The Complete Spectrum Guide to Top Quality Anodizing: Maximizing Efficiency and Energy Savings

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A practical review covering the spectrum of energy savings and efficiency improvements for the Type II and III Hard Anodizing Processes will be presented. There are five specific areas which, when operating together, can give anodizing shops from 20 to 50% savings. The areas include: (1) modifying anodizing bath parameters, (2) using a unique pulse ramp procedure to start each tank load and (3) using a new capacitance shunt discharge system to initiate anodizing at a lower voltage. Data logger graphs will be presented from production facilities to verify all data presented including energy savings and quality standards.

Introduction

This article will present and review the important factors with which the anodizer should be concerned in order to improve quality to a high degree while, at the same time, improving efficiency and saving energy. A major part of the article will center around the complete spectrum of control factors at the anodizing tank. One very important fact needs to be emphasized and remembered throughout this article: Unless the anodizer familiarizes himself with and uses all of the factors together as they are noted here, the true great efficiency and energy savings will not be realized. There will also be one practical new development presented which is very important as related to all other factors operating together to initiate anodizing at a very low voltage.

Let me go back for a short time so that the reader can see where I'm coming from and better understand and appreciate this article. My past experience in the anodizing field has been (1) problem solving (*i.e.*, troubleshooting) and (2) education, such as process procedure development centered on quality control. In the early years, or maybe half of my 49 years' of experience, everything was centered on quality. However, for the last 15 years in particular, it seems like people want it produced faster at the lowest possible price or good enough to get by, along with energy savings and efficiency - but only when it's easier and costs less. This can also extend to the supplier products which are purchased with reduced prices and minimum usage ranges established to increase profits but not quality end results. Therefore, problem solving and education have been necessary on numerous occasions because the factors and information discussed in this article were not all used together as a Complete Spectrum Package.

After reading the previous paragraph, keep the following in mind throughout this article. If the proper steps are taken (using all information presented here) to improve quality and reduce process time, the efficiency and energy savings will be there and cost effectiveness will be realized. These steps will be analyzed in various areas of the anodizing process at the process tank. Specific factors will be emphasized in each area.

This article will focus on five specific areas as related to quality, efficiency and energy savings:

1. Chemistry: Specifications and modified formulations
2. Power supply electronics
3. Manual / Auto control procedures
4. Design factors at the anodizing tank.
5. New developments

The conclusions in the last section will note the 25 to 50% (and greater) efficiency savings which can multiply from one area to another.

Chemistry: Specifications and modified formulations

Basic sulfuric acid formulation

Some of the specification ranges for sulfuric acid are too high for efficiency, too low for various alloys and too wide for quality and energy savings. Our research and development pioneers set up ranges for Type II and Type III anodizing 50 to 60 years ago which in many cases are not acceptable to meet the quality and efficiency standards needed today on a continuous basis in production. These old basic ranges were passed on by technical writers who

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were not aware of technical developments or simply took the easy way out — copy that which worked in the past. This has developed into a real problem. Therefore, after careful evaluation, universal ranges which meet all major specifications will be presented here in order to address this problem.

Various operating ranges for sulfuric acid have been reviewed which date back over 50 years. We have also reviewed numerous Commercial and Military specification ranges in operation.[1-6] Finally, after reviewing over 25 of the latest high-tech Aircraft, Aerospace, Military and Commercial specifications, we are presenting the best operating ranges for Type II sulfuric and Type III hard anodizing. The operating range chart in Table 1 lists all the widest sulfuric acid ranges pulled from the various specifications. We have noted the best operating ranges underlined for Type II — overlined for Type III and combination Type II - III hard anodizing (Type 23).

The anodizing industry needs better quality Type II coatings which in many cases should meet the requirements for hard anodizing. Also needed is a superior hard anodize, far greater than the present national average. Engineers have been turning away from hard anodizing on certain alloys because many anodizers have been producing soft coatings and/or burning alloys like 2011, 2024, 2219, 7075 and 7050.

Additives, modifiers and accelerators

This is one area where quality, efficiency and energy savings can really be improved. I have researched and reviewed this area for decades dating back to my first patent application in 1962.[7-11] The additives are not being used at the proper concentration. The highest aircraft specification range is 4 to 5% for the Multipurpose Anodizing Electrolyte (MAE) called out in Boeing Specification BAC 5821. However, most additives, similar to MAE, should be used in the range 5.0 to 7.5% and higher.[12-13]

Table 1
Anodizing tank operating ranges

Free Sulfuric Acid	**Type II – III - 23** (11.0 - 13.5 - 15.5) {5.0 - [10.0 - (11.0 -13.5 - 15.5)] - 20.0 vol%} **Type II** [10.0 - 11.0] **Type II – III – 23** (20 - 25 - 27.5) 18 - 20 - 25 - 27.5 wt%/vol **Type II** (18 - 20) **Type II – III – 23** (200 - 250 - 275) 180 - 200 - 250 - 275 g/L **Type II** (180 - 200)
Sodium Bisulfate	3.0 to 7.0 wt%/vol
Additives	2.0 - 5.0 - 7.5% - (8.0 - 15.0%; Not needed with modifiers)
Modifiers Accelerators	1.0 - 2.0 - 3.5% (Modifier as presented in Ref. 13)
Temperature	**Type III** (35 - 55) 20 - 30 35 50 55 70 85 → 110°F **Type II - 23** (70 - 85)
Aluminum	3.8 - 8 - 10 - 15 - 20 g/L max.
Air Agitation	2.5 - 3.0 - 5.0 CFM/ft^2 of solution surface
Current Density (A/ft^2)	**Type III** (30 - 50) 18 < 20 - 25 - 30 - 35 - 45 - 50 - 60 - 75 - 125 **Type II** (18 < 20 - 25)
Hard Anodizing Rate (Type – III – 23)	1.0 mil, 10 to 20 min 2.0 mil, 20 to 35 min 3.0 to 5.0 mil/hr, 0 – 15 – 20 mils and greater (special process)
Type II Anodizing Rate (Type – II – 23) Type 23	CL–1 Clear (0.2 to 0.4 mil)…..10 – 15 min (20 – 24 Volts) CL–2 Dyed (0.5 to 1.0 mil)….. 20 – 35 min (20 – 24 Volts) 1.5 to 2.0 mils, 30 to 50 min (20 to 24 V) (dependent on alloy)

We should also realize that all additives are simply not the same. Some are in fact quite different. This can be verified by a simple quantitative redox titration to simulate the heat absorbance in the pore structure during the anodizing process. In addition, the increased conductivity and anodic coating formation early in the anodizing cycle can be realized by comparison.

There are modifiers and accelerators now available which can be added to existing additives to increase efficiency significantly and save energy by absorbing excess heat in the pore structure during the anodizing process so that the anodizing tank can be operated at higher temperatures up to and over 85ºF.[8-9]

If you run most anodizing additives at 5.0 to 7.5%, four improvements will be noted:

1. Faster initial anodized coating formation
2. Brighter dyed coatings.
3. Improved final microfinish.
4. Lower Voltage and/or Amperage (Dependent on the active additive/modifier concentarion)

Please note the additive and modifier concentration ranges specified in Table 1.

We should also note the ranges for temperature, air agitation, current density and aluminum which have been underlined and overlined according to coating type. The anodizing rates will be discussed later. The sodium bisulfate can be added for special coating applications to replace high sulfuric acid (to be discussed later).[10]

It should be stressed here that two ranges have been line indicated for Type II and III anodizing respectively. However, both Types II and III can be processed with the same formulation range as indicated.

Finally, I do have one suggestion for those who have the space and finances for a unique set-up to take advantage of maximum quality and efficiency. First, set up two separate tanks for Type II and Type III coatings, then two standby solutions to be used for transfer and/or adjustment. With this system, you have available four different process ranges which can be changed and/or adjusted quickly, within 30 minutes. Any aluminum alloy can now be processed with superior quality and maximum efficiency. I actually set up one particular system like this which was very successful. Standard two-mil hard anodized coatings can be produced on any and all alloys in 20 to 30 minutes with superior quality.

Power supply electronics

Rectifier types

Standard anodizing rectifiers are the full-wave type and should have both constant voltage (CV) and constant current (CC) controls represented by two knobs on the remote control panel located near the process tank. Rectifiers with silicon controlled rectifiers (SCR) in the secondary are preferred and more efficient for the Type II and III anodizing processes. Secondary SCRs perform both rectification and control simultaneously, giving a sharp SCR turn-on-time which will increase efficiency during the ramping cycle. The voltage requirements for Type II and III rectifiers should be as follows:

- Type II 24-30 V
- Type III 75-100 V

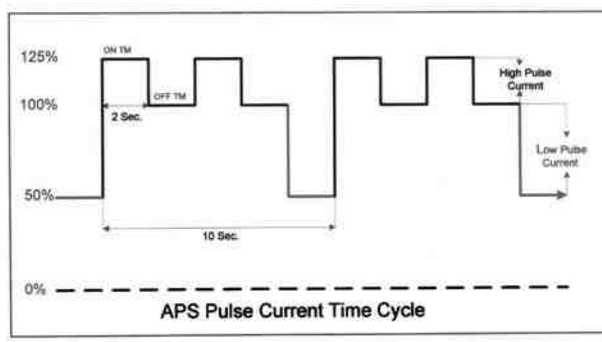
Special secondary half-wave rectifiers have been used very successfully for both Type II and Type III anodizing with excellent efficiency and energy savings.[1,9] The half-wave rectification works very well together with specific additive and modifier chemistry when processing difficult alloys like 2011 and 2024. However, half-wave rectifiers *should not be used* for chromic acid anodizing. Use only full-wave rectification for chromic acid anodizing.

The rectifier voltage specifications should always be 10 to 20% higher than maximum continuous production requirements. The current should not exceed 85 to 90% of the rectifier manufacturer's rating due to the consequences of heavy power output and pulse time on a continuous basis. Even though people may disagree, I have found this to be important when considering rectifiers from all leading suppliers and manufacturers.

Pulse specifications

High frequency pulsing is applicable to only very high current density requirements. Slower low frequency pulsing has been found to give the best results with energy savings on both Type II and III anodizing.[7-9] There has been a 20 to 25% or greater savings in power noted in numerous cases. Pulse parameters are all centered around slow (very low frequency) high and low pulse times so that we can take advantage of both relaxation and recovery times.[8] Pulse specifications are listed in Table 2 and its accompanying waveform graph, with additions and revisions.

Table 2
Pulse specifications with accompanying waveform graph



PSR Dwell Time (0.5-3.0 min.
(Data Logger and Graphs Available)

Pulse Time Cycle/Duration	10 – 30 sec
HP - High Pulse Specifications	
HP – On Time	0.5 – 4.0 sec
LP – Off Time	0.5 – 4.0 sec
HP Current	10-25-50% Above Operating Amps (During Ramp Period)
LP - Low Pulse Specifications	
LP – On Time	0.5 – 4.0 sec
LP – Off Time	Total HP Time Cycle
LP – Current	25 – 50 % Below Operating Current
PSR - Pulse Step Ramp Specifications	
PSR – On Time (Dwell)	0.5 – 30 Min
PSR – Off Time	Total HP/LP Time Cycle

Manual / Auto control procedures

The process procedure factors, methods and techniques reviewed in this section are very important for the production of high quality anodizing with maximum efficiency and energy savings. *It cannot be overemphasized that they should be used together as a total package*. Be sure to use everything in this section *for both Type II and III anodizing*. If this is done as a complete package, good results will be evident immediately with the first process run. Anodizers should have periodic refresher training (monthly or as needed) to reinforce these procedures.

Pulse step ramp

We have already stated that very high frequency pulse systems do not give the best end results. Slower pulse interval time (low frequency) is most important during the ramp cycle. Pulse time must be slow (0.5, 1.0, 2.0 or 4.0 sec) to allow for recovery time and maximum current efficiency. The high pulse or current amplitude can be 10, 25 or 50% of the amperage reading for both Type II and III anodizing during the entire ramp cycle. Pulse ramp has been proven to work effectively in most hard anodizing systems. However, pulse-step ramp (with the addition of steps or dwell periods) has been proven to be extremely beneficial in both Type II and Type III anodizing. The steps or dwell periods may vary from 0.5 to 4.0 min, depending on the alloy. Please note the following example, as illustrated in Fig 1.

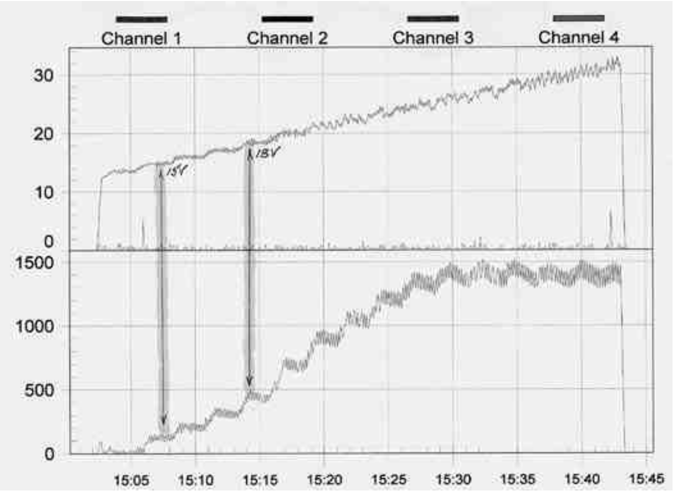


Figure 1—Data logger graph of pulse step ramp regime.

The amperage was in the pulse-step ramp mode to 1500 A. There is good ampere decay to 1300 A, including low pulse during constant current density. The wide step time range can be further defined by these suggested operating ranges for different alloys:

- Type III (Hard): 6061 — 0.5 to 1.0 min steps
  2024 — 0.5 to 1.0 min steps
  (with 1.0 to 3.0 min steps in the critical zone)

- Type II — III: 380 Die Cast — 2.0 to 4.0 min steps
  (Due to current drop-off not to exceed maximum rectifier voltage)

Charts and specifications are available (upon request) for processing all alloys (2000 – 8000 Series), including die cast materials like 380.

The total process ramp time is a key issue here along with starting and ending parameters at the constant or final running current density. Type II sulfuric anodizing should be ramped in the voltage mode over an approximate 10-min period to insure better dye absorption along with maximum sealing capability.

- Raise voltage manually to 10 to 12 V.
- Auto ramp (10 min) to 20 to 22 V.

These approximate values will produce 0.2 to 0.5 mil of Type II anodizing in 10 to 15 min, meeting the requirements of MIL-A-8625 F, Class-1 as well as most other sulfuric anodizing specifications.

Maintain constant voltage for 20 to 30 min and a final anodizing coating of 0.6 to 1.0 mil or more will be formed which meets the requirements of MIL-A-8625 F - Class-2. Maintain constant current density for a total of 45 to 60 min and a final 2.0 mils or more should be produced which meets the requirements for Type II and III anodizing per MIL-A-8625 F.

Hard anodizing should always be ramped in the voltage mode so that the amperage developed at a specific voltage is not limited from its naturally steady state (except in the case of surges which are controlled by short pulse ramp steps of 0.10 to 0.25 V). This technique is important. The voltage should always be ramped in short pulses (0.1 V or more) but never exactly linear. The voltage is ramped (0.5 to 1.0 to 1.5 V/min) to a specific amperage or total running constant current density (30 to 35 to 45 A/ft^2). The current may be alarm set or limited at two or more different set points during the ramp so that the work in process may be checked. This can be done with carefully programmed PLCs (process logic controllers) which, of course, depends upon the programmer and the procedures set up by the hard anodizer, his experience and his ability to run various alloys. However, an economical digital process controller or relay meter with two alarm set points is quite satisfactory. With some good professional training, the two alarm set points should be satisfactory for all alloys, including 2024 and 7075. There are relatively inexpensive data loggers with real time graphs that can be very helpful when running alloys like 2011, 7050 or A-203. Special pulse ramp procedures are available which are too detailed and lengthy to be included here.

A basic pulse ramp cycle, to and including constant current density, is outlined in steps as follows:

1. Load parts into the anodizing tank; maintain low voltage (3 V) during loading.
2. Manually increase to 10 to 12 V or 10 A/ft^2 [25% of Running Constant Density (RCD)].
3. Turn on / Set auto controller to 1.0 V/min.
4. Pulse-step ramp to running constant current density.
5. Continue constant current density to end of cycle (Cycle completed by time/A-hr/voltage).

Again, please note the Data Logger graph of Fig. 1.

Constant current density

This is an area which is simply not being used or properly used by most anodizing facilities. Constant current density should be used for both Type II and III anodizing, reducing process time by 25 to 50% in many cases. The following suggested revised ranges are the results of in-process production tests and records as related to quality, efficiency and energy savings.

- Type II Anodizing — 18 to 22 to 25 A/ft^2
- Type III Anodizing — 30 to 45 to 50 A/ft^2

When processing Type II anodizing, the anodizer shou ld use pulse-step ramping to a predetermined voltage (18 to 22 V) where the current density will be within the upper limits of the desired range (18 to 25 A/ft^2) without measuring each part in the tank. When the amperage drops off or decays due to anodic coating formation and build-up, the voltage is then increased to bring or raise the current back to the Running Constant Current Density (RCCD).

Considerable quality and efficiency is gained or lost here depending on the constant current density being used properly, including amperage decay, which will be discussed in the next section.

Amperage decay - amperage drop-off (ADO)

Anodizing should be run within a constant current density range - not at one exact value or set point - so that the current can decay or drop off (ADO) as the anodic coating builds up. The amperage decay can be controlled (5 to 10 to 15%) for different alloys by setting the current between two adjustable set points using a process controller or relay meter. When amperage decays to the low set point, it is increased by automatic control to the constant current density set point. This can also be seen in Fig. 1. This amperage decay principle should always be used in the constant current density range for all Type II and III anodizing. There are benefits to be realized here all related to quality (hardness) and energy savings. One obvious energy saving is the reduced final voltage for hard anodizing. Amperage decay has always made a considerable improvement whenever it is used to even a limited degree in the constant current density range.

Recorders, graphs and data loggers

Real time graphs of parts in process should be available to the anodizer for Type II and III anodizing along with adjustable amperage check points on the graph. The operator can observe and check a production job through the complete voltage-amperage-temperature process cycle. Process procedures can be checked and logged, including any problems and revisions for future reference.

There are various data loggers that have real time graph capability which are relatively economical to purchase. Some units are even available on a purchase lease program.

In review, one must remember that the real time graphic data logger can be very important in certain areas which represent a relatively fast payback:

- Production loads logged on a continuous basis (24 hr).
- Efficiency monitored on every tank load.
- Accurate permanent records (graphs) on all special jobs.
- Quality improvements with reference to past graphic records.

Finally, the real time graphic data loggers and recorders are excellent for periodic training programs. Anodizers can be trained to run special jobs with reference to the past performance records readily available in the data logger files.

Design factors at the anodizing tank

Bus bars, contacts and racking

There have always been problems with conductivity losses due to inadequate bus bar contacts or corrosion products. I will only note some basic problems and maintenance check points here since most qualified anodizers should be very familiar with this area.

Always make sure bus bars are sized properly with plenty of good flat contact area between joints all assembled with professional techniques and good practice. Contact between rack and work bus bar should be flat and clamped. There are too many anodizing facilities with only edge contact between rack and bus bar due to rack/hook design. In this case, double clamp racks until the system can be corrected.

Air agitation

We have been involved in the design, redesign and installation of numerous air agitation systems. I would estimate that 75% of all air agitation systems I have reviewed needed modifications which directly relate to efficiency and energy savings. The importance of sufficient, even air agitation in the form of tiny bubbles and/or microbubbles has been simply overlooked or passed by in many installations. Proper air agitation does improve the chemical reaction efficiency of some additives and a special wetting agent which I shall discuss later. The improvement in efficiency with proper air agitation can be noticed visually after the air is installed. The operator will witness better amperage decay or drop-off during the anodizing cycle which indicates a faster coating rate.

There are many types of agitation. However, in most cases, air or a combination of air and pumping has proven overall to be the most successful. After years of observations and experimental improvements, we came up with the following basic design data for good air agitation in tanks up to 10 ft long. Low-pressure, high-volume air from a regenerative blower supplies air to a manifold which feeds riser pipes in all four corners of the tank. The vertical riser pipes connect to a network of ½″. Schedule 80 air lines fabricated and drilled according to the following specifications:

- Hole size, 0.020 to 0.040 diameter (nominally 1/32”)
- Holes drilled horizontally, 1” apart
- 24 holes per foot (180˚ both sides of pipe)
- Air lines 6 to 10” apart along the length of the tank
- Air lines should be ½” Schedule 80 PVC
- Outside envelope lines must be ¾” Schedule 80
- Riser lines must be ¾” Schedule 80
- Air to manifold, 3 CFM per square foot solution surface.

The air pressure is critical and depends upon the solution depth and specific gravity along with the total CFM needed and total pipe length from the blower to the tank, including any 90° elbows or obstructions along the main air supply line. Three examples of proper air agitation are shown in Figs. 2a thru c.

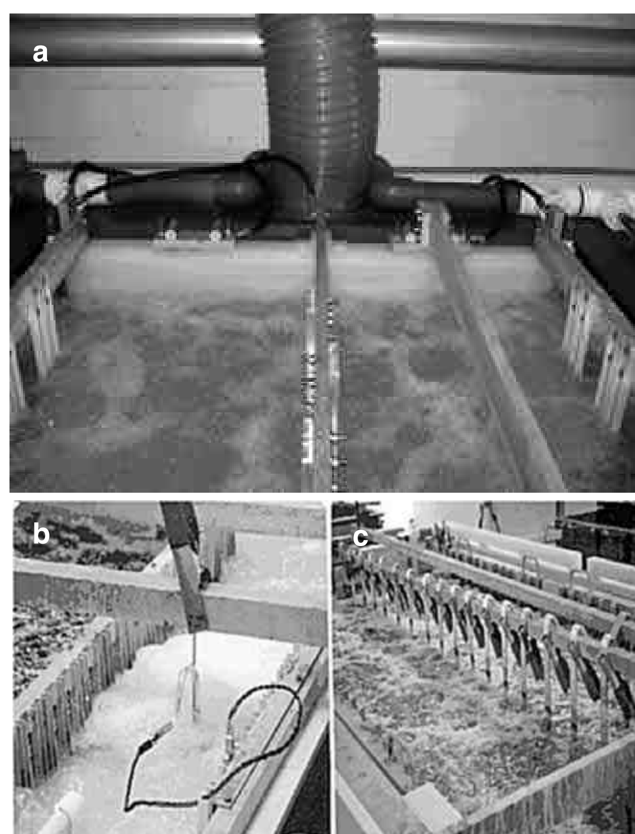


Figure 2—Three examples of proper air agitation.

A good wetting agent should be used in the anodizing tank to initiate the formation of tiny air bubbles. There are lignin sulfonate products like Orzan that work quite well because they also increase additive and modifier efficiency.

Aluminum cathodes

Aluminum cathodes should be used in both Type II and III anodizing systems. There are specific aluminum alloys and tempers which should not be used, due to dissolution, unless an electric charge is maintained on the cathodes when the tank is not in operation. I suggest 6063 T-6 which is available in most areas. Cathodes are also available which have been designed for better throwing power. In the past, a low cathode-to-anode area ratio (1:3) has been suggested. I maintain that this ratio can be raised higher (1:1) provided a good additive and modifier system is maintained. The cathodes should be placed evenly along the length of the tank on both sides for even current distribution.

Filtration

It is good practice to have continuous filtration on the anodizing tank. This has been proven to improve quality and promote longer tank life by some professional anodizers. Filtration with inside and outside tank systems are both being used successfully with two-stage filtration. In some cases 5 to 10-micron filters are being used with the second stage using 0.5 to 1.0 micron ones.

New developments

Capacitance shunt discharge: Practical revision 2

I would like to introduce a new development which increases the anodizing current flow at the beginning and throughout the ramp cycle. A new Capacitance Shunt Discharge System (CSD) has been developed and put into production operating more economically and practically by limiting its use to the pulse ramp cycle (5 to 20 V). The increased current density can range anywhere from 40 to 150% higher, depending on the system after maximum losses. The two data logger graphs presented in Fig. 3 (with the system in and out of service) prove the very significant improvement in efficiency and energy savings.

The system works in theory and practice by discharging capacitance reactance (impedance) on the anodizing tank resulting in a *higher amperage at the same voltage*.[12,15] This newly revised system has been used on both half- and full-wave secondary SCR rectifiers with great success.

It must be noted that the second set of graphs (Fig 3b - run with same 1500 A production load without CSD) are included to verify and prove just how well the system works in practice as indicated in Fig. 3a. Please note the increase in amperage when the CSD is introduced with 25 sec repeat pulses. We have checked the percentage increase in amperage at various points and listed them below including the *maximum possible losses due to bypass current during discharge*:

- 4 to 6 V (Anodizing Initiated)
- 7 V 140 A (3.5% TC) 75% above 80 A 40% after bypass
- 10 V 280 A (7.5 TC) 180% above 100A 105% after bypass

- 15 V 600 A (15% TC) 200% above 200A 144% after bypass
- 20 V 1440 A (36% TC) 80% above 800 A 61% after bypass

The anodizer can readily see the current increase results from CSD which represent a very significant increase in efficiency and energy savings. Specifications for specific economical CSD systems are available upon request from the author.

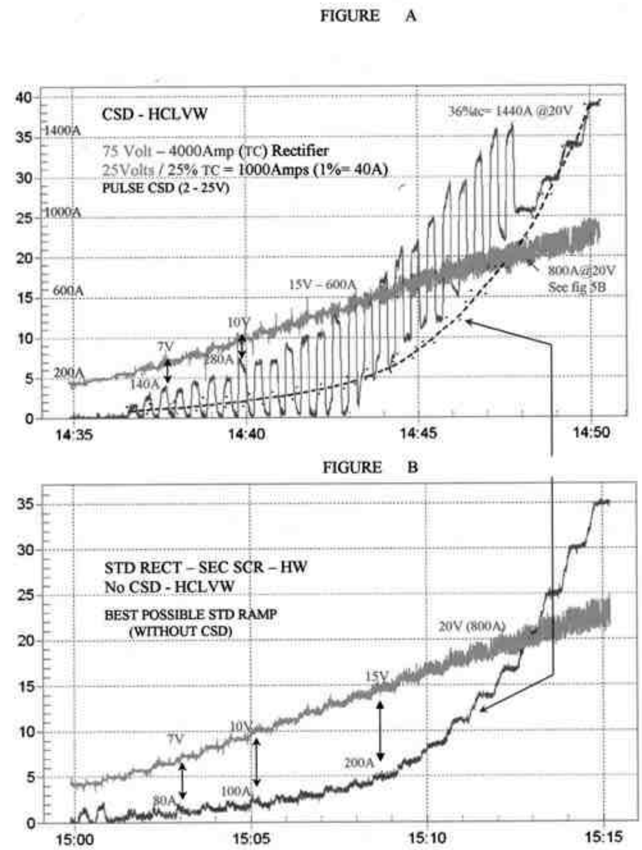


Figure 3—Data logger graphs showing performance of Capacitance Shunt Discharge System (a) in service and (b) off line.

Electrocolor — Two-step coloring

I ran some basic tests using CSD in two electrocolor systems. There were significant improvements in three areas.

1. Appearance (brightness)
2. Microfinish
3. Hardness (wear resistance)

This is one area which must be further explored because a major problem with electrocolor is *dull finishes*. However, it is evident that the efficiency and appearance (brightness) of all electrocolor systems can be improved using CSD along with all of the other areas reviewed in this article operating as a Complete Spectrum Package.

Conclusions

1. The major benefits realized as presented here should be considered as a *Complete Spectrum Package*, all directly related to quality, maximum efficiency and energy savings. *Remember — A chain is only as strong as its weakest link.*
2. The universal chemical operating ranges presented in this article should be used for all Type II and III anodizing, reducing process time by 25 to 50% and greater.
3. Additives, modifiers and/or accelerators should be used whenever possible; checked for efficiency and maintained at higher concentrations (5.0 to 7.5% in most cases) which allows higher anodizing tank temperature operation (50 to 85°F and higher).

4. A combination Pulse/Step/Ramp including Dwell should always be used at a very low frequency.
5. Sufficient proper air agitation in the form of tiny micro bubbles is necessary to allow all other systems to operate properly.
6. Amperage Decay must be used in the constant current density area to promote efficiency and energy savings. Current efficiency is also increased at a lower voltage.
7. All alloys can be processed with the same tank formulation (2011, 2024, 2219, 7050, 7075, 7178 and 380 die cast).
8. The final microfinish is improved along with brighter dye colors.
9. Smut (powder burn) and soft powdery coatings are eliminated even at high operating tank temperatures (70 to 90ºF) when other areas and parameters are operating together properly.
10. The Capacitance Shunt Discharge system (CSD) improves the efficiency in all other areas including electrocolor.
11. Improved quality, efficiency and energy savings can range anywhere from 25 to 100% depending on the original system in operation. Additional data logger graphs are available upon request to the author to verify these claims for specific systems in operation. *P&SF*

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6. Numerous process specifications and procedures; limited supplier list as follows:
   Boeing — Mc Donnell Douglas Long Beach
   Rockwell Defense Systems
   Mc Donnell Aircraft, St. Louis
   Mesa-McDonnell Douglas Helicopters
   plus three other Boeing facilities
   Bell Helicopters
   Lockheed Martin (3 Division Specs.)
   Northrop Grumman (3 Division Specs.)
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   Pratt and Whitney
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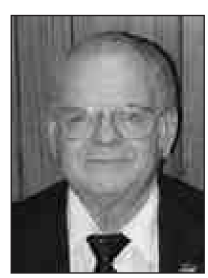
About the Author



Fred C. Schaedel has developed specialized anodizing additive modifiers, pulse ramp systems and established one-on-one training programs in the anodizing industry dating back to 1962. His early research work on complex ions and chelating agents at Drake University and Schaedel Laboratories led to the development of the first process (Patent issued 1968) for the hard anodizing of specific critical alloys including 2024 and 7075. He has held special certifications for testing and processing anodized coatings for the Apollo Program (NASA), YF17 (Northrop) later F/A18 Hornet and MK48 Torpedo (US Navy NUWS). He also developed commercial, high-speed, continuous anodizing systems for heavy production. Fred Schaedel continues to spend all his available time integrating his chemical formulations and electronic waveform technology together with pulse ramp procedures to cover the complete spectrum for aluminum and titanium anodizing through training programs focusing on quality and efficiency.