Electrolytic Machining, Deburring & Polishing

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Electrolytic machining, deburring and polishing involve selective removal of surface metal from a workpiece by conversion of the metal to its ions resulting from the flow of an electric current. This is one of the applications of electrochemistry discovered by Michael Faraday in the early 1800s. The principle of electrochemical decomposition was not employed as a manufacturing process until the mid-1900s. The most notable early application was machining of advanced aerospace materials. Since then, there have been many new applications and process innovations that have lead to broad implementation of the technology. Intrinsic process benefits, such as very fast removal rates, stress-free results, complex geometry machining, and non-consumed tooling have added to the popularity of electrolytic machining. This paper will include four aspects of this technology: selective burr removal and edge machining, surface finishing improvement, volumetric machining, and electrolytic rifling.

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THE ELECTROLYTIC PROCESS

Electrolytic machining is controlled metal removal via electrolytic dissolution which is accomplished using a shaped conductive tool to form a small gap (0.005 to 0.015 inch) between the tool surface and the workpiece; flowing conductive electrolyte in the gap; and allowing a DC current to flow between the two adjacent surfaces. The conductivity of the electrolyte solution allows the electric current from a 0 to 30 volt DC power supply to flow between the tool and workpiece. The electrolyte used in this process is a conductive salt solution such as sodium chloride (table salt) and water. The resulting current flow will cause atoms to be removed from the workpiece only and enter the electrolytic solution. The metal ions quickly form neutral metal hydroxides that are filtered from the recirculating electrolyte stream. Quick removal of: metal hydroxides, small bubbles from the hydrolysis of water, and heat; from the gap by the electrolyte permits high removal rates. The process is diagrammed in *Figure 1*.

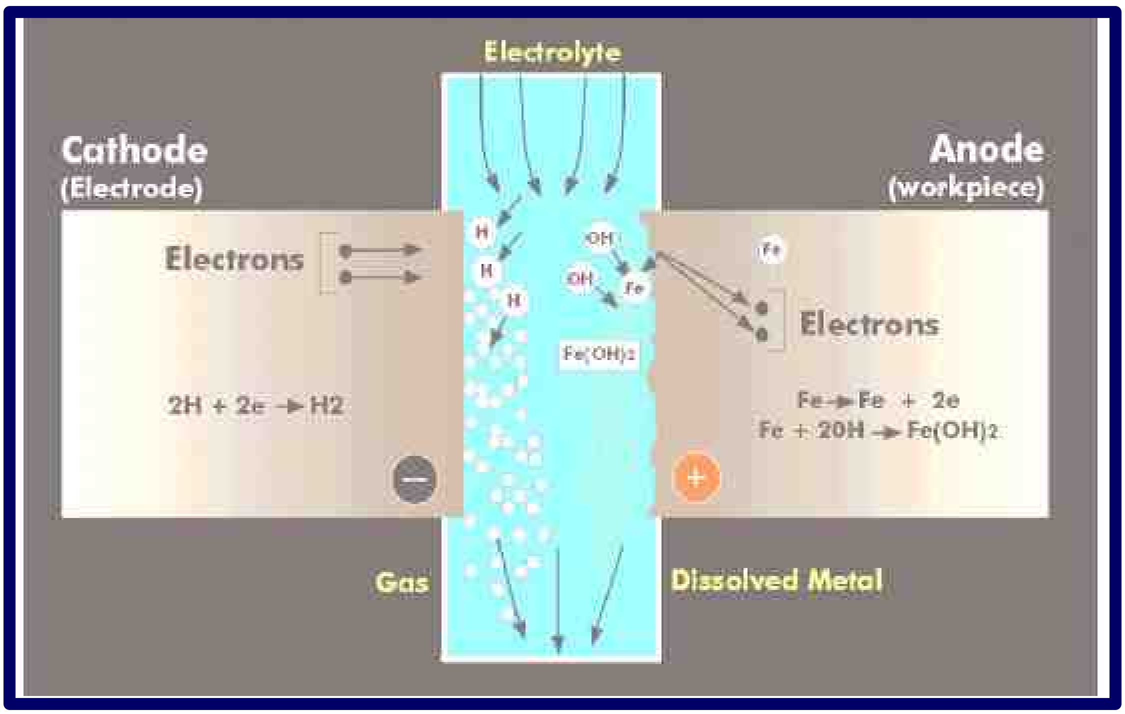

Figure 1

Diagram of the Electrolytic Metal Removal Process

The electrolytic process can be characterized as a high rate metal dissolution process used to remove material from designated areas on the workpiece. The material to be removed can be an unwanted burr, excess edge material, surface roughness, or a feature to be machined into the surface. The tooling and machine configuration required for these operations will be different with the system components and parameters typically chosen from an established set of constraints. These are based on factors that influence the process including the electrochemical properties of both electrodes (the cathode tool and the anode workpiece); electrolyte type, concentration, pH, and temperature; aspects of component geometry; process voltage and current.

The following are typical characteristics of these factors:

Anode (workpiece)

Materials that are electrolytically machined include most conductive metals. They electrolytically "dissolve" at approximately the same rate, regardless of hardness or tensile strength. The rate of dissolution is influenced by chemical and electrical properties, such as atomic weight and valence, rather than by mechanical properties. Anode contacts are made from materials that are less susceptible to electrolytic dissolution.

Cathode (tool)

Brass, stainless steel or copper tungsten is used for electrodes. Tooling tends to be robust and cathode tools do not wear or dissolve in the process which eliminates the need for costly frequently tool replacement encountered with other processes.

Fixtures

Fiberglass reinforced epoxy or plastic materials are used for the tool base and other structural parts of the fixture because these materials do not absorb moisture from the electrolyte and are good insulators. The workpiece positioning surfaces are usually made of titanium, plastic or ceramic material depending on the application.

Electrolyte

Electrolytes used in the electrolytic process are typically, aqueous salt solutions, containing 10 to 20 percent concentration of either sodium chloride (NaCl) or sodium nitrate ($NaN0_3$). Typical temperature of the solution normally ranges from 60^0F to 100^0F, with a pH ranging from 7 to 8.5. Various additives have been used with these two basic electrolytes but they are not required in most applications. Other electrolytes, such as sodium bromide and sodium perchlorate have also been used.

Electrolytic Equipment

Electrolytic machining equipment is generally built to suit specific machining tasks. A complete installation consists of the following components.

MACHINE	machine base (which may include a feed unit and work enclosure), fixture platen, and machine control
POWER SUPPLY	DC power source with features suited to the application, i.e. constant voltage, constant current, pulse, or variable voltage.
ELECTROLYTE SYSTEM	supply circuit, parameter regulation instruments and metal hydroxide removal circuit
TOOLING	cathode, flow chamber, fixture, anode contacts

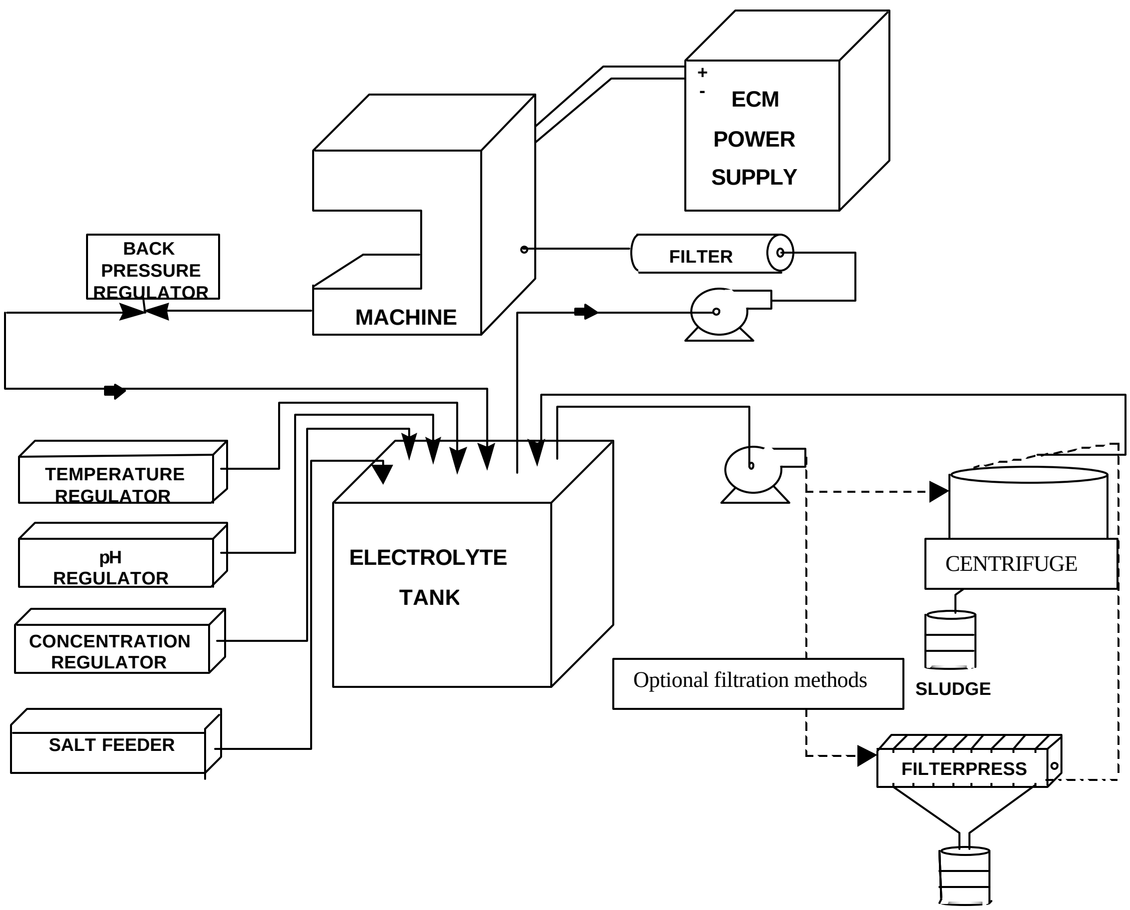

Figure 2
Electrolytic System Diagram

The equipment design for the electrolytic process is largely influenced by the workpiece to be processed. The dimensions of the workpiece, the production rate and quantity of material removal will determine whether a single station, dual station or a special fully automatic machine is required. Machines may also be equipped with indexing tables locating devices or other special configurations for workpiece manipulation. Some fully automated systems will also have integrated parts washing systems (figure 3). Small open machines have provisions for tools to be mounted over an electrolyte drain basin (figure 4). Semi-enclosed machines have an upper platen that holds anode contacts, part clamping points and electrolyte sealing surfaces (figure 5). A lower platen holds a workpiece fixture, cathodes and electrolyte connections.

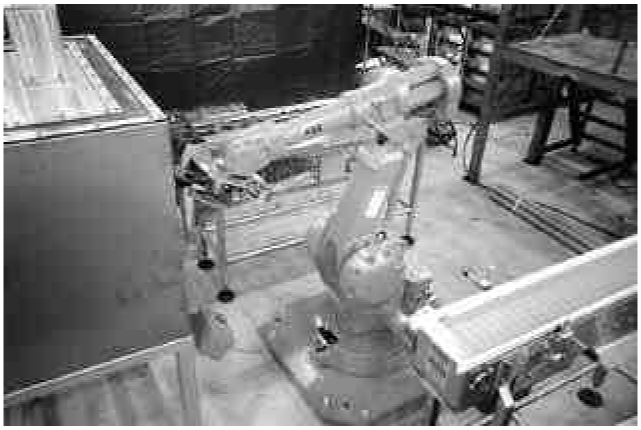

Figure 3

Figure 4
Fiberglass Bench Type Machine

Figure 5
Four Station Modular Electrolytic Deburring System

Tooling

Tooling generally consists of a workpiece positioning fixture, a clamping device, active electrodes, electrolyte supply lines, anode connection and sometimes loading and unloading hardware. The design will also depend on the required production rate.

While attempts have been made to create universal tooling, the best that has been achieved is modular tooling for a family or parts. Cathode shape and position with respect to the workpiece and electrolyte flow path determine the process results thereby limiting flexibility in tool design. However, large gaps using cathodes with minimum conforming geometry requirements have been used with some success but applications are limited to parts that can tolerate light etching over all surfaces, have extremely small burrs and can tolerate long deburring cycle time.

As with all specialized deburring techniques, there are certain part configurations or requirements that make a particular method most advantageous. Some good potential electrolytic deburring applications are:

- Intersecting holes or ports
- Inaccessible or hard to reach areas
- Complicated shapes

- Areas requiring consistent radiusing
- Areas which cannot be abraded
- Materials which may work harden
- Parts processed on automated lines where work flow cannot be interrupted
- Areas where large radii are required

The process requires that all grease, oil, hanging burrs and loose chips to be removed from the workpiece prior to the operation.

PRODUCTION EXAMPLES

The following examples of production applications demonstrate the range of electrolytic process capabilities including: deburring, radius forming, contouring and surface finishing, rifling, and micro machining.

Case I – Fuel System Components

Fuel system components like the housing of figure 5, that require burr free radiused edges at intersections are processed electrolytically in high volumes. The process parameters are adjusted to produce the desired degree of radius at each intersection. Each component is loaded onto tooling that locates the bores for automatic insertion of electrodes. When the tool clamping action is complete, electrolyte flow is initiated, and then the DC deburring power is switched on for a predetermined deburring time. At the completion of the process, the machine unclamps the workpiece for removal by the operator. Electrolytic machining time was less than one minute.

Figure 5
Sectioned View of Fuel Body

Case II – Valve Housing

Intersecting holes requiring burr free or readiused intersections are among the typical applications for this process. Figure 6 shows a cut away view of a stainless steel valve body with hole edges intersecting all three bores.

Figure 6
Stainless Steel Valve Showing Deburred Intersections

The requirement is to remove all burrs from seats and intersections. These valve housings are usually deburred in three setups. Each process step is approximately 15 to 20 seconds.

Case III – Airbag Housing Inflation Nozzles

Figure 7
Automotive Airbag Canisters

Nozzle holes of various sizes in aluminum airbag inflator housings (canisters) require burr free edges with a slight radius for proper performance. These housings are made of 6061 T6 aluminum, approximately 2.5 inch diameter, 10 inch long with a wall thickness of 0.125 inch and typically have from 20 to 60 holes with burrs generated on the ID surface by drilling or piercing operations (Figure 7 & 8).

Figure 8
Passenger Side Airbag Housing with Sections Showing Deburred Holes

The machining parameters are set based on the volume of burr material to be removed, the interelectrode gap, and the electrolyte characteristics. For example, the time required to remove all burrs could increase from 10 to 20 seconds if the amount of burr material increases as indicated in the time plot of Figure 10.

Typical machining parameters are:

Voltage:	18 V
Current:	150 A
Electrolyte:	$NaNo_3$
Electrolyte parameters:	75 ºF
	8.0 pH
	30 PSI

The electrolytic tooling is configured to simultaneously deburr all holes in one operation to achieve the shortest cycle time. The tolerance of hole position and the dimensions of burrs to be removed influences both tool design and machining parameters. The cathode tools for this application have insulated surfaces with exposed conductive surfaces adjacent to each deburring site as shown in Figure 9. The size of each conductive cathode surface is dimensioned to encompass the burr over the tolerance range of hole position.

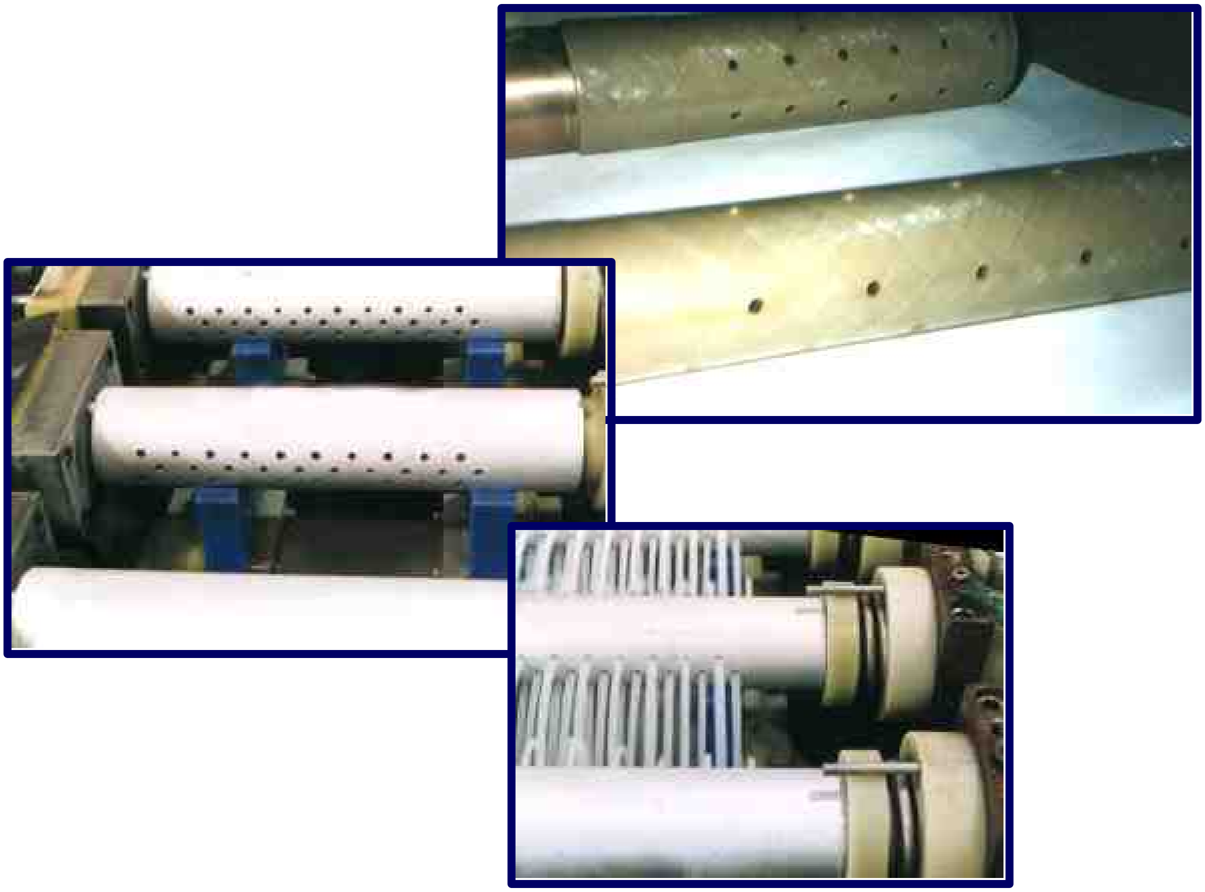

Figure 9
Tooling concept For Airbag Nozzle Edge Finishing

The low voltage used in the electrolytic process requires that the workpiece be free of contamination, particularly any substance that could retard current flow. Therefore, all parts are washed prior to processing to insure the desired gap conditions. After washing, parts are placed on a cathode and oriented to align the nozzle holes in the part to the cathode holes. The part is then clamped into position and the process cycle initiated. The parts are removed from the tooling then rinsed and dried. Quality inspection of the electrolytic process included both visual and profile tracing of the hole edges. Typically, 256 parts per day are visually inspected out of 12,000 parts processed.

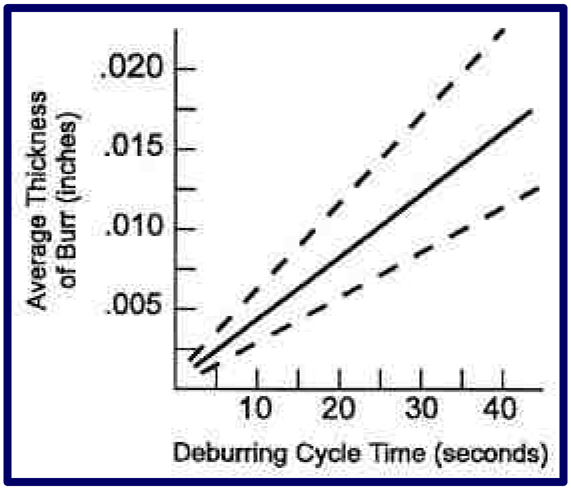

Figure 10
Relationship Between Time and Material Removal for Typical Edge Deburring Applications

High volumes are machined on fully automated machines that may include conveyorized washer lines to clean housings before ECD and rinse and dry them after deburring. These machines are typically capable of deburring 1,000 parts per hour. Lower volume requirements are deburred on manually loaded machines. Production rates on these machines depend on the number of cathodes and equipment capacity. A typical automated installation for passenger side airbag deburring is shown in Figure 11.

Figure 11
Electrolytic Machining Equipment Processing Airbag Housings

Case IV – Projectile Tail Cone

A tail cone for a 120mm projectile (Figure 12) made from an H-13 steel forging has critical edge requirements that are produced electrochemically. Nine holes are gun drilled at a slight angle to the major axis then internal and external conical surfaces are turned.

Figure 12
Cone With Electrolytic Formed Edges

The nine gun drilled holes that form an obtuse to acute angle intersecting the interior and exterior conical surfaces require deburring and a radius formed that varies according to the angle of intersection. Approximately on millimeter of material must be removed from the exterior acute angle to generate 1.25 mm radius. The exterior requirements are achieved in a 2.5 minute cycle with the cathode advancing toward the workpiece parallel to the axis of the cone.

The interior intersections are deburred and radiused in 1.5 minutes with fixed position cathodes. Shorter times for the latter is because of the small, consistent burr on these edges. Production quantities require two cones to be machined simultaneously.

Case V- EDM Recast Removal

Removal of EDM recast layer is often accomplished by electrolytic removal because of both the selectivity possible with the process and the method of material removal. Typically 0.0005 in. to 0.0015 in. of surface material is removed which is determined by the EDM machining that produced the Martensitic "recast" layer. Figure 13 is a photo of an EDM produced surface before and after recast removal.

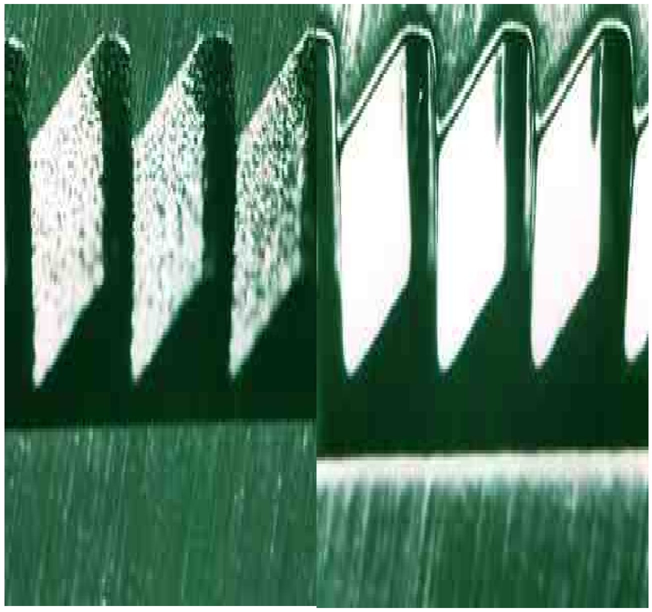

Figure 13
EDM Recast Layer Removal

Case VI - Flow Component Polishing

Surface finishes as rough as 120 to 150 micro inch R_a are electrolytically smoothed to an 8 to 16 micro inches R_a in a very short process cycle. The resulting finish is smooth, bright, and similar in characteristic to an electropolished surface on stainless steel and similar metals. Typical process time is a few minutes or less.

Figure 14
Internal surface polishing by Electrolytic Material Removal

Case VII -Volume machining

Electrolytic volumetric machining is a precise process of material removal made possible by controlling the process parameters to predetermined values. A cathode is made to a required shape based on the geometry to be machined. In the example of Figure 15, the diesel injector body has a fuel accumulation chamber machined from the main bore radially outward and opens an intersection with the pre bored fuel supply passages. The precise volume requirement is programmed into the machine control as process parameters.

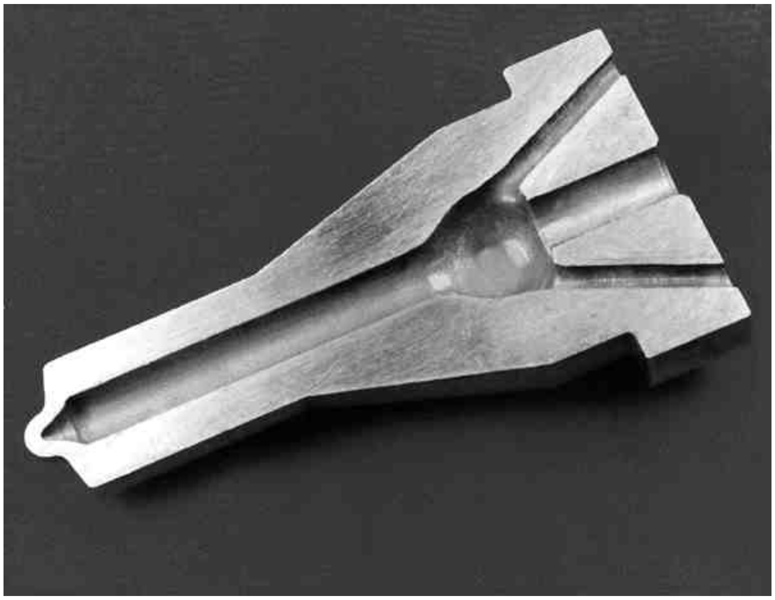

Figure 15
Diesel Injector Fuel Chamber Electrolytically Machined to a Volume Requirement

Case VII – Rifling

Gun barrel rifling can be produced electrolytically with either a stationary electrode spanning the length of the barrel or a short cathode that traverses the length of the barrel at a fast rate. The latter method is used on rifle and cannon barrels and is referred as ECM broaching. Here the cathode rotates as it traverses resulting in grooves electrolytically formed with the required twist. Short barrels for pistols are ECM rifled using a stationary electrode. In this case, a full length cathode is constructed with the mirror image of the lands and grooves.

Figure 16 a
Electrolytically Formed Rifling

Figure 16 b
Electrolytically Formed Rifling

The rifling grooves are produced by cathodes spaced away from the bore surface while the lands of the rifling are masked by insulated surfaces on the tool. Both constant twist and "gain twist" rifling can be formed with no tool wear. Variations such as rifling only a portion of the barrel length are possible with this process.

Case IX – Blade Tip Machining

Jet engine blades that are designed to self-seat while rotating inside a machinable shroud are manufactured with abrasive particles bonded to the blade tip. The abrasive particles, which are imbedded in a metal binder, must protrude from the blade tip by 0.15 to 0.25mm. The electrolytic process is used to remove metal binder from the blade tip exposing the abrasive grains. The excellent repeatability and fast metal removal rate results in a high quality, productive operation. This operation uses low electrolyte flow rates and a large gap. An adjustable head permits quick set up for different blade lengths.

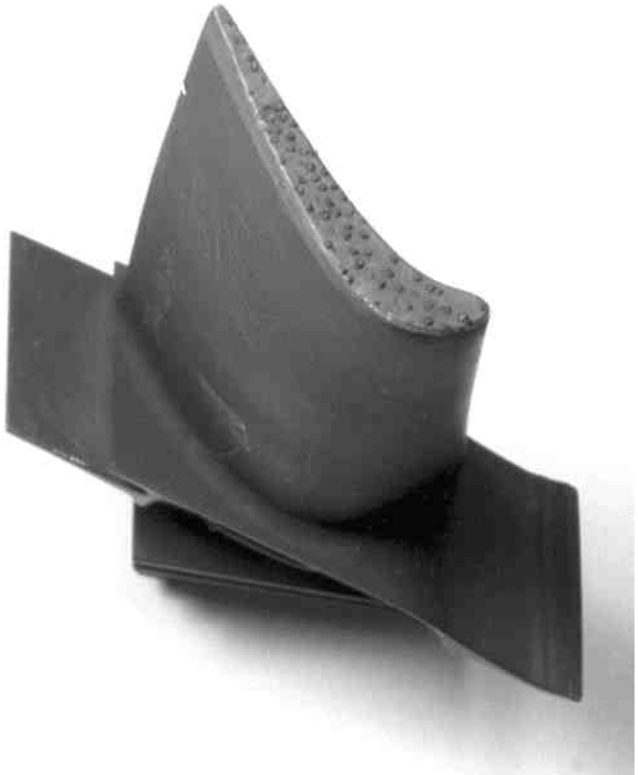

Figure 17
Turbine Blade with Tip Machined Electrolytically

SUMMARY

The application of electrolytic high rate metal removal to deburring, radiusing, etching, polishing and contour forming has resulted in improved quality and cost effective production operations. The examples cited are only a sample of the possible applications for the electrolytic process. The ability of the process to meet requirement for full form machining with non-consumed tooling is very attractive to manufacturing. The production systems that are now available have demonstrated that low maintenance, high reliability equipment is available.