Electrolytic Machining, Deburring & Polishing

by D.G. Risko*

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 led 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: (1) selective burr removal and edge machining, (2) surface finishing improvement, (3) volumetric machining, and (4) electrolytic rifling.

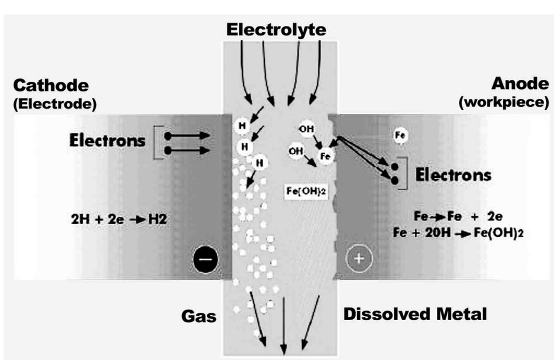

Fig. 1— Diagram of the electrolytic metal removal process.

Nuts & Bolts: What This Paper Means to You

Electrochemical metal removal is as important to commerce as electrochemical metal plating. Electrolytic machining, deburring and polishing involve selective removal of surface metal from a workpiece by anodically dissolving it away. There have been many new applications and process innovations that have led to broad implementation of this technology. This paper reviews four important aspects: (1) selective burr removal and edge machining, (2) surface finishing improvement, (3) volumetric machining, and (4) electrolytic rifling.

The Electrolytic Process

Electrolytic machining is controlled metal removal via electrolytic dissolution, which is accomplished (1) using a shaped conductive tool to form a small gap (127 to 381 μm; 0.005 to 0.015 in.) between the tool surface and the workpiece, (2) flowing conductive electrolyte in the gap and (3) allowing a DC current to flow between the two adjacent surfaces. The conductivity of the electrolyte solution allows electric current from a 0-30 V_{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 causes atoms to be removed from the workpiece only and enter the electrolyte. 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 flow permits high removal rates. The process is shown schematically in Fig. 1.

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

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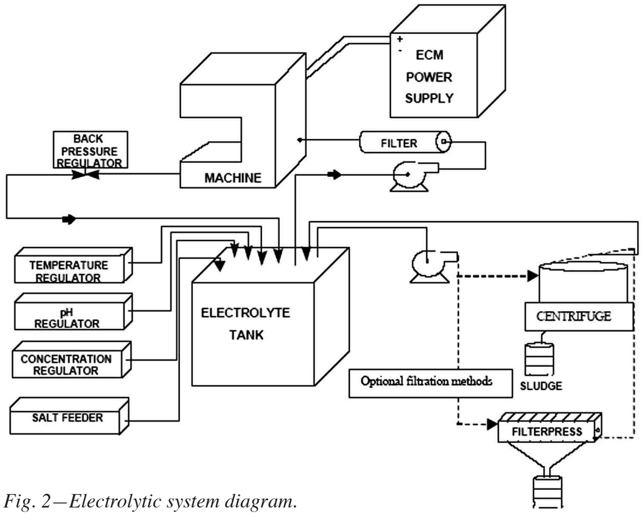

Fig. 2—Electrolytic system diagram.

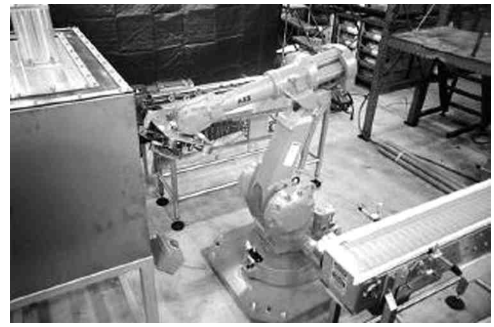

Fig. 3—Integrated parts washing system.

Fig. 4—Fiberglass bench type machine.

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 and frequent 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 wt% concentration of either sodium chloride (NaCl) or sodium nitrate ($NaNO_3$). The solution temperature normally ranges from 316 to 538°C (600 to 1000°F), with a pH ranging from 7.0 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 (Fig. 2) consists of the following:

Machine - machine base (which may include a feed unit and ork 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 and anode contacts

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 to be removed 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

Fig. 5—Four station modular electrolytic deburring system.

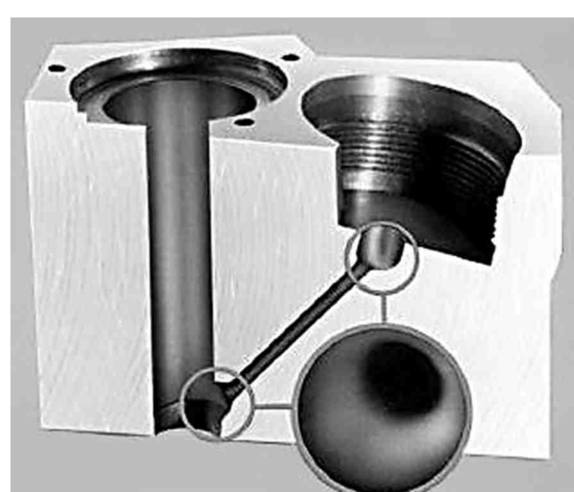

Fig. 6—Sectioned view of fuel body.

configurations for workpiece manipulation. Some fully-automated systems will also have integrated parts washing systems (Fig. 3). Small open machines have provisions for tools to be mounted over an electrolyte drain basin (Fig. 4). Semi-enclosed machines have an upper platen that holds anode contacts, part clamping points and electrolyte sealing surfaces (Fig. 5). A lower platen holds a workpiece fixture, cathodes and electrolyte connections.

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 of 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.

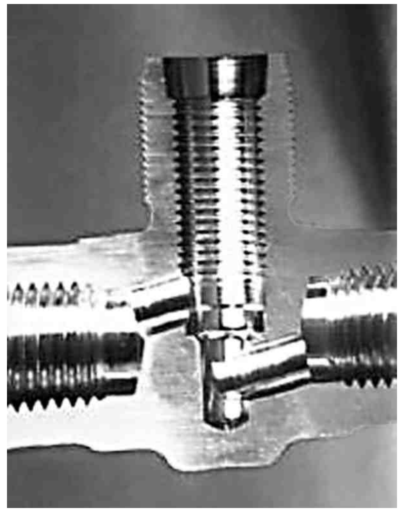

Fig. 7—Stainless steel valve showing deburred intersections.

Fig. 8—Automotive airbag canisters.

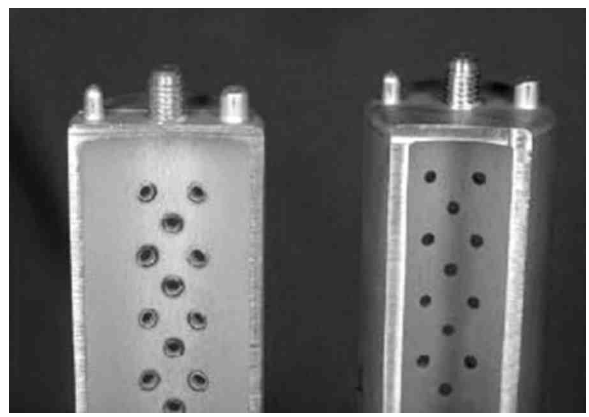

Fig. 9—Passenger side airbag housing with sections showing deburred holes.

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 be removed from the workpiece prior to the operation.

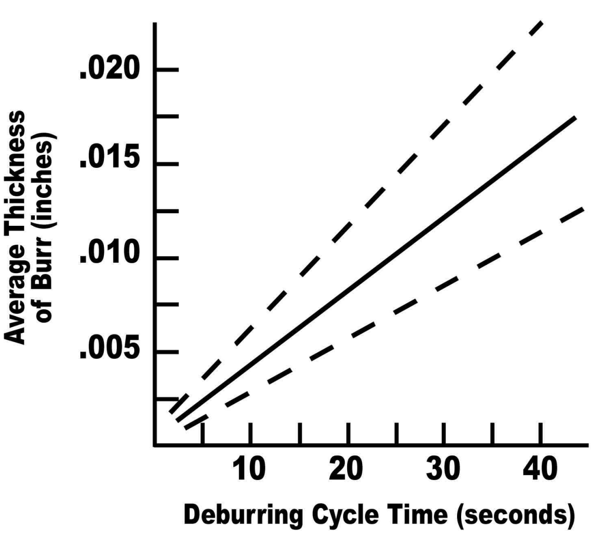

Fig. 10—Relationship between time and material removal for typical edge deburring applications.

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 shown in Fig. 6, which 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. Then the DC deburring power is switched on for a predetermined time. At the completion of the process, the machine unclamps the workpiece for removal by the operator. Electrolytic machining time is less than one minute.

Case II – Valve housing

Intersecting holes requiring burr free or radiused intersections are among the typical applications for this process. Figure 7 shows a cutaway view of a stainless steel valve body with hole edges intersecting all three bores. The requirement is to remove all burrs

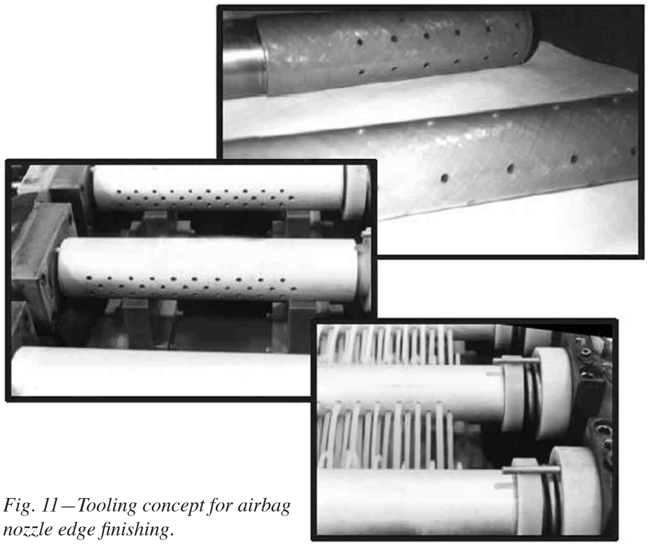

Fig. 11—Tooling concept for airbag nozzle edge finishing.

Fig. 12—Electrolytic machining equipment processing airbag housings.

from seats and intersections. These valve housings are usually deburred in three setups. Each process step takes approximately 15 to 20 sec.

Case III – Airbag housing inflation nozzles

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 6.35 cm (2.5 in.) diameter, 25.4 cm (10 in.) long with a wall thickness of 3.18 mm (0.125 in.) and typically have from 20 to 60 holes with burrs generated on the ID surface by drilling or piercing operations (Figs. 8 and 9).

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 sec if the amount of burr material increases as indicated in the time plot of Fig. 10.

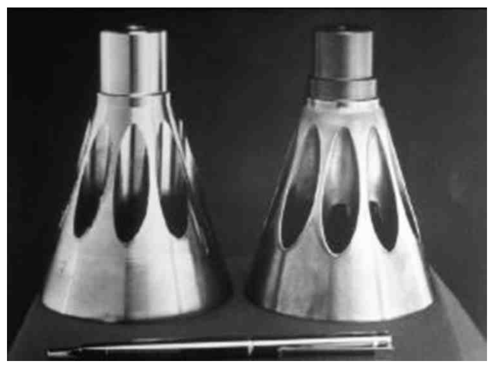

Fig. 13—Cone with electrolytically formed edges.

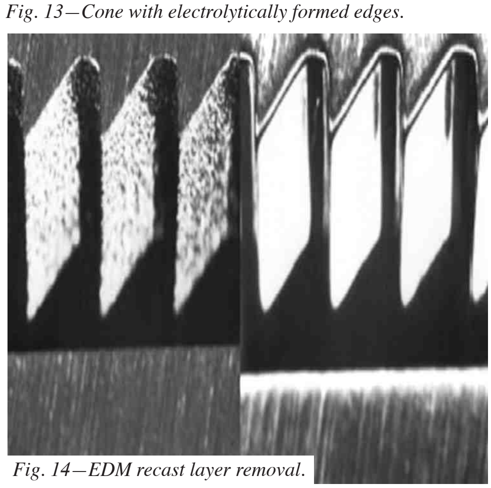

Fig. 14—EDM recast layer removal.

Typical machining parameters are:

Voltage:	18 V
Current:	150 A
Electrolyte:	$NaNO_3$
Electrolyte temperature:	24°C (75°F)
Electrolyte pH:	8.0
Flow pressure:	207 kPa (30 lb/in.^{2})

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 11. The size of each conductive cathode surface is dimensioned to encompass the burr over the tolerance range of hole position.

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 12.

Case IV – Projectile tail cone

A tail cone for a 120-mm (4.72-in.) projectile (Fig. 13) 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 the internal and external conical surfaces are turned.

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 1.0 mm (0.04 in.) of material must be removed from the exterior acute angle to generate a 1.25-mm (0.05-in.) radius. The exterior requirements are achieved in a 2.5-min 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 min with fixed-position cathodes. The shorter times for the latter come about 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 12.7 to 38.1 μm (0.0005 to 0.0015 in.) of surface material is removed which is

Fig. 15—Internal surface polishing by electrolytic material removal.

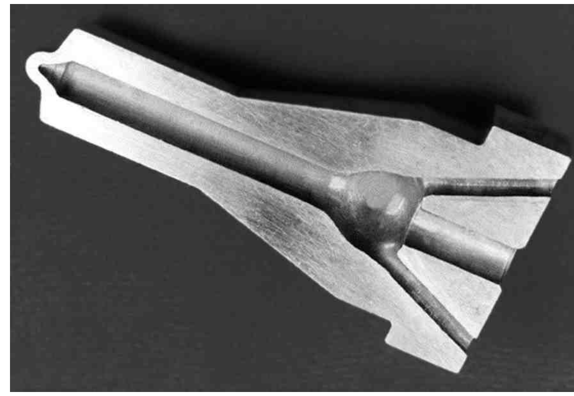

Fig. 16—Diesel injector fuel chamber electrolytically machined to a volume requirement.

determined by the EDM machining that produced the martensitic "recast" layer. Figure 14 is a photo of an EDM-produced surface before and after recast removal.

Case VI - Flow component polishing

Surface finishes as rough as 120 to 150 μ-in. R_a are electrolytically smoothed to 8 to 16 μ-in. 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 (Fig. 15). Typical process time is a few minutes or less.

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 Fig. 16, 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 in terms of the process parameters.

Case VIII – 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 to 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.

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 (Fig. 17).

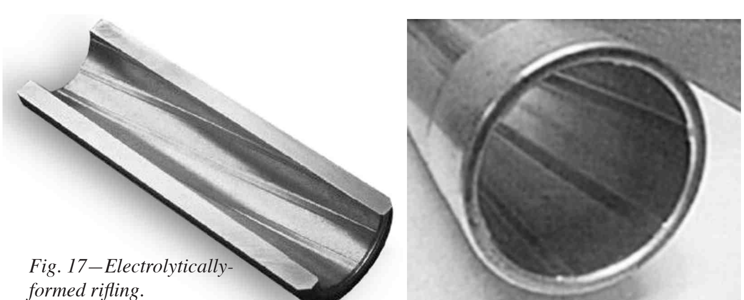

Fig. 17—Electrolytically-formed rifling.

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 (Fig. 18). The abrasive particles, which are imbedded in a metal binder, must protrude from the blade tip by 0.15 to 0.25 mm (0.006 to 010 in.). 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.

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.

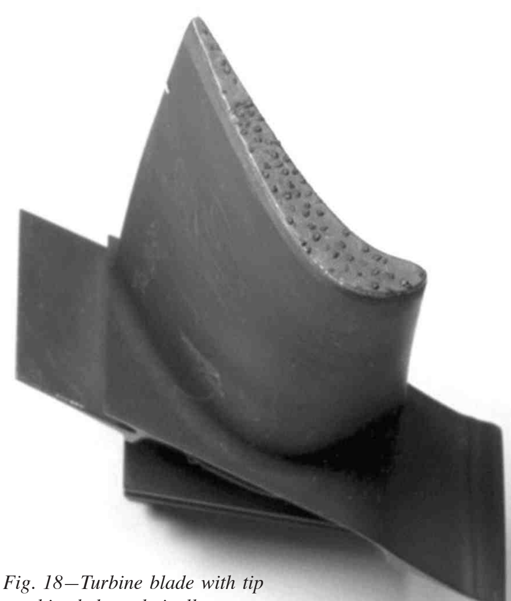

Fig. 18—Turbine blade with tip machined electrolytically.