CHAPTER

VI

Basic Tooling Concepts

6.1 CONSTRUCTION MATERIALS

Many factors determine the choice of materials used for ECM fixturing and tools. The principal one is resistance to chemical corrosion. Others include strength, stability, and ease of manufacturing and repair.

Fixtures are made from metals, plastics, or a combination of these, as illustrated in Figure 6.1. Metals such as copper, high-grade stainless steels, monel, brass, bronze, and gunmetal can be used, since they resist chemical corrosion. Within the machine work enclosure, fixtures are exposed not only to the corrosive effects of electrolytes such as sodium chloride, sodium nitrate, sodium bromide, and occasionally sodium fluoride at temperatures above 100°C, but also to electrochemical corrosion effects. It is the last factor that most limits the type of metals that can be used. Corrosion of normally corrosion-resistant metals occurs if more than one are used. This is due to the galvanic action between them in the presence of electrolyte. Over a period of fixture use this can cause severe damage. Again, materials immune from straight chemical corrosion in the presence of quite small electrolyzing currents, can exhibit severe pitting.

For example, a stainless steel corroded in this way will dissolve at its grain boundaries to a depth of inches; the damage only becomes obvious when the part crumbles away at a touch. Slow uniform dissolution of a single phase material is preferable to the more rapid, but selective, dissolution at the grain boundaries of a multiphase material. It is better not to use metals but this is not always possible. The small operating gaps, high electrolyte flow rates, and pressures used in electrochemical machining require maximum stiffness and rigidity in the construction of tooling. Continuous operational accuracy requires precise

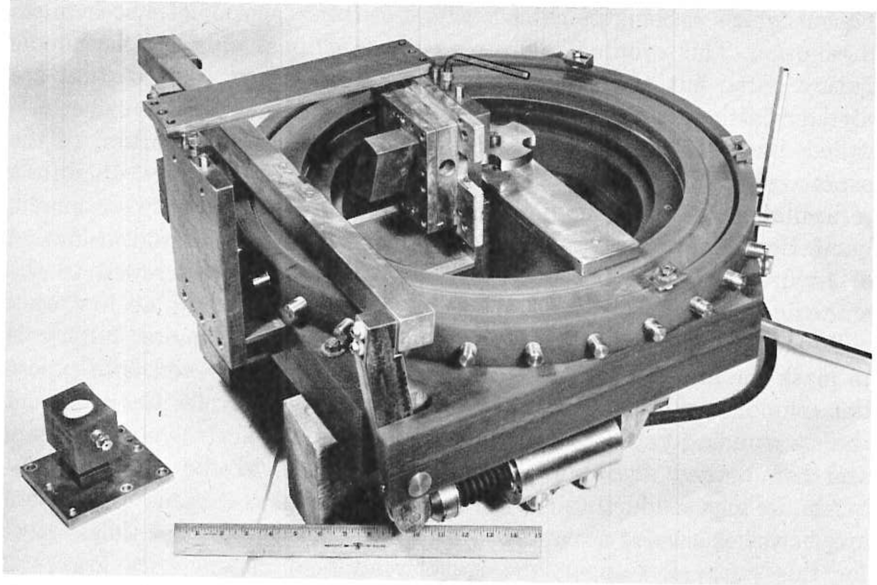


Figure 6.1 This fixture for electrochemically machining the inside of a jet engine casing illustrates the extensive use of reinforced plastic materials, while high load carrying parts and location surfaces are stainless steel. (Courtesy of the Anocut Engineering Company.)

fixture dimensions, hence the need for stable, wear-resistant materials. There is, therefore, much use of metals in fixture construction. Problems of corrosion are then overcome by the method of power distribution to the fixture, and in the handling of electrolyte. Metals that have a tendency to corrode by selective attack of the grain boundaries, with the chance of small particles breaking away, should not be used in electrolyte flow circuits. If plastic materials cannot be used, monel or copper parts are suitable for ducting electrolyte to the machining area. Stainless steel can also be used but must be accessible to permit periodic inspection for corrosion. Similar considerations apply to structures cast in bronze or brass, but gunmetal appears slightly superior in this respect while monel is very good. It is always worthwhile to consider the complete use of plastic in the construction of a fixture. Provided that strength, rigidity, and stability requirements meet the particular need of a fixture, plastic materials, such as resin bonded with fiberglass, paper cloth, or asbestos flock, can be used.

All anodically charged metal parts in the fixturing, including the component which is being machined, will show some sign of electrochemical dissolution. This eventually destroys the functional value of the anodic fixture parts, but also may be harmful to component surfaces that are already finished to size. The degree of anodic corrosion, as it is sometimes called, increases as the exposed cathodic surfaces, in proportion to the exposed anodic surfaces, are increased. It is good practice, therefore, to insulate or shield cathodic surfaces, especially if these are near anodic parts. Synthetic rubber insulations have proved best for liquid insulation of fixture parts. Rubber or poly-vinyl-chloride sheets, screwed to the cathodic surfaces, provide simple but effective shielding at low cost.

When faced with anodic component corrosion, a common fallacy is to mask the areas subject to corrosion; the answer, however, is to expose the component to the maximum extent possible and electrically shield the surrounding cathodic fixture parts. The stray electrolyzing currents are then limited and thinly spread over a large anodic surface.

Almost any conducting material can be used as a cathode tool. There are, however, several advantages in using either copper or stainless steel for this purpose. Copper, the commercial high conductivity grade, is normally the preferred tool material. It is easy to machine, and its high conductivity ensures distribution of the electrolyzing current to all parts of its operating surfaces, without overheating or power loss. In the event of process failure, spark damage of the copper tool surface is limited, because of the high electrical and thermal conductivity and high thermal capacity of copper. In addition, damage can be repaired by electroplating. The brightly polished surface of a copper tool resists corrosion and formation of smut films on its surface. It has the disadvantage that, where insulation is applied to parts of the tool, it is difficult to securely bond the insulation to the copper surface. Stainless steel electrodes do not have the qualities of copper with regard to thermal and electrical conductivities or thermal capacity, but their resistance to chemical corrosion is good and they can be made by electrochemical "back machining." The back machining method of forming electrodes is best used in the manufacture of airfoil and forging die electrodes.

6.2 FIXTURE ALIGNMENT

The alignment between the tenons on a machine's tool platen and work table, on recent models of electrochemical machines, are of sufficiently high standard to permit accurate alignment between tools and fixtures. If cross movements and height adjustment of the work table are provided, reference surface for use with slip gauges are the most effective for aligning tooling.

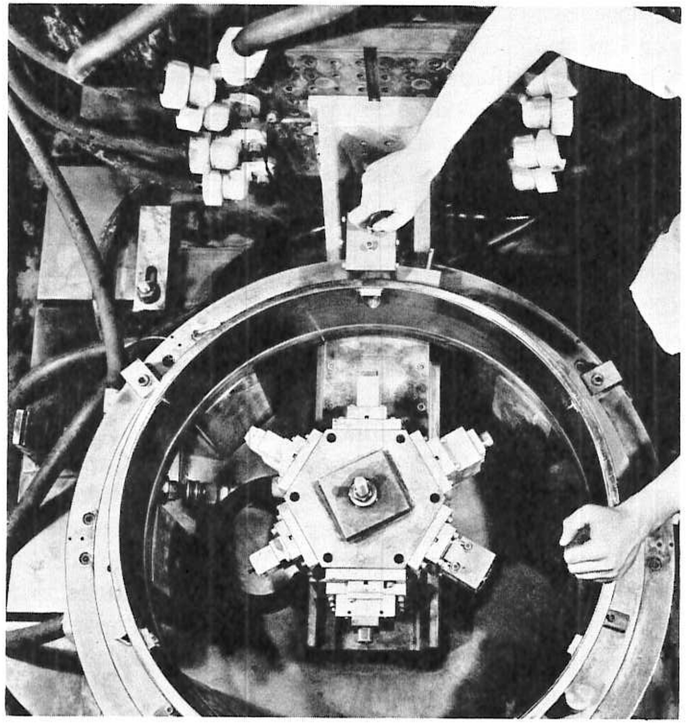
During the first operation of fixturing, small inaccuracies in the tooling can be compensated for by adjustable keys incorporated in the base of the tool. When the required alignment has been achieved the keys can be dowelled permanently in place. A suitable method employs three pins, each with two excentric diameters. One diameter of each pin locates in the tenons of the machine tool platen, the other in the tool base. Each of these is rotated, until the required alignment of the tool is obtained and then dowelled in position. The correct alignment of the tooling is then permanent, and thus saves time in setting up the tooling at a latter occasion and limits the possibility of error.

The use of die sets for alignment between tool and fixture, although used to advantage on low quality machines, is a poor and normally unnecessarily complicated method. There are several reasons why this method should not be used. Pins for the die sets, if uninsulated, must be removed prior to machining; otherwise they form an electrical short circuit. The clearances to permit removal of the pins also give rise to errors. Permanent pins, which must be insulated from the fixtures and tools, are subject to wear and corrosion. Suitable insulating materials are too soft and unstable for close alignment. It is also evident that the alignment, by this method, is achieved by the force of the pins pulling the fixture into line with the tool; inevitably, flexure and distortion cause errors. A measuring method using slip gauges is preferable. Normally strength, alignment, and insulation are embodied in the structure of the machine; to duplicate these in the tooling is costly and unnecessary.

If several tools are used in producing a component, time can be saved in setting and work handling by mounting tools on a turret as shown in Figure 6.2.

6.3 STRENGTH AND STABILITY OF FIXTURES

In the early stages of ECM development, it was thought that since the tool did not come in contact with the work, the machining forces involved were small. In practice, this is far from the truth. Machines and tooling must be of strength and rigidity equal or exceeding the requirements for conventional metal cutting techniques. At times the electrolyte pressure, within the working gap, exerts forces of several tons. There are configurations of electrodes in which the electrolyte,



Figures 6.2 This turret tooling arrangement reduces time lost between operations in electrochemically machining the inside contours of a jet engine casing. (Courtesy of Click Industries.)

traveling at high speed, possesses only kinetic energy and its pressures may well be less than atmospheric; there is then a tendency for the tool to be drawn onto the workpiece. The strength of machine and tooling must limit the deflections, because of these forces, to ± 0.001 in. While static forces must be considered, that sudden movement of the tool may initiate self-excited vibrations is of greater concern. To avoid this effect, which is known as "water hammer," there is a need for rigidity greater than that which would be calculated from straight consideration of electrolyte pressures. Usually these vibrations are excited by forces acting in the direction of tool feed, but transverse forces can cause the same effect. Although "water hammer" is the major reason for building strength and rigidity into the tooling, other factors, such as high magnetic forces between parts carrying heavy electrical currents and external vibrations of the machine structure, have to be considered.

Material stability is important in obtaining repeatable accuracy over the relatively long life of a fixture. Stress relieving metal parts and correct selection of nonmetallic materials is therefore important.

6.4 ELECTRICAL POWER CONNECTIONS

The main material used to bring the electrical power into the work enclosure and to the work component is copper. This is because of its very high electrical and thermal conductivity and its resistance to corrosion in the EC environment. Fixture parts in bronze or stainless steel may be used to conduct the machining current to the work, but heavy sections are then employed to avoid overheating and power loss. The section of stainless steel, for example, must be 40 times the area of a copper section to adequately carry the same electrical current. Generally the cross sectional area of copper required is 1 in.^{2}/1000 A. If the conductor is cooled by the flow of electrolyte, or alternatively by a special supply of cooling water through it, then half that section can be used with only small power loss. The conductors can be bus bars, structural members of the fixturing, flexible copper cables, or copper braid. The fineness of the strands in braid or cable make these materials very prone to corrosion. Cables usually carry terminal lugs, and providing that the rubber sheathing on the cables is sealed to the lugs with bitumen or similar impervious material, then useful cable life can be considerable. Braid parts, if unprotected against corrosion, are of simplified design to facilitate periodic replacement.

Electrical joints are reduced to the very minimum, since they are potentially a source of power loss and may completely fail under the wet corrosive conditions in the work enclosure. Area is not as important as the cleanliness and pressure of the joint, provided that the actual contact areas are adjacent to heavier sections of the conductor. These will then dissipate any heat generated in the joint. To obtain a good joint, the clamping forces must produce plastic deformation sufficient to bed the mating surfaces. Even good joints deteriorate, because of burning or chemical corrosion, but these effects can be avoided by the use of a contact grease. This greatly helps in the dissipation of heat away from local hot spots in the joint, and it keeps out air and electrolyte that would otherwise produce corrosion. A common waterproof grease is normally adequate, but the silvered electrical greases and paints will solve the problem of a joint that tends to overheat.

The method of making electrical contact to the work is of major importance. The occurrence of hot spots on the contact surface of the work can cause metallurgical damage, that cannot be tolerated on many components. There is another fault, however, that is not easily recognized as originating in the electrical contact to the component. Poor contact can give rise to local high temperature areas on the component. The resultant differential expansions then produce temporary distortion of the component during machining. The temperature differentials soon equalize after the machining current is cut, and dimensional errors will appear in what would otherwise have been an accurate component. If there are solid high pressure contacts to the component, then greasing the electrical joint will usually prevent hot spots from forming. A better method is to make the anode connection with a large area pad of copper braid, backed with flexible rubber. The pad takes up the shape of the component, even if it is a rough forging or casting, and so provides multipoint contact over a large area. Uniform distribution of the current is achieved, and also, light contact pressures are used. For that reason the method is suitable for supplying current to delicate thin section components.

In another method, which has been used with limited success, the electrical contact is made by casting a low temperature alloy between the component and a solid conductor. This provides excellent support for thin components and uniform distribution of the current. There are, however, many difficulties in obtaining consistent results. An additional fixture is usually required for casting, and even under well controlled conditions, a suitable joint between the component and casting alloy is not always obtained. The length of the procedure, to prepare a component for machining and subsequent stripping of the casting alloy, greatly adds to the overall cost.

While chemical corrosion of fixture parts can be avoided by the careful selection of constructional materials, the problems of anodic corrosion, due to stray electric fields, are more difficult to overcome. Those metallic parts of a fixture which carry an anodic potential will be liable to corrosion. Stainless steel is particularly bad in this respect. For example, it is possible for the grain boundaries to be etched completely away over a period of fixture use, and the damage not suspected until the metal crumbles away at a touch. Titanium resists this form of corrosion but its use is limited by cost. Local electrolytic cells can be set up between metals of different chemical composition, and this accounts for the deterioration of some fixture parts. Many of these problems can be avoided, if metal is used in fixture construction only where necessary to meet strength and rigidity requirements. If metals *are* used, they should operate at neutral or preferably, cathodic potential. Although compromises will be frequent, it is generally best to bring the power

connection direct to the component and insulate this from metal parts of the fixture. If possible, dissimilar metals should not be used.

6.5 ELECTROLYTE REQUIREMENTS

The following discussion develops a method by which the electrolyte flow and pressure requirements of a tool may be estimated. These dictate the minimum pumping requirements of the EC machine on which the tooling will operate.

It is the flow of electrolyte, between the tool and work, that promotes the ECM action. As the length of flow path across the tool increases, the flow must be increased to sweep away the products of the machining action. A good dilution of the gasses is particularly important, since otherwise they will reduce the conductivity of the electrolyte towards the exit from the tool, causing a reduction in machining gap size. This effect can be rendered insignificant by using high flow rates, rather than by trying to compensate for it in the shape of the tool. As an approximation, which is good enough, 50-psi pressure is adequate for a 0.1-in. flow path length and 250 psi for a 6-in. flow path length, with proportionate pressures in between. These figures are for tool operating gaps around 0.010 in., normal for most ECM applications.

After we have determined the likely tool operating pressure, then the velocity of flow in the gap is determined by

$$V = \sqrt{2gH}$$

where V = velocity (ft/sec)
H = pressure head (ft)
g = gravitational constant (32.2 ft/sec^2)

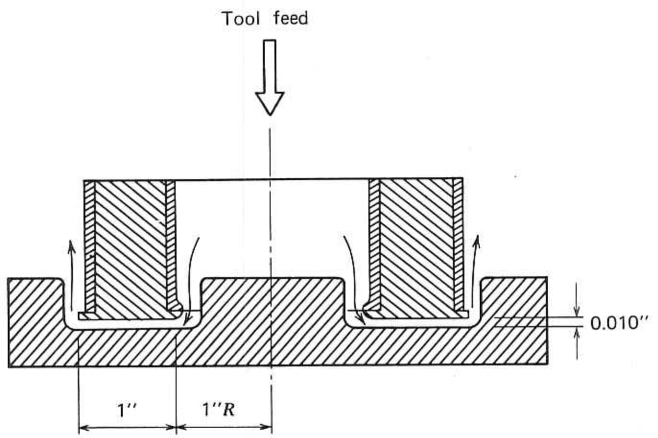
The above formula has been simplified by assuming the specific gravity of the electrolyte is that of water and by leaving out viscose pressure losses. Both factors have only a small effect on this calculation and may, therefore, be omitted, since only an approximate answer is required.

This velocity will be the maximum for the system; it occurs at the smallest cross-sectional area of flow across the tool. If this area is A ft.^{2}, then the flow $Q = VA$ ft^3/sec, or

$$Q = \frac{VA(62.4 \times 60)}{10} \text{ imperial gal/min}$$

or

$$Q = \frac{VA(62.4 \times 60)}{8.3} \text{ U.S. gal/min}$$



Figures 6.3 Cross-section of a circular tool machining an annular recess.

For example, the tool shown in Figure 6.3 is to produce an annular recess. The small arrows indicate the electrolyte flow and the large arrow the direction of tool feed. The flow path length across the machined area is 1 in. and so the tool operating pressure will be about

$$50 + \frac{200 \times 1}{6} = 83 \text{ psi}$$

Pressure head H in. feet of water:

$$= \frac{83 \times 144}{62.4}$$

$$V = \sqrt{2g\left(\frac{83 \times 144}{62.4}\right)}$$

$$V = 110 \text{ ft/sec}$$

The minimum cross-sectional area of flow A will occur at the smallest radius at the base of the tool. If this radius is 1 in. and a probable operating gap of 0.010 in. is assumed, then the area

$$A = \frac{0.010 \times 2\pi \times 1}{144} \text{ ft.}^2$$

and

$$Q = VA = \frac{110 \times 0.010 \times 2\pi \times 1}{144} \text{ ft}^3\text{/sec}$$

or equals 20 Imperial gal/min, or 24 U.S. gal/min.

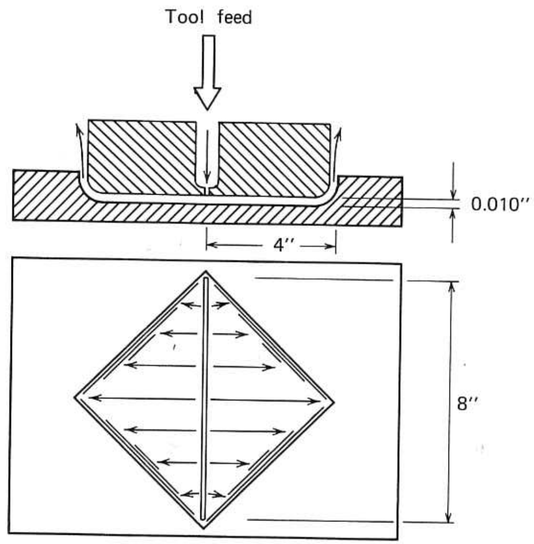


Figure 6.4 Diagonal section and plan of a tool machining a square recess.

In the second example Figure 6.4 the tool is required to machine a rectangular shaped recess. In this case the maximum flow path is 4 in. and this must be used in estimating the tool operating pressure and electrolyte velocity. The cross-section area of flow in this case will be $2 \times 8 \times 0.010$ in.^{2}; that is, twice the length of the slot times the operating gap size.

The method of calculating the pressure and flow requirements of a tool is only, and needs to be only, a rough guide. The pressure estimates used are empirical and based on tool feed rates for titanium- and nickel-based alloys of 0.040 to 0.080 in./min, and 0.070 to 0.150 in./min for ferrous alloys.

Operating at smaller tool working gaps in order to achieve greater accuracy will require higher pressures for the same flow. If less accuracy is required, then larger gaps may be used at lower pressure. In raising tool feed rates, a proportionate increase in flow will be required with a corresponding increase in pressure.

6.6 ELECTROLYTE SUPPLY DUCTS

The main pressure drop in the electrolyte circuit, after the machine pressure control valve, is needed across the working surface of the tool.

The cross-sectional area of the ducts supplying the working surface of the tool must be 10 times the minimum cross-sectional area of flow in the gap. Pressure losses in the ducts are then limited to 1 or 2% of the tool operating pressure.

This 10:1 area ratio is good to use as a general rule. Sometimes, because of limited space in the electrode body itself or in some other part of the tooling, it may be necessary to reduce the area of the supply duct. In such cases, the internal contours of the duct are smoothly blended and its cross-sectional area smoothly tapered down towards its entry into the machining area of the tool. Pressure losses in the ducts, to make sure adequate pressure is available at the tool for its operation, should be carefully calculated if the area ratio is less than 5:1.

All pipes and channels, used for ducting the electrolyte, must be of strength suitable to withstand the pressure. Distortion, due to pressure loading, can also affect the accuracy of the tooling. Joints and other interspaces of the tooling are ported to atmosphere, to avoid possible pressure build-up in these areas. Disasterous results may occur if this rather small point is overlooked.

Cleanliness in the electrolyte ducts is essential. The ducts must be designed for ease of inspection against corrosion and debris, and to ensure that seal or gasket material cannot enter the system.

CHAPTER VII

Procedure for Tool Design

7.1 COMPONENT APPRAISAL

The advantages of producing a component by ECM are either financial or metallurgical. These are assessed and compared with other methods of manufacture to determine the suitability of ECM for the manufacture of a particular component. In addition, the availability of equipment and so on are taken into account.

In costing an ECM operation, the capital depreciation of the machine, cost of tooling, labor, and electrolytes are considered. Other factors, such as lack of distortion when ECM is used, will simplify or remove the necessity for other supporting conventional operations with corresponding cost reduction. A thorough examination of costs is only essential, however, in marginal cases, since if the time of an ECM method is a tenth or less of the conventional method of manufacture, and the level of capital expenditure is similar then cost savings are assured.

The time required to perform an ECM operation is determined simply by the tool feed rate and the depth of cut measured in the direction of tool feed. Within the limitations of present production machines, it is usual to estimate the maximum tool feed rate at 0.050 in./min for nickel and titanium alloys, and 0.1 in./min for ferrous alloys. With experience in handling a particular material it is possible to stipulate the process limitations more accurately. These values, however, are intended for planning purposes, since they can invariably be achieved in practice; frequently they will be exceeded. The tool feed rate is estimated at the above values or lesser values, depending on the power available from the machine upon which the work is to be performed. A useful round figure for these calculations is that *10,000 A removes 1 in.^{3} of material per minute.* If, for example, a component of 10-in.^{2}