the bath - Lower temperatures appear to have more tolerance to ripple.
6. Contamination in the chromium bath - Metallic contaminants affect conductivity and, in most cases, the proprietary catalyst level thus making the bath more sensitive to ripple.
7. Type of system, *i.e.*, hand line, hoist line or full automatic

The visible effect of excessive ripple in bright chromium directly amplifies even small problems in the chromium system. At the same time, you may have burning and gray chromium accompanied by a fall off in coverage, depending upon ripple severity. In the case of hard chromium, the tendency is for gray deposits, softer chromium, and fewer crack lines per inch.

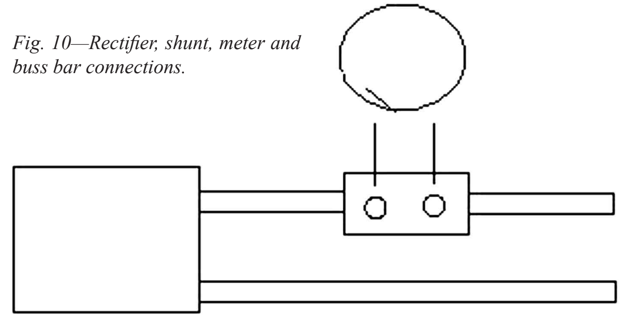
The per cent of ripple and the ripple wave form will govern the degree to which the plated work will be adversely affected and no one can point to a precise percentage and state that this value cannot be exceeded. The critical point is where unacceptable work is obtained. This will be a very sensitive area in some situations and of little consequence in others.

Using a VOM to Locate Short Circuits

The voltmeter sections of a VOM are important tools in troubleshooting electrical problems in plating. As stated earlier, they should always be used to check for voltage before making ohmmeter or ammeter readings.

The trick in using the voltmeter is in understanding how it works and the validity of the voltage reading as related to a suspected problem. For example, you might take a voltmeter reading from an anode or cathode bar to a steel catwalk and obtain a strong DC voltage reading. The first reaction might be that a short exists between the two where, in essence, the exact opposite is probably true (Fig. 6).

Fig. 10—Rectifier, shunt, meter and buss bar connections.



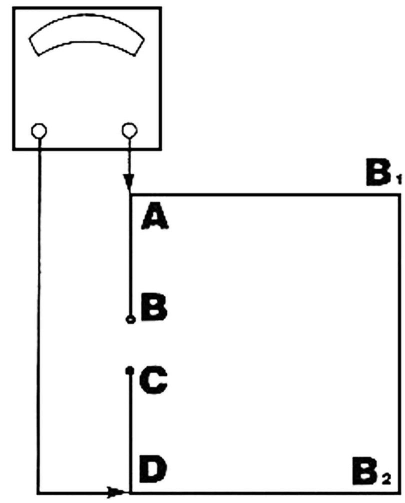


Fig. 11—Illustration of how an ohmmeter can be in error.

As you can see, the tank is insulated from ground, whereas the catwalks are at ground potential. Again, recall that this analog meter movement requires only 0.000050A or 50 µA to activate to full scale. This small amperage would actually be dissipated through the many grounds and, in all actuality, probably the only electrical connection between the anode bar and the catwalk is the one you just made when you hooked the meter in the circuit.

Truly, you should be more suspicious if no voltage, or a voltage much lower than the tank voltage, is registered on the meter since it can indicate a direct or high resistance short. A zero reading indicates two points of equal voltage (potential) or complete electrical isolation. Of course, it goes without saying that one probe attached to the bus bar with the other suspended in the air would also be a case of complete electrical isolation. However, this type of isolation of equipment rarely exists in plating.

Before considering why a no voltage or low voltage reading should be considered suspicious, remember that the DC voltmeter is basically a current responsive device with two wires (probes) and a high internal resistance in series with the meter (Fig. 7). Let us redraw the circuit of Fig. 6 to show the catwalk touching the tank (Fig. 8) to form a direct short.

If the meter probes were now attached to points A and B (Fig. 8), and assuming a direct short as noted, the meter would read zero or close to zero. Why? Because something in the system is shorted out, the meter would therefore measure zero voltage or zero potential drop across the direct short as shown. Being practical, this situation usually exists for a short time only since any direct shorts would immediately start smoking or become hot enough to notice.

If neither of the above is noted while they are active, then the short circuit either burns itself out, or the burned and oxidized metal becomes a high resistance and now we would note a voltage reading on the voltmeter. The lower this voltage reading in comparison to the tank voltage the higher the current passing through the oxidized or resistive contact point.

For example, if the tank voltage were 8V (and considering only the above illustration), and we measure a 1V drop across A and B, there is considerably more current flowing through the alleged short circuit than if we measured 6V since the voltage and current division of this parallel circuit are inversely related. Remember, the meter forms a parallel circuit with the alleged short circuit.

How would one run down a short circuit and correct it? First is just to use good common sense. Look for metal piping or bus bars touching equipment that could be held accountable for this and then place insulators in the suspected areas. Assuming this fails, we then revert to the ohmmeter.

Just remember that voltage cannot be present if a true reading is to be obtained and that after each reading the ohmmeter leads should be reversed in accordance with earlier instructions. You will also find that ohmmeter results are generally less confusing when taken with all DC equipment turned off. Probably the better way to check for short circuits and in some cases stray currents, particularly on automatics, is to connect the positive lead of the VOM to the anode bar, observing the correct polarity, and then touch or connect the other lead to the super structure. Be sure you touch bare metal. Some paint scraping may be necessary. Record the voltage reading, then connect the negative lead to the cathode bar and touch the same spot on the superstructure with the other lead. Record this voltage. Finally, measure the tank voltage at the anode and cathode bars. You now have three voltage readings. This should be performed on both the nickel and chromium tanks. For example, consider that the tank voltage is $8V_{DC}$, and the reading from the anode to the superstructure is $4.5V_{DC}$ (no problem there; good electrical isolation) and the reading from the cathode to the superstructure is $1.5V_{DC}$ or lower. Then any short that may exist is still likely to be in that circuit. It may or may not be a problem. Remember that these voltage readings are not absolute but relative to the tank voltage. If you do have a problem such as whitewash or staining after chromium plate, then you should start changing insulators in the nickel and chromium tanks and strongly consider doing the same for the other electrified tanks in the system. Shorts in any tank can often affect the quality of the plating. Remember the superstructure is a common ground. These statements would mostly apply to automatics having the cathode rail directly over the tanks. Side arm machines are a little different and the problem usually is a shorted arm. To check them use an ohmmeter at the lowest setting and stand at the load-unload station and check the resistance from the hanger to the super structure or drive chain which is common to the superstructure as well. A good arm should show a very high resistance while a bad arm will have a low resistance. It is very important that the probes make good electrical contact to the metal of the superstructure.

Locating Oxidized or Loose Connections

Oxidized or loose connections in the bussing from the rectifier to the racks cause increased resistance and voltage losses. These can be isolated by the use of the low voltage section of the DC portion of the VOM, which now becomes a millivolt meter.

For example, assume an oxidized joint where two lengths of 0.64 x 10.2 cm (1/4 in. x 4 in.) bus bar are joined together. Put a load in the tank and set the rectifier voltmeter at half of the rated output voltage. Measure the DC millivolt drop as shown in Fig. 9. Assume this to be 200 mV. Since this is at half load, we would multiply this figure by two to obtain the full load loss across this point. This would be 400 mV.

What does this mean to the plating foreman or engineer? Essentially, it warns of a bad connection and states there is a 400 mV loss because of it. If you normally ran at 8V and 8000A when the connection was good, you would now need 8.4V to obtain the 8000A, and would be generating 3.2 kW more in heat loss. Multiplying 3.2 kW with the cost of electricity (given in your electric bill as $/KW) will immediately translate into money unnecessarily wasted. You can also be assured that the connection will probably become worse as time goes on, and prompt maintenance should be considered.

If we work this back in terms of Ohm's law where $E = IR$ (volts = amperes x resistance), we would find that the added resistance or voltage drop would result in a loss of about 400A if we maintained the 8V setting on our rectifier.

You can do this on each and every joint, isolating and repairing those of a questionable nature. The common sense factor is very important at this point. Remember, you should have a 50 mV drop across a 50 mV shunt at full rated ampere output of the shunt. So let this be a guide in determining what millivolt reading across a bad connection is truly harmful.

Note the polarity of the probes when used on the negative bus bar as opposed to the positive bus. If more accurate readings are needed in the very low DC voltage range, then a standard millivolt meter may be used. Remember, it takes 1000 mV to equal 1V. It is very important that the probes make good electrical contact, so file or sandpaper the contact points. Otherwise the resistance of the oxidized layer between the probe and the bus bar will also be included in your reading.

Checking Rectifier Ammeters

In order to check the operation of a rectifier ammeter, locate the shunt in the bus bar and read the millivolt and amperage ratings stamped into it. This is on the flat part, but may be obscured by corrosion, so quite often a little sandpaper is necessary. This rating is generally 50 mV although you may find some at 75 or 100 mV.

You should also find two screws (clean them), one on each end of the shunt with wires attached. These are the ammeter wires. Merely attach the leads of the VOM to these screws, observing the correct polarity and read the DC millivolt drop. If this is a 50 mV shunt and the ammeter leads and shunt have been calibrated properly, and if the VOM is capable of reflecting this low voltage drop, you are now in a position to check the accuracy of the ammeter.

For example, if this is a 5000A shunt with appropriate meter and rectifier, and the VOM indicates 50 mV, then the ammeter on the rectifier should read 5000A. If the VOM indicates 20 mV, then the ammeter should read 20/50 x 5000, or 2000A. If the shunt is located inside the rectifier cabinet, obtain the help of a qualified electrician. A simpler method would be to open the cabinet housing the voltmeter and ammeter, attach the leads of the VOM to the two posts on the rectifier ammeter, observing the correct polarity, use the reading from the VOM and proceed with the calculations shown above.

Let's now discuss the analog ammeters used on the front panel of most of today's rectifiers. This type of ammeter has a printed scale showing the maximum output. It may be interesting to know that there is no real difference between an analog front panel ammeter for a 500A rectifier or one for a 5000A rectifier or any other amperage rating for that matter. Regardless of the scale shown on the front of the meter, full-scale defection occurs with 50 mV applied. The 50 mV comes from the meter being connected to the shunt as shown in Fig. 10. The shunt is nothing more than a precision resistor capable of carrying the maximum current of the rectifier. A 50 mV rating is the standard in the industry. Here's how it works. Calculate the resistance of a shunt for a rectifier at full output rated at 5000A using Ohm's Law. Resistance = Voltage (E) / Amperage (I); R = 50 mV / 5000 A = 10 μΩ. By Ohm's law, 5000A through a shunt with a resistance of 10 μΩ has a voltage drop across it of 50 mV. Since the ammeter is connected across the shunt, the 50 mV drop across it causes full-scale deflection of the meter at full output, *regardless of the amperage rating of the rectifier*. In other words any standard 50 mV ammeter can be used on any rectifier with a 50 mV shunt. It is merely a matter of changing the numbers on the face, which you can do by pasting a strip of paper along the top of the meter and marking off the divisions at zero, one half and full. There are some exceptions but for the sake of simplicity, we will overlook them. If you have questions regarding this refer to the manufacturer.

Miscellaneous

Should a piece of piping or metal heating coil be suspected of carrying current, break the joints and check for amperage, not only between the two sections, but from each section and to other possible grounds. Wherever possible, insulated joints should be used to block off current flow in critical areas using accepted electrical practices.

Although rare, direct shorts from an AC system concurrent with the DC system can modify the original waveform to such an extent as to cause problems, and the geographical location and polarity of a tank in another area can also result in stray currents of a harmful nature, thus compounding problem solving.

In some cases, the electrical measurements necessary to establish the source of a problem are best left for a shutdown period. During this period, rectifiers can be turned on or off one at a time until the source is found. At this point you may have found the source, but not necessarily the point at which the current passes from one area to another, so ohmmeter or continuity checks are now necessary.

Even when you have graduated far enough into the problem to consider using an ohmmeter, it can lead to some false conclusions. For example, in one problem, which is well remembered, an ohmmeter reading indicated a dead short. What we didn't realize until much later was that there was an obscure parallel circuit along with the suspected one that we were measuring, as illustrated in Fig. 11. We thought that the ohmmeter was measuring zero resistance or a short circuit in the broken circuit A-B-C-D where it was really the A-B_1-B_2-D circuit being measured. These two circuits were a combination of the bus bar, tank and some external piping. In this case, it was necessary to break the bus bar to the rectifier in order to isolate the suspected circuit.

The importance of Ohm's law should not be overlooked when using an ohmmeter. For example, 8Ω in parallel with an 8V, 5000A rectifier would pass only 1A at 8V. One ampere of stray current could be deadly, but a 1A leakage current in a system carrying hundreds or thousands of amperes, is virtually nothing. This, of course, again involves the common sense factor.

This brings us to the final point of this paper and why it was entitled "More of Those Elusive Little Amperes." Consider that in practically all the foregoing discussions we were dealing with small current values in comparison to plating amperage, probably in most cases way less than 10A. The damage can be amazing and the fundamentals interesting.

Conclusion

We must apologize for so lightly touching upon a subject that has many parallel areas. We are aware that much has been omitted but sincerely hope that what has been presented is clear and may, in some way, help you understand and resolve related problems.

This article is not meant to get you started on an electrical witch-hunt, but rather result in your consideration of electrical parameters when other methods fail to resolve a problem. In many cases, using the electrical information contained in this paper can solve problems that do not respond to chemical and physical methods of attack.

Remember, about 90% of your problems will be resolved by going no further than the fundamentals such as metal preparation, good bath maintenance and so forth, so take care of these first unless logic and experience definitely identifies the problem as an electrical one.

About the Authors

V.E. Guernsey obtained his BS in chemistry from Alma College, Alma, MI, furthered his education in chemical engineering and completed a two-year course in electronics. He spent three years in research and process development on continuous wire plating for Western Electric, Baltimore, MD, followed by 11 years in job shops. Guernsey was technical service engineer and technical service manager for 16 years at M&T Chemicals, Inc. He subsequently served for three years in Latin America as plating manager for M&T Chemicals, Inc., residing in Sao Paulo, Brazil. In 1972 he joined the Udylite Company as product manager. He then moved on to McGean Chemical Company, Inc., as marketing manager. Guernsey was an active member of the Detroit Branch of the AESF and upon moving to Broken Arrow, OK, became a member of the Tulsa Branch. In 1983 he started in business as Electroplating Consultants International and was joined by his son, Jeff, in 1987. Guernsey serves as the technical advisor for the business.

Jeffrey Guernsey attended Ferris State College in Big Rapids, MI. He served for 8 years in the United States Coast Guard as an electronics technician in the Great Lakes area and New York City. After leaving the USCG he joined Electroplating Consultants International and has obtained his CEF-SE and an Associates degree in chemistry and is currently Chairman of the AESF Tulsa Branch and President of Electroplating Consultants International.