shaded parts in Figure 9.2 are plastic and the remaining parts metal. Electrolyte flows axially along the test section of the specimen between the annular chambers at either end. The design shown is simple in order to minimize the tooling cost but provides positive location for the test specimen. The normal quantity of pieces to be processed does not warrant more elaborate tooling. An alternative type of tooling, however, is shown in Figure 9.4.

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CHAPTER X

Selecting Operating Parameters

Consider electrolyte composition (already discussed at length), electrolyte temperature and pressure, voltage, tool feed rate, and tool positional depth settings; these are controllable parameters. They must be established during the first tool trials and then defined, with their permissible variation, for control of future production. Previous experience of the material to be machined, consultation with analytically or empirically derived data sheets, and of course, values used as a basis for the tooling design, can be used to set up the parameters for the first tool trial. Changes will then be required, however, to obtain optimum tool performance with regard to speed, accuracy, and surface finish, or to correct faulty operation. Therefore a basic understanding of these parameters is essential.

10.1 MACHINING GAP

The minimum gap between the tool and work is an independent variable, but with only minor reservations, it is the variable that relates directly to the geometry of the machined component. It will be remembered that the design of tool contour was based on corrections for an estimated operating gap. The gap used in the tool design must be used in the operation of the tool. Some variation from this gap can be made to establish the precise overcut required, when using a generating type of tool; but no such liberty should be taken with a die sinking type tool. If there are contour errors evident in the machined surface, they are probably due to component distortion or inadequate electrolyte flow;

these will be discussed more fully later. If they are the source of error or if there is some error in tool design or manufacture, it is these which should be found and corrected, rather than compensated for by using a different gap size.

The controllable parameters, which together determine the gap size, are electrolyte temperature and composition, voltage, and tool feed rate. Those relating to the electrolyte will have already been determined in an initial study (Chapter 9) and will normally be maintained at constant values. Voltage and tool feed rate then become the means of adjusting the gap size to a required value.

At first, it would appear that there is a direct relationship between the gap size and both voltage and feed rate. Certainly feed rate, which is the same as metal removal rate under equilibrium conditions, is, for practical purposes, directly proportional to the current density. Thus if the feed rate is doubled, the electrical resistance in the gap will reduce to half to allow twice the current to flow. If the electrolyte offered the only resistance to current flow, then, in accordance with Ohm's law, the gap would be halved. While this is almost the case for some metals, there are additional resistive losses that occur at the surface of both tool and work. The voltage loss at the work surface is usually referred to as the "anode potential"; it is quite significant on nickel-base alloys and can be as high as 5 or 6 V on titianium alloys. Thus the gap size will become less than half in reducing the total resistive path to half to allow twice the tool feed rate. In summary, a change in feed rate produces more than an inversely proportionate change in the machining gap. The gap reduces with increasing feed rate.

The same reasoning is applicable to variations in voltage. In this case, the gap change is slightly greater than a directly proportionate change with voltage. If, for example, the potential difference between the tool and work were 15 V, and this comprised a 1-V loss at the tool surface, a 4-V loss at the work surface, and a 10-V ohmic drop across the machining gap, then a 5-V increase would enlarge the gap to one and a half times its original size, and a 5-V decrease would halve it. The voltage variation, with respect to the ohmic voltage drop across the electrolyte in the gap, produces a proportionate change in the gap. No published data relates these gap voltages to the many variations possible for different materials, electrolytes, and operating parameters. As a very rough guide, however, one can assume combined tool and work surface voltage losses of

4–6 V	for machining titanium alloys
1–3 V	for machining nickel alloys
0–1 V	for machining ferrous alloys

In practice, with an understanding of the way in which voltage variations affect the machining process, the required operating gap can be attained with only two or three adjustments of the machine voltage setting.

The model shown in Figure 10.1 may be used as an aid in understanding the relationships between operating parameters. It indicates the

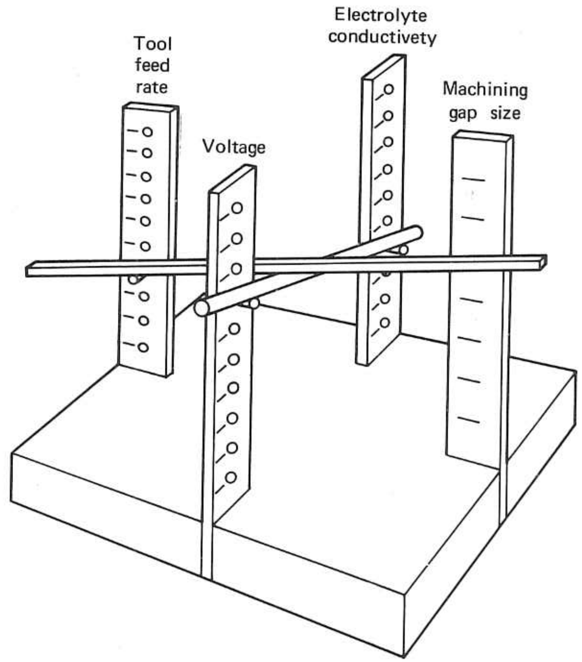

Figure 10.1 Model relating machining parameters.

change in the machine gap size, with variations in the three controlling parameters: tool feed rate, voltage, and electrolyte conductivity. The vertical scales represent the values of these, higher values being at the top of the scales. Each scale is not linear, as may be deduced from the previous discussions, but can be used as a guide for parameter adjustments. The model has round and square beams, which are supported by pegs in the three scales corresponding to the controllable parameters. The pegs can be set to the required values, just as these values may be set on a machine. The machining gap, however, is an independent variable and thus cannot be preset. The model can be used to demonstrate the effect of each parameter on the machining gap size, and the many variations of the controlling parameters that will produce any required machining gap value.

There is, at present, no methods for gap measurement while the process is in operation, which are supplied with commercially available machines. Some methods being considered, such as lasers or electronic monitoring of current with imposed tool vibration, are too complex for immediate, practical, and economic use.

Machines are usually equipped with accurate measuring systems that indicate the tool position from a fixed datum. These permit indirect measuring methods for determining the machining gap. The gap size, plus the total tool movement into the work during machining, equals the depth of machining, providing that all measurements are related to a common datum surface. In machining a recess into a flat surface, for example, the gap size will be the measured depth of the pocket from the surface less the movement of the tool past the surface to the point where machining was stopped.

It will be possible on many fixturing arrangements to retain the tool at the point where machining was stopped, and insert various size plastic shims between the tool and work, to determine the smallest gap. This is not only a direct method of measurement but is usually the most convenient.

The same direct measurement can be made by advancing the tool very slowly until it just touches the work, as indicated by an electrical continuity measurement. To do this, either the anodic or cathodic connections to the fixturing must be removed (to prevent completion of the test circuit through the current supply unit or its control circuits) and a test circuit applied across the tool and work piece. If the tooling is dry, then a battery, wires, and light bulb or buzzer is all that is required. When electrolyte is present, the different work and tool metals form a galvanic cell, so that a small potential is generated. This can be detected using a millivoltmeter; a sudden change in the reading indicates the point at which the tool and work touch.

The last method of gap measurement is incorporated into the electronic circuitry of the more sophisticated electrochemical machines. Needless to say, this considerably speeds the procedure for gap determination and is a very welcome convenience. The method also has the advantage that if it is used with electrolyte flowing through the tooling, the forces acting on the tool and its operating temperature are close to those during actual machining. Therefore, this takes into account work and tool movement due to thermal expansion or deflection. In using the other methods, careful appraisal for these effects must be made to avoid a significant error in the gap determination.

While not essential, knowledge of the relationships between machining parameters will reduce considerably the effort required to define their values for optimum tool performance. A simple tool may be used to conduct a complete study of the parameter relationships for particular material and electrolyte combinations. The data may then be tabulated or graphically presented for convenient future reference.

10.2 ELECTROLYTE FLOW

The criteria for selecting the correct tool operating supply pressure, back pressure, and volume of flow have already been discussed in Section 6.5. These values should have been established during the tooling design and specified on the tooling drawing. If not, then the same methods may be used to estimate their values. These flow conditions will be the most suitable for the first trial of the tooling.

Meticulous attention to detail in tool and fixture design, manufacture, and final inspection sometimes eliminates and will always minimize malfunctions in their operation. This, however, is an ideal difficult to maintain in the time- and cost-conscious ambience of modern industry. It is, therefore, advisable to flow test the tooling before starting an actual machining run. Low pressure flow should be used first, gradually increasing it to the required operating conditions. During this procedure frequent checks to ensure proper operation of seals, structural parts, and other factors should be made. Either visually or by measuring flow volume from various exit channels, it is often possible to check that the electrolyte is, in fact, flowing in the manner and path prescribed in the tooling design.

10.3 CONTROL POSITIONS

On a machine set for automatic operation, the sequence of events are typified as follows:

1. Rapid advance of tool towards work.
2. Change to controlled tool feed rate for machining and start electrolyte flow.
3. Start electrolyzing current.
4. At required machining depth, stop forward feed of tool, switch off electrolyzing current, and rapidly retract tool.
5. Stop tool movement at a suitable distance from work.

Event 1 may be started by the machine operator pressing a button. If the parts are being handled automatically as well, then the machine can be set to repeat its sequence as each component is secured in place.

All the other events will occur at positions of the tool, relative to the work, as determined, for example, by the positions of adjustable cams operating electrical microswitches. The change of feed rate and start of electrolyte flow (event 2) must preceed the switching of electrical power (event 3), sufficiently to allow for the transition in tool feed rate and to permit full build-up of electrolyte flow.

The relative positioning of the tool and work at the onset of the machining action, that is, when the electrolyzing current (event 3) is switched on, should be determined by the dimensional tolerance, shape of the initial work surface, and by the type of work geometry to be produced. Variations in dimension, from the surface to be machined to the surface locating the work, must be determined; so that the tool start position will provide a safe machining gap, as shown in Figure 10.2a. Otherwise, the tool may "crash" into the work before machining is started, when an initially oversize component is to be machined.

Other features of the initial work surface may necessitate starting machining when the tool is as much as 0.1 in. away from the surface. Castings and forgings, for example, have pronounced protrusions and irregularities in their surface. There will also be other variations between tool shape and initial work surface shape. Such irregularities pose problems of electrolyte flow at the start of machining. Too small a starting gap will cause shorting, since the electrolyte will tend to flow around the protrusions rather than across them. By starting the machine at a large gap, the work surface irregularities are considerably reduced by the time the tool is in close proximity, Figure 10.2c. Other less convenient methods, such as initially reducing the tool feed rate or increasing the voltage, can be used to produce the same effect. A flow restrictor device should be incorporated in the tooling to accommodate initial work surface to tool contour variations greater than 0.075 in.

Another factor in determining the starting gap is whether the work is to be produced with large or small radii, as shown in Figure 10.2b. The larger the start gap, the larger is the entry radius produced. If this factor conflicts with one of those previously discussed, then some monitoring of size for each component may be necessary, with a corresponding adjustment of the machining start position. Components requiring a small entry radius but having a wide initial dimensional variation will have to be measured individually, and the machining start position adjusted to give the same small starting gap for each.

The same reasoning applies to exit radii, when a tool passes completely

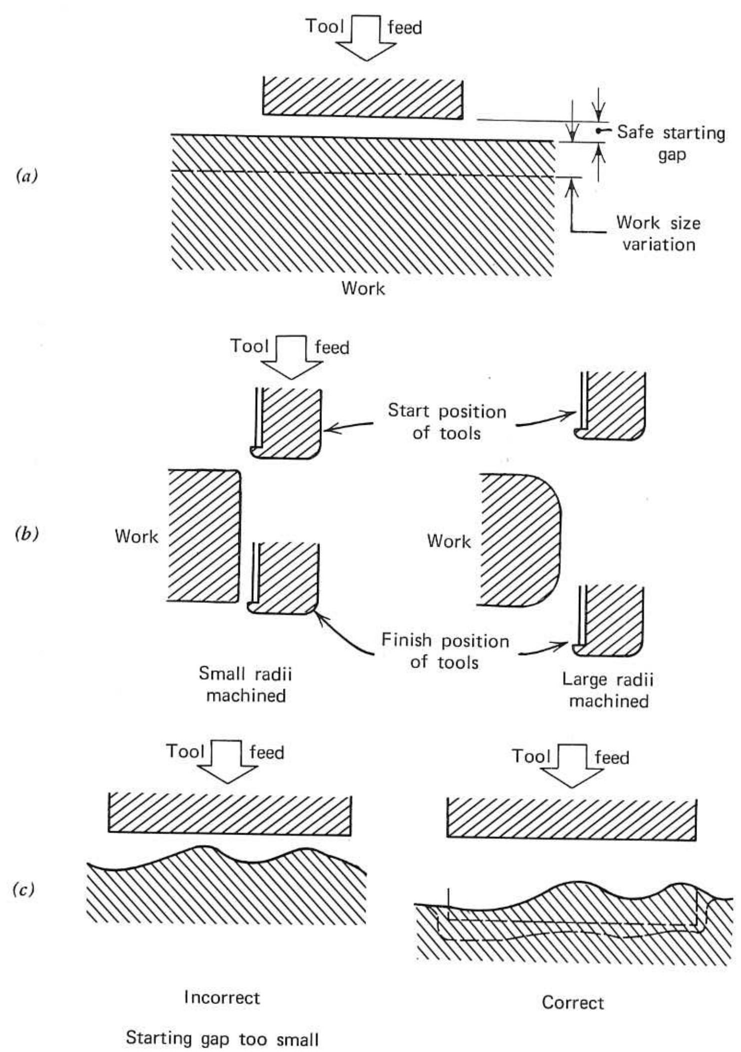

Figure 10.2 (*a*) Setting the tool to a safe starting gap. (*b*) Start and finish tool positions are used to control work piece radii. (*c*) Starting tool position for machining into an irregular surface.

through the work, as also shown in Figure 10.2b. For this, the full advance position of the tool at completion of machining (event 4) is either at the point where the side land of the tool is just leaving the lower work surface to produce a minimum radii, or up to 0.1 in. past this point, for larger radii. Normally, however, the full advance position of the tool will be determined by the full depth of the shape to be machined in the work, less the machining gap size.

After completion of machining, the tool should retract from the work sufficiently to provide space for removal and replacement of the work, without risk of accidental damage to the tool.

10.4 SURFACE PREPARATION

Grease, paint, oxide films, and scale on the surface of a component can interfere with an ECM operation to be performed on it. Such debris is a barrier to the passage of the electrolyzing current; it may result in unduly small gap sizes at the start of machining and so cause electrical shorting or direct mechanical damage to the tool. Prior to ECM, components should be cleaned by degreasing, acid pickling, grit blasting, or by other similar methods. It is sometimes impractical to remove completely an oxide film, for example, on titanium alloys. Grit blasting then becomes a preferred method, since the stressed and rough textured surface provides numerous nuclei, which help the breakdown of oxide films during the start of machining.

Burrs and other projecting edges may either short the tool at the start or, in subsequent machining, break away and become trapped in the machining gap. They should be removed prior to the ECM operation.

CHAPTER XI

Tooling Faults and Their Correction

One of the predominant misconceptions of electrochemical machining is that tooling requires a time-consuming period of development before it is suitable for production use. Certainly the author's experience, at one time, did indicate this, but it also indicated that 80% of the faults were mechanical errors in fixturing design and manufacture. The machine is a very expensive "bench" upon which to discover these errors. Resist those who say, "Never mind if it's right; is it ready?" Apply the proper diligence from conceptual design to final inspection of the tooling to ensure that it is right. The purpose of this book is to help users of the process avoid ECM process faults by properly designing the fixtures and tools. A fault discovered at the machine is a design error and should be recognized as such. Faults occurring at the machine and the details of their subsequent correction should be fed back to the drafting room for incorporation into tooling design instructions. This ensures that the fault will be avoided in future designs, and that there will be an improving, rather than stagnant, process capability within that company.

If all is not perfect, however, and faults become evident, then some corrective action must be necessary. The reader will, no doubt, take care of all mechanical faults without need of further advice. Some of the more frequently encountered process faults and the methods of overcoming them are discussed in the following sections.

The more obvious process faults result in visual imperfections on the surface of the component. A machine, with a very sensitive spark detection and protective system will detect faults and shut the machine down without visible spark damage. It may then be necessary to slow down