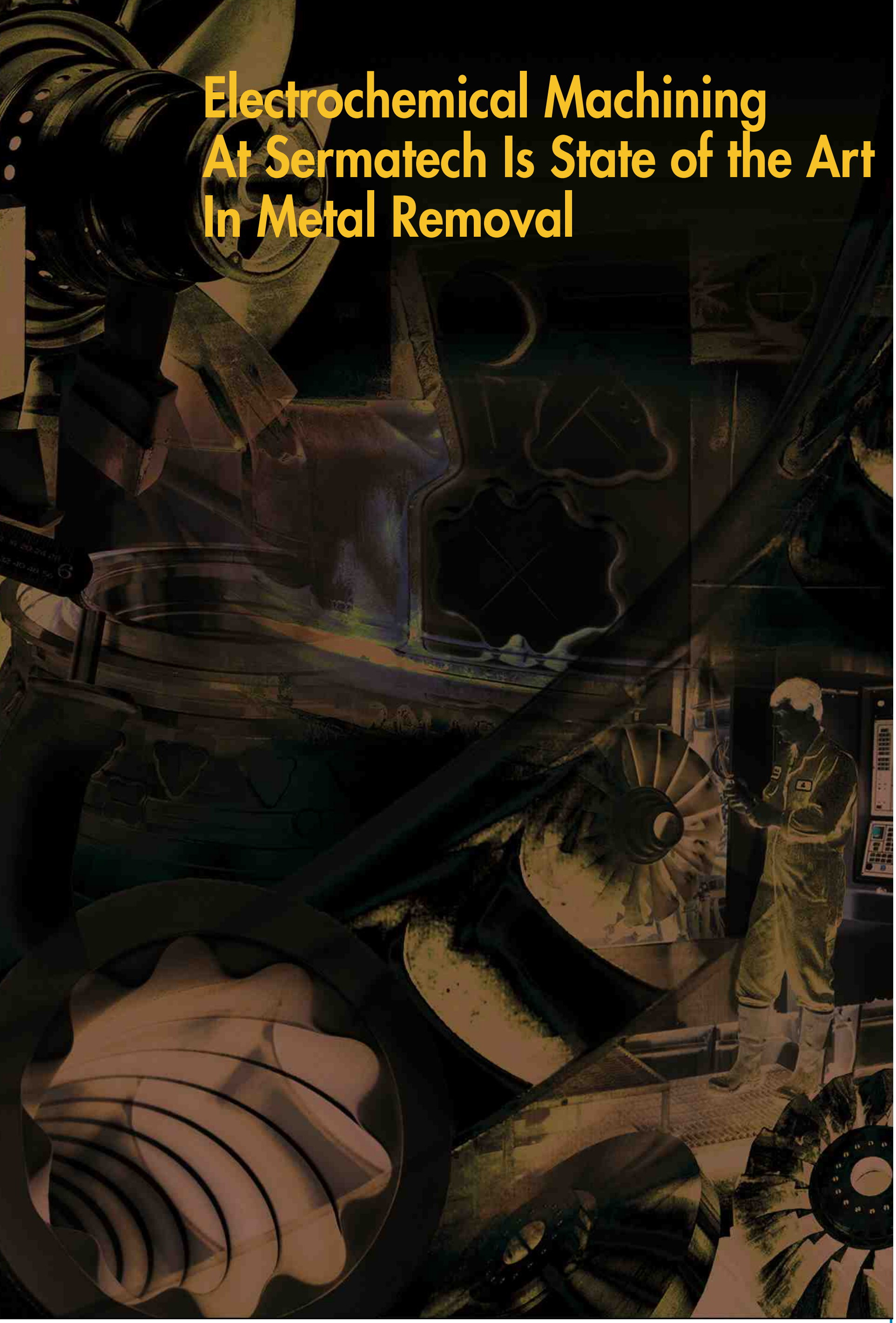
Electrochemical Machining At Sermatech Is State of the Art In Metal Removal



Anyone working in the surface finishing industry has adopted a certain mindset in doing things. Among these is "The workpiece is the cathode." Right off the bat, electroless plating, conversion coating and the home-brew "hang it on a wire and dip it" processes come to mind. Of course no one … absolutely no one … would ever make the workpiece the anode. Right? Well, wrong. Anodizing comes to mind, but that is not the focus here. Less known is that some of the most advanced electrochemical work out there makes the workpiece anodic, through electrochemical machining. This feature tells how.

To those unfamiliar with it, electrochemical machining is incredible. Consider high-speed electroforming, where complete parts are built up, atom-by-atom, on a mandrel. Now imagine reversing the polarity, and removing material from blank stock, atom-by-atom, and coming up with a desired shape in a matter of minutes. That is what electrochemical machining does.

One of the leading practitioners of electrochemical machining (ECM) is the Sermatech Manufacturing Group, in Cincinnati, Ohio.

About the Company

The Sermatech Manufacturing Group is part of Teleflex Incorporated (TFX), based in Philadelphia, PA. Teleflex, a NYSE-listed $2.1 billion company, is an international leader in providing products and services for the aerospace, automotive, industrial, marine, medical and power generation industries. The company's name derives from three elements of their business: SERvice, MAterials and TECHnology.

The Sermatech facilities in Cincinnati produce precision components for use by manufacturers of flight and ground turbomachinery. The company is billed as the world's leading practitioner of ECM. It is more than a $60 million business, with 260 non-union employees. Seventy percent of the business is in aerospace and 20 percent is in industrial gas turbines. The remaining 10 percent covers a diverse collection of products, including heat exchanger tubes (inside diameters), surgical instruments, medical implants and golf club heads. On the matter of scale, there is quite a range.

The largest segment of the business involves the fabrication of jet engine components, including bladed disks (blisks), compressor blades, vanes and cases, many of which require exacting tolerances despite their massive size. To that end, Sermatech believes in having as much as possible under the same roof, for communication if nothing else. Among manufacturing jobshops, there are few who can design and build their own equipment anymore.

The engineering design philosophy of the whole operation is akin to one of those souvenir Russian dolls, a shell within a shell within a shell … and so on. They begin with a part, and build cathodes around it. The tooling is then built around the cathodes. Taking it one step further, the machines are then designed and built

ECM	Chemical Milling	EDM
Uses salt solution	Uses acid solution	Uses dielectric solution
Ionic dissolution with electricity	Ionic dissolution with chemicals	Melting process with electricity
No recast; parent metal undisturbed; capable of complex contours	No recast; cuts constant or stepped depths	Leaves recast; capable of complex contours
Fast metal removal rate	Slow metal removal rate	Slow metal removal rate
Larger volume contouring	Shallow contouring	Smaller volume contouring
All byproducts are easily recycled	Acid makes byproduct handling difficult	Requires dielectric disposal

around the tooling. Finally, building and support facilities are built around the machines. The latter may sound trivial at first, but it is critically important to overall operational efficiency.

Electrochemical Machining

As noted, ECM is the reverse of plating. The workpiece is made the anode. Depending on the application, it can be either bar stock or a forging. The working tool is made the cathode, and its shape is the reverse contour of that of the part.

The electrolyte is fairly simple for most purposes. The people at Sermatech refer to it as "salt water." Simply put, it is a 120 g/L (1.0 lb/gal) solution of sodium chloride, held at a neutral pH. Sodium nitrate salt is sometimes preferred over sodium chloride, which is more aggressive. There are more complex proprietary electrolytes, developed by Sermatech, for the more complex titanium and other aerospace alloys, but most iron-based materials merely require the "salt water."

There is no "process tank" *per se*. Rather, a sealed chamber surrounds the fixture. Depending on the size of the job, the electrolyte is pumped under a pressure of 0.7 to 2.4 MPa (100 to 250 lb/in.^{2}) at flow rates ranging from 375 to 1500 L/min (100 to 400 gal/min). A DC voltage of 10 to 25 V is applied, producing cell currents of 10,000 to 40,000 A. At 10,000 A, 16.4 cm,^{3} or one cubic inch of metal per minute is removed.

While the metal removal is proceeding, the cathode is being fed toward the anodic workpiece until the predetermined part shape is produced. Depending on the geometry and applied current, this feed rate is in the range of 0.5 to 8.0 mm/min (20 to 350 mil/min).

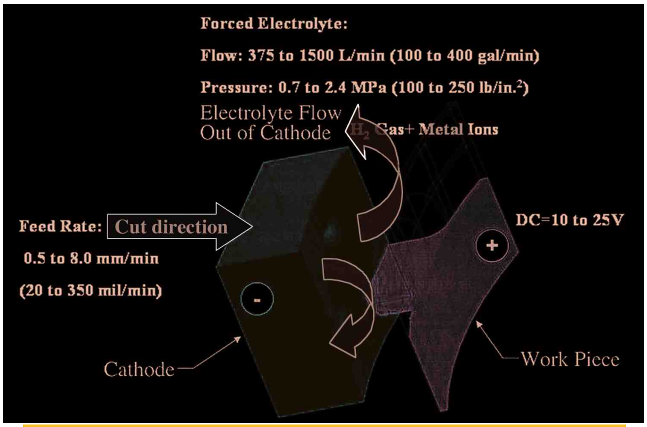
ECM is often competing with mechanical milling. In some cases, the desired geometry simply cannot be produced with the mechanical counterpart. The operation can be accomplished for complex shapes in a single pass in most cases, regardless of the metal hardness. The complexity of some of the products may require a few stages from the rough cut to the desired end. Nevertheless, the end result is a finished component that has close tolerances and very good surface finish. Indeed, many components can be produced with thinner walls, and therefore reduced weight.

There are certain aerospace materials, such as the titanium-aluminides, that cannot be conventionally machined at room temperature effectively because they are extremely brittle. At the operating temperature of a jet engine, on the other hand, the material is completely functional, and machinable at that temperature as well. ECM eliminates the need for the high-temperature mechanical machining of this material.

In electrogalvanizing of sheet steel, much is gained from the use of an insoluble, dimensionally-stable anode (DSA). Deposit thickness and cell geometry are reliable maintained more long periods. The ECM cathode is insoluble as well. It does not wear; thus dimensional variation and product consistency are assured.

The accompanying chart compares some of the benefits of ECM against other chemical metal removal processes.

Because it is advancing progress in the electroplating end of things, the use of pulsed or non-DC electrical waveforms offers potential advantages in the electrochemical removal business. Recognizing this, Sermatech has formed an alliance with Faraday Technology, Inc. to leverage the knowledge and research development of each firm in electrochemical technology. Faraday is a research, development and engineering company working in the area of electrically-mediated electrochemical technology with a



Schematic diagram of the ECM process.


Compound curved airfoil: (left) as-forged, (right) after ECM. The surface finish and dimensions are as specified in a single ECM operation.

proprietary process* for edge and surface finishing as well as ECM. The companies will explore and address different types of electrolytes, new applications and products, and changing characteristics of ECM.

Products

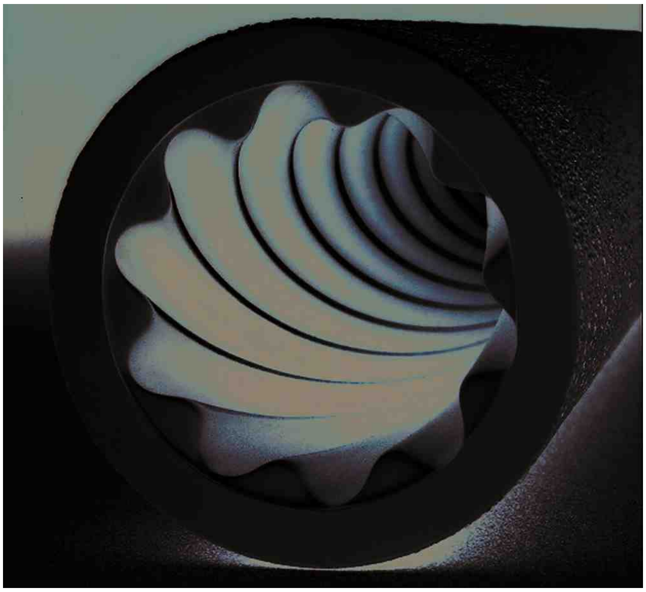
The company manufactures several complex items that are critical components in jet engines, including various-sized blades and vanes. These are not simply flat blades, but rather complex shaped airfoils, to achieve maximum flow efficiency during engine operation. As shown in the figure, the ECM process begins with a rough forging. With a single ECM step, the finished product presents a smooth surface and the compound radii designed into the surfaces are as specified. The ECM surface is the final one. No further polishing is required, a step that would be necessary if this part were machine milled to shape, where cutter lines would remain. Similar blades and vanes can be manufactured from bar stock as well as forgings.

An example of a larger jet engine part amenable to ECM is the outlet guide vane (OGV). Made of Inconel 718, it consists of a rather large, complex ring, roughly 2 m (~ 6 ft) in diameter. The vanes along the edge in the figure are produced by ECM. In this case, only a segment of the ring is processed during a single operation. The entire ring is too much to handle all at once. Nevertheless, the vanes are rough machined in multiples in three operations to produce a complex through-slot. Final airfoil shapes are completed in one pass per vane, both in terms of finish and dimensions. Once a given vane is completed, the OGV is rotated to the next segment, and the process is repeated until the entire OGV ring is done.

Interestingly, sacrificial anodes are used to protect the finished vanes adjacent to the segment being processed.

Outlet guide vane (OGV) showing a portion of the ring of vanes formed by ECM (width = approximately one inch).

View of the outer surface of a jet engine case showing the variety of embossments created by ECM.



Spiral rifling in a section of heat exchanger tube produced by ECM. An entire 10-ft length of tubing can be so contoured.

Though the segment in process is sealed, there is some leakage to those adjacent surfaces. Small strips of anodic material are simply hung over the lip of the vanes and, like zinc-coated steel, the sacrificial anodes protect the newly formed vanes from the previous operation.

The outer case of a jet engine section is very complex and contains several orifices and locator holes on its outer surface. Their locations are obviously critical. Starting with an oversize forging, ECM comes into play in establishing the wall surfaces. Achievable wall thicknesses are thinner and tolerances are closer than those obtained with machining of cast cases while also having superior material properties. As noted in the figure, ECM is used for a variety of complex boss and cavity shapes for the various inlets and other orifices required in this jet engine case.

One of the more intriguing turbine components is a bladed disk, or blisk. Another name for this product is an integral bladed rotor (IBR). In more conventional designs, the airfoil blades are individually fabricated and mechanically attached with fir tree roots and slots.

The fabrication of a blisk by ECM is one of the most impressive operations. By its geometry and size, the blisk presents a challenge. This is one application where proprietary ECM electrolytes are used on some of the more complex titanium alloys used for these items. Further, the blade formation is done in more than a single stage. The accompanying figure shows the entire sequence of operations. The original blank, seen at lower right, consists of a precision machined disk. Like a sculpture, within that blank disk lies a series of blades. The first ECM stage is a rough cut, but that so-called "rough" cut is something to see. As seen at the lower left, the blades are fully formed, right down to the hub. One pass of the cathode tool plunges into the blank, at a current of 30,000 to 40,000 A, dissolves the metal and

**Faradaic™ Process, FaradayTechnologies, Inc., Clayton, OH* leaves behind the rough blade, complete with complex curvature. Like the OGV, the entire set of blades is not produced in one cycle. Rather, they are produced in indexed segments as before.

The final step is a finish ECM operation, which results in each blade as specified in the engineering drawing, in terms of both geometric shape and surface quality. The finished article can be seen at the top of the photo on the previous page as it is removed from the ECM machine. The sophistication required to produce such a shape, with the complex, compound curvatures present in each blade is the result of Sermatech's machine design capability. This unit is designed specifically for that specific blisk. The motion of each element uses five-axis rotation to guide the cathode tool into the blank at the proper speed and position at any given moment in time. This is where CADCAM software is indispensable.

Another interesting aspect of blisks made by ECM is the necessity that they be perfectly in balance. The degree of balance makes wheel balancing on a typical automobile look elementary by comparison. At full rotation speed, the balance must be down to 10 gm-in. of torque. The mixed metric-English term is the preferred one in the industry.

Another application is the production of heat exchanger tubing. Here, the inside diameter is formed by ECM through 3-m (10-ft) lengths of rod of up to a 20-cm (8 in.) outside diameter. As shown in the photo, the contours are not your average bore hole. A serpentine contour is provided for greater heat exchange area. Further, that is not an optical illusion. The hole is rifled with a spiral contour. Straight contours can be formed as well. Tolerances are held to 0.25/0.75 mm (0.01/0.03 in.).

ECM processing of a bladed disk (blisk). The rough, machined disk is shown at the lower right. To its left is a blisk after the ECM rough cut stage. The upper part of the photo shows a finished blisk being removed from the ECM processing cell. The folded pattern in the rear is part of the machine which allows axis motion while sealing out the salt water.

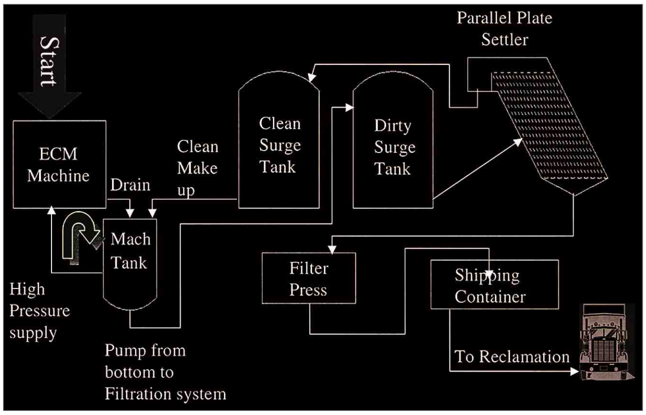
Metal Reclamation

The prospect of 10,000 A of current dissolving 16.4 cm^3 (1.0 $in.^3$) of metal per minute gives rise to no small amount of metal hydroxides. Sermatech's operations dissolve away 1800 kg (4000 lb.) each day. The schematic diagram shows how these metal hydroxides are handled.

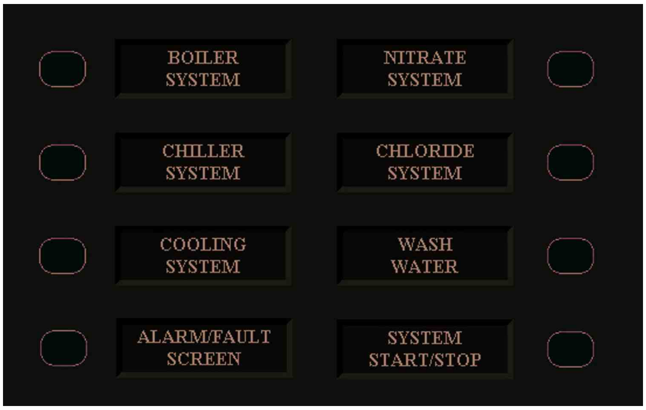
A working ECM solution occupies several thousand gallons, and is sized to the specific ECM facility. It is not unexpected that the working volume for ECM processing of vanes is somewhat smaller than the facility for the blisks and OGVs, located at a separate plant. In any event, the total electrolyte volume is sufficient to allow for an entire turnover every four hours. The hydroxides resulting from the process, depending on the percentage of metals other than iron in the alloys, amount to 8 to 10 kg (18 to 22 lb.) for each kilogram (2.2 lb.) of metal produced by ECM.

The first step in the hydroxide removal process is to transfer the metal-laden solution from the bottom of the working tank to a surge tank and into a parallel plate separator. Here, the heavier metal sludge slowly falls to the bottom, separated from the solution, which is decanted at the top of the separator. The clean solution is sent to another surge tank, and ultimately back to the working tank.

Meanwhile, the hydroxides are run through a filter press. The filter cake still is composed of 70 percent water. The remainder is half salts and half metal, by weight. Therefore, only 15 percent of the weight of the filter cake is recovered metal. Still, this cake is sent



Schematic diagram of the ECM metal removal and waste treatment system.



Master screen for electrolyte control system.

Hydroxide recovery and electrolyte handling system.

Chemical handling system.

out and processed as a high grade "ore" at a mill, resulting in 100 percent reclamation. The metals from the machined alloys can be fairly well separated gravimetrically in the parallel plate separator.

There are other environmental issues that are well-addressed in this installation. One of the alloying metals is chromium, so both hexavalent and trivalent chromium are produced in the system. For this reason, all facilities are designed with spill protection and closed-loop design. The hexavalent chromium itself builds to a saturation level and is ultimately reclaimed in the metal hydroxide "ore" noted above.

Such high currents produce copious amounts of hydrogen. Air scrubbers are employed to remove any droplets of electrolyte that are carried away in the ventilation system. Thus, these stray amounts heavy metal are also kept under control.

All of Sermatech's environmental operations have the approval of the U.S. Environmental Protection Agency, the State of Ohio and the City of Blue Ash (the Cincinnati suburb where the company is located).

All electrolyte systems are under computer control, accessed via computer screens located in the work areas, as shown. The other photos show more of the chemical handling operations, including chemical makeup addition facilities (for pH control, etc.) and the circulation system for hydroxide recovery. *P&SF*