

making the cut

An electromechanical process that shapes complex turbine parts is shopping for more jobs to take on.

By Michael Valenti, Senior Editor Mechanical Engineering Magazine

Manufacturers of jet engines machine the casings, compressor blades, and bladed disks, or blisks, of their products from the hardest alloys to one-thousandth of an inch tolerances. Precision cutting and milling titanium aluminides, Inconel 718, and Waspalloy, among others, is a painstaking process that places thermal and mechanical stresses on the part, and shortens the life of tooling.

An alternative method, especially efficient in working complex parts out of very hard conductive metals, is electrochemical machining, or ECM, a noncontact technology that spares both tool and part from machining wear, and finishes some parts in half the time of conventional mechanical machining techniques. The Sermatech Manufacturing Group, a leading user of ECM, is researching new applications for the technology, which the company uses principally on turbine components and various aircraft parts.

Meanwhile, electrochemical grinding, a related process also used to shape turbine parts, has established itself in other fields, including the precise machining of medical devices.

Electrochemical machining was first proposed by the Russian scientists B.R. and N.I. Lazarenko in 1943, who theorized that electrolysis could be used in order to remove metal from a workpiece, a reverse of electrolytic coating, which adds material.



The three stages of electrochemical machining: in the foreground, a forging (right) and a rough cut; a Sermatech technician removes the finished bladed disc from an ECM unit.

The basic components of ECM are the workpiece, the conductive tool, a recirculating electrolyte, and a power source. The part must be made of a conductive metal. The tool is typically made of copper, brass, or stainless steel, while the most commonly used electrolyte is a concentrated solution of inorganic salts, such as sodium chloride, and the direct current power source is low voltage and high amperage.

In the ECM process, the dc power source charges the workpiece positively and charges the tool negatively. As the machine slowly brings the tool and workpiece close together, perhaps to within 0.010 of an inch, the power and electrolyte flow are turned on. Electrons flow across the narrow gap from negative to positive, dissolving the workpiece into the shape as the tool advances into it. The recirculating electrolytic fluid

carries away the dissolved material as a metal hydroxide.

This noncontact capability means the ECM tool does not have to be made of expensive alloys tougher than the workpiece, as would be necessary for mechanical machining. The process also reduces tool wear and minimizes scrap costs. ECM places less heat and mechanical stress on the workpiece than mechanical machining does; such stresses can damage a part's microstructure.

ECM can make a virtually finished part in one pass, regardless of the metal's hardness. The tool can be used over again to make many parts.

Among the drawbacks of ECM is its high tooling costs. The tool and the programming must be tailored to make the correct inverse part geometry. Power, up to 40,000 amps, also must be bussed into the workpiece. Most tooling components have to be made from copper alloys or stainless steel, to hold up to the saline electrolyte. Also, manufacturers of ECM systems must ensure that the salty electrolyte does not corrode the equipment or the workpiece.

For these reasons, the real value of electrochemical machining is in metalworking applications that are too difficult or time-consuming for traditional mechanical fabrication, such as the mass production of complex shapes from conductive materials that are difficult to mill, drill, deburr, mark, or etch. These characteristics suit gas turbine engine components to a tee.

Lighter and Stronger Engine Parts

Sermatech has 62 ECM machines, most of its own design, at its Cincinnati manufacturing site. The machines are grouped into three facilities, each dedicated to making engine casings, compressor blades, or blisks. All of Sermatech's ECM systems use computers to precisely control the key parameters of voltage, electrolyte flow, and movement of the tool and the workpiece.

The biggest production items are casings for jet engine manufacturers. The casings house smaller engines used on the Boeing 737 and Airbus A320 commercial airliners and larger engines used on Boeing 767 and 747, and Airbus A300/A310 commercial airlines, as well as FA-18 and F-16 military aircraft.

The Sermatech engineers begin by designing the tooling to machine the embossments for each section of the casing. These embossments include holes, channels, and concave or convex portions. When this is completed, the casing is clamped into the fixture.

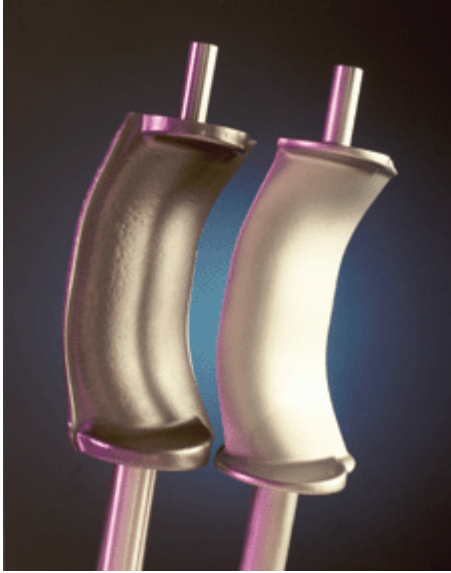


A major advantage of ECM over traditional machining is that it can impart complex shapes, such as embossments on engine casings, in one pass, instead of requiring multiple cuts.

Up to a six-axis machine slowly moves the tool into the casing, creating the desired form as it proceeds in a single pass per section. Tools of different geometry are used to work different sections of the part.

Usually, only a few secondary machining operations are needed after ECM, and these are carried out on three- or five-axis CNC milling machines. Coordinate measuring machines are used to inspect the finished casing.

"This illustrates a major advantage of ECM over traditional contact machining, because the process imparts complex shapes, such as multiple holes or embossments, in one pass," said Larry Alexandre, vice president for sales and marketing at Sermatech Manufacturing Group. "Conventional machining would require multiple cuts."



Typically, Sermatech machinists forge a rough cut of a part, like this spindle vane (left), then finish it to the specified tolerances by ECM processing (right).

Because of its precision, ECM is able to machine structural walls as thin as 0.010 to 0.020 inch to make lighter casings without compromising strength, said Alexandre.

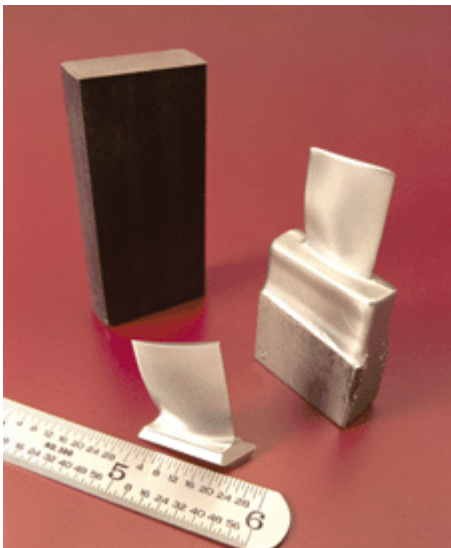
Sermatech also machines compressor blades, for aircraft engines and for industrial land-based gas turbines. Sermatech often specifies electrochemical machining as a cost-effective way to craft blades up to 12 inches long. Because the ECM tool does not wear down like a conventional mechanical tool, the process can produce complex airfoils with highly uniform shapes and edges without hand polishing.

This is also true of Sermatech's ECM-made blisks—bladed disks, also known as IBRs, or integrally bladed rotors. These components are replacing conventional blade and disk arrangements to improve turbine performance.

Finding Nuclear Applications

Sermatech's ECM facilities make key aircraft parts in addition to turbine components. "For example, we machine special 12-point bolt heads used in an aircraft engine application, out of a high nickel, cobalt, and rhenium alloy," said Bob Schubert, a member of ASME and director of marketing at Sermatech.

The company also machines the rectangular hole electrochemically in a titanium helicopter hub that locks the aircraft's rotors in place. Ordinarily, the rectangle would be made by a 14-inch-long, 1.25-inch-diameter end mill.



The platform, and all edges of this compressor airfoil (foreground), machined from bar stock, were electrochemically machined in a single operation.

Sermatech, which showcased its ECM process at the ASME Turbo Expo in New Orleans last June, is exploring applications for its noncontact machining technology beyond aviation. For example, Schubert said the firm is discussing using ECM to machine the slots in the disk through which blades, for land-based as well as airborne gas turbines, are mounted. Conventional practice involves using a broach—a cutting tool 30 feet or more in length—to cut one slot at a time in the disk. The setup is laborious and time-consuming, and the broach must be sharpened periodically.

"With ECM, we can cut multiple slots in a single machine cycle, and eliminate the need for sharpening the

roughing tool," said Schubert. A short broach is then used for finishing. In this way, ECM would save significant perishable tool cost and still provide a part that is finished by a tested method.

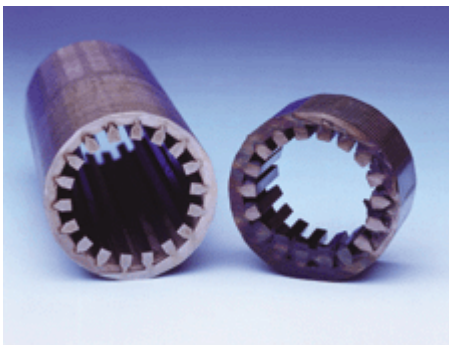
Sermatech is working with clients in oil and gas exploration and others in the military to design an ECM system to shape the internal geometries of metal tubing. In this version of ECM, the charged tool would be slowly fed through the interior of the tubular workpiece, creating features as it proceeds. It may one day make fins to improve heat transfer, or carve the spirals for rifling in weaponry.

Schubert sees an opportunity for internal geometry ECM in manufacturing boilers for nuclear power plants. "Nuclear steam generators are made of the hard, exotic metals that ECM can easily accommodate," he said. "Because these boilers transfer low-grade thermal energy in the first place, ECM's ability to improve heat transfer by upgrading their internal design could translate into a smaller boiler, reducing material cost and equipment footprint."

Some Contact—But Not Much

Electrochemical grinding, or ECG, is a variation of ECM that combines electrolytic activity with physical removal of material by means of charged grinding wheels. ECG can machine very smooth edges, without the burrs, caused by mechanical grinding tools, which require further machining. Like ECM, electrochemical grinding generates little or no heat that can distort delicate components.

ECG machines made by Everite Machine Products Co. in Philadelphia work in very distinct markets. Jet engine manufacturers, including General Electric and Pratt & Whitney, use the machines to form-grind refurbished aircraft engine blades and vanes. Medical device manufacturers, such as Sherwood Medical, Becton-Dickinson, and Tyco Kendall, use the ECG machines to cut tiny tubing for hypodermic needles and medical implants.



Machinists use ECG to precision-cut parts (left) without imparting the thermal or mechanical stresses that can cause surface flaws (right).

and last longer.

The basic components of the process are a conductive grinding wheel, typically made of a matrix of copper, abrasive and resin, a tank that holds an electrolytic solution, and a direct current power source.

The wheel is mounted on an electrolytic spindle equipped with carbon brushes that serve as a commutator. The dc power supply charges the spindle negatively, and charges the workpiece positively.

When the workpiece contacts the wheel, a nozzle applies the electrolyte, typically sodium nitrate, much like coolant in conventional mechanical grinding. The coolant fills the tiny irregularities in the grinding wheel, creating an electrochemical cell that oxidizes the workpiece surface. The abrasive wheel carries away the oxide film, thereby exposing fresh metal to the process.

Because the oxidized material is fluid, it requires much less force to be removed. Pressures are frequently 20

psi or less, depending on the area of contact between the wheel and the workpiece, according to Everite. This virtually eliminates the distortion that purely mechanical grinding causes to metal surfaces.

The dissolved oxide surface puts very little wear on the grinding wheel. The wheel is essentially self-cleaning, which greatly reduces the dressing and truing required with abrasive or creep feed grinding.

Whether operating in semi-automatic mode, the most popular, or by CNC, Everite's machines control the feed rate of work material, the voltage, and the electrolytic flow.

"Like ECM, the hardness of the workpiece is not a factor affecting electrochemical reactivity, so we can machine the hardest alloys, including Hastalloy, Inconel, and Stellite," said Tom Travia, a manufacturing engineer and sales manager at Everite.

Electrochemical grinding can simplify the repair of blades and vanes on aircraft. Repair technicians weld the worn spots on engine blades and vanes, and then grind them to the correct shape. Mechanical grinding can heat the weld until it cracks. As a result, repair personnel painstakingly remove a few ten-thousandths of an inch of material at a time from a weld that may require one or more sixteenths of an inch to be removed. "This can take five to eight minutes. We have found that our ECG machines can machine a jet engine blade in less than a minute. An operator can finish from 100 to 150 blades before needing to dress the wheel," said Travia.



Electrochemical grinding puts an edge on these stainless steel trocars, surgical instruments used to perforate the body and drain fluids.

GE Engine Services in Arkansas City, Kan., for example, refurbishes helicopter engine blades with Everite's ECG machines. The process can also machine more delicate internal aircraft components, such as the honeycombed air engine seals, and honeycombed structural parts.

Everite engineers developed a thinner cutting wheel version of its ECG machines to cut fine stainless steel tubing for medical devices without burrs. The most popular medical application for this model, called a TC-1C cutoff machine, is for hypodermic needles. It can handle up to 86 0.012-inch-diameter stainless steel tubes at a time.

"The machine can make three cuts per minute, producing 258 needles in 60 seconds," Tavia said.

Other tiny medical devices made by Everite machines include biopsy needles, nickel titanium threading catheters, and cobalt-chrome alloy joint implants.

A delicate tube-cutting job for the TC-1C in the industrial field is cutting the tiny nozzles for the tips of acetylene welding torches, which can be distorted by the stresses of conventional machining. Thermodyne Engineering Ltd. in Toronto uses Everite ECG machines to make them.

Reprinted from November 2001 issue of Mechanical Engineering Magazine

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