Electrolyte Flow Restrictions

- A flow restrictor will need to be used, if the tool engages a limited area of the work surface during some part of its operation.
- Place the restriction, entry or exit dam, or flow slot close to or over the limited area of engagement.
- Extend restriction to follow progressive engagement (or disengagement) of tool with work.
- Limit flow path length through restrictor to 0.1 in.
- Consider each flow problem on its merits; decide where the restrictor is needed and then design it. Do not rely on repeating previously successful tooling.

Tool Insulation

- Insulate tool surfaces where machining action is not required.
- Insulate or shield all cathodic surfaces where stray corrosion of the component is not permissible.
- Insulate anodic parts of fixture to protect them against corrosion.
- Use solid plastic insulation bonded and secured with plastic screws where practical.
- If it is only practical to use an insulation coating, specify approved insulation method and an experienced, qualified source for carrying out the work.
- Shield the edges of coated insulation from high velocity electrolyte flows.

Tool Correction

- Decide if tool correction is necessary, based on component configuration and tolerances.
- Estimate tool operating gap and use this value in determining tool correction from data sheet.
- Prepare glass layouts of corrected tool shape.
- Sometimes an envelope shape of the required work contour will fit the true corrected shape closely. This can then be used to simplify tool manufacture.
- Excessive material dissolution will occur at sharp features having radii smaller than 0.050 in. or at boundaries. Use field theory to calculate additional tool correction at these points.
- Or refer to empirically developed data.

CHAPTER

VIII

Generating Surfaces of Rotation by Electrochemical Turning and the Use of Tapered Electrodes

8.1 ELECTROCHEMICAL TURNING

Electrochemical turning adds a new dimension to electrochemical machining application but requires little extension of the ideas already discussed on tooling.

Concentricity and balanced material distribution are often requirements for circular components. It is the ability to produce these properties that gives turning its advantage over the single motion ECM tools. Ordinary ECM tools could be used, in many instances, to produce the same component but less accurately. Large surfaces of rotation can be machined with small segmental tools. These operate at high current density so that requirements for surface integrity of the component can be met while fully utilizing the machine's amperage capacity.

The rotational movement of the tool, relative to the component, does pose some new problems in the use of flow restrictors, back pressure devices, and so on. On the other hand, the rotation effectively camouflages many flow defects and local tool inaccuracies, so that excellent results can be obtained with simple tooling. In addition, circular parts are easily fixtured. Generally, the principles already outlined for ECM tool design apply to turning. Alternative or new concepts are discussed in the following sections.

8.2 BASIC CONCEPTS OF TURNING TOOLS

One of the fundamental advantages of ECM over conventional mechanical methods is that all points, on a very large area, may be machined simultaneously. The entire surface may be machined, in one operation, by a single tool. In considering EC turning, it is naturally useful to apply the same principle—the tool having the same area as the work. The tool is, except for the normal small correction factors, an inverse replica of the surface to be produced, with provisions for directing electrolyte flow. Such a tool will work whether the work is rotated or not.

Rotation of the work does have advantages, however, since imperfections in tool manufacture, misalignment with the work, or electrolyte flow problems are minimized or limited in their effect. These simple tools, however, do have disadvantages. They become cumbersome and require large supplies of both electrolyte and electrolyzing current, and robust machinery to operate them. They are limited to movement along the axis of component rotation.

It is usually necessary to machine components at current densities above 200 A/in.^{2} to obtain an acceptable surface finish. In using a full area tool to machine one side of a 20-in.-dia. turbine wheel, for example, a minimum current of 60,000 A would be required. In addition, electrolyte flow at 600 gal/min, and a machine to withstand 30,000-lb. loading, would be needed. Not many components, machined in this way, can economically justify the high costs of such a large facility.

An example of the full area type of tool is shown in Figure 8.1*a*. Some of the objections to it, however, have been overcome by using only segmental cathodic surfaces, interspaced with an insulating material. The total segmental area can be designed to suit whatever amperage is available and, incidentally, this ensures efficient use of the available power. Using small width segments and high speed rotation of the work, the electrolyte flow is deflected across the segments as shown in Figure 8.1*b*. The flow path lengths across the working surfaces of the tool are then reduced, so that lower electrolyte pressures and flow rates are adequate. Assuming a minimal pressure of 25 psi, the radial flow velocity will be 60 ft/sec. Since only viscose forces act to deflect the path of flow, a rotational speed of 1000 rpm is required to produce a significant effect. A better result could be obtained by rotating the tool itself; the

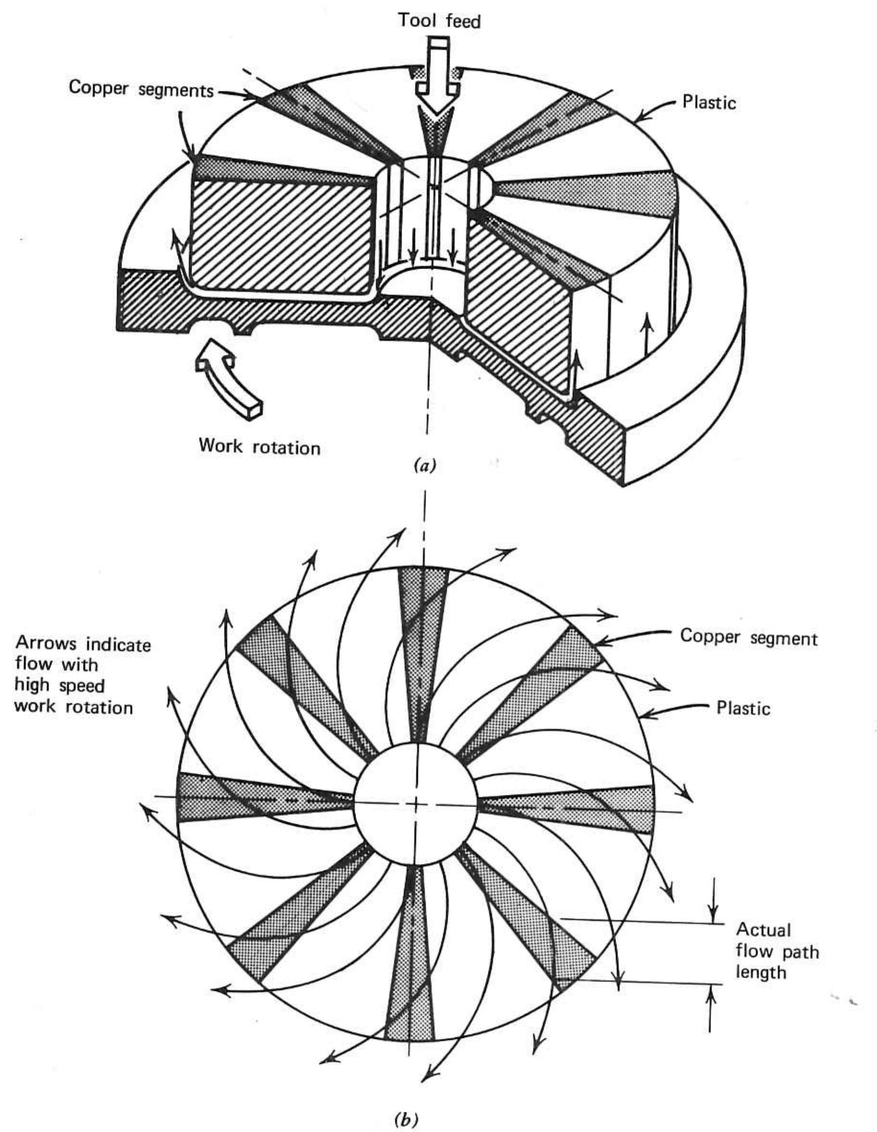


Figure 8.1 (*a*) Full area turning tool with segmental copper electrodes. (*b*) Electrolyte flow distribution across segments of a turning tool with high speed work rotation. (*c*) Individual segmental tool.

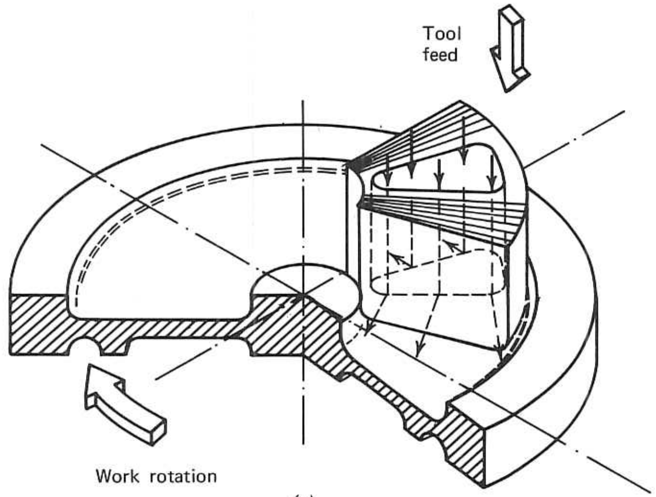


Figure 8.1 *(Continued)*.

lack of high viscose forces would then be an advantage in obtaining flow across the segments. This, and similar approaches, are unnecessarily complex.

While the above tooling methods have been discussed in some detail, it was for the sake of completeness and a warning of the problems involved. It also serves as an introduction to the individual segmental tool approach. This tooling concept solves the problems of available amperage, flow capacity, and machine strength; tools are not limited to axial feed directions and are adaptable to suit almost any turning requirement.

The individual segment tooling method is shown in Figures 8.1*c* and 8.2. The similarity to the tool shown in Figure 8.1*a* will be noticed. In fact, the segment may be of any angle, and so at 360° it becomes the tool shown in Figure 8.1*a*. The electrolyte flow is directed across the pure segmental cathodic parts of the tool from a duct cut in the insulating material between them. The flow channels can be designed as if for a normal ECM die sinking tool.

If flow channels are separate from the cathodic areas of the tool, this considerably simplifies the design. This is because the operative cathodic surfaces of the tool are then pure segments; so that the operative arc length of tool, at any diameter, is proportionate to the circumference of the work at that diameter. This permits the use of normal tool correction methods for defining tool contour.

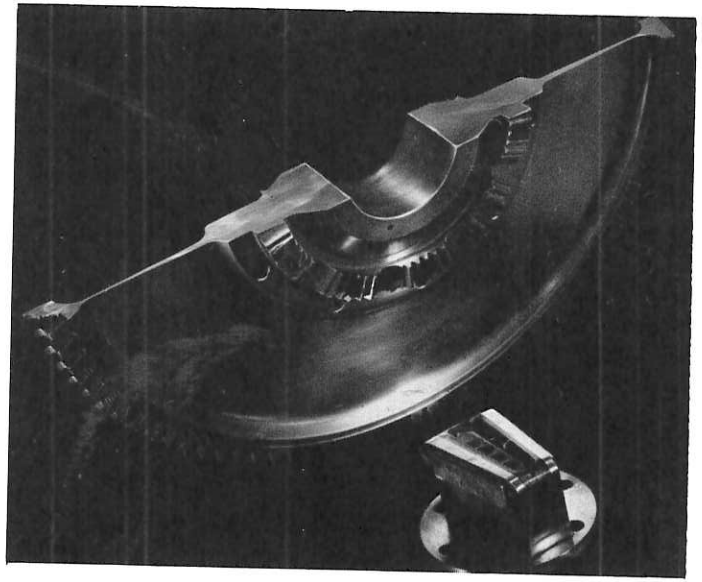


Figure 8.2 Segmental ECM turning tool and 30-in.-dia. turbine wheel in which it produced the thin web contour. (Courtesy of the Bristol Engine Division, Rolls-Royce Limited.)

8.3 COMPONENT APPRAISAL

The appraisal of a component, to determine whether it should be produced by electrochemical turning, will include most of the factors covered in Section 7.1. There are some variations, however, in attainable accuracy and in the method of estimating machining time.

Increased accuracy is, first of all, due to the elimination of small alignment errors in positioning the tool to the work. This is because the rotation distributes the error evenly, ensuring a perfectly concentric component. The error of component location to the rotating table of the machine may be eliminated by machining a register diameter at the same time as the main areas of the component are produced. The tool feed direction must be partly radial to obtain this advantage, so only segmental tools (Figure 8.1*c*) are suitable. In-process gauging may be used to monitor continually and control component dimensions to accuracies of ± 0.0001 in., since the machined surfaces are partly exposed when a segmental tool is used.

There are many factors involved in the determination of tool segment size and number of operative segments, or alternatively, determining whether a full face tool should be used. These factors are discussed in the following sections. It is safe to assume that the operative areas of the tool will run at current densities of at least 500 A/in.^{2}; thus the total tool area times 500 A/in.^{2}, or the machine's current capacity, whichever is the least, determines the rate of metal removal. *One cubic inch of metal removal per 10,000 A/min* still applies as a good approximation.

Alternatively, the tool feed rate can be derived by reducing the normal 0.050-in./min. tool feed rate, at 500 A/in.^{2}, in proportion to the ratio:

component area : tool area

$$\text{tool feed rate} = 0.050 \times \frac{\text{tool area}}{\text{component area}} \ (\text{in./min})$$

$$\text{machining time} = \text{tool feed rate} \times \text{depth of cut}$$

This is a more accurate method, since the total tool movement may include safe starting gaps and localized operation of the tool until it fully engages with the work. These factors may be missed, if the volume method of calculating machining time is used.

8.4 TOOLING AND ELECTROLYTE FLOW ARRANGEMENTS

The main principles of axially moving tools for electrochemical turning flat components have already been discussed. However, tool feed directions, from purely axial to purely radial, will be required to produce the varied types of circular components.

It is the radial component of tool movement that limits the size of segment that may be used. This is because the machined surface changes in diameter as metal is removed, but the tool is of fixed geometry. The tool will, of course, machine the work even though it does not conform to the work surface; but it does so less efficiently because of gap size variation. A practical method for determining the limiting segment size is shown in Figure 8.3*a*. The two circles represent initial and final work sizing. In this case the tool envelopes the work by 0.010 in. in its final operating position. The segment size should be limited so that at the start of the operation, the variation in gap size does not exceed 0.010 in. This concept is simple to apply when purely radial tool feeds are used; generally a few drafted layouts will show the limiting condition, which depends on the smallest diameter to be machined. The tool will operate less efficiently at the start of machining because of larger gaps, but a higher operating voltage may be used to compensate for this effect.

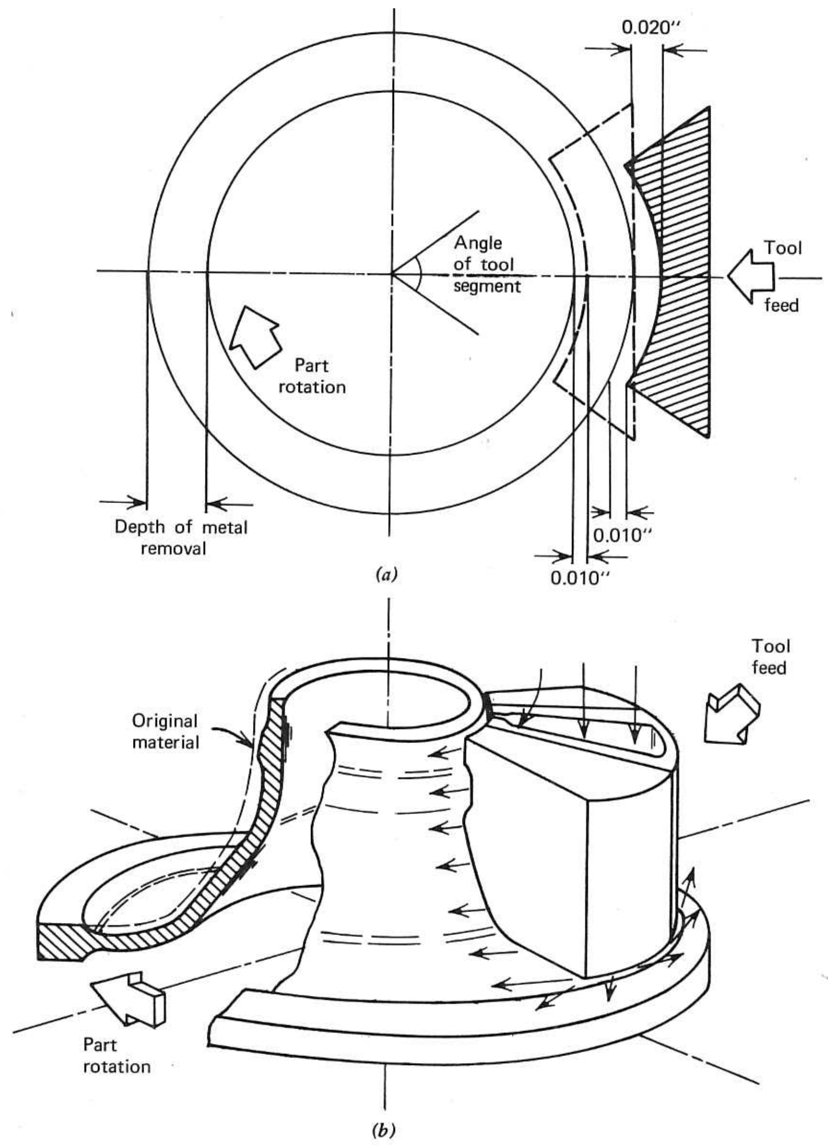
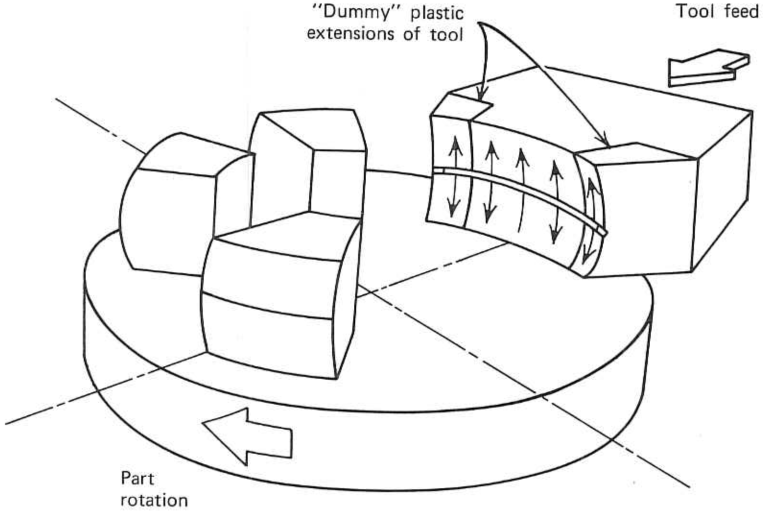


Figure 8.3 (*a*) Change in gap geometry with radial depth of machining. (*b*) Segmental tool with angled feed direction. (*c*) Intermittent turning with a segmental tool.



(c)

Figure 8.3 (*Continued*).

A larger segment, which will machine faster, can be used if its shape is designed to conform to the work at some midpoint during machining. In this way lack of tool conformity occurs at both initial and final machining diameters. The method is suitable if close component accuracy is not required. The former method should be used, however, if it is required to precisely design the tool contour for accurate work generation. A component requiring radial tool movement is shown in Figure 8.4.

To produce close accuracy, the tool should be designed to envelope the work surface by 0.010 in. at the point where the direction of tool feed is orthogonal to that surface. Normal tool correction methods are then applied, but only two dimensionally, in a plane coincident with the axis of the component. No corrections are necessary for the work curvature, since the rotation cancels gap variations that would be evident with a normal die sinking tool.

A typical application of a segmental tool, with an angled feed direction, is shown in Figure 8.3*b*. The component is typical of a gas turbine engine hub, with closely dimensioned thin sections and requiring precise concentricity for good balance. The tool feed direction is selected to divide the maximum angle formed by the surfaces to be machined. In the case shown an angle of 45° to the component axis is suitable. This

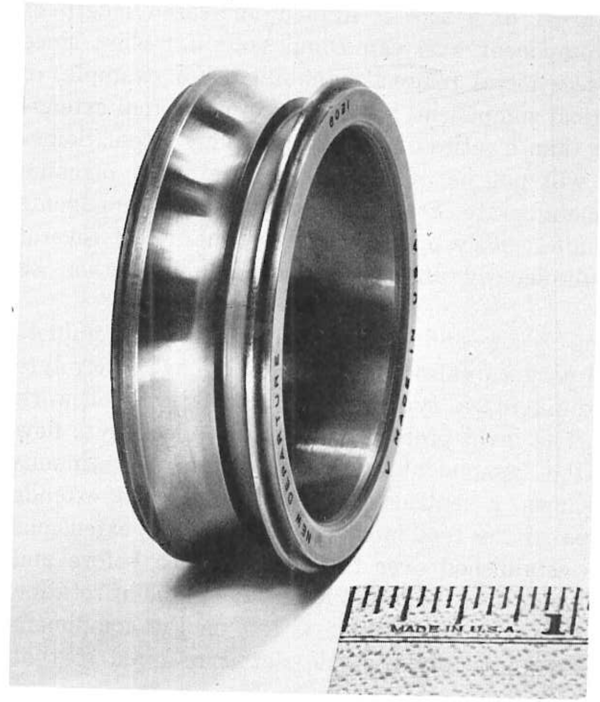


Figure 8.4 Electrochemically turned component produced by a radially moving segmented tool. (Courtesy of the Anocut Engineering Company.)

limits the tool approach angle, at all parts of the surface, from 45 to 90°. As with die sinking work, the closer this angle is to 90° the smaller are tool corrections; hence component tolerances are easier to meet.

Electrolyte is supplied through a narrow slot, running the length of the tool and backed with an electrolyte reservoir. The cathodic areas of the tool are retained as pure segments by placing the electrolyte slot within a segmental plastic insert in the tool.

This narrow tool slot is a flow restrictor. Since all areas machined pass under the slot, it is the only flow restrictor device required. For example, in Figure 8.3*b*, the irregular forged surface causes machining at a localized diameter on the component surface, while parts of the tool are still remote from the component surface. Despite this, the tool will operate satisfactorily.

A tool, similar in principle to that shown, could be used to turn the internal contour of the component. This simple tooling concept can, in fact, be used on most electrochemical turning applications.

While the segmental angle of a tool is limited, increased length of engagement along the component axis can compensate for this; since a larger tool area increases metal removal capability. For example, in machining a long cylindrical component, it is better to use a tool extending its full length, rather than a series of simpler individual tools. Sometimes a single segment will not be of large enough area to machine a component at an economic rate. Stacking a number of components and machining them simultaneously or, alternatively, the use of several duplicate segments simultaneously on one component should then be considered.

Electrochemical turning is not confined in its application to complete circular parts. Segmental parts can also be produced, although electrolyte flow arrangements are different. A typical tool for this type of work is shown in Figure 8.3*c*. The main problem is to ensure electrolyte flow between the tool and the component surface, despite discontinuous machining. In the tool shown, a central electrolyte supply slot extends outside the operative area of the tool into "dummy" plastic extensions of the tool. The flow is established over the work surface before and after it passes the operative part of the tool. Slots in the plane of rotation do have the disadvantage that a small ridge is left on the component surface. In most cases, however, only a single slot is required so that tool construction is simple.

8.5 THE USE OF TAPERED ELECTRODES

In most ECM generating operations, as shown in Figure 8.5*a*, the cutting action is concentrated on material lying in the path of tool movement. The machining gap is small, and current density and metal removal rate are high. The surfaces of the work that are parallel to the direction of tool feed, however, which are usually the most important functional surfaces of the work, are generated at large machining gaps and low current density. Dimensional control is limited, therefore, because of the remoteness of the tool; and surface finishes are usually poor, because of the low machining current density. Also, because of the relatively slow movement of the tool, these side walls are subjected to stray machining long after the operative surfaces of the tool have passed by them. This causes further dimensional errors and loss of surface quality. It is usual for holes to have tapered, rather than parallel, walls when produced in this way.

Very much better surface quality and dimensional control can be obtained if a secondary operation is used, in which a tapered tool removes

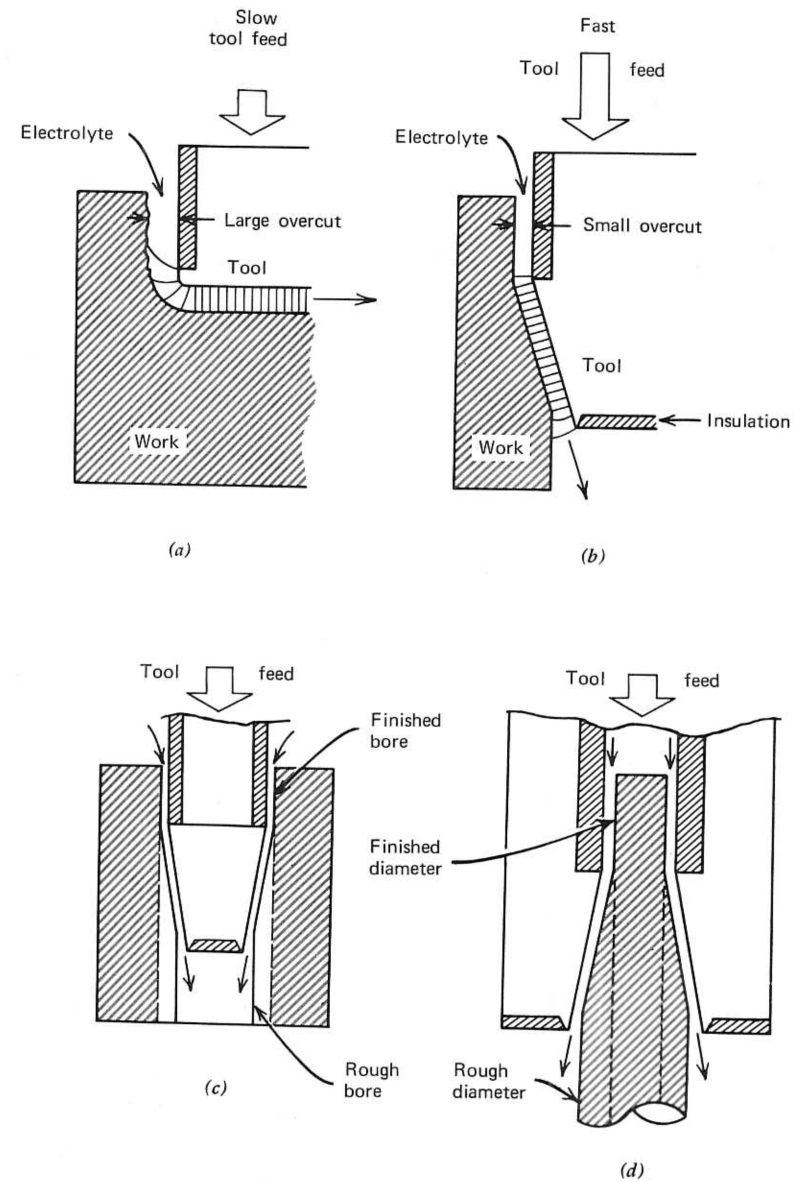


Figure 8.5 (*a*) Low current density and poor finish on side wall. (*b*) High current density and good finish on side wall. (*c*) Precision sizing of a round hole. (*d*) Precision sizing of a round rod.

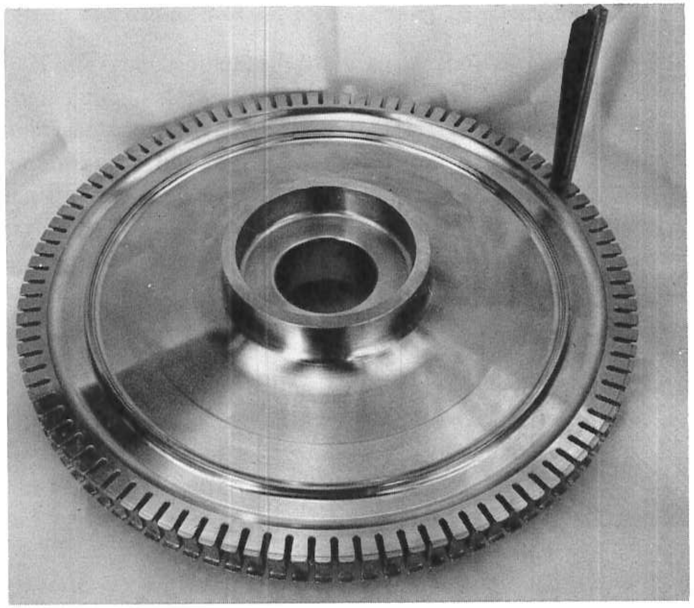


Figure 8.6 Turbine wheel EC slotted by a bank of tapered electrodes feeding axially. The slots, 0.5-in.-deep, 1.0-in.-long, 0.09-in.-wide, are produced simultaneously by a single pass of the tapered slotting tools. The complete operation takes 20 min in this tough nickel alloy. (Courtesy of the General Electric Company.)

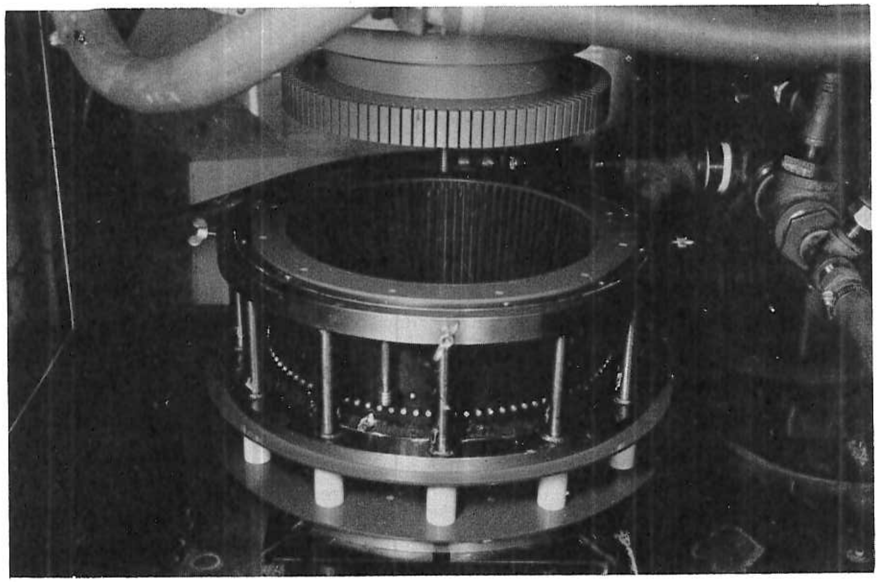


Figure 8.7 Bank of tapered tools and locating fixture for machining the slotted turbine wheel shown in Figure 8.6.

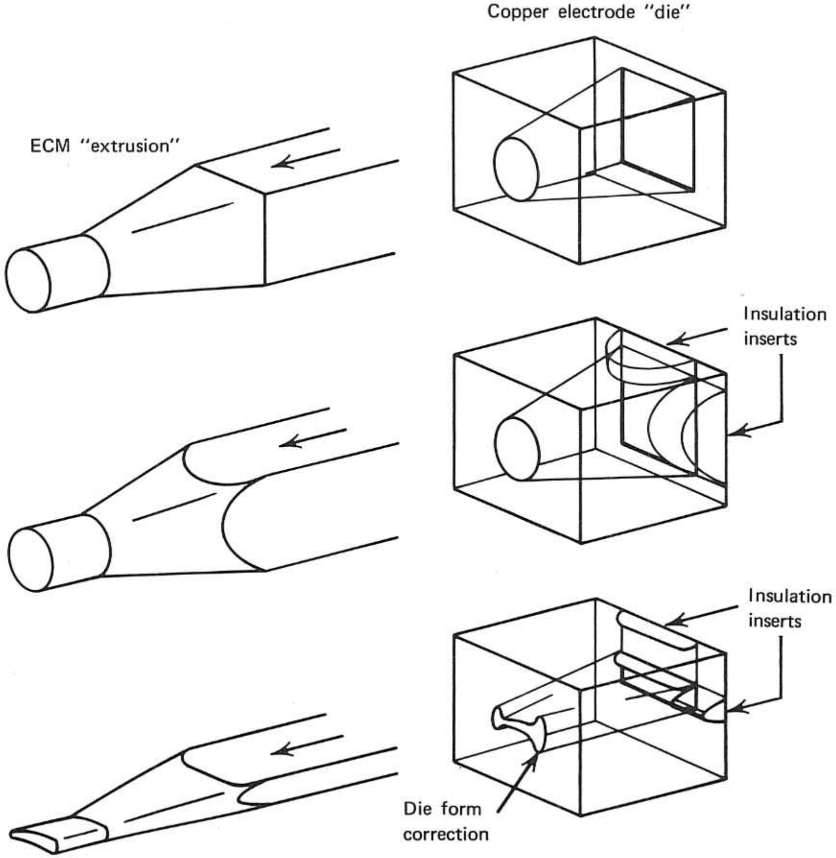


Figure 8.8 A wide variety of two dimensional shapes can be produced by ECM extrusion.

a final layer of material, as shown in Figure 8.5*b*. Since there is no work surface orthogonal to the direction of tool feed, the smallest machining gap occurs between the tapered surface of the tool and the work. Because this taper is very shallow, the overcut, that is, the gap between the extremities of the tool and the vertical surfaces of the work which they generate, is almost as small as the machining gap. Small overcuts of 0.010 to 0.005 in. are possible, so that dimensions can be closely controlled. Also, good quality surfaces are produced, since the high current density cutting action is directed sideways rather than in advance of the tool. The shallow taper of the tool, by presenting a large operative cathodic surface to the work, permits very high tool feed rates. Thus the finish generated surfaces are subjected to stray

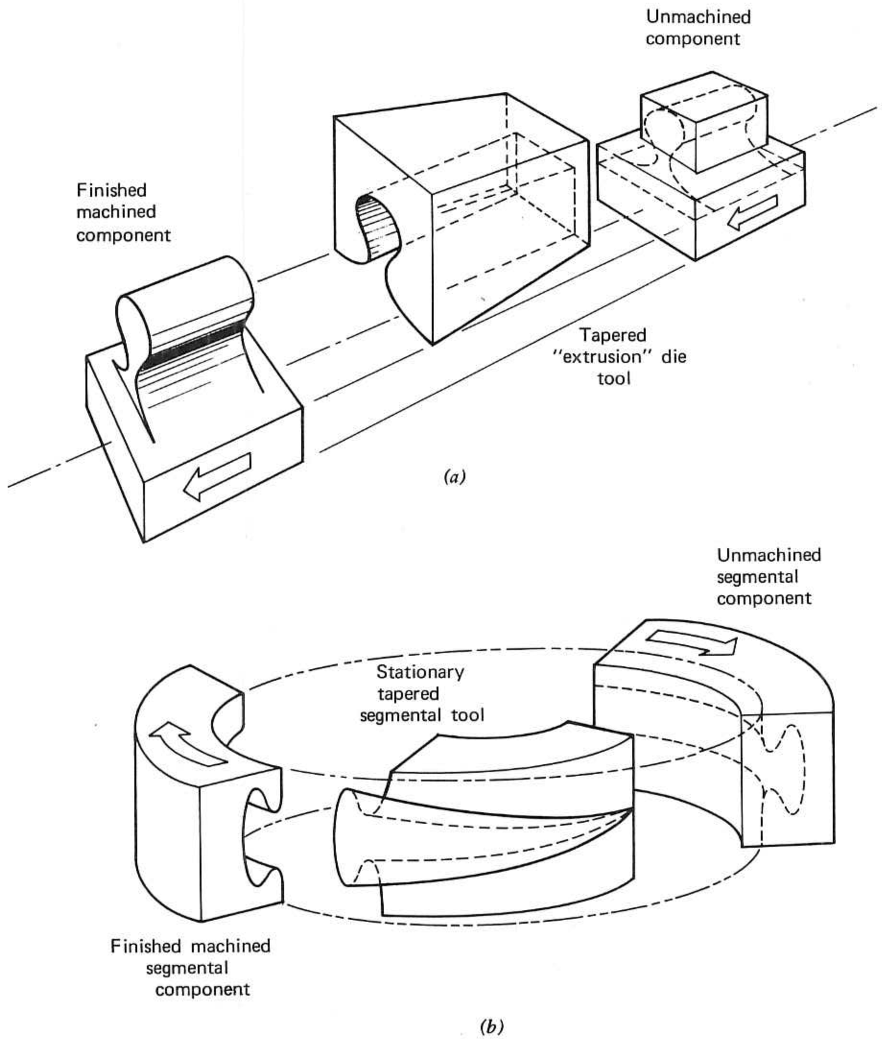


Figure 8.9 Continuous component production using tapered EC tools.

machining for a very short time, so that there is only slight deterioration of surface finish and minor dimensional loss. The more gradual the taper of the tool, the faster will be its feed rate and rate of metal removal; better surface finish and dimensional control will result.

The most straightforward applications for this machining technique are the final sizing of round holes using an electrode, which is essentially a tapered but partially insulated rod, and sizing of rods with a tapered

ring electrode. These are shown in Figures 8.5*c* and *d*. A more advanced application of tapered electrodes is shown in Figures 8.6 and 8.7.

The direction of electrolyte flow is very important if a high degree of precision is required. It is best to supply electrolyte from the finishing end of the electrode taper towards the end where machining starts; since clean electrolyte, which has uniform electrical properties, is then in use during the final generation of part size.

Almost any two-dimensional shapes can be produced with tapered electrodes as shown in Figure 8.8. The work and electrodes resemble the extrusions and dies of a mechanical forming process. The figure also illustrates how insulation inserts can be used to make the electrode "die" conform to the shape of the bar stock material. By so doing, it limits premature machining of the bar material, which might otherwise adversely influence the final sizing of the "extrusion," and establishes a uniform flow of electrolyte around the bar.

Intrinsically the electrochemical tapered electrode machining technique promises high accuracy, but in producing long strips of finished material the means of feeding the strip, supplying the electrolyzing current, and monitoring and controlling process parameters will require sophisticated methods. The applications of the method appear numerous. A single strip or a succession of individual small parts may be fed continuously and linearly past or through the tapered electrode for example, or segmental parts rotated in succession through a circular tapered electrode, as shown in Figures 8.9*a* and *b*.

Although much presented in this section is speculation, many of the ideas have been tried and the technique is already used in the manufacture of internal and external splines and rifling bores. In the latter application the tapered lands on the electrode are helical, the electrode being rotated as it advances into the bore of the work.