CHAPTER

III

Electrochemical Machines and Supporting Equipment

In recent years electrochemical machinery has been developed to excellent standards of performance and reliability, and many sizes and types of equipment are available as standard models. Also, it has been the practice of some EC machine tool makers to supply any combination of the machine, electrical power unit, electrolyte system, or specially engineered facility, to meet a customer's particular manufacturing need. Many sophisticated extras are offered with the machines. The choice is so wide that selection of a machine to meet a particular manufacturing need is difficult. The possibilities may be narrowed down by a close study of the anticipated work load, which will define the required size and accessibility of the machine work enclosure, the amperage range, and electrolyte flow requirements. If high volume production of components is involved, a specially tailored machine may be considered. A sound understanding of the purpose and merit of all the features which comprise of a machining facility will permit either correct selection of a standard machine, or specification of a special machine. Both the machines and the extra features offered with them are expensive; thus it is important not to use a too sophisticated or versatile, hence more costly, machine to perform simple work. Whether officially accounted for or not, each component machined has to bear some part of the initial machine costs. Thus an unnecessarily costly machine affects adversely the price of the product. A component requiring only 5000-A machining current, for example, should not normally be produced on a 40,000-A machine, or a small component machined in a very large machine.

Vertical "A" frame machines have excellent rigidity and should be

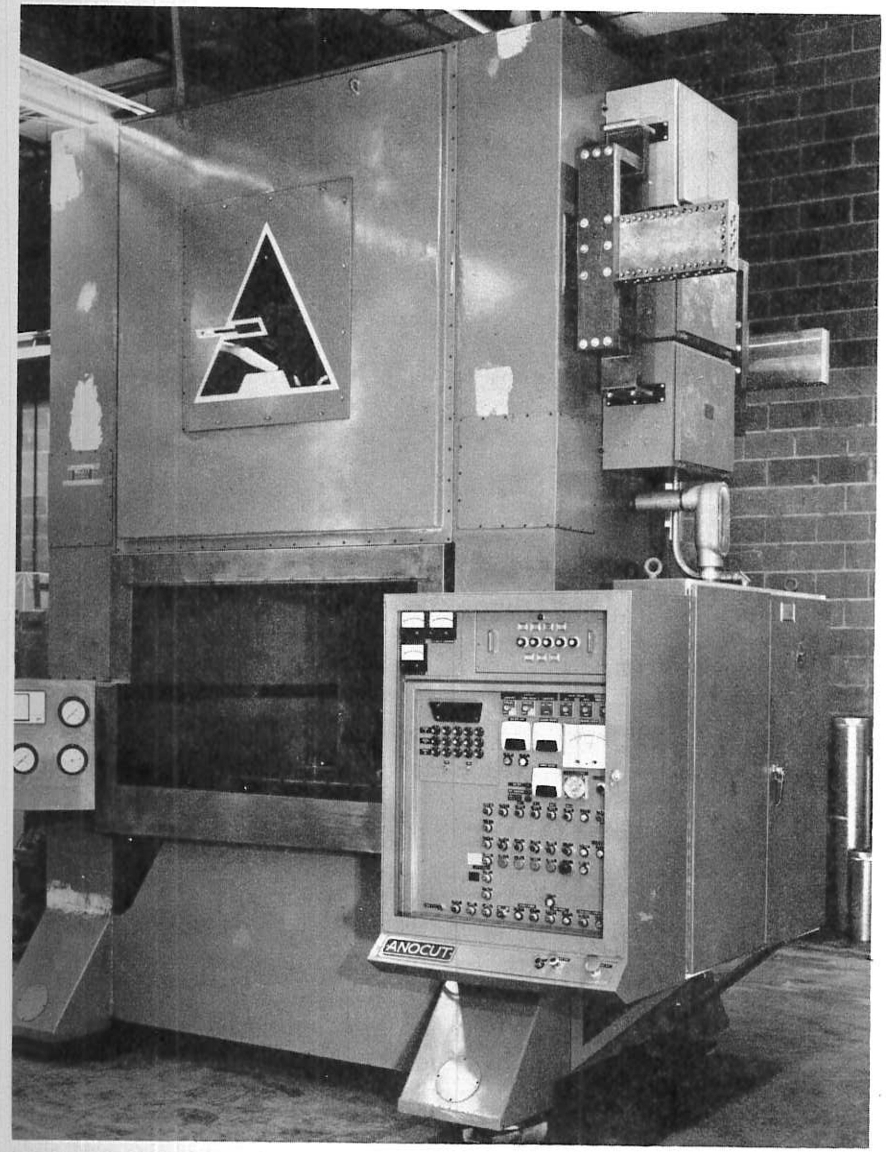

Figure 3.1 Vertical, 40,000-A electrochemical machine. The box, at the upper right, contains a silicon-controlled rectifier system which short circuits the electrolyzing current in the event of process malfunction so that work piece and tooling escape damage. This machine is very sophisticated in the control of process parameters and monitoring of process faults. (Courtesy of the Anocut Engineering Company.)

the first choice for precision work (less than 0.001-in. tolerance) requiring close spacing between tool and work, or when high electrolyte forces are anticipated. A machine of this type is shown in Figure 3.1. High pressure and precision work are usually synonymous, since high electrolyte flow rates are required to ensure predictable tool cutting. This type of machine, however, has limited access to the work enclosure, which is also small in proportion to the machine structure. Heavy or awkwardly shaped tooling and components are difficult or impractical to handle. Tooling set-up times, maintenance of the tooling during operation, measurement of work geometry, and loading time will be extended. On the credit side, the work enclosure is sealed effectively with sliding doors which can be automated. The ram and control systems are set above the work enclosure, which reduces the possibility of damage in the event of electrolyte leakage. This type of machine is easy to keep clean and pleasing in appearance. Several of them can be placed in close proximity for operation by a single person.

Another version of an "A" frame machine is the *vertical* "underdrive," where the drive mechanism is mounted under the work enclosure and motivates the work table, as shown in Figure 3.2. The size of the machine structure is reduced considerably while still providing good rigidity. The cost is significantly lowered, but a little more work enclosure accessibility is lost, and electrolyte leakage can cause serious corrosion problems if not promptly detected and corrected.

The *vertical "C" frame* type of machine offers greater accessibility to the work enclosure, which can be opened on three sides. There is a fair degree of flexibility permissible in specifying the work enclosure and open height between tool platen and work table, even when ordering a standard machine. This is because the work enclosure and work table can be extended on any of the three open sides, and also, since there is usually a horizontal joint in the "C" frame construction, the open height can be increased easily. It is not suited to high precision work, because of a slight lack of rigidity. On some models extra rigidity is obtained by support bars joining the head and base at the front of the machine. An example of a "C" frame machine, in this case with an open work area, is shown in Figure 3.3.

A *horizontal frame* machine provides excellent accessibility to its work enclosure. The latter may be constructed of almost any size and slide away, completely clear of the machining area. A machine of this type is shown in Figure 3.4. Very heavy tooling and components can be handled using overhead lifting gear. Many types of components can be accommodated by remodelling or even dispensing with the work enclosure. One ECM user machines the internal contour of a large ring, while

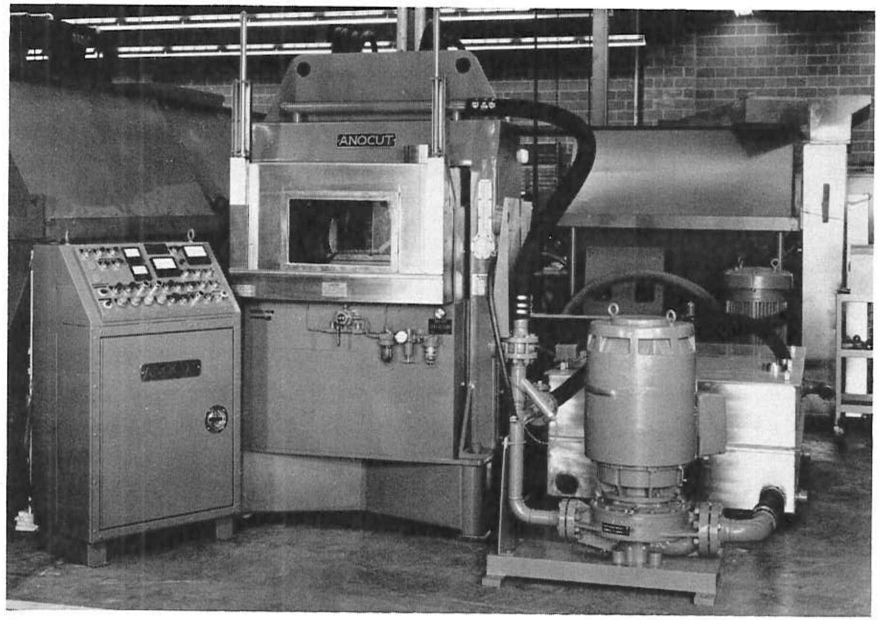

Figure 3.2 Vertical, underdrive electrochemical machine. The upper tool platen remains fixed while the work is fed towards the electrodes by the upwards motion of the horizontal table. The drive mechanism is housed in the lower half of the machine. (Courtesy of the Anocut Engineering Company.)

it encircles his machine. Rotary indexing tables, electrochemical turning heads, and so on have been used on this type of machine. Again, the structure is not as suitable as an "A" frame for precision work, and the orthogonal attitude of tool platen (the surface on which the tool is located) to the work table demands rugged tooling. Certainly if large components, or a varied range of work, are to be handled, or if the future applications for ECM are uncertain, then a horizontal machine is a very safe choice. The predominant factors in selecting a machine type will be the geometry of the component and how this will be handled and fixtured in the work enclosure. Tooling to machine a forging die, for example, is most suited to a vertical machine, since the EC tool approaches the die block as in a, very much slowed down, forging operation. The same tooling used in a horizontal machine would require a robust right angle block, to present the work to the tool in the same manner. There would then be extra expense in the tooling and a loss in overall rigidity. On the other hand, a large ring, requiring contouring of its outer diameter, is best located on a horizontal index plate in a horizontal machine.

Figure 3.3 Specially built machine for electrochemical cutting of large billets of material not easily cut by mechanical methods. (Courtesy of the Anocut Engineering Company.)

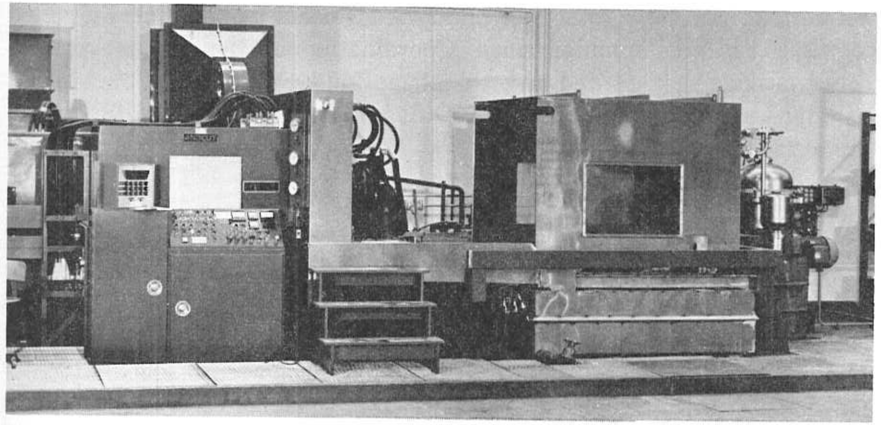

Figure 3.4 Horizontal electrochemical machine. The work enclosure slides to the right, to the position shown over the electrolyte tank, to give acess to the tooling. (Courtesy of the Anocut Engineering Company.)

Component presentation, at a suitable angle to the motion of the EC tool, invariably complicates and raises cost of fixturing. This is particularly important in fixturing large components. There is some point at which it is economic to build this orientation feature into the machine, rather than into fixturing. For this reason the rather expensive *beam-machine* as shown in Figure 3.5, has received a degree of popularity.

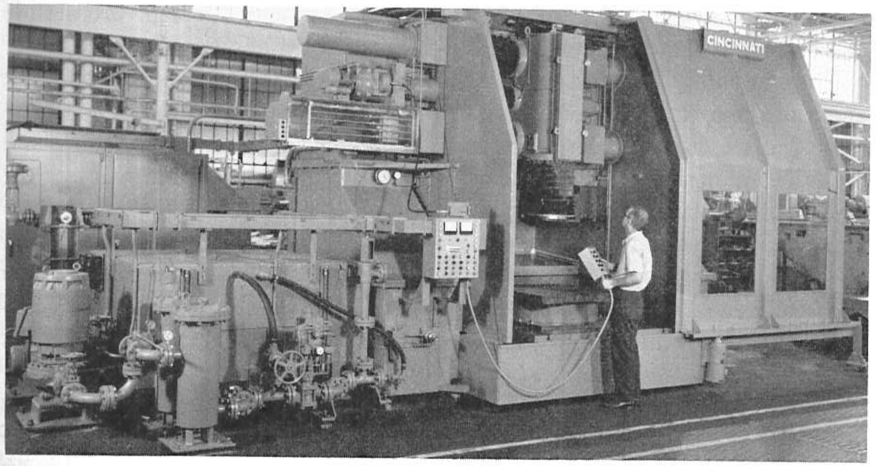

Figure 3.5 Electrochemical beam machine used mainly for both inside and outside contouring of large annular components. The tool platen has controlled motion in both vertical and horizontal directions. (Courtesy of the Cincinnati Milacron Company.)

Its vertical and horizontal tool platen movements make it ideally suited to work on large annular rings. Coordination of the two movements could provide any desired directional movement of the tool platen, but to my knowledge, this possibility has not yet been put to use in production.

3.1 GENERAL MACHINE FEATURES

Whether a machine should have cross movements of the tool platen relative to the work table has been a matter of controversy. Most machines today, however, do not have this feature, the table and axis of platen movement being fixed. There are many good reasons against cross movements; a prime reason against is extra machine cost. The precision slideways are protected against corrosion, but this remains a possible maintenance problem. ECM is essentially a repetitive production process, and so flexibility and adjustments built into the machine are potential sources of operator error and inevitably extend tooling set-up times. If, on the other hand, tool platen and table are fixed and have accurate alignment key slots, these can be used for rapid tool location. New tooling will inevitably display some small alignment errors, but these can be corrected by reworking defective parts, using offset keys, and so on. The correction is then permanent and the possibility of incorrect alignment, during later use of the tooling, is avoided. Since the alignment is built into the machine, this otherwise expensive factor does not have to be included in tooling designs. A further adverse effect of cross slide movements is that they reduce the rigidity of the machine.

The methods of bringing electrical power and electrolyte into the work enclosure are worth careful consideration. The neatest method is to enclose the electrical power leads within the structure of the machine and make permanent electrical connections to the tool platen and work table. The tool platen can also form a manifold, permanently connected to the electrolyte supply. The work enclosure is then completely free from electrolyte hoses or electrical power leads. Since these are cumbersome to handle in a confined space, their absence makes tool and work handling more convenient and improves the esthetic appearance of the work enclosure.

There are, however, several important aspects of the ECM process which makes it necessary to modify this seemingly ideal work enclosure arrangement. In many tooling designs electrolyte is forced across an electrode rather than through it. Supply hoses running directly to some part of the fixture are therefore better than complex channels through the electrodes. An auxiliary manifold, to which hoses can be connected

at some suitable location within the work enclosure, overcomes this difficulty.

A built-in electrical connection to the tool platen never seems to be a compromising factor in tooling design and so this space-saving convenience should always be specified. The anodic electrical connection to the work table, however, can be detrimental to the life of tooling and the machine table. This is because all anodic parts are subject to anodic dissolution during operation of the ECM process and will deteriorate. On some tooling it is relatively simple to control these corrosion effects adequately. Insulation of exposed cathodic areas, sacrificial parts, and the use of plastics are some of the methods employed. In heavily structured fixturing, however, materials such as stainless steel and brass are best for strength, and since the above methods are then impractical, these must carry a cathodic potential to prevent corrosion. To do this, the anodic electrical connection is made directly to the component to be machined, and insulation materials are used to isolate it electrically from the remainder of the fixturing. The tool platen, electrodes, fixturing, and work table are operated at a cathodic potential and the anodic cables led directly to the work. In equipping a machine for this type of tooling operation, cables are led into the work enclosure through a fluid trap. They may then be connected directly to the work table or to some other location of the fixturing as required.

Process-generated hydrogen must be removed from the work enclosure to prevent a serious explosion. The lower explosive limit for hydrogen is four parts per one hundred parts of air by volume. A forced circulation of air through the work enclosure must be maintained, therefore, at a rate to keep the hydrogen concentration below 0.4% by volume. That value includes a safety factor of 10. This is a matter often taken too lightly and frequently misunderstood. An opening should be provided to allow air to flow into the work enclosure in addition to an exhaust duct. The extraction fan should be adequately proportioned to the amperage rating of the machine. A protection device is also needed to ensure that circulation of air occurs during a machining operation. This is preferably a fail safe, flow-indicating switch placed in the entry air flow to the work enclosure. Such a device, placed in the extraction duct, can be rendered inoperative by salt deposits.

Machine-feed systems are well-developed, reliable units, and will normally have a degree of ruggedness comensurate with the machine's electrical power and electrolyte systems. It is worth checking the load rating of the system against the electrolyte forces anticipated for the planned work applications, however, and if inadequate, one should specify a more rugged feed head or select a more suitable machine.

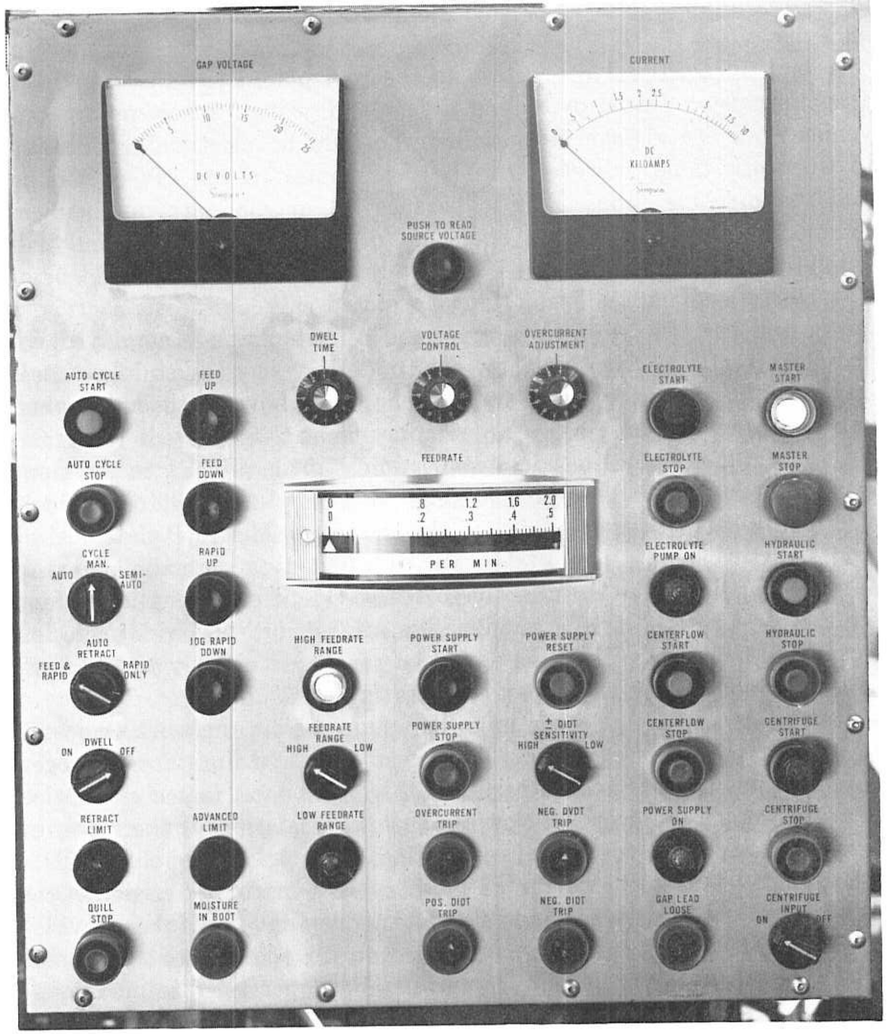

Figure 3.6 Typical electrochemical machine control panel. Buttons on the left are for automatic cycling of the machining operation while those on the right are for manual control. (Courtesy of the Cincinnati Milacron Company.)

Several methods of indicating tool position, automatic cycling, and so on are offered in varying degrees of sophistication and cost. The control panel of a moderately versatile machine is shown in Figure 3.6. In the right hands, the more complex systems will reduce the machine's nonproductive time. The more complex systems are best justified when production runs are short, and trials of new tooling are frequent. Simpler

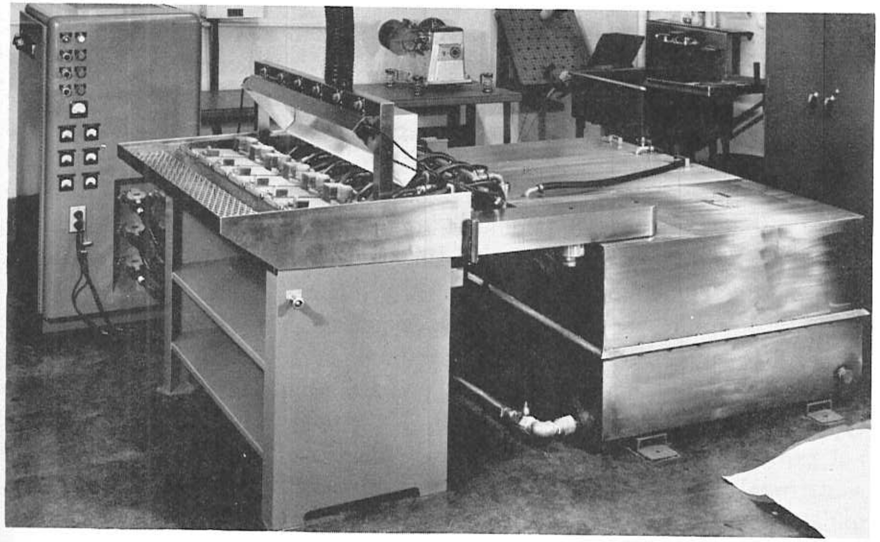

Figure 3.7 Electrochemical deburring machine used mainly in the automotive industry for processing several components simultaneously. The machine normally handles over 100 components per hour. (Courtesy of the Anocut Engineering Company.)

systems are quite adequate for continuous production, with only occasional fixturing changes. Some ECM work is performed with static tools and the machine can be very simple, as is the one shown in Figure 3.7.

3.2 THE AUXILIARIES

The electrolyte system basically comprises pumps, filters, piping, control valves, a storage tank with means for temperature control, and a clarification system. The functions of these pieces of equipment were described briefly in Chapter 2, but the merits of the various types of equipment are worth further discussion. This is particularly relevant to the "would be" user of ECM, since the system is best tailored to meet the user's special needs, such as type of work, quantity of work, and available factory space.

When ECM equipment was in its infancy, the need for smooth high volume flow at high pressure was not easily met. High pressure reciprocating pumps could not provide volume or smoothness, and centrifugal pumps were largely for low pressure operation. Multistage centrifugal pumps technically appeared to be suitable, but the specialized nature of these and stainless material construction made their price prohibitive. Fortunately, the performance of single-stage centrifugal pumps were improved to give the high pressures required and are now supplied as standard on EC machines. The pumps are run at very high speeds and have specially developed shaft seals. They give reliable performance today but were once a continual source of failure. Care must be taken, therefore, that the type of pumps that are to be supplied have proved performance on EC machines. Naturally, a performance problem is unlikely with pumps supplied by an experienced EC machine tool company. Pump flow capacities of 10 to 30 gal/min per 1000-A electrolyzing current, and pressures of 100 to 400 psi are required, depending on the type of component to be machined. High flow and high pressures are not normally used at the same time. Since the flow characteristic of a centrifugal pump is one of falling pressure with rising flow, it is best to define the output, for example, of a 10,000-A machine, as

0–100 gal/min at 400 psi
100–300 gal/min at 100 psi

A pump with an output defined as 300 gal/min at 400 psi would grossly exceed the true performance requirement.

It is best to standardize on a single make and size of pump; and preferably operate two pumps in parallel on a single machine. Two 150-gal pumps are suitable for a 10,000-A machine, four for a 20,000-A machine, and so on. In this way a machine is never completely out of action because of a single pump failure, since it may operate on its remaining pumps, a pump borrowed from another machine, or a reserve pump.

The process cannot start to operate without a pump, but will fail without proper filtration. Stainless steel (316 series) or monel mesh filter screens are the most suitable and are in use almost exclusively. Their purpose is to provide absolute protection against small particles of grit, metal, plastic, wood, paper, or other "foreign" materials, which reach and cause process interference at the tooling. Filtration of one third the size of the operating gap spacing between tool and work provides adequate protection. Most ECM tools operate at gaps of 0.010 in. or more, and so 0.003-in. filtration (75 μ or 70 mesh) is suitable. Filters of this size permit the passage of most process hydroxides, and so require cleaning only once every 30 hours of machine operation. Smaller filter sizes, commensurate with the small machining gap sizes required for very precise machining (0.001 in. or less tolerance), require cleaning every 8 hours of machine operation. For ease of cleaning, the filter media

is carried on a number of spools, which are mounted in a pressure vessel. Each spool is constructed from wire mesh material, usually convoluted to increase flow area, mounted on a cylindrical support structure. While the metal hydroxides in the electrolyte initially pass freely through the wire mesh, the individual wires eventually become clogged with a compacted layer. Cleaning of the filter elements is performed chemically since mechanical contact can damage the wire mesh. The cleaning procedure is as follows.

Immerse the dirty elements in dilute (10% N) acid for 1 hour. The hydroxide cake, which partially dissolves from the inside of the element, then falls off or may be removed with a spray jet of water. Use nitric acid for 316 series stainless steel, and hydrochloric acid for monel filter elements. Regularly cleaned filter elements give long service, but if left uncleaned for extended periods will display severe localized corrosion. This is because of electrolytic cell action, where large particles are trapped on the filter mesh. In specifying a filter unit for a machine, emphasis should be placed on accessibility for ease of servicing the filter elements. It is prudent to maintain a spare set of filter elements, since these may be used for quick replacement of dirty or accidentally damaged elements. Maximum process protection is obtained by placing the filter in the supply pipe just prior to the work enclosure. Some users prefer to have two in-line filter units in the electrolyte supply. This is not essential, although it does provide double ensurance against failure in this vital aspect of the process.

The pipes, which supply electrolyte to the ECM tooling, must not themselves introduce foreign material into the electrolyte, for example, corroded particles, scale, or pieces of broken seal material. Solid piping of stainless steel (316 series) is suitable, but can corrode under certain conditions. Stray electrical currents, which cause anodic corrosion, are the problem; but they can be eliminated by electrically connecting all metalic parts, throughout the electrolyte system and the machine, to a common ground. Cathode (tool) potential is normally ground potential. Welded pipes also corrode if improperly heat treated after welding, so these should be accessible for periodic inspection. Other types of solid piping have been used successfully, such as glass fiber reinforced plastic, plastic-lined mild steel, and so on. Solid pipework, however, has to be engineered to suit a particular arrangement of the ECM equipment and is, therefore, inflexible to any future rearrangement. It also tends to amplify pumping noise. The use of flexible neoprene rubber hoses permits rearrangement of equipment, with a minimum of inconvenience, and temporary equipment can be installed quickly to replace equipment undergoing maintenance or repair. These synthetic rubber hoses are also smooth bored, immune to chemical corrosion, reduce pulsations in the electrolyte flow, and quiet in operation.

Each EC tool operates at a pressure carefully predetermined to produce the best machining result. A lower pressure may cause a loss of accuracy, or a higher pressure produce cavitation in the electrolyte flow. Thus pressure control is needed. A simple throttle valve is adequate, but needs the constant attention of the machine operator. A better method is to use a bypass relief valve. This can be preset to any required pressure. The valve opens to maintain a steady pressure once the preset value is reached.

An electrolyte flow meter is not essential, but is a useful convenience. Knowledge of tool flow requirements defines the necessary machine capacity. This is useful information for planning work schedules to obtain full utilization of several EC machines, and for estimating flow requirements on new tooling designs.

The minimum capacity electrolyte tank required per 10,000 A is about 500 gal; much larger tanks, often referred to as swimming pools, may be used to service several machines. Much has been said, and a lot not said, about the various types of electrolyte tanks and storage systems used in conjunction with EC machines. Each system has virtues that favor it above others for a particular type of ECM work. The following paragraphs describe the popular alternate systems and the situations in which they are most applicable.

Single Small Tank

In this system all pumps, filters, centrifuges, and so on are grouped around a single tank of 500-gal capacity per 10,000-A machining amperage, a machine with this system is shown in Figure 3.8. The system can be arranged in close proximity to the machine itself; but it is best separated from it by a wall, to reduce noise and to leave the machine area clear to improve work-handling efficiency, as shown in Figures 3.9 and 3.10. Electrolyte is maintained at a temperature of 100 to 130°F, to an accuracy of ±2°F. The elevated temperature improves the chemical activity of the electrolytic process and, from a practical standpoint, simplifies the equipment needed for the dissipation of process-generated heat. The close degree of control is to limit variations in the machining gap produced by changes in chemical activity and electrolyte conductivity, and to limit positional errors caused by changes in the thermal expansion of tooling, fixturing, machine, and so on. Both factors affect the dimensional repeatability of the machined components. A control

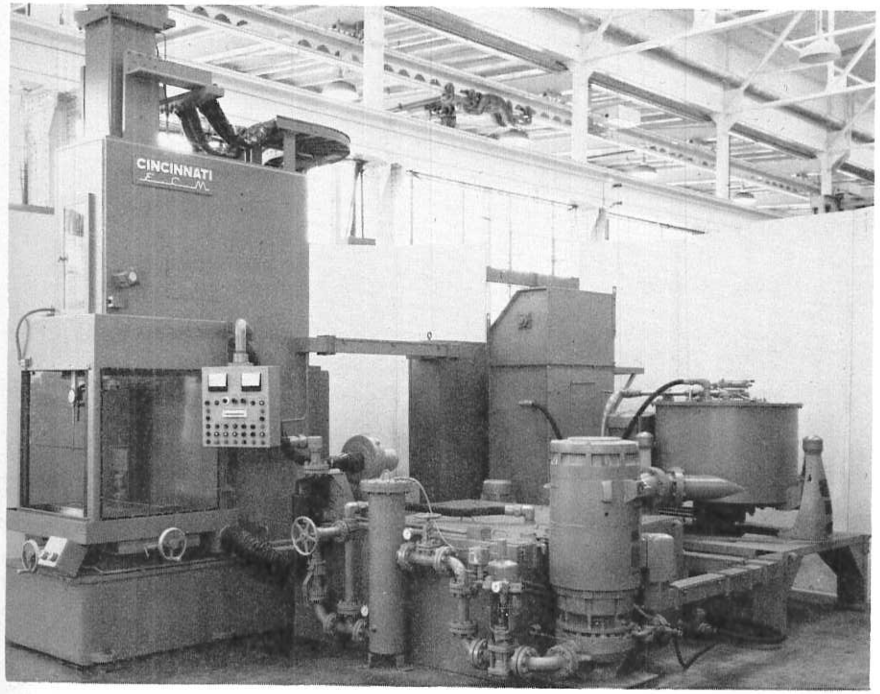

Figure 3.8 Vertical electrochemical "C" frame machine. The auxiliaries in the foreground are high pressure pump, filter, electrolyte pressure and temperature controls, and hydrogen extraction fan; in the bacground are centrifuge, evaporative condenser, and electrical control cabinet. (Courtesy of the Cincinnati Milacron Company.)

instrument, which may be set to any desired temperature, controls both electrolyte heating and cooling systems.

Small tanks are heated with immersed quartz-tube electrical heaters, or stainless tubing carrying hot water or steam. Heating capacity should be sufficient to raise the electrolyte tank temperature 50°F in 30 min. This minimizes delay in starting an EC machine, after it has been idle, and also reduces the mixing time for new electrolyte, since it can replenish the considerable heat absorbed as the electrolyte salts dissolve in water.

The process generates heat, primarily by the passage of the electrolyzing current through the electrolyte but, also, by the dissipation of pumping energy. A large flow rate of cooling water (about 100 gal/min for a 10,000-A machine) is required to take the heat away, via a heat exchanger. Direct supply of this flow rate of water can only be considered

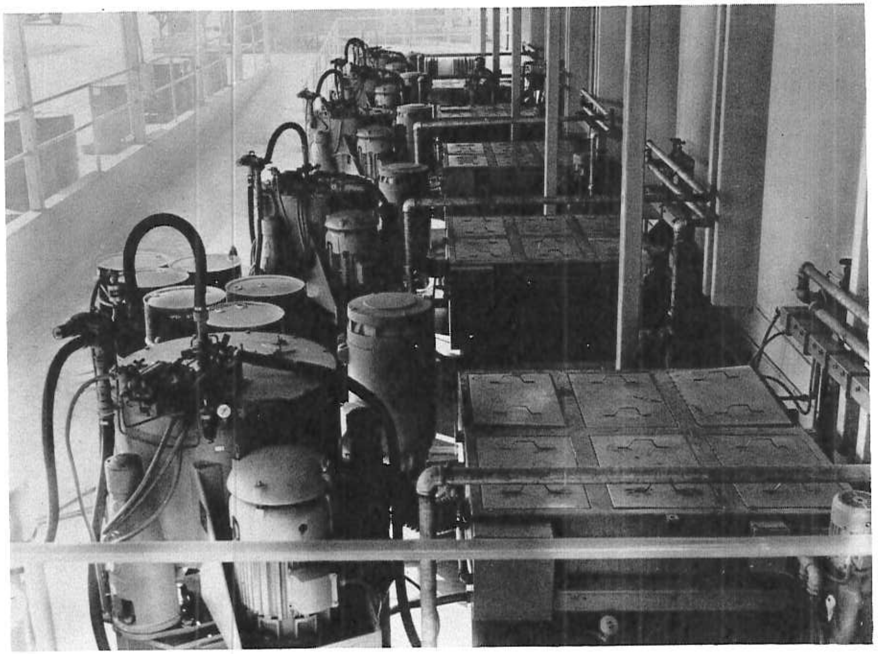

Figure 3.9 Electrolyte systems in an area separate from the machines which they service. Each comprises a tank, high pressure pump, and centrifuge. The drums are used to transport away the concentrated metal hydroxides. (Courtesy of the Cincinnati Milacron Company.)

practical at a sea, lake, or river location. An evaporative condenser, however, will dissipate the process-generated heat for a modest loss of water, compared to the volume of recirculating water it cools. Electrolyte may be circulated by a small centrifugal pump, directly through coils in the evaporative condenser, or through a heat exchanger supplied with the cold water from the condenser.

Process-generated hydroxides are removed by circulating the electrolyte through a centrifuge. Many types of centrifuges have been tried in service on EC machines, but the simple bowl type, equipped with automatic or manually operated concentrate discharge, has proved the most effective and reliable.

In operation, electrolyte is supplied into the center and at the closed end of a cylindrical bowl rotating at high speed. Simple radial vanes accelerate the fluid to the wall of the bowl, where it flows axially toward the opposite partially open end. The centrifugal force settles the hydroxide precipitate onto the wall of the bowl, where it forms a semi-fluid

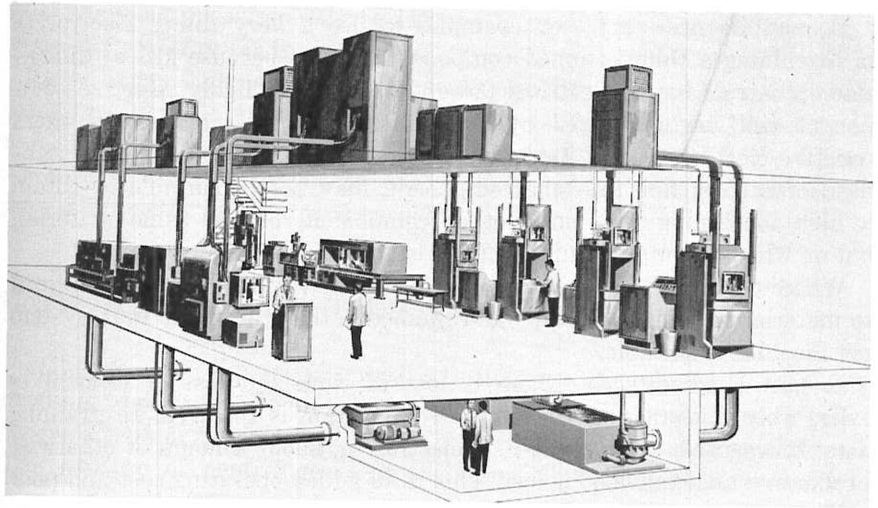

Figure 3.10 Streamlined electrochemical machining factory arrangement. Noisey auxiliaries are separate from the machine shop. Electrical equipment is placed on the floor above and electrolyte handling equipment on the floor below. (Courtesy of the Anocut Engineering Company.)

cake. Clean fluid, spilling over the rim of the bowl, returns to the electrolyte tank. An excess of hydroxides in the return flow indicates that the bowl is full of the hydroxide. Discharge of this concentrate, into a disposal drum, is achieved by radially feeding a skimmer pipe into the cake while the bowl is rotating. This operation takes only a few minutes and does not interrupt the clarification process. It has not proved practical to use ultra high speed or multiplate centrifuges, since the hydroxides have formed too solidly to permit automatic discharge of the concentrate.

The above equipment is typical of that used in conjunction with single small tanks. The system is flexible since its small volume minimizes the time and effort required to make up new electrolyte solutions. It is the most suitable system for a machine on which new tooling concepts or component materials are to be investigated; many electrolyte changes are then necessary, not only to machine each type of material, but also to control accuracy and surface texture. When a variety of materials are to be handled on a production machine, such freedom to select any type of electrolyte is frequently mandatory, but is always helpful in obtaining optimum machining rates, dimensional control, and surface integrity. Component geometry is also significant in the selection of a suitable electrolyte.

It may be necessary, for example, to use a very dilute electrolyte in machining a thin sectioned component. This is because loss of dimensional control, due to electrical power losses in the highly resistive component, will be minimized by the larger power loss across the extra resistive electrolyte gap. Again, an electrolyte, chosen to provide a standard of surface finish on one component, may not be suitable to obtain a high machining rate on another component, of the same material, but on which an inferior surface finish is acceptable.

Where the range of work to be performed is varied, either with regard to material or component type and geometry, then the single tank system per machine is suitable.

It has disadvantages. There is loss of time and loss of electrolyte salts, when a change in electrolyte composition is required. In draining a tank, cleaning, and mixing new electrolyte, about 4 hours of otherwise productive machine time is lost. This is an added operating cost and poor utilization of a large capital investment. The small volume of the electrolyte is not conducive to close control of temperature, composition, or degree of contamination with metal hydroxides. These factors are important in controlling the machining gap size which relates directly to the accuracy and repeatability of the work performed. Therefore, the single small tank system is not well suited for close tolerance work (less than 0.002 in.).

The Storage Tank System

The limitations of the single small tank system can be partially overcome by using additional electrolyte storage tanks. Three to six tanks are used dependent on the range of electrolytes needed to meet the work load. Where there is only occasional use of a particular type of electrolyte, it is mixed in the small machine tank and discarded after use. Each storage tank has a capacity exceeding 2000 gal. Piping between machine tank and storage is separate for each electrolyte type to prevent contamination. The main advantage of this system is that complete electrolyte changes can be made within half an hour, and material and labor costs of mixing are avoided. An ample supply of water is needed for flushing the entire electrolyte circuitry during the electrolyte change procedure. A single set of storage tanks, of suitable capacity, can serve a number of machines and these are then easier to justify economically. Large volume storage also simplifies the task of controlling electrolyte composition. The large volume is subject to gradual change only, so that a routine analysis, every two days or so, accompanied by corrective additions of salt or water, involves little work and gives close control. The machine tank is replenished frequently so that its electrolyte composition cannot stray far from standard.

Essentially, bulk storage tanks permit greater productive use of EC machines, provide easier and better control of electrolyte parameters, and, therefore, give closer control of machining accuracy. They are best where several machines are in use, tooling changes frequent, and component geometry and material varied.

Combined Storage and Electrolyte Clarification Tank

It has become a popular practice to dispense entirely with the small machine tank and mechanical centrifuge, and provide a single very large concrete tank or "swimming pool." The system has two main advantages. The expense of centrifuges and their suspect reliability are avoided. Also a single "pool" may serve several machines, so that overall installation costs are greatly reduced. Electrolyte flow through a "pool" is slow enough, because of its volume, to allow gravitational settling of metal hydroxides. These are periodically removed by a suction pipe scanning the bottom. The electrolyte temperature is very stable so that it is easily "trimmed" to the required value using a heat exchanger. Electrolyte composition control is also straightforward. The system is ideally suited to machines engaged on long production runs of similar components. A steel factory, for example, could perform all its ECM work with sodium chloride electrolyte, and would benefit from the "swimming pool" type installation. In summary, its advantages are low cost, easy maintenance, good control of the ECM process, and reliability.

If the types of components and materials to be machined are varied, however, the inflexibility of the system makes it a block to progress and effectiveness in applying ECM.

A reasonable compromise, to combine flexibility with the "swimming pool" concept, is to provide a series of pools containing mixes of electrolyte that will give optimum machining characteristics for most of the work to be performed. This arrangement is suitable for a large installation of EC machines engaged on many types of production work. It has a moderate installation cost, is easy to maintain, gives close process control, and has the flexibility, in choice of electrolyte, to permit full and efficient use of ECM (Table 3.1).

The direct current power unit is the most expensive piece of auxiliary equipment. Its purpose is to supply smooth, direct electrolyzing current, at a constant voltage, and to provide protection against damage at times of process malfunction. A typical power unit comprises transformers,

Table 3.1 A Summary of the Characteristics of Electrolyte Handling Systems

Electrolyte system	Installation costs	Maintenance	Type of work to be performed
1. Individual small tank per machine.	Fixed high cost per machine—centrifuge is a prime expense.	Considerable production machine time lost for electrolyte mixing. Centrifuge requires maintenance.	Development of ECM tooling or research. Small quantity production of geometrically and materially varied components
2. Same as 1, with additional storage tanks.	Same cost as 1, plus cost of additional storage tanks and electrolyte handling equipment.	Maintenance of electrolyte is minimal. Little interference to machine operation during electrolyte changes.	Production of geometrically and materially varied components.
3. Single "swimming pool."	Cheapest system if used to serve several machines. Centrifuges are not required.	Very little equipment maintenance. Easy to control properties of the single electrolyte.	Repetative production of geometrically and materially similar components.
4. Several "swimming pools."	Proportionally more expensive than single "swimming pool" system but less than systems 1 and 2.	Very little equipment maintenance. Easy control of each electrolyte.	All types of production including close tolerance work.

rectifiers, control and protective circuits, and air or water cooling systems.

There are two basic types of power unit supplied with the latest EC machines. Their difference is in the manner of regulating the voltage of the DC output. In one, a saturable reactor transformer has its primary winding in series with the primary winding of the main step-down transformer. Variation of the output DC voltage, from a set reference value, is fed back and amplified, to control the flow of DC current in the secondary winding of the reactor transformer. The degree of magnetic flux resulting, controls the impedance of the reactor, hence the input voltage to the primary winding of the main step-down transformer. The high current, low voltage AC is then rectified using germanium rectifiers. The system provides a smooth DC output, has adequate response for the slow rate of current change in ECM work, is well tried, and is reliable.

The rapid fall in the price of silicon-controlled rectifiers (SCR), during recent years, has given rise to the second type of power unit. An SCR is used both for the rectification and as a means of voltage regulation. In operation, an SCR only conducts current from the time it is electronically signalled to do so, until the end of a cycle, that is, to the point where its input is at 0 V.

The electronic signals are at the same frequency as the alternating current, but by varying the phase, the power output of the SCR is precisely controlled. The timing of signals to the SCR is controlled by feedback from the DC output. The system has very rapid response to changes in process load; it is more compact and is potentially cheaper than the saturable reactor type. Its DC output is very "spiky," and while this does not affect the ECM process, it may adversely affect the operation and sensitivity of spark protection equipment. In electrochemical turning, fast voltage response to sudden changes in amperage load is very important. The SCR power units are preferred, therefore, for EC turning machines.

Voltage regulation of $\pm 1\%$ is adequate control for most ECM precision work. In specifying equipment, however, it is important to request that the voltage can also be set to the same $\pm 1\%$ accuracy. Instrument grade large-scale voltmeters, or digital read-out voltmeters, provide this degree of accuracy.

In a well-operated ECM operation sparks between tool and work do not occur. However, lack of process control, equipment failure, operator error, and so on, can result in this type of process malfunction. During the proving of new tooling, and in establishing operating parameters, some process malfunctions usually occur. In fact, it is normal to test tooling over a very wide band of operating conditions to establish the limits for consistent production operation. Power units are equipped with electronic protective devices that detect small electrical transients in the insipient stage of process malfunctions. The electrical power is then cut before damage occurs to the tool or work surfaces. The two main process malfunctions are sparks and local passivity of the work surface.

Sparks show as spike transients in the DC voltage. Passivity of the work surface, while it causes a slow fall of machining current, is often accompanied by cavitation of the electrolyte flow. This effect gives a sharper change in current, that is *detectable*. The electronic circuitry detects these transients and logically separates them from normal electrical noise. The machining power must be cut in less than 10 μsec to prevent severe electrical spark damage to work or tools. Power supplies using SCRs can be shut down in 10 μsec. This method of switching is adequate on most ECM applications although some damage to tooling does occur.

On very precise tooling, damage is not acceptable; it may be eliminated by using an SCR bank placed across the DC input to the machine. In the event of a process malfunction the SCR bank is electronically signalled and immediately short circuits the machining current. Tool damage is usually undetectable. This type of protection is expensive but very worthwhile for proving development tooling, operating sophisticated tooling, or providing protection in machining components of high surface integrity.

CHAPTER IV

Economics

It is wise, of course, to carefully review the economic merit of electrochemically machining a component, before committing to this method of manufacture. There are many facets of cost which must be fully considered, and many, when given a generalized understanding of them, may be dismissed as trivial. The economic considerations fall into three categories. These are actual operating costs, cost compared with alternative processes, and equipment investment.

4.1 OPERATING COSTS

Accounting practice varies from company to company, so on "face value" an identical ECM operation in one company may show different operating cost from that in another. This is because, for convenience in controlling the overall finance of a company, factors such as tool maintenance and repair and capital depreciations are covered by a blanket "overhead" charge. The overhead is a percentage of the direct labor used in performing the operation. In ECM, however, there are aspects of the cost, some beneficial and some not, that, if included as part of a general overhead rate, would be misleading as to the true operation cost. Hence it is more accurate to identify separately costs that relate directly to the ECM process. These are itemized in the following paragraphs.

Direct Labor

- Loading and unloading of the component.
- Indexing of the component or tool changes, where a number of separate areas of the component are machined.