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**Deburring: Technical Capabilities
and Cost-Effective Approaches
Lessons 7 and 8**

By L. K. Gillespie

Published June 1980

Prepared for the United States Department of Energy
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**Kansas City
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DEBURRING: TECHNICAL CAPABILITIES AND COST-EFFECTIVE APPROACHES,
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Prepared by L. K. Gillespie

This ten lesson text on deburring is designed to provide engineers and production supervisors with an overall understanding of deburring economics and current capabilities. The material included describes economics, side effects, process selection techniques, product design influences, standards, plantwide approaches, burr formation, and prevention. Deburring methods described include barrel, centrifugal barrel, vibratory, spindle, manual, electrochemical, electropolish, brush, abrasive jet, abrasive flow, water jet, thermal energy, and mechanized mechanical. Lessons 7 and 8 describe electropolish and electrochemical deburring, and mechanized mechanical deburring respectively.

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Deburring: Technical Capabilities and Cost-Effective Approaches

by LaRoux K. Gillespie

Lesson 7 Electropolish and Electrochemical Deburring

SUMMARY

Electropolish and electrochemical deburring (ECD) are not the answer to everyone's deburring problems. They are high technology processes when compared to tumbling processes. They require more care, skill, and knowledge than many of the older processes. They are not mass finishing processes. In contrast, they can deburr areas totally untouchable by other processes, and electropolish can produce brilliant finishes. ECD selectively works only in one area, and neither process exerts cutting forces which would distort thin sections. ECD is applicable to all metals and all sizes of burrs. Once established, both processes can be controlled by unskilled help.

LESSON 7

ELECTROPOLISH AND ELECTROCHEMICAL DEBURRING

Electropolish and electrochemical deburring (ECD) use a combination of electricity and chemistry to remove burrs from metal parts. Electropolish deburring, in addition to deburring as many as 1,000,000 holes in 15 minutes, is widely used to improve finishes. Electrochemical deburring is widely used in the automotive industry and in applications involving hard-to-reach areas. The electropolish process is used to remove small burrs, while ECD is used to remove burrs 0.005 inch (127.0 μm) or thicker burrs.

ELECTROPOLISH DEBURRING

Electropolish deburring is widely used on surgical and medical equipment because it leaves a surgically clean surface. One advantage of this process is that it can remove very small burrs very quickly, economically, and with a minimum of edge break. As an example, on production and experimental parts, the edge radius left after removing burrs 0.0005 (12.7 μm) thick was 0.0005 inch (12.7 μm). Even when one removes burrs more than 0.003 inch (127.0 μm) thick, the edges are still almost sharp. This is a significant advantage for many situations in which burrs are otherwise inaccessible. In addition, the process normally polishes surfaces and finishes of 2 $\mu\text{in.}$ (0.051 μm) can be produced while deburring.

Because this process uses a liquid to provide the deburring action, it can deburr all surfaces and edges in otherwise inaccessible areas. This makes the process attractive, particularly when the part has many edges or otherwise inaccessible edges. The fact that it cleans the part and passivates the surface is also an advantage in this process. Passivation provides a thin coating which effectively prevents corrosion from occurring on stainless steel.

Basic Process Operation

As shown in Figure 1, the process requires a direct current (DC) power supply, a weak acid, an electrical connection to the workpiece, and a metal part. If one so desired, a car battery or simple flashlight battery could be used to make an effective electropolish system for small parts. The acid used is relatively mild although it will still cause a burning sensation when splashed on skin. Typically, the acid is a combination of phosphoric acid and some additional proprietary chemicals.

Figure 1. Basic Electropolish Schematic

To use this system, one merely attaches one wire of the electropolishing unit to the workpiece, inserts the part into the solution and turns on the power. After 5 to 30 s, one removes the part, places it in a neutralizing solution such as baking soda to counteract the acid on the surface, rinses it off and blows dry. Under normal circumstances, this is essentially all there is to using this process to remove burrs. To speed up the reaction, one normally will heat the solution to approximately 120 to 150°F (49 to 65°C).

This process uses low voltage to remove burrs. In many situations, one will use only 5 to 10 V for deburring. The amount of current drawn depends upon the size of the part which is to be deburred. Larger parts having larger surface areas require higher currents than small parts.

Figures 2 and 3 illustrate the simple system used to electropolish deburr precision miniature gears in a job shop operation.

The work-holding clip or rack is made of titanium which the solution does not attack. For very small parts, a spring alligator type clip is used.

Figure 2. Schematic of Electropolish Deburring System

Figure 3. Flow Chart of Electropolish System

The work connection is attached to the positive terminal of a source of direct current; copper plates or lead cathode bars are connected to the negative side of the current source.

A direct current source is supplied by rectifiers or motor generating systems. Operating voltage is in the range of 6 to 14 V, the amperage range from 0.4 to 1.5 amps per square inch (0.00062 to 0.0023 A/mm²). Temperature control of the bath should be automatic, and will range from 80 to 200°F (27 to 93°C), maintained at ±2°F at any one setting. All electropolishing units have an ammeter and a voltmeter as well as a means for adjusting the current.

Tanks are of mild steel lined with polyvinyl chloride, or made of stainless steel. While plastic lined tanks can be used, they are

limited to operating temperatures below that which the lining will soften. The work is agitated in the solution with a back-and-forth movement to prevent gas streaks over part surfaces.

Ventilation, as in electroplating, is highly recommended. The operation of small electropolish deburring baths is performed under a fume hood with a minimum exhaust capacity of 200 cubic feet per minute ($0.0943 \text{ m}^3/\text{sec}$). Because hydrogen gas is produced in this process, smoking cannot be allowed in the immediate area.

Facilities for cleaning, such as vapor degreasing, ultrasonic cleaning or alkaline cleaning are required, to prepare the work for electropolish deburring. Oil, grease, and solid particles must be removed prior to electropolishing.

Rinsing is very important in this process. For small installations deburring miniature parts, the rinse tanks do not need to be very large. For stainless steel, a water rinse followed by a dip into a solution of 10 percent nitric acid, water rinse, and a distilled or de-ionized water rinse will prevent water spots. Oven drying is recommended, but if the last rinse is with hot water, the oven dry is not required.

Typical Applications

Some of the normal applications for this part within industry are:

- To remove heat treat tints;
- To remove surface oxides;
- To passivate surfaces;
- To clean metal parts after soldering, brazing, and welding;
- To produce hydrogen-free surfaces;
- To produce very low friction surfaces;
- To increase emissivity in electronic tubes;
- To better show the quality of cast surfaces;
- To dimensionally change the size of a part;
- To improve reflectivity of light and heat;
- To remove mechanically disturbed metal;

- To stress relieve surfaces;
- To improve surface finishes;
- To remove imbedded material; and
- To remove burrs.

Because this process removes material from all surfaces as well as the edges, it is normally used only when there are very small burrs on precision parts. If the parts were not precision, then this process could be used for almost any size burr. As a typical example, it is used to remove sanding, grinding and honing burrs in as little as eight s.

Variables in the Process

Because electropolish deburring is so simple, there are very few variables to be changed within the process. Among those factors which can be altered to provide different results are:

- Composition of the chemicals;
- Temperature of the solution;
- Time of run; and
- Voltage selected.

One will typically use one solution for all 300 series stainless steel materials and another for all other stainless steels. Copper, aluminum, and other materials require their own solutions. By increasing the solution temperature, the reaction rate increases, which in turn reduces the time required for deburring. In some respects this is a disadvantage because if parts are deburred in only 5 or 6 s, then any air bubbles on the parts or any dirt or contamination will not allow the chemicals to attack the desired edge or surface. This will result in portions of the parts which have the original material condition on them and other portions which have been polished as desired. As shown in Figure 4, longer run times in the solution will increase the amount of material removed. If burrs are very large, then they must be run for longer times. As seen in this illustration, a 60-s deburring time may remove as much as 0.002 inch (50.8 μm) from the diameter or thicknesses of workpieces. This is normally totally unallowable on precision parts. Even the use of only 10 s in many cases would remove as much as 0.0002 inch (5.1 μm) from diameters or thickness. This too may be totally unallowable. This illustration demonstrates the need for small burrs. If a burr, for example, is 0.010 inch (254 μm) thick, then from this illustration, since that much material must be removed one

Figure 4. Effect of Burr Size on Removal Time for Stainless Steel Workpiece

will also change the entire thickness or diameter part by a similar amount. For this reason, it is re-emphasized that this process is most applicable to very small burrs on precision parts or large burrs on parts having large tolerances.

Potential Problem Areas

Because this process is so simple and involves so few variables, there are actually very few problem areas one might expect to incur in this process. Among those areas in which one may have problems are:

- The process will change all dimensions on a part;
- The process may distort dimensions;

- Surface finishes will be improved;
- Clamping devices will mask portions of the workpiece;
- Corrosion on electrical contacts may affect the efficiency of the operation;
- Contamination on the workpieces will prevent uniform stock removal; and
- Because acid and electricity are involved, safety precautions must be taken.

Today a wide variety of electropolishing equipment is available for all applications. The schematic diagram of Figure 5 illustrates the different types of machines, beginning with normal machines for the treatment of fixtured parts.

ELECTROCHEMICAL DEBURRING

Electrochemical deburring (ECD) is very similar in many respects to electropolish deburring in that it uses a solution and electricity. In the case of electrochemical deburring; however, one must have a tool which matches the area to be deburred. In addition, the solution is a salt solution not significantly different from common table salt.

Capabilities of Electrochemical Deburring

The basic asset of electrochemical deburring is the speed at which it removes burrs. In most instances, deburring of an entire part can be completed in 60 s or less. In addition to removing both large and small burrs, electrochemical deburring has a distinct advantage over electropolish deburring in that it works only at the edge of the workpiece and does not affect the dimensions of the workpiece. If, however, one is not careful in designing the tooling, or if the cycle operates too long, it is possible to change some of the dimensions near edges.

As in the case of electropolish deburring, this process requires that the workpiece must be a metal. Any metal which will conduct electricity can be used in this process. Stainless steel is an ideal material for the process. Aluminum and copper alloys have also been deburred using this process.

If one begins with a very rough surface, this process can provide a very smooth surface around the deburred edge. In most instances; however, the surface finish is only slightly better, and if the electrolyte is not flowing properly, a mottled surface texture occurs.

1. Standard and automatic equipment

work or jugged component (anode)

2. Equipment for the electrochem. polishing and deburring of bulk components

Batchwise treatment in the tipping barrel (anode)

work

Batchwise treatment in the portable immersion-barrel (anode)

cathode
work

Continuous treatment in the barrel-conveyor (anode)

feeding device

3. Installations for the continuous electrochem. polishing and deburring of small parts.

feeding device
cylinder with helical multilane track (anode)

Figure 5. Schematic Diagram of Electropolishing Units

Basic Process Operation

As shown in Figure 6, the process involves a direct current power supply, a solution (electrolyte), a tool, and electrical connections between the part and one side of the power supply. Under normal circumstances, one will force electrolyte to flow between the tool and the part in order to conduct electricity. In some instances, it is possible to simply immerse the part in some solution but this is generally not the most appropriate approach. The electrolyte flow drags away the by-products of the chemical reaction. If left in place, these by-products could eventually cover the part, preventing effective electrical conduction.

To operate this process, one merely places the part on the tool (Figure 7), and pushes the two buttons that initiate the cycle. The machine automatically clamps the part, turns on the electrolyte flow, checks to determine if there is a short circuit between the tool and the part, and then begins the deburring cycle. When the cycle is complete, the electrolyte flow stops and the clamp retracts to allow one to remove the part. The part is normally then placed in a soapy solution and when all parts in that lot have been completed, they are rinsed and blown dry.

In most instances, it is advisable to place oily parts with burrs on them in a soapy solution before the deburring begins. This removes any oily films which would inhibit the electrical and chemical reaction. In some cases, if this film is heavy and in hard-to-reach areas, it is also desirable to use a small tooth-brush or tube brush to scrub the surfaces prior to electrochemical deburring.

The workpiece can be any size or shape but it must be electrically conductive. This then limits the process to metallic parts. While burrs can be at any location on the part and can be any size, it is essential that the orientation of the burr be consistent on every part. Thus, if the tooling is designed to accommodate a burr thrown into the large diameter of two intersecting holes, the burr must always be in the large diameter. If it is not, a short circuit will occur which can destroy or damage the part and the tool.

Some metals do not deburr well with the conventional electrolytes, but special electrolytes are available which will provide the necessary deburring. Sintered tungsten is one such resistant metal.

Electrolytes

To provide a solution which concentrates the cutting edges near the tooling, salt solutions are used. Table salt (NaCl) for

Figure 6. Schematic of Electrochemical Deburring System

example can be used in concentrations of 2 pounds per gallon (1.06N/l) of water. To provide better finishes or more uniform stock removal, sodium nitrate (NaNO_3), sodium nitrite (NaNO_2) or potassium chloride (KCL) are used. In some cases, a mixture of two or more of these electrolytes or a proprietary solution will be used.

Tooling

The single most important key to the success of ECD is the tooling. The tool design affects loading and unloading time,

Figure 7. ECD Tool Used to Deburr Part With 14 Holes Per Side

deburring time, edge quality, and stray etching. Tool design affects the tool cost and therefore, also the cost of deburring. It affects tool life and maintainability.

Since every feature deburred must have a tool designed for that feature, some individuals have ignored ECD, believing it to be too expensive. The fact is that today one can design and make permanent or temporary tooling quickly and inexpensively. At least two manufacturers offer modular tools which are constructed from standard simple elements. Inexpensive tools for short-run applications only require individuals who truly understand tooling needs.

Typical Applications

The ECD process has several features which provide significant advantages in deburring:

- It provides a smooth radius rather than a chamfer;
- It is a process which exerts no mechanical forces on the part;
- It does not affect a part's dimensions except at edges;
- It can be used as a manual or a fully automated process;
- It is a relatively low cost process;
- It can be used to produce a burr-free shallow slot, or related depression; and
- It can also be used to number parts if one uses correct tooling.

The fact that the process produces no mechanical forces on the part allows it to be used on very thin sections without fear of distortion or part damage. Most deburring processes change the dimensions of a part slightly. The basic size of parts deburred by ECD remain unaltered except at the very edge of the part.

At the present time the majority of applications involve very hard-to-reach or the very complex edges on parts. While the process can be used to deburr entire parts, it is frequently more economical and faster to only deburr the more difficult ones by this process. One of the reasons for this is the fact that tools must be designed to match the area to be deburred. In many cases, designing tools to completely deburr parts may cost \$4,000 to \$10,000 per part. In addition, if there is a short circuit or damage to a tool in operation then one cannot deburr any more parts until the entire tool is corrected. For this reason and many others, it is advisable only to use it for those instances where deburring may require more than three minutes per feature.

Variables in the Process

The variables in this process which influence the amount of deburring and edge radiusing one receives include:

- Voltage;
- Tool design;
- Electrolyte;
- Temperature of electrolyte;
- Cycle time; and

- Workpiece material.

As shown in Figure 8, if one increases the voltage it takes less time to remove burrs. Similarly, if the burr is very thick it will take a longer time to remove.

If one heats the electrochemical deburring solution, the deburring will occur faster. Since the process also removes metal in areas adjacent to the edges, high temperatures will also accelerate the dimensional change in these areas. For precision parts, it is therefore desirable to keep the electrolyte cool. This concentrates all the electrochemical deburring action at the edges and minimizes any dimensional change to the workpiece. Most commercial parts use warm electrolytes to reduce cycle time.

Although tool designs are basically simple, the basic design approach used can significantly affect the deburring time. In addition, the tool design will also influence the amount of stray cutting which occurs on workpieces. While tool design can minimize these conditions, it alone cannot successfully solve the problem of very thick burrs which must be removed with a minimum of side effects.

Burr Removal Rate

In Figures 9 and 10, the relationship between thickness of burrs removed and cycle time can be seen graphically for both steel and aluminum applications. For applications involving iron based alloys, many burrs average approximately 0.007 inch (0.18 mm) in thickness and cycle times are usually 15 to 20 s in duration. Aluminum burrs average about 0.005 inch (0.13 mm) in thickness and the cycle times are usually less than 15 s. The extremes, above and below the average lines in these figures are determined by how closely the tooling can be made to conform to the part configuration. If the edge from which a burr projects is defined by two surfaces machined to close tolerances, the cathodic electrode can be positioned accurately within perhaps 0.020 inch (0.5 mm) from the root of the burr for every part that is loaded in the fixture. However, if the edge is caused by a roughly machined surface intersecting a cast or forged surface, the anode/cathode distance must become correspondingly larger to accommodate the greater dimensional tolerances. As the distances increase between electrodes and the burrs, the cycle time increases. If ECD is simultaneously deburring four separate areas on the same workpiece, the total cycle time is determined by the individual area with the longest cycle time. While theoretically ECD performance might be even faster than indicated by these values, these graphs represent actual performance on the production floor.

Figure 8. Effect of Voltage on Deburring Time

Tooling Life

The durability of tooling in an ECD application is one of the most significant elements determining production cost. Of course, when a system is operated manually, the operator himself is the most costly element. However, in today's market, we are dealing with completely automated systems as well as manually operated systems. Thus, the ability to predict tool life and cost becomes more critical.

When designing tooling for any component, regardless of the process, certain details must be considered expendable on high wear items. Even in a simple production drilling fixture, the drills, bushings, locator pads and clamps are all considered wear items and are designed for easy replacement and/or adjustment. The tooling for electrochemical deburring is no exception. The expendable components in an ECD fixture are the electrodes, the nonconductive locator masks and the positive contacts. The positive contacts experience the highest rate of wear because they, with the workpiece, are the anodes in the cell which are destined to give up metal to the process. Nevertheless, with properly designed tooling, a set of expendable components, including several positive contacts, will last in production long enough to provide effective deburring for over 100,000 cycles. In some cases, expendable details have lasted effectively twice that long. The rest of the components in ECD tooling, with no more than common sense care, can last indefinitely.

Potential Problems Areas

There are several concerns in the use of this process. Among these are:

Figure 9. Burr Removal for Iron Base Alloys

- The process leaves a residue in the area around deburred edges;
- The process can cause stray pitting on workpiece surfaces;
- The process will change dimensions at edges; and
- The process may relieve desirable stresses on workpiece surfaces.

Figure 11 illustrates the size change occurring at the edge of a 120 pitch gear. In this instance approximately 0.001 inch

Figure 10. Burr Removal Rate for Aluminum

(25.4 μm) of stock was removed for a distance of 0.005 to 0.010 inch (127 to 254 μm) from the edge. In this case a small edge break was required. Most parts will have 0.005 inch (127 μm) or larger edge radii. Some materials exhibit stray etching or pitting at distances far from the edges which are deburred. Figure 12 illustrates one such example on a stainless steel workpiece. While this etching is apparent at the magnification shown, it is actually extremely small. The depth of etching in most instances is in the order of 0.0002 inch (5.1 μm). In most applications this is probably not detrimental but for others it may be. Each part must be judged individually as to whether this is a major limitation or not.

Figure 11. Dimensional Change at Edge of Miniature Gear Tooth

The process will leave a white or black residue on workpieces which can be removed readily with the use of sandpaper, brushes or blasting abrasives. In the case of stainless steel parts, brushes can typically remove this very readily. In the case of aluminum, one may have to use an abrasive filled nylon brush or a sandpaper-like product.

Economics

In many situations the most economical approach may be to use ECD for burrs in hard-to-reach places and use conventional deburring processes for more accessible burrs. While ECD can totally deburr parts, parts having many edges may require intricate tooling and parts having many inches of edges to deburr may require more current than available at the machine. The burrs must be consistently oriented in the same direction for this process to work. The choice of direction may affect tool design, removal time, and machine time.

Figure 12. Etching Occurring at Center of Gear Tooth

Any ECD machine has a limited current capacity. If one uses the rule of thumb that 10 amps are required for each inch of edge to be deburred, then a 500 amp machine will have enough capacity for 50 inches (1.27 m). It is easy for an intricate part 2 inches by 3 inches by 1 inch (50.8 x 76.2 x 25.4 mm) to have 50 to 100 inches (1.27 to 2.54 m) of edges. Thus, even though a part is small it may require the full current output. In addition, the rule of thumb frequently understates current needs. High production rates can be achieved with appropriate tooling, automation and by deburring two or more parts at a time.

As with most processes the choice of working parameters and tooling is an economic consideration. While little data is available in the literature on the economics of the process, one can make some reasonable cost estimates using the following formula.

$$C = \frac{C_D + C_M + WC_P}{N} + \frac{(K_1 C_L + K_2 C_A)(1 + D_O)}{N} + \frac{C_T}{N_P} + \frac{C_S}{N_{P_1}} + \frac{C_F}{N_{P_2}} + \frac{A(F + H + L_i + I + G)}{H_Y N}$$

where:

C = Deburring cost per part.

C_D = Depreciation cost per hour = machine cost per operation hours.

C_M = Maintenance cost per hour of operation.

C_L = Labor cost per hour to run machine.

C_P = Cost of power used (\$ per kilowatt hour).

C_A = Cost of cleaning per hour after deburring (labor + material).

D_O = Overhead as percentage of labor rate.

N = Number of parts run per hour = n/t .

n = Number of parts run per cycle.

t = Time (hours) per cycle.

N_P = Total number of parts run.

N_{P_1} = Number of parts run for a given quantity of solution or tool life.

C_T = Total tool cost.

C_S = Total cost of solution.

W = Power used, in kilowatts (1 hp = 0.75 kW).

C_F = Time (hours) for setup and cleanup.

N_{P_2} = Number of parts run per setup.

H = Yearly heating costs for deburring area (\$/sq.ft./yr.)

L_i = Yearly cost of lighting for deburring area (\$/sq.ft./yr.)

- I = Yearly insurance costs for deburring area (\$/sq.ft./yr.)
- G = Any other yearly general overhead costs (\$/sq.ft./yr.)
- H_y = Hours per year the deburring area is used.
- A = Floor area of operation (sq.ft.)
- F = Yearly floor space costs (\$/sq.ft./yr.).
- K₁ = Percent of cycle time operator actually spends controlling deburring operation.
- K₂ = Percent of cycle time operator actually spends controlling cleaning operation.

For the first example, assume that the machine is used in a job shop for short runs of precision parts. A \$16,000 machine is estimated to last 8 years with a use of 2,000 hours per year. Direct labor costs are \$6.00 per hour and overhead costs are 20 percent of direct labor. Equipment maintenance is estimated at 10 percent of depreciation costs and after deburring each part must be cleaned thoroughly manually. The cleaning for this example is estimated to require as much time as deburring. Fifty parts per hour will be run. The tool cost is \$500 and a total quantity of 500 parts will be run over the life of the tool (but only 100 parts will be run in this setup). The combined cost of electrolyte salts and water is estimated to be \$.50 per gallon. An estimated solution life is 500 parts per 50 gallons (47.6ℓ). The estimated time to set up and clean up is one hour.

For the indicated values the cost of deburring is \$1.37 per part (Table 1). While this is expensive compared to the cost of vibratory finishing or related processes, it is not expensive if the feature being deburred could not be quickly deburred by another means. Consider hand deburring for example. If one assumes that hand deburring costs, plus overhead, are \$7.20 per hour and that no other costs are involved, then \$1.40 represents 11 minutes of hand deburr effort. In other words, in a job shop situation such as described above, ECD is the more economical process if hand deburring requires more than 11 minutes per part.

When one looks closely at the elements which are responsible for this cost, it is obvious that tool cost is the biggest factor (\$1 per part). The total labor costs of cleaning and deburring is \$0.30 per part. If one could build an ECD tool for \$250 and eliminate one-half of the cleaning time allocated in this example, then the cost of deburring would be \$0.83 per part. For this example, power costs amount to less than \$0.01 per part.

Table 1. Examples of Unit Deburring Costs

Cost Item	ECD Example 1	ECD Example 2	Electropolish Example 3
C_D	\$ 1.00	\$ 3.00	\$ 0.20
C_M	\$ 0.10	\$ 0.30	\$ 0.02
C_L	\$ 6.00	\$ 6.00	\$ 6.00
C_P	\$ 0.04	\$ 0.04	\$ 0.04
C_A	\$ 6.50	\$ 7.00	\$ 7.00
C_T	\$ 500.00	\$3,000.00	\$ 25.00
C_S	\$ 25.00	\$ 150.00	\$ 20.00
C_F	\$ 1.00	\$ 2.00	\$ 0.50
D_O	0.20	0.20	0.20
N	50	600	60
N_P	500	10,000	2,000
N_{P1}	500	10,000	2,000
N_{P2}	100	10,000	2,000
W	7.5	7.5	0.0016
A	150	1,000	10
F	\$ 5.00	\$ 5.00	\$ 5.00
H	1.40	1.40	1.40
L_i	\$ 0.50	\$ 0.50	\$ 0.50
I	\$ 0.10	\$ 0.10	\$ 0.10
G	\$ 1.00	\$ 1.00	\$ 1.00
H_Y	2,000	2,000	2,000
K_2	1.0	0.5	1.0
K_1	1.0	0.5	0.0
C	\$ 1.374	\$ 0.341	\$ 0.126

ECD's biggest cost advantage is in automated lines where hundreds of parts can be run per setup. Assume now an automated facility which costs 3 times as much as the one cited earlier and which takes 6 times more floor space. Assume a production rate of 600 parts per hour and that the cleaning is automated such that one man can control both deburring and subsequent cleaning. Using the values shown in example 2 of Table 1, the cost per part would be \$0.34. In this instance also, the cost of the tool proves to be largest single cost element (\$0.30 per part). In a more highly automated facility in which several hundred thousand parts were deburred and multiple copies of the tools are used, the cost per part can be significantly less than the example cited. With appropriate conditions, it is possible to ECD parts for a cost less than \$0.10 per piece.

Because electropolish deburring generally requires less expensive equipment and essentially no tooling other than contacts, the deburring cost can be much less. Consider the case of a small job shop which purchases a \$2,000 bench top unit. The life of this unit is 10,000 hours. It is a manual operation requiring one minute per part total cycle time (including cleaning). A \$25 titanium electrical connection is used to deburr one lot of 2,000 parts. Because the parts are small, the power consumed is 10 volts x 1 amp x 0.16 minute = 1.6 watt per part. The solution which will process 2,000 parts costs \$10 per gallon and two gallons are required. As seen in Table 1, the deburring cost per part is 12.6 cents.

Fully automated electropolish units, while much more expensive, also will reduce high volume costs to less than \$0.01 per part. By racking several parts per load, even manual handling will reduce costs to less than \$0.05 per part.

Safety Considerations

The fact that ECD uses a simple salt solution makes the chemicals inherently safe. In some instances, however, individuals may have skin irritation caused by contact with any salt; however, this is not normally the case. The solution represents no problem to health or safety. The fact that it is used at 60°F to 120°F (15.6°C to 49°C) temperatures also enhances its safety, since one cannot be scalded or burned by such solutions.

Electropolishing solutions require care in handling since they are acids and typically 150°F (65°C).

Both processes do use a direct current, and as such, one must take some simple precautions because of electricity. Existing national standards indicate that voltages less than 32 V direct current are considered safe to use. For this reason (most

machines produce at most 24 V DC) the processes are basically safe. If one were to touch both ends of the electrical circuit, one should not incur any more damage or sensation than occurs from the current passing through two or three flashlight batteries.

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Deburring: Technical Capabilities and Cost-Effective Approaches

by LaRoux K. Gillespie

Lesson 8 Mechanized Mechanical Deburring

SUMMARY

The mechanical cutting away of burrs can be accomplished in a variety of ways. Many shops have adapted conventional machines and tools to this task with a variety of ingenious approaches. While mechanical deburring is not generally a competitive finishing method for small parts which can be satisfactorily vibratory finished, it is the most economical process for many larger parts and gear shapes.

LESSON 8

MECHANIZED MECHANICAL DEBURRING

Many commercial parts are deburred in some form of automated equipment employing cutters, brushes and sanding heads. Such mechanized equipment produces up to 600 commercially burr free parts every hour. While many of these machines are custom built for a specific product line, several universal machines are also available.

TYPES OF MECHANIZED MACHINES

There are almost 50 manufacturers of equipment designed for the removal of burrs. Yet, the diversity of these machines is not widely known. This overview then, will discuss the basic characteristics of those used both in job shops and in automated facilities. Type ranges from simple, low-cost units to high-volume transfer lines.

Mechanical deburring processes include those which perform burr removal by cutting, brushing or sanding. Although manual techniques require mechanical action, it is not a mechanized process as such and will not be included in the discussion.

The word "cut" is actually too general to define the action involved with mechanized machines. However, Table 1 lists these actions into the various subcomponents employed. These actions, in turn, are combined in a variety of ways which result in the types of machines shown in Table 2.

Sheet Metal Edgers

Sheet metal edgers use either small grinding wheels or pinch rolls to remove burrs. Those employing grinding wheels are adjustable in order to vary chamfer (Figure 1). Some machines will deburr both the top and bottom of one side and will accommodate sheets ranging from 0.025 to 1/4-inch (0.63 to 6.35 mm) thick and in widths of 1/2-inch (12.7 mm) or more. Linear feed-rates of 60 fpm (0.3m/sec) are possible.

Machines using pinch rolls to remove burrs or re-roll the material into the edge can deburr both sides of a sheet as well as the top and bottom in a single pass (Figure 2). This equipment can process sheets ranging from 0.125 to 0.025 inch (3.175 to 0.63 mm) and in widths up to 48 inches (1.2 m). Feedrates of 100 fpm (0.51m/sec) are possible.

Table 1. Types of Mechanized
Mechanical Deburring

Cutting with Rotary Cutter
Grinding with Small Wheel
Honing with Small Reciprocating Machine
Rolling Burr Back into Parent Metal
Trimming Off Excess Material with Dies
Sanding
Brushing

In one instance the stock passes through a set of wide pinch rollers to provide stock feed. A subsequent set of V-shaped disks or rollers set on a vertical axis set up the edges for finishing. The shape of these rollers, which are hardened and ground, is similar to a small V-belt pulley. A second set of power driven rollers perform the edging and a third set finishes the edge. Either chamfered or radiused edges are possible. The pressure exerted by the rollers progressively forces the burrs and sharp edges over, under, or into the stock. While the approach has worked well on steel, stainless steel, and aluminum strip, it will not deburr dead soft copper or aluminum. These metals tend to buckle under roller pressure.

End Finishing Machines

Tube and bar end finishing equipment is available in various degrees of sophistication and automation. In one case, a simple rotating tube deburring cutter (Figure 3) is mounted on the same spindle as an abrasive cutoff saw. In use, after a part is cut to length it is then merely poked into the enclosed cutter.

Other small, manual end finishing machines allow users to deburr 1500 ends an hour. Such units can face the end as well as chamfer an ID and OD. Automated machines deburr both ends of a tube or bar at rates up to 2000 parts per hour. Such machines are often integrated into lines using a special magazine or cradle loading and unloading/storage devices. Most accommodate a full range of tube or bar diameters.

General Purpose Part Edgers

Two basic approaches are used for general purpose part edgers. First, rectangular parts are laid into an angle iron trough and

Table 2. Types of Mechanized
Mechanical Deburring
Machines

Sheet Metal Edgers
Tube and Bar End Finishing Machines
General Purpose Part Edgers
Cutting Tool Hones
Special Design Single Purpose Units
Sanders
Brushing Units
Trimming Presses
Robots

hand fed over a small grinding wheel which provides a small, but adjustable chamfer (Figure 4). The second approach is to put a piloted chamfering tool up through a flat table (Figure 5). The rectangular or flat part is then moved until it touches the pilot. The part is then fed across the cutter using the pilot as a guide or stop. Chamfer depth is controlled by adjusting the cutter up or down.

Another approach is to install a permanent stop or a magnetic device to guide the workpiece--then use a standard chamfer tool (Figure 6). These highly flexible units are convenient, small and relatively inexpensive--plus they operate with air or electric motors.

Gear Deburring Machines

Gear deburring machines employ a variety of approaches. In some cases a rotating chamfering tool or small grinding wheel traverses all tooth edges and chamfers the teeth (Figure 7). In others, a skiving tool is combined with a subsequent brushing action to remove burrs. In still others, a belt sander or grinding wheel grinds surfaces flat (thus removing the hobbing burr); then brushes are used. In some instances parts are placed in a separate cabinet and blasted with steel shot to improve fatigue life and remove any fine or brittle burrs. When burrs are relatively thin, however, just brushing is used. To assure long life, brushes are often rotated in one direction and then reversed.

Figure 1. Small Grinding Wheels
Deburr and Chamfer Top
and Bottom Edges of
Sheet Stock at Feed-
rates up to 60 fpm

For transmission gears, which have several gears attached to a single shaft, brushes frequently will also reciprocate along the axis of the shaft to provide improved action. Low production, standard, off-the-shelf machines are available which can handle 60 parts per hour while special designed or tailored machines can finish up to 400 parts per hour. Many standard off-the-shelf machines can handle a wide variety of gear or sprocket shapes with simple adjustments.

For heavy burrs it is possible to combine a milling operation with the tooth chamfering (Figure 8). Where desired, small brushes can also be combined with a small grinding wheel. This type of machine offers considerable flexibility in that it can accommodate different gear sizes and types such as spur gears, straight bevel gears, spiral bevel, pinions, internal and external gears. Unsymmetrical parts can be finished on some machines equipped with tracer attachment. In some cases even lead screws and racks can be deburred.

Many gears, particularly those used for the watch industry, are being deburred on a gear hobbing machine in order to eliminate a second operation. Small watch pinions are deburred by automatically holding a lathe tool or small disc like cutter against the hob exit side of a part (Figure 9). While it is rotating, the tool shears off the burr. When the part is completely hobbed, it is also free of large burrs. Some machines retract the burr cutting tool several rotations prior to the end of a hobbing cycle. This allows the hob to remove remaining burrs

Figure 2. Pinch Rolls Are Often Used to Remove Burrs From Sheet Stock Ranging From 11 to 24 Gauge

produced by the skiving tool between the teeth. A combination of hydraulic tool feed and spring loading maintains tool contact. Rotating milling cutters are used on larger pinions.

Cutting Tool Hones

Machines are now available with a capability of producing radii up to 0.0016 inch (40 microns) on carbide metal cutting insert tooling. In operation, fixtured carbide inserts are pushed into contact with a silicon carbide impregnated rubber or rubber-like wheel. With proper application this results in a radiused edge and burnished surfaces with no stock loss from surfaces. This semiautomatic equipment is capable of finishing up to 40 pieces per load with a finishing time of 30 to 60 s and a load/unload time of two minutes. Up to 800 pieces per hour have been produced by this type of equipment.

While designed for carbide inserts, the equipment is also applicable for many small parts of similar size provided burrs are tiny and small edge breaks are desired. The radii produced are increased by increasing the pressure between parts and honing wheel. On carbide parts it is possible to achieve an edge finish of 80 μ in. (2 microns).

Another machine designed initially for sharpening dental and surgical instruments is now being used for deburring and

Figure 3. Single Piece End Deburring Cutter Mounted in Abrasive Cutoff Saw Spindle is Used to Finish Ends of Cut-to-Length Tubing. Another Approach Involves the Use of Four Segmented Blades and a Reamer

deflashing miniature piece parts. In this unit a honing stone is placed on a reciprocating carrier and the parts to be sharpened or deburred are held against the stone while it reciprocates. A wide variety of honing stone shapes can be used to match piece part needs.

Special Single Purchase Machines

At least a dozen companies manufacture machines to deburr or deflash a specific part on a production line basis. Some of this equipment, such as centerless brushing machines, will accommodate different parts and some require rearrangement of deburring heads. Some are specifically designed for a single part.

Machines of this general type use some combination of sanding, grinding, cutting, filing, brushing and buffing. In one

Narrow slot for workpieces
of 1.5 mm. at least.

Wide slot for workpieces of more
than 1.5 mm thickness and for
45° chamfers up to 3 mm width.

Figure 4. Edge Finishing Rectangular Parts

KONTUR chamfering-plus-deburring concept shown with pilot cutter for straight and contoured edges.

Figure 5. Edge Finishing on a Table Top Machine

Straight-edge chamfering-plus-deburring cutter
with guide bar for uniform chamfer or radius cutting

Figure 6. Using A Guide Rail on
a Table Top Machine

Figure 7. Universal Gear Deburring Machine

Figure 8. Milling Heavy Burrs Off Large Gear

instance, grinding wheels deflash four different faces of engine blocks. A number of machines deflash hand tools, grind flat surfaces and buff/polish according to customer requirements. These arrangements frequently use rotary automatic transfer design with 20 to 30 stations per machine (Figure 10). Up to 3000 parts per hour can be finished on multiple spindle machines; single spindle machines can finish 200 to 300 parts per hour. Some can rotate a part both clockwise and counterclockwise in order to reach recessed corner areas not otherwise available. While most machines use a single motor to drive all part spindles, machines are available with individual spindle drives.

Machines are available in off-the-shelf sizes of 18 inches (0.46 m) in diameter to 10 feet (3 m) in diameter with 31-foot (9.4 m) diameter machines being built to order. Gears, flat round plates and cylindrical parts are frequently finished with this equipment. Parts are held by collet, vacuum or magnetic chuck or other mechanical means.

Figure 9. Deburring Gears
While They Are
Being Hobbed

In some situations parts reciprocate past a rotating stationary brush. To facilitate deburring finishing heads are frequently located at some angle to the part axis. Some use a cam to rotate irregularly-shaped, pan-like parts in front of finishing heads. In addition to the rotary automatics or semi-automatics, several manufacturers offer straight line systems.

For brushing or sanding operations some machines are designed with dust collector hoods and exhaust ducting. To compensate for tool wear some machines use a spring tension system to allow the brushing head to "float" over the part. Air pressure is often used to bring file segments, grinding wheels or cutters into contact with parts having heavy burrs.

There is considerable diversity in both standard and modular-designed equipment--one company alone has over 50 basic rotary machine designs. The majority of the companies that manufacture the single-purpose machines also provide design services to accommodate most any need.

Mechanized Sanding Units

Over 30 companies offer sanding machines and a number of others produce hand-held units. While sanding equipment is generally well known to U.S. industry, it is significant to note that sanders are basically designed for either edge sanding or flat surface sanding. The latter operation is performed with equipment that typically employs a short conveyor which pulls a part

Figure 10. Rotary Transfer Machine Arrangements for Brushing Operations Include Eight-Spindle Version at Top and Wheel Buffering Technique at Bottom

under the sanding head (Figure 11). In addition to removing all burrs projecting above a surface, these machines clean the surface and, with proper backup rolls, provide a surprisingly large radius on the edges. While most leave a small burr, this latest capability of providing a radius offers significant advantages to many users. The majority of edge finishing sanders require manual part movement although some automated equipment is available.

Brushing Machines

Bench top, pedestal, or stand alone brushing machines are available from at least 25 firms. As with sanding units and special design machines, brushing units vary from a very simple single head to automated multihead units.

Figure 11. Table Top Conveyorized Flat Sanding Machine

While brushing is used by a large number of companies, it is not employed to its full potential. After evaluating the 500 to 600 combinations of brushing type wheels which are available, it is obvious that this is one of the most versatile deburring processes available today. One unique advantage that brushing and buffing have that many other processes do not is that it provides a relatively large radius--it does not produce another burr if used properly.

Trimming Presses

Hydraulic and mechanical trim presses are widely used to remove excess material from drawn parts as well as to deflash die cast parts. In some cases, trimming is performed by mechanized roller cutters rather than by a press. This approach requires less expensive tooling than trim dies. This type of equipment can accommodate stock up to 1/2-inch (12.7 mm) thick at production rates of 50 to 500 parts per hour. Another approach uses vertical press action to hold a part while trimming is performed by a cam actuated lateral movement of the die plate.

Conventional trim presses are not noticeably different from blanking and forming presses at first glance. Those used for die cast parts typically require less tonnage than for press working steel. In many cases a four corner approach is used to guide the ram although some C-frame, open gap, or arch units are available. Some use a rapid feed platen which automatically slows as the tool contacts the workpiece.

To provide rapid action many hydraulic presses use pneumatic over hydraulic actuation. As in most cases, deburring capabilities range from simple models to fully automated machines with a capacity for 100 tons (890 KN) of trimming force. Stroke lengths of 14 to 24 inches (0.36 to 0.61 m) are common. Some units have a shuttle table to move parts into and out of the die area. The platen feed rate into the workpiece varies from 70 to 390 ipm (30 to 166 mm/sec) depending on the machine and the control employed.

Mechanical presses provide 90 to 300 strokes per minute. Part output is in the order of 600 parts per hour; if four parts are held together by gates and runners then up to 2400 parts per hour can be produced. Trim accuracies of 0.005 inch (127 μ m) are claimed for this type of equipment. Several presses, including large and small ones, can be easily equipped with a rotary index table to provide rapid loading/unloading of small parts. Small bench top presses are also available for trimming parts which require 4 tons (35.6 KN) of force or less. When conventional die shearing does not provide adequate edge quality, broaches can be incorporated in a press operation to achieve desired results.

Robots

Some industrial robots can be programmed to deburr parts. While the potential is relatively unlimited, these units are not widely used for this purpose at the present time. It is possible on some machines to insert a live spindle in the "hands" of a robot, and with the use of a rotating bur type tool, to chamfer all edges of a part (Figure 12). Some units can be programmed by manually leading them through a desired path the first time.

Current limitations are primarily associated with high costs which range from \$10,000-\$80,000. While some are capable of maintaining large chamfers, it does not appear that the majority can maintain small radii such as a 0.003 inch (127 μ m) maximum chamfer. Most robots are not designed to produce the precision associated with the latter requirement. Technology is available; however, to produce micro-motion as well as gross movement.

One major advantage is that those with programmable memories can be easily adapted to other configurations or other types of tasks. In addition they can work in dusty, hot, cold, smoky, or other types of environments. The fact that they are automated largely eliminates the problem of missed areas.

Other Types of Mechanized Machines

Some special designs use an opposed spindle arrangement for deburring both sides of small drilled holes. Band saws and fixture trim die cast parts. One machine chips off casting flash with punches and chisels. Plastic parts are deflashed using ultrasonic "hammering." Broaches in conventional broaching machines have also been used to deburr heavy mill burrs. And in some cases, the use of a ballizing machine to force an oversized ball through holes is adequate to remove drill exit burrs.

Some manufacturers have found that existing N/C machines can be used as deburring and/or chamfering machines. They are ideally suited to precision motions and only require an extension of a program. While such use of this equipment is expensive, in many cases it does provide a part finished enough to eliminate all hand work and it eliminates the need for a special purpose deburring machine. In some cases, rather than using a deburring cutter, it is possible to make a high-speed second finishing cut using an end mill. While this does not eliminate the burr, it does remove heavy burrs common with some materials.

When considering N/C machines for precision deburring, it is important to consider the following items:

- All chamfering cutters will provide two new burrs on each edge (they will, however, generally be smaller than the initial burr).

Figure 12. Robotic Arm With Live Spindle for Deburring

- If one has a thick burr but must maintain a small edge break, chamfering may not remove all of the original burr (Figure 13).
- Rotary burrs are designed to be used at high velocities and low forces. Many N/C spindles will not approach the recommended cutting velocities for these tools.
- When deburring and machining are performed on the same setup one has better control or visibility on appropriate tool change times. If dull tools cause too large a burr the burrs will not be removed by machining chamfering.
- Abrasive stones or filled rubber tools generate a large number of fine abrasive particles which can become lodged in collets, holding fixtures, and machine ways.
- Thin flanges may distort during machining to the extent that chamfering tools may not even touch the edges. This possibility is probable when flanges are less than 0.030 inch (0.75 mm) thick and chamfers of 0.003 inch (127.0 μ m) maximum are required.

Figure 13. A 75- μm -Thick Chamfer on a 125 μm -Thick Burr Still Leaves a Noticeable Burr

The use of N/C deburring requires several geometry considerations. Among these are:

- In which planes will the burr exist?
- Which type of tool will fit within the required space?
- Can the edge produced be deburred with a machine having only three axes of movement (Figure 14)?
- Is the cutter geometry compatible with all the contour it must produce?
- On parts having many inches of edges will the cutter be worn before it completes all edges of a single part?

Figure 14. Deburring Feature May Require More Than Three Axes of Machine Motion

- If parts were partially produced in another operation is edge location consistent?
- On small diameter holes does one plunge down to provide a chamfer or should one traverse the profile? (As a result of tool or cutter compensation limitations.)
- Does the number of tools required for deburring exceed the available tool changer capacity? and
- Does combination of small tool size, working space and available spindle speed result in large feedrates per tooth?

ECONOMICS

Technical capabilities and limitations are not the only driving force in prescribing processes. In most industrial settings one must also consider:

- Economics;
- Machine availability;
- Flow times;
- Reliability of hand deburring; and
- Queues.

If one has a part such as shown in Figure 15, requirements for 0.003 or 0.005 inch maximum edge break can be met by N/C, special deburr machines and manual techniques. Assuming that an N/C machine is available and that flow times and queues are not problems it is necessary to evaluate the economics of mechanized deburring.

The following equation provides a reasonable estimate of cost for mechanized or hand deburring. In this equation it is important to note that C_O represents overhead costs for the individual performing the work and C_D includes such factors as machine cost amortized over its life, maintenance, accessories and support devices.

$$\left[C = C_L + C_O + C_D \right] \left[\frac{T_f}{60} + \frac{T_R}{60L} + C_t \right]$$

where:

C = Cost per part (\$)

C_L = Direct labor cost (\$/hr)

C_O = Cost of personal overhead (\$/hr)

C_D = Machine depreciation cost (\$/hr)

C_t = Cutting tool cost (\$)

T_f = Time required for tool feed or travel (min.)

T_R = Time required for tool presetting, replacement and accuracy checkout (min.)

Figure 15. Edges Chamfered on N/C Machine

L = Life of cutter (number of parts)

To illustrate comparative costs assume that data in Table 3 is representative. The values for C_D assume a \$100,000 N/C machining center has a life of 3 shifts, 200 days per year, for ten years. Accessories and related overhead for the machine are assumed to add \$1.00 per operating hour of the machine. Because the tools must be accurately controlled the first part machined after a tool change represents a trial cut. For the part shown it is assumed that a total time of ten minutes is required to make the change and verify the tool adjustment is satisfactory. Under these assumptions deburring costs would \$0.63 per part.

Table 3. Example Data of Deburring Costs

Example Number				
Item	1 N/C Machine	2 Hand Deburr	3 Commercial Rate	4 Gear Deburring
C_L	8.00	8.00	25.00	8.00
C_O	4.00	4.00	0	4.00
C_D	3.00	0.01	0	1.25
C_t	2.00	7.00	0	25.00
T_f	1.0	3.0	1.0	1.0
T_R	10.0	1.0	10.0	5.0
L	15	100	15	600
C	0.63	0.27	0.69	0.26

Hand deburring just the edges numbered in Figure 15 could be completed in three minutes. Because the tool requires no setup accuracy, the setup can be completed in one minute. In addition those performing hand deburring would use a knife and brush rather than the rotary bur. The composite life and cost for these tools would be approximately 100 parts and \$7 respectively. This results in a cost of \$0.27 per part for this deburring.

In this instance normal machining produces a burr too large for mass finishing processes to remove without exceeding the maximum edge break.

As an alternative approach assume that a vendor is machining the part and that he uses a labor rate of \$25 per machine hour which includes all overhead. At this rate the cost of deburring is \$0.69 per part.

From these comparisons it is obvious that hand deburring is the least expensive approach for this part. If, however, the part configuration becomes more complex, edge break requirements drop below 0.003 inch (76.2 μ m), or precision deburring personnel are not available in the necessary quantities, then these economics may not be the driving force. In these later cases there is no choice to be made, the N/C machine is the only viable process.

In actual implementation with edge requirements of 0.005 inch (127.0 μm) maximum or greater, N/C deburring only remains economically competitive on complex parts. Even in these instances N/C deburring would probably only be performed on the more difficult or time consuming features. When edge break requirements approach 0.002 inch (50.8 μm) maximum reliability requires machined edges in many instances.

This analysis of costs has ignored the fact that extra programming time and flow time is required if N/C deburring is used. At the same time any form of deburring on critical parts requires engineering planning or thought if indeed the most consistent and economical approach is to be selected.

Consider now the deburring of the gear as shown in Figure 8. Assume the machine costs \$60,000, has a life of two shifts, 200 days per year for 15 years. Cutting tools cost a total of \$25 and have a life of 600 parts. The deburring cycle requires 60 s, including loading and unloading. For the values shown in example 4 of Table 3 the deburring cost per year is \$0.26.

By using higher automation to provide up to 300 parts per hour for example, costs for this gear deburring could be reduced to roughly \$0.05 per part.

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SPECIAL PROJECTS: Deburring

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