Edge and Surface finishing with ECM

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ABSTRACT

Components ranging from artificial implants to diesel injector parts have requirements for edge and surface finishing that are becoming more challenging to meet on a cost effective basis. Manufacturing engineers are more frequently drawing on the capabilities of Electrochemical Machining (ECM) to meet these requirements that are as varied as the range of applications. Deburring, edge radiusing, contouring, and surface roughness reduction are some of the material removal objectives being met with ECM. Intrinsic process benefits, such as, very fast metal removal rates, stress free results, internal surface polishing (including some complex geometry), and non-consumed tooling have added to its popularity. ECM finishing provides high quality, accurate results on medium to high quantity applications and a sampling of these will be used to describe the different ways this technology is applied to production parts. Production equipment and process factors are described.

THE ELECTROLYTIC PROCESS

Electrolytic machining is controlled metal removal via electrolytic dissolution which usually requires a shaped conductive tool to form a small gap (0.025 to 0.75 mm) 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 electric current from a 5 to 30 volt DC power source to flow between the tool and workpiece. A typical electrolyte used in this process is a conductive salt solution such as sodium chloride (table salt) and water. The resulting electrical conduction within the solution is possible because dissolution in water breaks down the molecular restraining forces, so that the ions, called cations (Na+) and anions (Cl-), are free to move through the electrolytic solution. Application of an electric field causes migration of one ion species with respect to the other. Since each ion carries a charge, this movement constitutes an electric current.

Electrolytic current flow will cause atoms to be removed from targeted areas on the workpiece only and enter the electrolyte 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*.

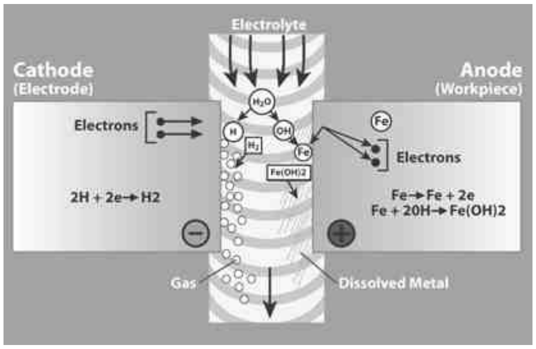


FIGURE 1

DIAGRAM OF THE ELECTROLYTIC METAL REMOVAL PROCESS

The electrolytic process is usually characterized as a high rate metal dissolution process when 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.

Material removal rate for ECM is essentially independent of material hardness but can be affected by alloy composition and grain size of the material. A general rule of thumb for ECM removal rate is that a tenth of a cubic inch (0.1 in^3) of material is removed per minute per 1000 ampere current flow. The theoretical removal rate can be calculated based on Faraday' s law, for example, Nickel has a theoretical removal rate of 0.129 in^3/min., aluminum 0.126, chromium 0.137, and iron 0.135. Due to the complex nature of the activity in the machining gap limitations of the actual machining rate exist.

ELECTROLYTIC BURR REMOVAL

Electrolytic deburring is a targeted metal dissolution process that uses stationary tooling to focus a deburring current on only those areas where burrs are to be removed. Since the deburring tooling, known as a cathode, never touches the workpiece, there is virtually no tool wear in the process. Typical deburring times are extremely fast (10-30 seconds for most applications, see Figure 2). Depending on production requirements and the workpiece size, multiple part fixturing is used to obtain high production rates.

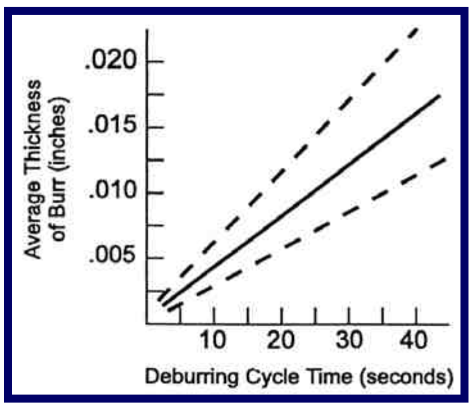


FIGURE 2
RELATIONSHIP BETWEEN TIME AND MATERIAL REMOVAL FOR
Typical Edge Finishing Application

Components requiring an edge radius from hundredths of an inch to less than a thousandth of an inch are excellent applications for the electrolytic process. Edge radii can be produced repeatedly with cycle times of 30-90 seconds.

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 a consistent radius
- 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.

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

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 64 mm diameter, 250 mm long with a wall thickness of 3 mm and typically have from 20 to 60 holes with burrs generated on the ID surface by drilling or piercing operations (Figure 3).

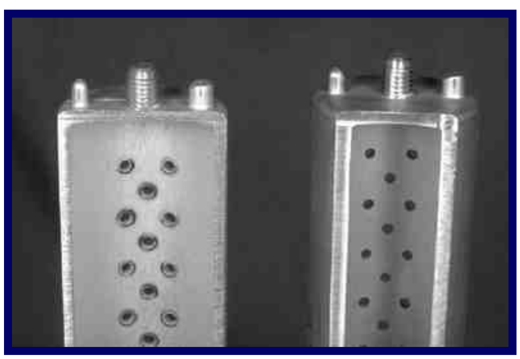


FIGURE 3
PASSENGER SIDE AIRBAG HOUSING (SECTIONS SHOWING DEBURRED HOLES)

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.

FIGURE 4
AIRBAG CANISTER CATHODE

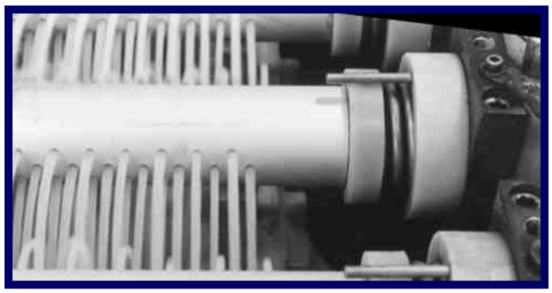


FIGURE 5
ELECTROLYTE FLOWING THROUGH NOZZLE HOLES DURING DEBURRING OPERATION

The cathode tools for this application have insulated surfaces with exposed conductive surfaces adjacent to each deburring site as shown in Figure 4. The size of each conductive cathode surface is dimensioned to encompass the burr over the tolerance range of hole position.

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 2.

Typical machining parameters are:

Voltage:	**18 V**
Current:	**150 A**
Electrolyte:	**$NaNo_3$**
Electrolyte parameters:	**25 C**
	8.0 pH
	1.5 bar

Valve Body

Intersecting holes requiring burr free or radiused intersections are among the typical applications for this process. Figure 6 shows a cut away view of a stainless steel valve body with passages intersecting the valve seat area. The requirement is to remove all

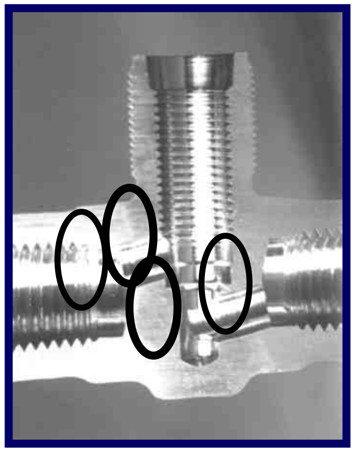


FIGURE 6

STAINLESS STEEL VALVE SHOWING DEBURRED INTERSECTIONS

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

Gears

Critical edges are produced via electrolytic deburring and radiusing of gear teeth. Applications range from automotive transmissions to fishing equipment. The deburring and radius requirements vary depending on the application and design. Burrs can range from 0.02 to 0.2 mm. In these applications shaped cathodes are fixtured a predetermined distance from the gear edge such that burrs are positioned in the electrolyte flow path without touching the cathode. (A short circuit detection system is used to confirm that no burrs are in contact with the cathode prior to power being applied.) 78 shows typical gear edge conditions before and after processing. Cycle times for gear deburring range from 5 to 30 seconds and edge radiusing times range from 15 to 90 seconds depending on the radius requirement.

FIGURE 7
DEBURRING AND RADIUSING OF GEARS

Fuel System Components

Fuel system components like the housing of Figure 8, that require burr free radiused edges at intersections are good examples of electrolytic deburring and radiusing applications. In this example, other features such as edge contouring are also produced electrolytically in one operation.

FIGURE 8
SECTIONED VIEW OF FUEL BODY

Other fuel system components that rely on the electrolytic process are injector nozzles for diesel engines. The nozzles require a fuel accumulation chamber (referred to as a gallery)to be machined into the main bore (Figure 9). A gallery is a burr free and stress free undercut of precise volume machined into the plunger bore. The gallery is electrolytically machined with a stationary tool that produces an increasing volume as the machining gap widens. In this application a constant current power source is used to produce an accurate volume. Electrolytic machining time is typically less than two minutes.

Figure 9

Diesel injection nozzle with cathode used to machine gallery

Projectile Tail Cone

A tail cone for a 120mm projectile (Figure 10) 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 10
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 one millimeter of material must be removed from the exterior acute angle to generate 1.25mm 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 due to the small, consistent burr on these edges

ELECTROLYTIC POLISHING

Electrolytic Polishing (or Electrochemical Polishing-ECP) is a process of applying conventional Electrochemical Machining methodology to improving surface finish of metals, primarily high chrome materials such as stainless steel. The process is orders of magnitude faster than electropolishing (EP) and can remove very rough surface conditions as well as brightening (improving the reflectivity) of a surface. In contrast to EP which is a bath process, ECP is a fixtured process requiring small spacing between tool and workpiece with constant flow of electrolyte. The process does not use acid electrolytes and therefore does not have the same environmental or operational concerns as electropolishing. The salts used in the ECP electrolyte are generally very easy to handle and store (table salt is one of the common electrolytes). The ECP process has many excellent applications but is not a universal substitute for EP. The potential applications are estimated to be between ten and twenty percent of EP applications and most of those will not only replace the EP step but will also replace the surface roughness improvement step done prior to EP.

Electrolytic polishing is a process of surface roughness reduction that is usually accompanied by surface "brightening". A typical arrangement for polishing a surface is depicted in Figure 11. The cathode tool is held a small distance from the workpiece surface. The distance is typically in the range of 0.7 mm. As a result of this requirement, the tool must be shaped similar to the surface to be polished.

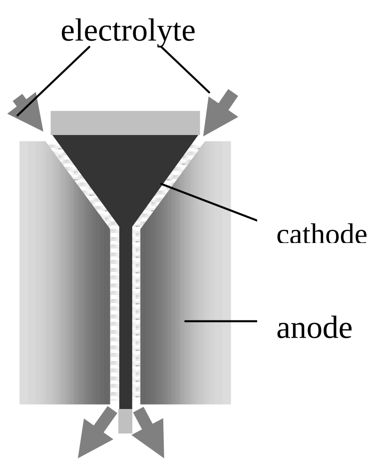
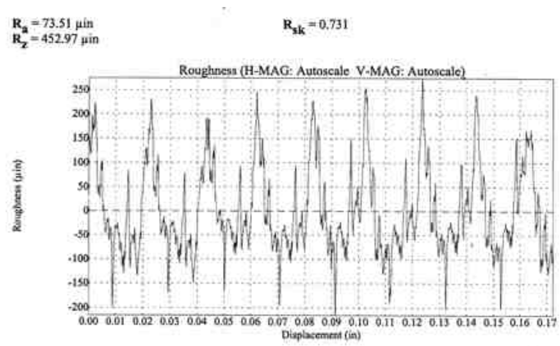


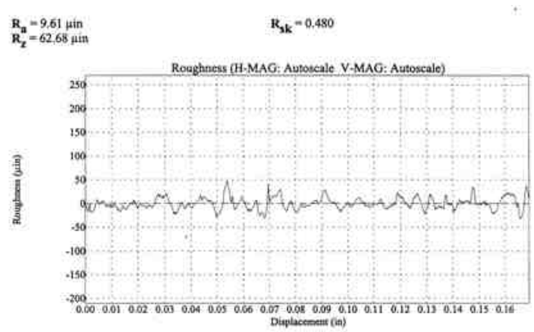
FIGURE 11

SCHEMATIC OF ELECTROLYTIC POLISHING (ECP) OF INTERNAL SURFACES

The electrolyte required for the current flow is pumped through the tool in this example. The current flow "smoothes" the surface by a "deplating" action that removes material from the peaks of the surface roughness at a rate slightly higher than the material from the valleys. This results in an overall material removal from the surface on the order of 0.01 to 0.02 inch to improve a surface roughness by a factor of ten. Figure 12 is a before and after trace on a stainless steel component (Figure 13) polished from 73 micro inch Ra to less than 10 micro inch Ra in 3 minutes.



BEFORE ECP



AFTER ECP

FIGURE 12

FIGURE 13
ECP POLISHED FLOW VALVES

OTHER ELECTROLYTIC MATERIAL REMOVAL APPLICATIONS

Surface "etching"

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 non-conductive 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.

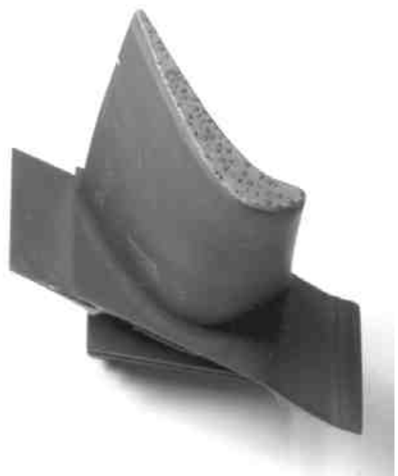


FIGURE 14
TURBINE BLADE WITH TIP MACHINED ELECTROLYTICALLY

OVERVIEW OF PRODUCTION SYSTEMS

Production equipment consists of the five elements listed below.

- **MACHINE**
- **CONTROL**
- **POWER SUPPLY**
- **ELECTROLYTE SYSTEM**
- **TOOLING**

Each of the elements is selected to provide the required process control.

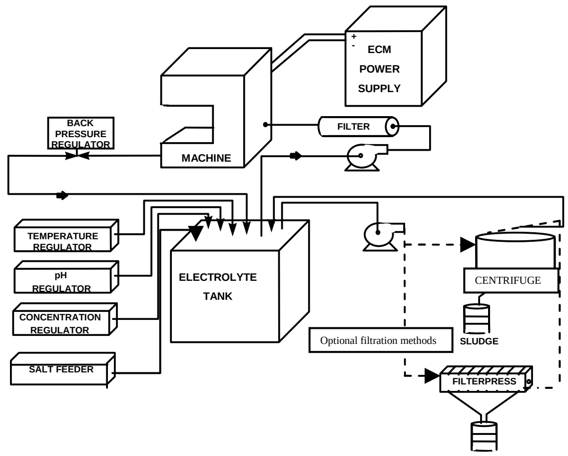


FIGURE 15
ECM PROCESS CONTROL ELEMENTS

A schematic of a production system showing the process control elements generally required for consistent results are shown in Figure 15

<u>Electrolytic Equipment</u>

Electrolytic process production machines are used in conjunction with tooling designed to suit specific workpiece geometry. A typical machine used for many of the above applications is shown in Figure 16.

FIGURE 16

STANDARD ELECTROLYTIC PROCESS MACHINE

The machine in Figure 16 is constructed of stainless steel with separate compartments for the electrolyte reservoir, power supply, and control circuits.

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 17). Small open machines have provisions for tools to be mounted over an electrolyte drain basin (Figure 18).

Tooling configurations for these machines typically consist of an upper platen that holds anode contacts, part clamping points and electrolyte sealing surfaces. A lower platen holds a workpiece fixture, cathodes and electrolyte connections.

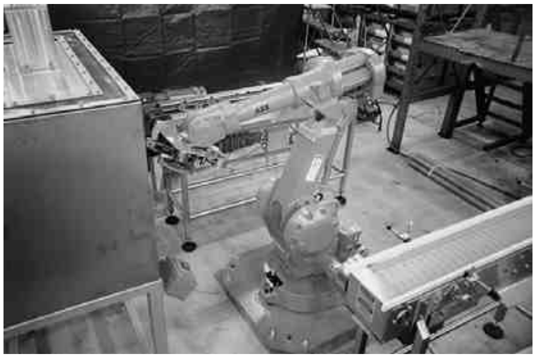


FIGURE 17
AUTOMATED MACHINE

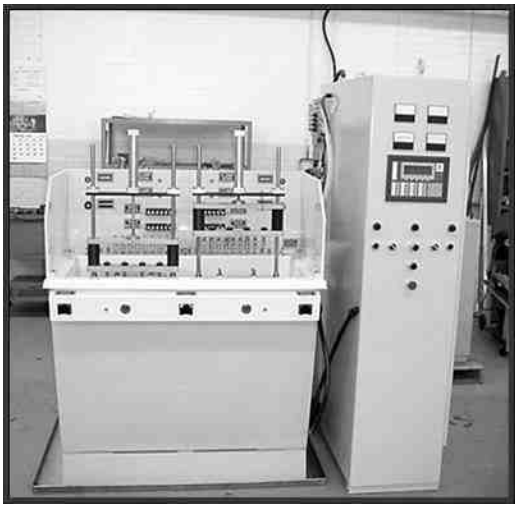


FIGURE 18
BENCH (OPEN) MACHINE CONFIGURATION

CONCLUSION

Electrolytic material removal technology has improved and expanded applications as a result of advances in pulse machining and electrolyte management. Medium through high volume production applications in automotive, aerospace, medical, computer, and other markets has continued to expand as advancements are made.

The process is characterized by very fast metal removal rates and the ability to focus the process on only those edges or surfaces to be finished. Edge finishing, polishing, and micro machining are some of the example that demonstrate the range of capabilities of the process. Larger radius requirements in higher pressure fuel components for diesel engines and more cost effective finishing of valves for food, pharmaceutical, and semiconductor applications, are some of the reasons for the increased use of electrolytic machining processes