27
1/28/69
T.S.
24071715

MASTER

BDX-613-2382

**Deburring: Technical Capabilities
and Cost-Effective Approaches
Lessons 5 and 6**

By L. K. Gillespie

Published June 1980

Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

**Kansas City
Division**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche \$3.00
 Paper Copy \$6.00

DEBURRING: TECHNICAL CAPABILITIES
AND COST-EFFECTIVE APPROACHES

LESSONS 5 AND 6

By L. K. Gillespie

Published June 1980

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Technical Communications

**Kansas City
Division**

DEBURRING: TECHNICAL CAPABILITIES AND COST-EFFECTIVE APPROACHES,
LESSONS 5 AND 6

BDX-613-2382, Published June 1980

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 5 and 6 describe plantwide approaches to reducing costs and loose abrasive finishing processes respectively.

DC/djb

This report was prepared as an account of work sponsored by the United States Government. Neither the United States, nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, expressed or implied or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

A prime contractor with the United States
Department of Energy under Contract Number
DE-AC04-76-DP00613

Deburring: Technical Capabilities and Cost-Effective Approaches

by LaRoux K. Gillespie

Lesson 5 Plant-Wide Approaches to Reducing Costs

SUMMARY

The effective plant-wide reduction of deburring costs can best be achieved by considering the following factors.

- Determine the people who should be involved in a plant-wide review of deburring.
- Define the approach to be used in a plant-wide review of deburring.
- Provide some form of training for both engineers and production workers.
- Establish in-plant standards for burrs and deburring.
- Understand the capabilities of the available deburring equipment.

The key to plant-wide control of deburring costs lies in considering deburring as integral as drilling or milling to the manufacturing process, in respecting the difficulty that deburring presents, in recognizing those who contribute to the success of deburring operations, and in using the large quantity of data that already exists. Plant-wide control of deburring costs is the difference between 25 years of experience and one year of experience repeated 25 times!

LESSON 5

PLANT-WIDE APPROACHES TO MINIMIZING DEBURRING COSTS

Although most of the techniques described in this book can be implemented by individual engineers and supervisors, effective cost reduction can best be affected by a coordinated plant-wide program. The reason such an approach is needed is because of the complexity of the problem and the need to involve individuals from several departments.

As an example, consider the following aspects of minimizing deburring costs:

- Design to minimize deburring costs;
- Practice burr prevention;
- Minimize burr size; and
- Improve deburring processes.

The design aspect requires input from product designers and draftsmen, and if standards are involved, of inspection and manufacturing. Burr prevention requires nontraditional machining techniques which require input from manufacturing engineers. Minimizing burr size requires input and cooperation from machinists, methods engineers, and manufacturing engineers. Improving deburring processes requires an analysis of existing capabilities and the cooperation of deburring workers. In addition to these already named, machining department foremen, quality control engineers, safety engineers, and production control individuals may also be involved.

Plant-wide approaches to deburring require the:

- Establishment of a basic rationale for controlling costs;
- Coordination of people;
- Evaluation of economics;
- Establishment and enforcement of in-plant standards;
- Development of communication techniques;
- Coordinated analysis of existing knowledge; and
- Basic experimentation.

CHOOSING A BASIC TECHNICAL RATIONALE

Minimizing deburring costs requires:

- A knowledge of what current deburring costs are;
- A knowledge of where the high deburring costs are;
- A knowledge of existing plant standards;
- A knowledge of which plant standards are actually followed;
- A knowledge of burr formation, prevention, and minimization; and
- The establishment of a basic plan or rationale for reducing these costs.

Establishing a plant-wide approach to reducing deburring costs has to begin with a knowledge of what actual deburring costs are. This requires an evaluation of what the total cost is as well as a breakdown of individual cost components. It is easy to overlook some of these factors, but an analysis such as described in Lesson 1 will provide much of the detail required to single out areas on which to concentrate.

An analysis of formal plant standards and actual practice, when combined with the economic evaluation and the concepts of burr prevention and minimization presented in earlier lessons, generally provides enough background to establish a basic rationale or plan for making major improvements.

In some instances the overall rationale used to effect improvements may be to initiate the edict "all parts will be designed so that no deburring will be required." In other cases the rationale may be to purchase more appropriate or faster mechanized deburring processes. In most instances, however, the rationale will probably entail the use of several of the following approaches.

- Design to accommodate burrs,
- Practice burr prevention,
- Control burr size,
- Provide formal burr related training,
- Improve deburring processes,
- Improve in-plant standards,

- Initiate or improve accountability for deburring costs and quality,
- Subcontract deburring operations,
- Improve communications,
- Provide a central source of burr related assistance, and
- Make one individual the ultimate authority on what will be done.

LACK OF KNOWLEDGE ABOUT BURRS

One of the major reasons deburring is still treated as an art rather than a science is that few people know anything about burr properties. The whole subject of burrs and deburring appears to most individuals to be a terribly complex subject (Figure 1). With a little study; however, the picture becomes clearer (Table 1). There are five factors which influence deburring. The material properties and the machining parameters determine the burr properties. The burr properties and the part definition in turn dictate the allowable deburring processes.

With the exception of burrs produced by blanking and piercing, until recently no one had taken a close look at burr properties. The few authors who discussed burr size used only burr height as the feature which identified the burr properties. More recent studies indicate that burr thickness, hardness, and shape at the workpiece surface are more significant properties. In general for most situations, burr height does not have any apparent relationship to burr thickness and only a secondary relationship to difficulty of removal.

Another serious problem is the lack of a generally accepted definition of a burr. To some, a burr is any material extending past a 90° corner. To some "extruded" metal at an edge is a burr, to others it is not. To some a "little burr" is not a burr; to others any burr which does not interfere with the next assembly is not a burr. With no universally accepted definition of a burr, it is not surprising that control of costs can be a problem.

A RATIONAL APPROACH TO REDUCING DEBURRING COSTS

With 132,000 manufacturing plants in the United States spending at least two billion dollars annually to remove burrs, it is obvious that a rational approach is at least desirable, if not desperately needed. The obvious question that comes to mind is, what is a rational approach?

Deburring requirements must be considered before the final decisions are made on the fabrication process and the workpiece geometry and material. Ideally a tentative but detailed machining sequence would first be prepared. Then those individuals responsible for deburring would review these working instructions to determine the optimum deburring approach to suggest changes which would facilitate deburring (Figure 2). The machining instructions would then be finalized; then a final deburring review would be made. Suitable changes would also be made as dictated by the initial manufacturing run.

7

Table 1. Factors Influencing Deburring

Material Properties	Machining Process	Burr Properties	Deburring Processes	Part Definition
Hardness	Type	Hardness	Type	Tolerances
Toughness	Tool Design	Toughness	Cycle Time	Edge Requirement
Thermal Conductivity	Machining Rates	Width	Burr Size	Size
Specific Heat	Coolants	Length	Cost	Geometry
Density	Machining Sequence	Abrasion Resistance	Repeatability	Function
Chemical Composition	Tool Wear	Thermal Conductivity	Lead Time	
Abrasion Resistance	Cost	Chemical Composition	Quantities	
Metallurgical Phase		Specific Heat	Burr Location	
Yield Strength		Mass		
Ultimate Strength		Repeatability		
Melting Point

Figure 2. Processing Event Flow Chart

be answered and then implemented in both the initial and final reviews of work instructions. How many of these questions can the originators of the machining work instructions correctly and satisfactorily answer? What penalty in cost, performance, rejects, safety, and delays does one face if the wrong "guesses" are made?

When a single end mill produces eight different burrs on a single cut, each with a different height, thickness, hardness, and shape, is it reasonable to guess? Is it economical to process parts "the way we've always done it," or is cost reduction important?

Hasty selection of deburring approaches can dramatically change residual stresses, distort parts, change part size, impregnate foreign material, contaminate surfaces, shorten cutter life, cause cracks in welds, and prevent acceptable electroplating adhesion. Many of these occurrences are never attributed to deburring because it is not obvious that deburring is responsible for them.

Table 2. Deburring Check List

-
- What level of deburring quality is needed?
 - Do all edges have to be burr free?
 - How do we define acceptable edge conditions?
 - Do fixtures have relief for burrs and sharp edges?
 - Can we prevent some of the burrs?
 - How can we economically minimize the burrs?
 - Can we change machining sequences to make the burr easier to remove?
 - Can we use the heat treat operation to make the burr brittle?
 - Can we use different cutting tool geometry to make it easier to remove burrs?
 - On what operations can the operator remove these burrs?
 - Can we economically justify the optimum equipment?
 - Can we design special hand deburring tools to speed up the operation?
 - What change in product geometry or material will reduce deburring costs?
 - How much stock will the deburring process remove from the feature of the workpiece? How repeatable is this stock loss?
 - What is the most economical process to remove these burrs?
-

EFFECT OF MANUFACTURING CHOICES

The sequence of cuts and tooling approaches can greatly affect the cost of deburring. A plant-wide emphasis on education can help reduce these unnecessary costs.

Consider Figure 3. This part has five holes, four of which require countersinking or counterboring on the bottom surface. By drilling this part with the "to be countersunk" side down, some deburring of heavy burrs can be saved. The countersinking tool will remove these heavy burrs while countersinking. If the part is drilled with side A down, the heavy burr will have to be removed in a special deburring operation.

Although tubular sieve-like parts normally are drilled or punched from the outside inward, this does not have to be the case. One

Figure 3. Part Orientation for Minimum Deburring

company designed a punch (Figure 4) to pierce outward to put the heavy burrs on the exterior where they can easily be removed.

On small precision gears, it is highly desirable to put the burr on a face which has room for a burr knife. If the burr is allowed to form in the small step where the diameter changes, as shown in Figure 5, it will be extremely difficult to remove the burr without scratching the part.

When holes are drilled and tapped, removing a long rollover burr is often easier after tapping because the tap cuts away the root of the burr.

Although a number of deburring tools can be purchased commercially, special design tools can often save time. Figure 6 illustrates a punch designed to remove the burrs caused by drilling into the 6.35-mm-diameter hole. This punch, which is a piece of drill rod relieved at one end, saves hours of work with conventional knives. The small burrs left by the punch can easily be removed by liquid hone or abrasive flow deburring. Such tools should be considered whenever cross holes are encountered.

Figure 4. Piercing Burrs Placed on Exterior of Tabular Sleeve

A simple sanding block with a slot milled to accept a hub saved hours of deburring time on the aluminum gear shown in Figure 7. If the burr had been produced on the flat surface, such a tool probably would not have been required. On extremely small gears, sanding blocks such as this may not be successful because only a narrow strip of the sandpaper is available to deburr and it quickly wears.

Every year new deburring tools are introduced commercially. As an example, it is now possible to obtain cross hole deburring brushes only 0.032 inch (0.82 mm) in diameter. These brushes are ideal for removing burrs from small threads.

If heavy burrs form in a lathe operation, an extra lathe step of machining off this burr may be much less expensive than using traditional deburring methods. This is frequently true of all heavy burrs--they can be machined off cheaper than deburring.

As indicated in Lesson 4, it can be cheaper to combine the deburring operation with the machining operation than to perform

Figure 5. Identify Desired Burr Location and Use Backup Materials to Minimize Burrs

two separate operations. It is cheaper to do this in the machining cycle than to have an operator pick up, fixture, deburr, and verify an edge. In addition, it eliminates the flow time associated with an extra deburr operation, it is controllable, and it is independent of operator efficiency. Examples of this include brush deburring on screw machines and lathes, touching edges with sandpaper while the part is still chucked on the lathe, and milling off a heavy rollover burr. These steps can be added on lathes, automatic screw machines, and numerical controlled drills and mills.

MACHINIST INFLUENCES ON DEBURRING

Production operators can help minimize burr removal costs. They can deburr parts while their machine is cycling on the next part. Even a partial deburr will save time in subsequent operations. Shops in which deburr operators and machine operators are in separate labor classifications should encourage machine operators to work with deburr operators in deciding when tools should be changed. In many shops, unfortunately, the machine operator could care less about the burr he produces because he is not held accountable for the extra work required to remove gross burrs. It is situations such as this which require plant-wide emphasis by management.

Figure 6. Punch Designed for Deburring Intersecting Holes

STANDARDS

As discussed in Lesson 3, the single most significant factor in minimizing deburring costs is knowing what edge condition is actually required on each edge of a part. The second most significant factor is defining these conditions in such a way that manufacturing engineers, production operators, and inspection personnel know exactly what is allowable. In some industries, it is possible to establish a standard which says, "Deburring not required unless otherwise noted." Unfortunately, for the majority of companies, it is not that easy. Most products require that the majority of edges be burr-free. This requires:

- That in-plant standards of what constitutes burr-free and what edge and corner breaks on radii are allowable be available;
- That cases in which a burr can be permitted be explicitly defined; and
- That exceptions to allowable edge breaks be explicitly defined.

Failure to be explicit will sooner or later result in parts which the designer thinks are bad but by conventional standard are acceptable. As an example, members of the National Screw Machine Products Association have standards which allow small burrs. If deburring or chamfering (to eliminate big burrs) is not specified, it will not be done. Failure to know the standards of a particular industry or to specify requirements explicitly, will sooner or later result in rejected parts. It is significant to

Figure 7. Sanding Block for Gears With Hubs

note that larger companies may need to have general plant standards on burrs, standards specific to given products, standards for burr minimization, and standards (or procedures) for assuring consistent use of deburring equipment.

While design standards of some form are necessary, they may not provide all the information needed by the machinist. If in-process deburring is required, for example, which edges to deburr at what time must be indicated, and if no blanket standard exists, the final edge condition must be specified. Figures 8 through 10 illustrate techniques which have been used. In some cases, the workmanship standard defined the required final edge condition. In others, the standard defined several levels of allowable quality on an individual part. To minimize confusion, specific edge requirements were specified to the production department.

In discussing standards, it is important to recognize the reasons that burrs must be removed or certain edge qualities must be provided. Some of these reasons are:

- To prevent hand injuries;
- To prevent mechanisms from jamming;
- To prevent interference of mating parts;
- To prevent scoring of mating parts;
- To minimize friction;

Figure 8. Shop Instructions on
Deburring Simple Parts

- To reduce wear on mating parts;
- To prevent electrical short circuits from loose burrs;
- To prevent cut wires from sharp burrs;
- To minimize possibility of high voltage breakdown of dielectrics;
- To provide uniform electrical/magnetic fields;
- To minimize the "detuning" of microwave vacuum tubes;
- To prevent metal contamination in aerospace assemblies;
- To prevent miniature filters from being blocked by loose burrs;
- To help assure that rubber seals are not cut;
- To eliminate stress concentrations; and
- To prevent plating build-up on edges.

The subject of standards encompasses several aspects. These include national standards, industry standards, in-plant standards, inter-plant standards, standards on individual products, and nomenclature standards.

There are as indicated elsewhere several national standards relating to such deburring products as blasting or tumbling media. In addition to those mentioned in those publications, the

Figure 9. Shop Instructions on Deburring Complex Parts

Figure 10. Shop Instructions on Allowable Edge Breaks

United States Department of Commerce Handbook H28 which defines screw standards contains some isolated comments about the burr or shape of the first threads on threaded features. A long burr is formed at some of these thread starts and must be removed for any thread to operate properly. ASTM standard D2967 represents a national standard to evaluate edge coverage of coating powders.

The American Metal Stamping Association has published standards relating to burr size or burr conditions on stamped products. The Washer Division of the American Metal Stamping Association has its own standard related to burrs and edge conditions on washers.

Standards for the screw machine industry have been discussed in a previous chapter. Underwriter's Laboratories and the Consumer Product Safety Commission have issued several industry standards or related reports on edge requirements for safety.

INSPECTING FOR BURRS

Determining if burrs are present is in many cases a relatively easy technique, and several pages have been published already on this subject. In other cases, it is not that straight-forward because the relationship between existing standards is not explicit enough to provide adequate information. One approach to solving this on situations in which burrs are of concern is to establish an inspection standard (as opposed to design or workmanship standard) such as the following.

The following technique shall be used to verify that loose burrs are not present on edges:

After ultrasonic cleaning to remove any loose chips or burrs, wipe a small diameter wire over burr-laden edges. If the wire breaks any metal from the burr without scratching the workpiece, loose burrs are present. If no metal particles are broken free, the burrs shall be judged as firmly adhered.

The wire used in this inspection shall consist of 0.022 inch diameter steel spring wire (piano wire) projecting 3/4 to 1 inch from a holder. The end of this wire shall be approximately spherical to prevent scratching. The wire shall be drawn across the edge as opposed to pushed into the edge.

When sharp edges are not acceptable it is possible to use a sharp edge tester developed by Underwriter's Laboratories and is now commercially available. This simple tool uses only adhesive

backed foam and teflon tape to determine if part edges are sharp enough to cut an individual's hands. Over 2500 of these tools are currently in use.

While a special micrometer has been used for measuring burr height in Germany for several years, it is currently not available in the United States. At least one company now manufactures an acoustical die monitor which detects wear on dies and can determine the noise generated when excessively large burrs are produced. This is one of the few instruments available which detects burr size at the instant they are produced.

One company depends on water flow to determine if burrs exist on an edge. In this case, precision holes which must be absolutely burr free are mounted into a container and water is forced through those holes. Any burr on the hole will disrupt the fluid flow on the backside (Figure 11). One can determine if burrs exist on the hole just by visually monitoring the water path.

A related product is commercially available which is used to determine coverage of shop peening. In this situation, prior to shop peening a sample part is coated with a fluorescent tracer die which is removed by peening when one achieves 100 percent peening. If a part has not been totally covered by blasting media, small bits of white will be visible underneath an ultraviolet light. This may be of some benefit to those who must not only look for a complete burr coverage but must verify surface quality as well. It may also be beneficial when one must determine the effectiveness of loose abrasive finishing.

One recent reference indicates that General Motors is using automated laser inspection to check for burrs on threaded nuts. Other references indicate that hypodermic needles are routinely inspected by laser beams to determine if edge quality is adequate. In this instance, the needle defracts the laser light in relation to the sharpness of the needle tip. Hooked or blunt tips or those with burrs would quickly be detected. This system is reportedly capable of performing eight inspections per second. As indicated elsewhere, the testing and reporting of wear of tumbling media is performed in different manners by each media producer. The considerations in developing a significant standard for such tests have recently been reported in an excellent report.

DEBURRING RECORDS

Modern manufacturing requires the establishment of consistent approaches. This normally requires some permanent record of how parts should be machined and finished.

Figure 11. Burr on Hole Disrupts Fluid Flow

To indicate how to deburr parts in-plant one can use brief routing sheet descriptions such as those shown in Figure 12, or more detailed information including illustrations as shown in Figure 13.

One company has a very simple approach for deburring commercial parts. They paint an entire scrap part white and then color code each feature to be deburred. Each different color code indicates a different type of deburring tool. As an example, in Figure 14 one would first flat sand the surface around hole number 1 and then use an MX wheel in an air motor. In this case, the sequence of color code also indicates the sequence with which one performs the work. The color band closest to the edge indicates the first operation, while that farthest from the edge indicates the last operation to be performed. While this technique does not indicate the required edge break, or the exact tool to use, it represents a color-coded scheme which a new worker can quickly go to when he has doubts. One advantage of this approach is that it requires no paperwork but it does require a storage facility to store all the sample parts.

Figure 15 illustrates another simple approach for designating which edges to finish, the allowable edge break, and the technique which should be used.

Table 3 is a FINISHING PROCESS SHEET, on which the mass finishing cycle is developed, proven, accepted, and finally signed by the

PRODUCTION TRAVELER

GUIDE, LONG RETAINER BAR

M. ACKMANN

93

262169-101

9A

8-27-74

Opr.	Dept.	Type of Opr.	Hrs/Part
50	93	Z902	3.175

Remove heavy burr in square hole and (2) c'bored holes in preparation for vibratory deburring. Brush polishing not required.

REQUIREMENTS LIST:

Kit 48002259

Figure 12. Sample of Basic Production Routing Sheet
Instructions to Those Performing Deburring

DEPARTMENT 1360		SET-UP AND WORKSHEET				PART: 6807	
DATE: 4-28-80						SHEET 1 OF 2	
	SEQ.	WORK AND SET-UP DESCRIPTION	STAT	TOOL AND TOOL NO.	S. U.	PCS/HR
30	WORK AND SET-UP DESCRIPTION APPLY WHATEVER DESIGNATED TOOL NEEDED TO STRAIGHTEN PART IF NECESSARY. WHEN USING ARBOR PRESS INSERT FIBER STRIP INTO CHANNEL. SHEARBLOCK HAS TO BE SQUARE TO CHANNEL WITHIN ± 0.003	3-1	SPREADERS FIBER-STRIP MALLET, ARBOR PRESS		30
50	REMOVE ALL SHEARBLOCK BURRS ON WIRE WHEEL. HOLD EDGE TO BE DEBURRED AT 45° ANGLE TO WIRE WHEEL AND MOVE PART ENTIRE BURR SIDE. ATTENTION: DO NOT PUT RADIUS ON SHEARBLOCK AREA MARKED X	1-11	NOT TOOLING REQUIRED		120
PULLEY HOLDER	70	PUT PULLEY (6647) INTO CHANNEL WITH PULLEY HOLDER (HAND MADE). DROP RIVET (6848) INTO HOLE. REPEAT SAME WITH SECOND HOLE. LAY THIS ASSEMBLY INTO FIXTURE (T-4188) PEEN END OF RIVET FACING YOU AND RIVET FLUSH WITH CHANNEL.	21-10	RIVETING FIXT. T-4188 RIVETING PUNCH T-4188-1			

Figure 13. Sample of Detailed Deburring Instructions

<u>HOLE NUMBER</u>	<u>COLOR BAND</u>	<u>HAND DEBURRING APPROACH</u>
1	RED	FLAT SAND
1	GREEN	MX WHEEL IN AIR MOTOR
2	BLUE	SWIVEL BLADE KNIFE
2	BLACK	TRIANGULAR KNIFE
2	GRAY	ABRASIVE FILLED RUBBER IN MOTOR
3	RED	FLAT SAND
4	NONE	NONE

Figure 14. Example of Color Coded Deburring Guide

CODE	INSTRUCTION
1	DEBURR A BREAK EDGE 381 TO 635 μm (0.015 TO 0.025 IN.) RADIUS
2	DEBURR A BREAK EDGE 127 TO 254 μm (0.005 TO 0.010 IN.) RADIUS
3	DEBURR A BREAK EDGE 127 μm (0.005 IN.) MAX RADIUS
4	DEBURR A BREAK EDGE 50.8/76.2 μm (0.002/0.003 IN.) RADIUS
5	DEBURR A BREAK EDGE 50.8 μm (0.002 IN.) MAX RADIUS
11	REMOVE HEAVY BURR ONLY
12	REMOVE FEATHER EDGE
13	CHAMFER FIRST AND LAST THREAD
A	BURR KNIFE
B	WIRE BRUSH
C	NYLON BRUSH WITH AL_2O_3
D	240 GRIT PAPER
E	STRING BRUSH WITH AL_2O_3
G	FILE
J	CRATEX "BULLET"
S	BURR BALL

Figure 15. Example of Shop Instructions for Edge Requirements

Table 3. Finishing Process Sheet

FINISHING PROCESS SHEET

CUSTOMER'S NAME _____ OUR JOB NO. _____
 PART NAME _____ PART NO. _____
 PCS/CYCLE _____ MATERIAL _____
 RESULTS DESIRED _____

PROCESSING DATA	OPERATION NO. 1	OPERATION NO. 2	OPERATION NO. 3
MACHINE NO.			
WORKLOAD - NO. PCS.			
AMT. TYPE & SIZE MEDIA			
AMT. & TYPE OF COMP.			
AMOUNT OF WATER			
ANGLE, WEIGHTS, ROTATION			
TIME CYCLE REQUIRED			

ADDITIONAL OPERATIONS OR PROCEDURES: _____

SPECIAL HANDLING: _____

SEPARATION _____ SCREEN SIZE _____

PROCESSED BY _____ DATE _____

APPROVED BY _____ DATE _____

responsible engineer. Theoretically, with this process the plant can achieve the same production results on the second shift, or six months from now, with any operator. Almost every plant depends on a record such as this to assure consistency.

The most important feature of this FINISHING PROCESS SHEET is the clear, concise and realistic RESULTS DESIRED. Very often, the instructions to the operator consist of one word: "deburr," "tumble," "vibrate" or the trade name of the deburring equipment, media, or compound. These leave the production deburring requirements up to sometimes questionable interpretation, often to variable results, and more frequently to scrap, salvage, or

reclamation costs. Much time and thought is devoted to specify what actually is required, in terms of radius, surface, texture, dimension or approved samples, and print or process notation. Reference to photographs or approved samples must be readily available for comparison and guidance.

Table 4 is a PROCESS WORK SHEET, used by the production engineer, or the industrial engineer, on the initial production cost and production planning phase of the deburring problem. This information is also required to develop initial quotations, and as a basis of re-evaluation when production requirements change or when new processes become available.

Table 5 is the back side of the PROCESS WORK SHEET, on which the details of the operation are entered--material, labor and machine costs--to develop the bottom line cost for each product. The detail and comprehensive data included are proportional to the relative costs involved and repeatability desired.

THE USE OF EXISTING KNOWLEDGE

Since 1974 major advances have occurred in our knowledge of appropriate deburring solutions. Despite these advances, however, it is relatively obvious that there are still some major problems in using what is already known. There is today within the world some 36,000 pages of information on burrs, deburring, deburring equipment, processes, burr prevention, and related facts. Despite this tremendous amount of knowledge, which is readily available, it is obvious that many potential users are either not aware that it exists or have some problem in implementing the suggested solutions.

From a close examination of the situation it is obvious that a number of concentrated sources of information are available. Many of these are described in the texts Deburring Capabilities and Limitations and Advances in Deburring. Reviewing those books reveals that information sources can be categorized at least into the following subdivisions:

- Books;
- Magazines;
- Manufacturers brochures;
- Manufacturers newsletters;
- Films;
- Videotapes;

Table 4. Process Work Sheet

PROCESS WORK SHEET	DATE
CUSTOMER'S P. O. NO.	OUR
Name	Job #
Address	Order #
City, State	Approved By
Contact	
Phone Number	Processed By
	Completed By
Part Number	Inspected By
Part Name	Weight-Count
Quantity	Quantity
Weight	Weight
Wt/cu. ft.	Wt/cu. ft.
Parts/cu. ft.	
	Lead Angle degrees
Machine Model	Weights
Work-load, pieces	Rotation RPM
Media Type & Amount	Weight
	& Type

Results desired, special instructions and sketch of part:

- Seminars;
- Conferences;
- Workshops;
- Technical Reports;
- One-on-one discussions; and
- Formal training programs.

While an indepth analysis of materials available in each of these categories is beyond the scope of this lesson, some of the more comprehensive sources are listed in the reference section of this lesson.

It is appropriate to explore further why more deburring information is not used. The following list provides some known and suspected reasons that the existing written technology has not been assimilated as best it could.

Table 5. Back Half of Finishing Process Sheet

Job Order No. _____								
	MATERIAL			LABOR			MACHINE	
	COMPOUND	COST	EXTENSION	TIME	COST	EXTENSION	TIME	= COST/HR.
Load								
Operation §								
Debur Rinse Neutralize Rinse								
Operation §								
Debur Inhibit Rinse								
Operation §								
Debur Inhibit Rinse								
Unload								
Separate Manually Mechanically								
Screen Size								
Change Media								
Dry - Load Process Unload								
Totals								
_____ Lbs. Compound Cost \$ _____ Lb. \$ _____								
_____ /Hrs. Labor Time x Cost \$ _____ /hr. \$ _____								
_____ Hrs. Machine Time x Cost \$ _____ /hr. \$ _____								
_____ Hrs. Machine Time x Media Wear Rate, _____ lb./hr. x _____ \$/lb. \$ _____								
Totals Job Cost \$ _____								
Unit Cost \$ _____								

- Personnel responsible for deburring at engineering levels are constantly changing.
- There is little specialized in-depth training for deburring.
- There is an implied assumption that deburring does not require a high level of intelligence.
- Users expect ready made answers to be available in the written literature.
- Published literature is pitched to too low an intelligence for those who need the information.

- The published literature is lacking specific facts (it deals with concepts rather than details).
- There is no truly unbiased source of factual (quantitative) deburring information.
- There is no long term commitment by company management to improve deburring.
- We do not apply the best approaches for solving deburring problems.
- We are not willing to have translations made of foreign literature.
- We do not feel we have the time to become knowledgeable about deburring.

To become truly proficient at solving deburring problems in a medium or large sized company requires several years of study and daily experience. Transferring individuals in and out of such responsibility on a six month or yearly basis will not provide the necessary training and experience to allow one to quickly or completely solve deburring problems.

The question has been asked several times, "What kind of training is best for solving deburring problems?" There is, of course, no single solution or answer to that question because every company has different needs and capabilities. It should be noted; however, that four individuals at least have received Doctor of Philosophy university degrees in some facet of burrs or deburring and more are expected in the future. The formation of burrs and removal by many processes is a mathematically highly complex subject.

It does not take such high levels of study; however, to be able to solve practical on-the-shop-floor problems for specific parts. It does; however, take a commitment, a knowledge of existing in-house facilities, and capabilities outside a given plant. In addition, it requires an ability to categorize facts and assimilate them for later retrieval.

For some reason, it is common experience to expect an individual to quickly solve a deburring problem or to quickly select the appropriate process which will work. At the same time when one is given a part to manufacture, it is not unreasonable to expect to wait days before one develops an in-depth manufacturing process to produce the basic shape. We have all too often arbitrarily put constraints upon solutions to deburring that require immediate short term fixes. What we should be doing is

developing a rationale for solving deburring problems so that they can be prevented not only months but years ahead of time.

As an example of a rational approach to solving deburring problems, consider Figures 16 and 17. The geometry and dimensions of the part are used to categorize families of parts so that solutions can be made for families of parts very quickly and readily. This same approach generally classified as 'group technology' is necessary in deburring before many of the deburring problems are solved expeditiously. The key to success with this approach is in categorizing all the features which influence the choice of deburring processes.

DEBURRING TEAMS: AN ORGANIZATIONAL APPROACH TO PLANT WIDE CONTROL

Any company can save money through the efforts of a single individual; however, if the objective of a deburring program is to eliminate all unnecessary burr-related costs, the advantages and disadvantages of all of the following approaches should be considered:

- The lone innovator;
- The engineering team;
- The plant-wide team; and
- Plant-wide emphasis on individual improvements.

These approaches are illustrated by the matrix shown in Figure 18. As indicated, plant-wide emphasis can be on the basis of either individual or group contributions.

The Lone Innovator

As shown in Table 6, utilization of the lone engineering innovator has several advantages and disadvantages. Its greatest advantage is that it doesn't preempt the time of a group of people that are needed for other projects. Also, it doesn't result in standoffs or weak, ineffective solutions because of disagreement between committee members, nor does it require the time necessary to fully educate a team.

In contrast to the stated advantages, a lone-innovator's optimism or biases, if not realistic, may totally nullify the potential benefits. In addition, if he leaves the company, all of the knowledge that has been gained will be lost. Furthermore, a representative of only one group within a manufacturing company often has difficulty in obtaining full support from the other groups that are required to help implement the necessary

	0	1	2	3	4	5	6	7	8	9
0
1
2
3
4
5
6
7
8
9

Figure 16. Classification of Parts by Shape

solutions. In many instances, the involvement of only one individual requires longer implementation time since he alone must do all of the work.

The Engineering Team

In some cases, an engineering review team has been established to evaluate all designs and processes. Its assignment consists of the following four actions.

1. Review current practice and procedures to understand what actually happens to parts being deburred as opposed to what the specifications indicate is supposed to happen.
2. Commit to paper the procedures that should be used and the standards by which inspection personnel will monitor the burrs.
3. Pursue one of the following three approaches:
 - a. Obtain time-study records for every part and review first those representing parts having the more expensive deburring operations;

Figure 17. Characteristics of Parts Requiring Consideration in Deburring and Group Technology

- b. Pursue solutions for the parts causing problems (although some parts require a long time for deburring, they represent no particular problem); or
 - c. Quickly review all parts, attempt to categorize them into families of shapes, and then pursue solutions for entire families of parts.
4. Prepare a procedure to assure that all future parts are reviewed for deburring equally well.

Although these four basic steps appear to be straightforward, conceiving and implementing the improvements are difficult. People are required who have a strong desire to minimize costs, who have a sound knowledge of the capabilities of all deburring

	ENGINEERING INPUT	PLANT-WIDE INPUT
INDIVIDUAL ACTION	LONE INNOVATOR	EVERYONE OFFERS SUGGESTIONS
TEAM ACTION	ALL ENGINEERS EVALUATE DESIGNS AND PROCESSES	COMPOSITE TEAM REVIEWS DESIGNS IN WORK AND IN PLANNING

Figure 18. Approaches to Plant-Wide Reduction of Deburring Costs

processes, who can develop inexpensive tools, and who can listen to and work closely with all workers concerned with deburring. The success of the endeavor depends upon finding a realistic solution to Action 2.

Consider for a moment whether you ever have had to tell someone exactly how to determine whether a burr is "loose." Is there a difference between a "burr" and "raised metal?" How large a burr is acceptable? How are burrs to be measured? When should an operator change tools? How does an operator know when a burr is too thick? How does he measure it? No truly optimized deburring program can exist within a plant until these questions have been answered.

The fact should be noted that often there is a difference between a difficult deburring job and a job that consumes a large amount of time; the difficult job is one in which special care must be exercised. Such jobs, producing operator fatigue and frustration, frequently result in high scrap rates, morale problems, and long cycle times. These attitudes and results may carry over into less-difficult deburring assignments.

Frequently, the engineering teams consist of all engineers that are responsible for the design of parts and the selection of

Table 6. Advantages and Disadvantages of the Lone-Innovator Approach

Advantages	Disadvantages
It doesn't preempt the time of a group of people.	Conclusions are often the result of individual biases.
There are no committee standoffs.	If the innovator leaves the company, all knowledge gained is lost.
It doesn't require educating the individuals on a team.	The innovator may not have the necessary authority or the full cooperation of all affected departments such as production, inspection, and engineering.
	Innovator must be carefully selected to assure positive results.
	An individual typically requires longer to implement all required changes than does a multidiscipline team.
	Solutions often are not as imaginative or effective as those developed by a team.

manufacturing processes. As a result, the individuals who must make the changes have a voice in deciding what changes are needed. Typically, this approach makes easier the acceptance of the desired changes. Table 7 lists some of its other advantages and disadvantages.

In many companies, there is an unwritten policy that each manufacturing engineer is responsible for selecting all of the optimum processes for the parts to which he is assigned. While the desirability of having a large group of individuals familiar with the mechanics of all processes is obvious, sooner or later some of the members will lose the state-of-the-art knowledge that is required to guarantee the lowest deburring cost.

The Composite Team

Some of the companies which have been more successful in eliminating deburring costs have established a review team with

Table 7. Advantages and Disadvantages of the Engineering-Team Approach

Advantages	Disadvantages
It provides multiple viewpoints for all considerations.	Team members are required to defer other tasks.
The work can be divided among the group.	Persons responsible for making or inspecting parts are not involved.
Individuals who are responsible for changing the designs are involved.	A group of people who may have little interest in the problem must be educated.
It provides an engineering approach to a plant-wide problem.	

members from the production, inspection, and engineering departments.

This team approaches problems in much the same manner as the engineering team with the added advantage that all facets of manufacturing have a voice in the decisions that are made. This type of approach reduces the reluctance to accept changes, and it offers the assurance that all members are familiar with the impact which the changes will have on the day-to-day mechanics of performing the work. Too often, those who are not involved with the performance of the work overlook some major problems in incorporating the changes. Often, this approach will identify some of the labor and personality problems that can nullify any new solutions before they have been given a reasonable opportunity to succeed.

The composite team does not have to consist of a balanced membership; it can be composed primarily of engineers or of shop foremen. The essential requirement is that all three phases of manufacturing be given an equal voice in adopting the solutions. Table 8 lists some of the advantages and disadvantages of this approach.

The "Everyone Contribute" Team

Because deburring is essentially a plant-wide problem, a logical approach consists of asking everyone involved to help improve the

Table 8. Advantages and Disadvantages of the Composite-Team Approach

Advantages	Disadvantages
All elements of manufacturing are represented.	The time of several individuals is required.
Personnel problems which impede success are often identified.	
A large working task force is made available.	
It provides a fully coordinated approach.	

situation. If each one contributes solutions as he encounters problems, many of the problems will be short-lived. Workers in the shop often have problem-solving ideas which are not tried for one or more of the following reasons.

- It's not my responsibility,
- I don't know with whom to discuss it,
- I don't have authority to make the change,
- Problem-solving is not included in my job classification,
- Who cares?, and
- I don't know how to obtain the needed equipment.

Plant-wide recognition (publicity, remuneration, or both) of those who make suggestions which result in the adoption of significant improvements is a common method for overcoming some of the deterrents to individual innovation. This method may consist of an official, plant-wide program to improve productivity in general, or a program devoted exclusively to improvements in the field of deburring.

The major advantages of the "Everyone Contribute" approach are that it often involves many more people than the other approaches, and it includes the individuals who do the work and who therefore, are familiar with the problem.

As shown in Table 9, this approach has some disadvantages, the greatest of which is that it does not provide a coordinated solution for the problem. The fact should be noted; however, that many of the ideas for minimizing deburring costs have been proposed by production operators. Unfortunately, these individuals seldom receive their deserved share of recognition.

Multiple Teams and Approaches

Thus far, this discussion has pertained only to the concept of using a single team; this however, does not have to be the case. From the standpoint of assuring that the more effective deburring procedures are employed, the ideal situation would be to have at least one individual continuously investigating solutions to deburring problems while a composite team composed of members from the inspection, engineering, and production departments establishes a review of all current designs and practices in order to implement timely plant-wide solutions. While this team would initiate conceptual needs and perform a portion of the review, most of the work would be performed by the engineering team. At the conclusion of the review, and after all changes had been implemented, a plant-wide cost-savings program with special emphasis on the savings to be realized from deburring could be implemented. The lone innovator could work with the individuals who offer suggestions to assure full acceptance of worthy ideas. He also could monitor the new designs and processes that are adopted after the review team has been disbanded.

The following advantages are offered by this total approach:

- Everyone concerned is involved;
- Implementation of changes is accomplished in a short time;
- The advantages of all approaches are combined;
- The concern of management for an often-overlooked area is emphasized; and
- One key individual is always used to coordinate new ideas.

Up to this point, this discussion has assumed that engineers have the primary role in the effort to reduce deburring costs; quite often, this is not the case. The lone innovator can be anyone in the matrix shown in Figure 19. In many shops, a deburring foreman is responsible for reviewing drawings and processes, as well as for experimenting with new approaches. In others, the inspection group has the major role in determining what is allowed. In a few companies, the deburring workers have sufficient knowledge, interest, and fortitude to assume the total responsibility.

Table 9. Advantages and Disadvantages of the "Everyone Contribute" Team

Advantages	Disadvantages
Individuals who do the work and are familiar with the need are involved.	The development of a coordinated plant-wide philosophy regarding burrs is difficult.
Everyone, rather than only a small team, is involved.	Special incentives are required to bring forth suggestions.
	Individuals who are closely involved in the problem often are unaware of the wide range of solutions that are available or that have been tried in other industries.
	Personnel who are responsible for changing designs and processes are not immediately involved.

In large shops, non-engineers often have difficulty in assuming an effective role because the piece-part production areas are far removed from the assembly areas. In cases such as this, the piece-part foreman may never know the actual edge requirements of the assembly.

One company solved this problem by moving an aggressive assembly foreman to the deburring department. Having had several years of experience with assembly problems and requirements, this individual, through a strong desire to eliminate wasted effort, saved the company several thousands of dollars and quickly eliminated a nine-month deburring backlog.

In the formation of a team, the inclusion of someone who knows absolutely nothing about burrs but who is not afraid to learn may be advisable. This individual may be free of many of the biases which prevent more experienced people from arriving at obvious solutions.

In other cases, a consultant may be employed as a member of the team. His experience can help to eliminate many of the ineffective measures that an inexperienced group may attempt.

ENGINEER	FOREMAN
QUALITY REPRESENTATIVE	PRODUCTION WORKER

Figure 19. Types of Individuals Having Key Responsibilities for Solving Burr Related Problems

PERSONNEL PROBLEMS

Personnel problems that a company will encounter in its efforts to reduce deburring costs will embrace the attitudes of the individual toward the following aspects of the program:

- Deburring;
- Other people;
- Change; and
- Data and formulas.

Attitudes Toward Deburring

Throughout industry, deburring has an undeservedly poor image. Often, it is thought of as a repair job or a white elephant rather than an integral part of the manufacturing process which adds value to the workpiece. Because much deburring is performed with simple tools and machines, it frequently is considered a mundane task that can be easily mastered by anyone. Management has helped to perpetuate this image by utilizing the lowest-paid workers, by purchasing the lowest-cost rather than the most functional equipment, by placing the deburring benches in a corner where no one will see them, and by failing to provide engineering and management support for the deburring processes.

As a result of these attitudes, few engineers want to be associated with deburring activities. Engineers that have deburring responsibilities are faced with a difficult job that requires a

sophisticated understanding of the plasticity of materials, and a thorough knowledge of the techniques for producing electrical, chemical, thermal, and mechanical erosion. They must interface daily with shop, management, and engineering people who may neither appreciate nor understand the factors involved. In many companies, high labor-turnover rates in the deburring departments further complicate efforts to implement improvements.

Engineers, like most other people, are hesitant about entering an unfamiliar field of work. Until recently, little useful information has been available on deburring. Traditionally, deburring has been considered a necessary evil which interferes with production and causes great annoyance.

As a part of the total program, any plant-wide improvement effort should include an investigation to determine the deburring image within the facility. The following obvious corrections should be employed to improve a poor image:

- Emphasize the fact that deburring is a challenging job;
- Demonstrate that management is willing to support changes;
- See that funds are made available for buying needed equipment;
- Provide recognition for individuals who make improvements;
- Request the assistance of everyone in minimizing deburring problems;
- Provide well-lighted worktables, microscopes, and any special hand tools required to do efficient work; and
- Provide remuneration that is commensurate with work efficiency and quality.

Attitudes Toward Other People

As one speaker recently noted, "People are not like a good piece of steel--they vary considerably." The greatest single personnel factor which must be solved is assuring responsiveness to the needs of the deburring worker and his foreman. This often requires "looking at" a situation through the eyes of the worker who has little contact with the available knowledge on deburring.

Attitudes Toward Change

Unfortunately, many individuals resist change. High deburring costs may well be the result of the wrong person being in charge

of deburring. The field is changing rapidly, and there is no place for those who do not believe in change.

Attitudes Toward Data and Formulas

Many vendors of equipment believe that deburring and edge-finishing is unique for each part and that quantitative data in this field are therefore meaningless. Unfortunately, inspection and assembly departments have a different viewpoint; they must have quantitative knowledge about part edges. As a result, some quantitative data on deburring capabilities have been recently published. Unfortunately, such data are not yet available in most industries for indicating the edge conditions that can be tolerated. Each company, therefore, must establish its own criteria for determining acceptable and nonacceptable burrs, thus creating the requirement for quantitative measurements. This, in turn, will produce some comments to the effect, "We never used to need data."

Once the data are available, they must be put in a format that can be easily used by the shop. This also is true of data defining in-plant equipment capabilities.

Many nongraduate engineers, production workers, and foremen are uncomfortable in working with mathematical formulas. Apparently, they are afraid that they will make a serious mistake that will reflect upon their ability. As a result, to be effective, data either must be put into graphs and charts, or these individuals must be trained to manipulate equations.

Start-Up Problems

Whenever new deburring processes are implemented or new deburring techniques are introduced, some mistakes will be made and rejection rates will temporarily increase. These problems also will temporarily increase the resistance to both change and the acceptance of new ideas. This situation, however, certainly is not unique to deburring. The following comment was made by Thomas Edison.

. . . Remember on the average, it takes seven years for men to accept a different proven solution to a problem. . .

Each time there is a layoff of workers, similar problems occur. After a layoff, part quality suffers because new people become involved in the deburring and inspection operations. Often, these individuals have not received any training in the finer aspects of their assigned jobs.

EQUIPMENT AND SUPPLIES

The following four aspects of obtaining equipment and supplies must be considered by every company:

- Determining what equipment is available to do the job;
- Determining the relative merits of the available equipment;
- Justifying the purchase of the equipment; and
- Anticipating changes in requirements.

As previously mentioned, a guide has been published which describes the equipment, supplies, and services produced by over 400 companies. This guide essentially solves the first aspect listed.

Evaluating the relative merits of various types of similar equipment is always a difficult task. Although there is no published item-by-item comparison of equipment features, noteworthy check-lists for comparing some deburring equipment has been developed.

Justifying the purchase of new equipment always seems to be more difficult for finishing processes than for machining operations. Some of the reasons and solutions for this dilemma have been previously described. One of the key measures of the need, however, is a comparison of annual expenditures by all industries. As indicated elsewhere, the capital-equipment funds that are allocated annually for cleaning and finishing equipment typically range from only 5 to 10 percent of all capital-equipment expenditures.

While equipment often is purchased with the intent of refining its capabilities, the purchase of a turn-key operation is typically much safer. There are a number of subtleties in all finishing processes which are a deterrent to many proposed improvements. In addition, the purchase of a turn-key operation eliminates the man-hours and flow time that are required for development.

Deburring concepts and equipment are changing rapidly. As a result, companies should expect to periodically review equipment needs and to replace equipment that may not be worn-out.

JOB SHOP USE

In many instances using a commercial deburring facility can help reduce burr related costs. While companies which have their own deburring facility tend to overlook this source of assistance, it is important to at least consider the following advantages of these job shops:

- No company investment in equipment is required.
- The job shop can provide immediate service.
- The job shop can act as a temporary part storage area.
- The job shop eliminates the in-house dirt and mess associated with some deburring.
- The job shop provides immediate visibility of deburring costs.
- The job shop can serve as a periodic evaluation of in-house shortcomings.
- The job shop can act as an overload area for deburring.
- The job shop can provide a means to continue production when plant catastrophes or OSHA and EPA citations close areas of a plant.
- The job shop also acts as a consultant to assist on in-house problems.

Deburring shops are often asked to evaluate and update existing production cycles and to adjust existing in-plant equipment to achieve optimum production. They may also help to establish new product deburring processes, assist or suggest new plant or departmental equipment layout and material flow, and to train the production plant's deburring equipment operator, in-plant or in the deburring shop.

Some shops find that they are getting deburring work merely as a periodic evaluation of the production plant's existing deburring costs or techniques. Or, it may be because such plants have an inexperienced part-time or underpaid deburring equipment operator, or because, considering the value or importance of the work, they have generated a salvage or reclamation problem. In addition, it may be caused by an inexperienced operator using the wrong media size or composition.

The deburring job shop also handles the metal finishing end of production while a new plant is being equipped or started up. Some have handled the total deburring work from new plants some distance away for several months while their "more pressing problems" were solved.

Some have also handled the deburring work of an established plant which suffered fire, accident or other catastrophe. They have received several truckloads of work-in process salvaged from burned-out plants, primarily to remove foam, chemicals, roofing tar, mud or oxidation from the parts.

In those instances where a production plant has a confrontation with OSHA, EPA, or other regulatory agencies, which sometimes closes a department or a section of the plant until the cause for the citation is corrected, some have provided for continued production by performing the deburring work in the job shop.

Job shop deburring does have some disadvantages:

- Lack of a true quality control center--Most job shops do not even have a micrometer or microscope to verify the work. Some do not keep records on how to duplicate an order on its next arrival. If one has critical parts that are just within the low tolerance, the vendor must be notified. Thickness controls and finishes should also be noted on purchase orders.
- Immediate response to high priority jobs--Getting the vendor to work during late hours or emergency programs is difficult. Few job shops will respond to "hot" orders. Look for a deburring vendor that offers 24-hour service and is open those 24 hours.
- Loss of parts--The mass tumbling process is an easy process to lose parts. Separation of parts and media is difficult. The smaller the part the greater the risk of loss. Hold vendors responsible for losses. This will keep separation methods honest.
- Rarely are the non-mechanical or recently defined "non-conventional" deburring approaches justified in the commercial deburring job shop. The owner cannot hope to justify many of the 37 proven and established deburring methods. The vendor will generally have the "conventional" tumbling barrels, vibrators, burnishers, washers, and drying equipment which provide production type and odd-lot flexibility. Specialized or fully automated equipment is often easier to justify in a captive department with established product lines.

VALUE ENGINEERING

From the discussion thus far, it should be obvious that much of the effort for plant-wide control of deburring is actually a form of VALUE ENGINEERING. The effort involves making the following value judgments on burrs, deburring, and edge conditions.

- What is it?
- What does it do?

- What does it cost?
- What is it worth?
- What else will perform the function?
- What does that cost?

REFERENCES

- ¹L. K. Gillespie, editor, Deburring Capabilities and Limitations, Dearborn, Michigan: Society of Manufacturing Engineers, 1976.
- ²L. K. Gillespie, editor, Advances in Deburring, Dearborn, Michigan: Society of Manufacturing Engineers, 1978.
- ³Mass Finishing, Metal Finishing Suppliers Association, Birmingham, Michigan, 1975.
- ⁴L. K. Gillespie, A Guide to Deburring, Deflashing, and Trimming Equipment, Supplies and Services, SME Report (no number), 1976.
- ⁵H. J. Plaster, Blast Cleaning and Allied Processes, Volumes I and II, Letchworth, Hertfordshire, England, Garden City Press, Ltd., 1972.
- ⁶James A. Murphy (Editor), Surface Preparation and Finishes for Metals, McGraw Hill, New York, 1971.
- ⁷Brian F. Blundel, An Introduction to Industrial Finishing Equipment, Pergamon Press, New York, 1971.
- ⁸L. K. Gillespie, Deburring--An Annotated Bibliography, SME Bibliography Series, 1974.
- ⁹L. K. Gillespie, Deburring--An Annotated Bibliography, Volume II, SME Paper MRR75-04, 1975.
- ¹⁰L. K. Gillespie, Deburring--An Annotated Bibliography, Volume III, SME Paper MRR76-07, 1976.
- ¹¹L. K. Gillespie, Deburring--An Annotated Bibliography, Volume IV, SME Paper MRR77-04, 1977.
- ¹²L. K. Gillespie, Deburring--An Annotated Bibliography, Volume V, SME Paper MRR78-07, 1978.
- ¹³L. K. Gillespie, Deburring--An Annotated Bibliography, Volume VI, SME Paper MRR79-05, 1979.
- ¹⁴L. K. Gillespie, Effects of Deburring Contaminants on Electroplating Adhesion, Bendix Kansas City: BDX-613-1757, April, 1977, (Available from NTIS).

¹⁵Guide to Deburring of Machined Components, Part IV--Power Tools, Production Engineering Research Association Report #45, England, circa 1958.

¹⁶Guide to Deburring of Machined Components, Part II--Manual and Chemical Deburring, Production Engineering Research Association Report #35, England, circa 1958.

¹⁷Tom Drozda, "Deburring: The Common Cold of Industry," Production, November, 1977, pp. 62-75.

¹⁸L. K. Gillespie, Economic Tradeoffs in Deburring (Topical Report). Bendix Kansas City: BDX-613-1620, September, 1976 (Available from NTIS). Also published as SME Paper MRR76-17, 1976.

¹⁹F. Schafer, Entgraten, Krausskopf, Mainz, West Germany, 1975 (in German).

²⁰P. K. Clarke, "What Comes After the Make or Buy Decision," Machine and Tool Blue Book, October, 1966. pp. 106-109.

Deburring: Technical Capabilities and Cost-Effective Approaches

by LaRoux K. Gillespie

Lesson 6 Loose Abrasive Finishing Processes

SUMMARY

The loose abrasive finishing processes are the most widely used deburring processes in the world. They are simple, easy to change, adaptable to almost all metals and part shapes. They typically will not deburr internal features or small cutouts. The economies of these processes are relatively easy to calculate provided conditions are known which in fact will remove the burr satisfactorily. Despite their simplicity, there are a large number of facets to these processes which are not immediately obvious. For versatility and efficiency users should become familiar with the major publications on these processes.

LESSON 6

LOOSE ABRASIVE FINISHING PROCESSES

The majority of parts produced in industry are deburred by one of the loose abrasive finishing processes. These processes rely on the friction and scrubbing action which occurs when one places parts in a moving container of rock-like loose abrasives. Like driftwood on the seashore, the continual action of abrasive particles and water on parts smooth surfaces and radius edges. Those processes which allow parts to be placed in mass in the abrasive particle container are known as the mass finishing processes.

Barrel tumbling, centrifugal barrel tumbling, and vibratory deburring are the most widely used mass finishing. Spindle finishing is the most widely used loose abrasive finishing process other than the mass finishing processes. This lesson discusses the capabilities and limitations of these four processes.

BARREL TUMBLING

As implied by its name, barrel tumbling uses a rotating barrel to provide motion to the abrasive particles and the parts. The parts are placed in this machine with the media (Figure 1) and some abrasive compound containing soap and very fine abrasives and then covered with water. Normally the barrel is half filled with parts and media. As the machine rotates, the parts and media tumble together hour after hour until the external surfaces are polished and the sharp edges are removed.

In the case of barrel tumbling the rock-like media acts to support the parts so they do not bang against each other in tumbling action. In addition, the rough surfaces of these particles slowly grind and hone away the burrs and surface material. The small abrasive particles act like lapping compound. In this case the soap suds lift the small abrasive particles such that they can be entrapped between the media and parts. The abrasive particles being very fine help the grinding action and yet roll out of the way when excessive force is used.

For more aggressive action one uses either larger size particles or more abrasive particles. This allows the barrel tumbling process to be very flexible; the amount of abrasive action can be varied by changing only the very fine abrasive particles. If desired, one could also change the rock-like media to different sizes or different degrees of roughness.

Figure 1. Tumbling Barrel

The Advantage of Barrel Tumbling

Barrel tumbling has at least two very significant advantages. The first is that it is a mass finishing process rather than a one-at-a-time process. In barrel tumbling if parts are small enough, one can finish or deburr 100 to 10,000 parts in a period of only a few hours. In some instances the barrel may only be used four hours to deburr 10,000 parts. This is obviously much more economical than handling each part individually and finishing it by hand.

Barrel tumbling has a capability of also providing excellent surface finishes. In some cases it can provide surface finishes of 1 to 2 μ in. While these fine surface finishes are not normally produced in a deburring operation, they can be produced in a subsequent polishing operation.

Variables in Barrel Tumbling

One can change a number of parameters in barrel tumbling to provide more aggressive or gentle action. The variables in this process include:

- Media size;
- Media shape;
- Media composition (material);
- Abrasive size in the media;
- Abrasive type in media;

- Abrasive quantity in media;
- Type of abrasive compound;
- Amount of abrasive in compound;
- Size of abrasive in compound;
- Time of operation;
- Barrel speed;
- Type of barrel; and
- Water level.

The rock-like media used for tumbling is often a man-made product (Figure 2). It can be made in many sizes and shapes or compositions. Over 500 combinations of sizes, shapes and materials are commercially available on an off-the-shelf basis. Many of these rock-like media consist of abrasive filled porcelain or abrasive filled plastics. In these products one can change the size and the kind and amount of abrasive in the media. Any of these single changes can dramatically affect the deburring and finishing action.

As already mentioned, the abrasive compound consists of a soap and fine abrasive particles. Thus, one can change the type, amount, and the size of abrasive in these compounds. The longer one runs in normal circumstances, the more deburring or finishing action occurs. Very long runs; however, break down the media and abrasives into very fine abrasives and wear them out to the extent that aggressive action quits, and only a small polishing action occurs. If barrels are operated too fast they tend to throw parts around the circumference rather than allow them to slide through the sliding zone. Conversely, if the barrel operates too slowly, it takes a longer time to provide the same deburring action.

A wide variety of barrels is available, some of them with six sides, some perfectly round. Each of these have their own advantage. It is also possible to purchase a wide variety of differently arranged barrels. Some machines allow one to run four or five barrels at the same time (Figure 3). Some units provide quick loading and unloading while others provide particularly aggressive action or meet special part shape needs. Others cushion the action or provide multi-compartment capabilities. Some have built-in part/media separation, and a wide variety of tub liner materials are available to fit special needs.

Figure 2. Man Made Rock-Like Media Used for Tumbling

The more water one inserts in the barrel, the softer the action will be. Similarly, if one fills the barrel more than half full of media, then there will be a shorter length of sliding zone and a gentler action will occur.

Potential Problem Areas

All mechanized processes have some attributes which must be carefully considered prior to use. One may not wish to put very delicate parts in a barrel because of the possibility of delicate parts banging against each other. This of course will cause dented edges, changed workpiece dimensions, and scarred surfaces. This may not be allowable particularly on very soft aluminum parts. Most stainless steel parts, however, or beryllium copper can be successfully deburred in barrels.

Figure 3. Eleven Design Concepts of Tumbling Barrels That Are in Use Today

Blind holes are one problem faced by all mass finishing processes. If media can lodge in these holes it may be very difficult to remove. A judicious choice of the right size of media can prevent this. In many cases occasional lodging of media in holes is not detrimental and can be easily removed. In the case of very small holes; however, this is not the case.

Barrel tumbling works successfully only on external edges. It does not work well on small holes or internal recesses. The rock-like media just cannot reach these difficult access points. For this reason one may barrel tumble external edges to remove the majority of burrs and then hand deburr the hard to reach areas. On any part barrel tumbled one should closely scrutinize small holes to assure that media has been removed.

Barrel finishing processes can be accelerated by automating equipment, using fixtures, adding chemical accelerators, and purchasing centrifugal barrel machines. Some of the automated equipment tumbles and dries in a single machine. Many machines have quick loading and unloading capabilities. Fully automated

barrel machines include automatic part/media separation and media return capabilities. These capabilities are relatively expensive.

Accessories

As is the case in setting up most mass finishing processes, the price of the barrel tumbling machine may not be the only equipment cost incurred. Part/media separators, dryers, barrel-lifting cranes, restorage devices, holding pans, cabinets for media or compound storage, part storage, dipping tanks for applying rust-preventative coatings, and media sizing screens may also be required.

CENTRIFUGAL BARREL FINISHING

Centrifugal barrel finishing equipment is comprised of a number of drums mounted on the periphery of a turret (Figure 4). The turret is rotated at a high speed in one direction while the drums are rotated at a slower speed in the direction opposite to that of the turret. Generally drums are loaded in a manner similar to that for conventional tumbling or vibratory finishing, i.e., with components to be finished, media, water, and some form of compound. In operation the turret rotation creates a high centrifugal force of up to 25 times gravitational weight. This force compacts the load into a tight mass. Rotation of the drums causes an activity of the load in which parts and media slide against each other, removing burrs and refining the component's surface.

This abrading action under high centrifugal force results in very short process cycles. A product very lightly rubbed by an abrasive is not affected significantly. The same abrasive, however, will change the surface condition when rubbed with pressure increased up to 25 times. Obviously, speeding up the finishing process reduces costs and improved work flow.

Capabilities of Centrifugal Barrel Tumbling

Some basic capabilities of centrifugal barrel tumbling are shown in Figure 5. As seen there, if one has a part with 0.003 inch (76.2 μm) thick burrs on accessible edges, this machine will remove them in 20 minutes or less. In the same time span it can produce parts with edge radii of 0.003 to 0.008 inch (76.2 to 203.2 μm), surface finishes less than 20 microinches (0.50 μm), and changes to workpiece dimension of 0.0001 to 0.0015 inch (2.54 to 38.1 μm).

Figure 4. Centrifugal Barrel Tumbling Schematic

As shown in Figure 5, the size of the workpiece makes a significant difference in the amount of action edges received. As seen there, large samples generally are radiused considerably more than small samples using the same media, compounds, and same run time. Changing any one of the process variables in loose abrasive finishing can significantly change the action within the barrel. Figure 6, for example, illustrates the difference caused by the selection of different media, sizes, and shapes. As seen there, larger media will take off the burr much faster and similarly provide an edge radius much faster than will small media. The large media also has an advantage that it will produce a better surface finish in general than will the small media. The large media, however, has a disadvantage in that it will tend to remove slightly more material from the workpiece under the same conditions than the smaller particles.

Like all mass finishing processes, centrifugal barrel tumbling has some specific limitations. These include:

Figure 5. Harperizing Effects on Stainless Steel Cylinders, Using 3/16 Triangles and 1A-1 Compound at 15 g's

- = N14
- ▲ = DOLAMITE
- = TRIANGLES
- △ = N24
- = PLASTIC

Figure 6. Harperizing Effects on 0.5-Inch (12.7 mm) Stainless Steel Cylinders, Using Various Media and 1A-1 Compound at 15 g's

- It will not reach deep internal cavities;
- It does not remove large burrs from small holes;
- It may distort thin sections;
- It may distort soft workpieces;
- It may damage very large parts;
- It may not deburr all edges equally;
- It may contaminate surfaces;
- It may jam media into blind holes and slots; and
- It cannot produce a radius smaller than the initial burr thickness.

Because centrifugal barrel tumbling employs centrifugal forces which effectively make parts up to 25 times heavier than their actual weight, very thin sections can distort. For this reason, very delicate parts are frequently either not run in this process, or run under very gentle conditions. The same is true of very soft parts. It is very easy, with soft parts, to cause them to slam into each other or into harder media. This results in small pits, gouges, and cuts on the workpieces which, in many cases, is not allowable.

Very large parts have the same limitations. When the machine starts up, it throws all parts to the outside edges of the barrel. If two large parts happen to hit each other, then they will knick or cut edges and surfaces. The larger the parts are, the larger the force is with which they hit. In actual practice, thin, soft, and large parts can be run in these machines, but they require special considerations and care.

All edges are not radiused uniformly if geometries are such that media cannot uniformly work on each edge. On external edges, the uniformity is reasonably consistent. However, as shown in Figure 7, if the media must work at the edge of a step, then the edge of that step must be compatible with the media size and shape selected. If the media is too large, it cannot scrub the burr away. When one has several sizes of steps on an individual part and only one media size to work with, then uniform action does not occur. Even with the use of several media sizes, there will be some difference in radius performance. For this reason, on complex parts, some verification of edge quality may be required after the process is completed. In addition, if the part is very complex, some hand deburring may have to be performed on the hard-to-reach features.

Figure 7. Deburring Media Must be Consistent With Geometry

As shown in Figures 8 and 9, the angle at which the edges meet can make a major difference in the amount of radius each edge receives. This effect occurs in barrel tumbling and centrifugal barrel tumbling as well as in vibratory finishing. Assume for example, one wants to produce a 0.003 inch (76.2 μm) edge break on a 90° edge. Figure 8 illustrates the fact that 0.0012 inch (30.5 μm) of material must be removed. To provide the same radius on an edge which has a 120° included angle requires that only 0.0004 inch (10.2 μm) be removed. For a 30° included angle, the same edge radius requires that 0.0116 inch (294.6 μm) of material must be removed to provide the necessary radius. Figure 9 illustrates the actual radius produced on a phosphorus bronze workpiece having three different edge angles. As seen there, there are some significant differences in the radius as a function of these angles.

All mass finishing processes contaminate surfaces. The abrasive compound and the media are beat into the workpiece surface. In many cases, the particles are so small and the function of the part is such that this does not represent a problem. Parts which are welded, brazed, or soldered required the use of either silicon carbide or plastic media; however, one cannot normally see the contamination. It must be detected with sophisticated instruments. In some cases, this contamination will also affect the plating of metals on to these workpieces.

If one does not choose the most appropriate media, it can easily become lodged in holes, slots, or other features. In some cases,

Figure 8. Effect of Edge Angle on Stock Removal to Provide Specific Edge Radius

Figure 9. Effect of Edge Angle on Radius

these particles can be readily removed. In other cases, the particles cannot be removed and the parts in which they are lodged must be scrapped.

One of the most overlooked facets of mass finishing processes is that they cannot produce a radius smaller than the initial burr thickness. As shown in Figure 10, to wear away the burr one must wear away a thickness of material equal to the thickness of the burr. If one has burrs which are 0.005 inch (127.0 μm) thick, then the smallest edge radius one can obtain under normal conditions is 0.005 inch (127.0 μm). For this reason, it is very difficult on some parts to use this process to maintain the very small edge breaks. Under normal circumstances, the burrs produced on most parts will be 0.003 to 0.005 inch (76.2 to 127.0 μm) thick.

Figure 10. Relationship Between Burr Size and Final Radius

VIBRATORY DEBURRING

As seen in Figure 11, vibratory deburring uses a vibrating mass of media rather than a tumbling action to abrade burrs from parts. The basic constituents of the process are the same as used for the barrel processes. Vibration frequency and amplitude are varied rather than barrel speed.

The vibratory finishing industry began in 1957 with the first tub type vibrator introduced commercially in this country and in Germany. The first tubs merely shook. Parts and media were separated by hand. Today one can purchase equipment with tilting devices to dump out media and parts onto a screen, a door in the end of the vibrator for discharge of media and parts onto a screen deck, drains to permit soiled solution to flow through the vibrating chamber, media return conveyors and hoppers to develop semiautomatic production, dividers to separate large parts, flow-through solution systems, automatic tilt mechanisms to facilitate emptying out parts and media, long continuous single tubs up to 20 feet (6 m) in length for continuous processing, and long connected multimodular machines with unlimited length capabilities for the processing of parts 30 feet (9 m) or more in length. Variable speed, direct and indirect drive systems, two or more eccentric weight assemblies, and pressurized devices are also available to increase the capabilities of the tub vibrator.

Figure 11. Action in Vibratory Machines

The round or doughnut shaped vibratory machines were developed about 1963 (Figure 12). These machines offer simple weight adjustments and the potential for greatly simplified media-parts separation. Integral screen decks, automatic or semiautomatic gate operation, flow-through solution systems, underscreen feed chutes, noise covers, automatic weight shifters for control of continuous processing time, and simple or complex screen decks offer improved mixing and easier parts handling techniques when compared to tub vibrators. These units come in small and large sizes--to 100 cubic feet (2800 L) in size. Round vibratory steel ball burnishers carry up to 18,000 pounds (8160 kg) of steel media and exceed 12 feet (3.7 m) in overall diameter.

With at least 13,000 machines in use, vibratory deburring is one of the most widely used mechanized processes in the U. S. for removing burrs. There are, for example, approximately 165 standard models of vibratory finishing equipment available today from 25 major manufacturers.

With appropriate media choices, vibratory deburring can produce the same edge radii as barrels. The actual magnitude of the radius produced is a function of time, workpiece material, media and other variables in the process.

Parts having an initial surface finish of 62 μ in. can be improved to approximately 32 μ in. after 3 hours or less. Parts initially smoother will be similarly smoother when the cycle is completed.

While vibratory deburring can provide finishes of 8 μ in. such finishes are not commonly provided in a deburring operation. As

Figure 12. Doughnut Style Vibratory Machine

a general rule of thumb one should not expect vibratory deburring to remove burrs and provide a finish better than 20 μ in.

Like all mass finishing operations, changes of 0.0001 to 0.001 inch will occur to exposed external surfaces as a result of this process.

Figure 13 illustrates the effect that burr size has on the time required to remove the burrs in a vibratory operation. Although Figure 13 is applicable only to a specific set of conditions, the general observation that thicker burrs take much longer to remove is true of all loose abrasive processes.

Figure 13. Effect of Burr Thickness and Time on Burr Height Reduction for Simulated Burrs

SPINDLE FINISHING

Spindle finishing is one of the most frequently used processes for hand size cylindrical parts. Unlike the mass finishing processes, parts are deburred one at a time. The same abrasives, compounds, and process variables apply to this process as are used in mass finishing.

In this process parts are mounted on a spindle and then immersed into a tub of rapidly moving abrasive slurry. The velocity of the abrasive is generated by rotating the tub at a speed suitable

for the specific process requirement. The abrasive particles swiftly flow over rough edges and through holes in the workpiece removing sharp edges and improving surface finishes (Figure 14).

The holding fixtures are designed to hold the workpiece in such a manner that the areas to be treated are exposed. The tub is rotated in one direction, while the spindle or spindles normally turn in the opposite direction. As the tub rotates the media is forced to the outside by centrifugal force. The layer of abrasive formed as a result of this action is dense and firm and therefore provides aggressive action on the workpieces immersed in it. Fixtures usually consist of chucking devices which are spring loaded for clamping and released by an air cylinder--making the machine operation extremely simple.

Because parts are fixtured, there is no danger of impingement, nicks or scratches from parts colliding with one another. Since fixturing is needed these machines are most effective for mass production operations on a single or similar range of parts.

Generally the spindle is adjusted to place the workpiece as close as possible to both the outer periphery and the bottom of the rotating tub for maximum effect. There are two reasons for this--first, the abrasive velocity is proportional to the radius from the tub's center, and second, there is advantageous pressure effect created by compressing the moving abrasive between the workpiece and the tub bottom and side wall.

Processing cycles for spindle finishing are comparatively short. In many applications, a cycle of 5 to 20 s is sufficient although cycles up to five minutes and longer are not uncommon--determined by the complexity of the parts, which can range from engine valves to complex gears, while surface finishes range normally between 5 and 10 $\mu\text{in.}$ (127 and 254 μm), and with edge radii consistently produced down to 0.001 in. (25.4 μm).

Because of repetitive loading and unloading requirements because of the relatively short time cycles full time operators are required; however, in some specific and more refined operations, mechanical loading arms and industrial robots can be incorporated to reduce operator time.

Equipment and Operation

Spindle finishing equipment is available in a variety of configurations and with design features unique towards specialized process requirements. However, the majority of equipment manufactured to take advantage of the flowing abrasive mass principle consists basically of a structural steel frame and housing which support the rotating processing tub and fixture holding spindles.

Figure 14. Spindle Finishing in Motion

Depending on the requirement, spindle machines may commonly be designed with from one to twelve spindles, with the single or two spindle machine at this time being the most popular because of greater versatility.

The rotating tub is motor driven, and usually by a variable speed drive to allow flexibility of operation.

The spindles are also motor driven either by constant or variable speed drives to rotate the part in the abrasive mass to equally expose all surfaces for finishing. Spindles are generally pivoted or lowered into the finishing mass by means of air cylinders for processing and raised to a convenient position for loading and unloading. The majority of spindle machines used for high production operations also include provisions for air operated fixtures for quick loading and unloading of parts.

Machines designed for wet processing incorporate a rotating tub having perforated sections on the bottom or side wall to allow water based chemical compounds, that are injected automatically and continually, to flush away any metal chips, abrasive "fines"

or sludge for maintenance of efficient cutting action and continuously clean parts and a contamination-free mass. Discharged liquids flow into a collection ring positioned around the tub and further to a common drain fitting where "spent" solutions may be channeled to drains, settling tanks, or filtration/recirculation systems for re-entry into the processing tub.

Accurate control of processing cycles is maintained by electric timers, process tub speed by direct reading tachometers showing surface feet per minute, spindle speed by tachometers showing revolutions per minute, and liquid flow meters measuring the amount of water and/or liquid compounds introduced into the process.

To allow versatility in processing a relatively wide range of parts and configurations, most spindle equipment includes "adjustment features" in the spindle design, including a provision to adjust the spindle up or down, to adjust the spindle towards or away from the tub wall, to pivot or angle the spindle head to allow proper positioning of part for maximum exposure to flowing mass.

At the end of the predetermined process cycle, the spindle is automatically raised out of the processing tub where finished parts can be manually or automatically sprayed with water or with a cleaning solution to flush away any loose abrasive particles and residue from the abrasive mass.

With the process completed, the operator can remove the finished parts which, in most production installations, is accomplished by pressing a foot switch which actuates the fixture collet to release the finished parts. Upon removal of finished parts, the next process cycle begins by loading unfinished parts on the fixture and repeating the process cycle.

Processing Materials

Processing media includes a wide variety of abrasive materials and chemical compounds. The most popular media is fine grit aluminum oxides because it can effectively accomplish common deburring and edge radius operations with controlled accuracy on precision metal parts. Subject to part configuration and degree of cut or finish requirements, larger size random shaped aluminum oxide or preshaped ceramic based media is used for more aggressive finishing action. Sometimes a large sized media is mixed with a smaller sized media which can allow aggressive action on the outer edges and surface of a part and still deburr or improve the surface finish of small, restricted areas and holes by allowing the smaller media to reach areas not effectively reached by the larger media.

Where fine, low micro finishes are required, plastic based media with low abrasive content is used; and where high luster and polishing effects are desired, dry media such as maize or walnut shell compositions, along with steel balls for "burnishing," is highly effective on parts such as aluminum die castings and related soft metals.

Along with a wide range of abrasive media used in spindle finishing, there is also a wide range of chemical compounds available to enhance or complement the finishing process. Compounds can be in powder or liquid form, with liquids being more popular in wet spindle processing because they can automatically be injected through controlled injection systems.

Generally, specific compounds are required for each different application; however, there are standard compounds formulated to be compatible with a wide variety of processes to keep the parts and media clean, provide lubrication, provide protection against rust, and to aid in the abrasive action of the media during processing.

Capabilities and Advantages

The following list summarizes some of the major advantages of this type equipment:

- Rapid precision finishing of parts by taking advantage of centrifugal forces created by a rotating tub which forms a compact layer of abrasive media through which the part is exposed to high density abrasive action.
- A wide variety of specific finishing results can be obtained by controlling the tub speed, spindle speed, amount and grade of abrasive media and chemical compound, and cycle time.
- Part dimensions can be maintained to extremely close tolerances.
- Uniform deburring, radius forming, blending of machine or grind lines, and improved microinch surfaces finish can be accomplished on external surfaces--with a high percent of recessed or internal work accomplished through proper part positioning and media selection.
- Short process cycles, generally five seconds to five minutes, with the average cycle being approximately one minute--resulting in high production.
- Parts are fixtured resulting in no damage because of part-on-part impingement.

- Eliminates rejections because of discrepancies attributable to variations in manual performance.
- Can effectively reduce direct and indirect labor costs.
- Process repeatability--under controlled process conditions with operation established for tub speed, part position, media and compound, etc.
- Production requirements or operational standards are easily maintained once operation is established.
- Self-contained machines requiring a relatively small amount of floor space and can be used in production line sequence planning.
- Installation is relatively inexpensive and does not require special facilities. Services include only normal plant water, air, electrical and drain facilities.
- Low operational noise level, generally in the range of approximately 80-85 decibels (dBA).
- Minimal media wear which in normal operations amounts to a media loss of approximately one to two percent of the tub's volume over an eight hour shift.
- One operator can run two machines subject to number of spindles and time cycle.
- Process applications include: rough deburring, internal or recessed burr removal, descaling, ball burnishing, dry polishing or scuff sanding, micro finish improvement and stress relieving.
- Automatic, quick change, high production tooling and fixtures generally related to one of the five basic fixture concepts.

Limitations

In spite of the many favorable characteristics of spindle finishing, there are limitations which must be recognized:

- All parts must be fixtured or "held" for processing, opposed to "batch" processing in tumbling barrels or vibratory finishing equipment.
- Spindle finishing operations, in the majority of cases, must have a full time machine operator.

- It is not practical for many types of small sized parts, particularly when the finishing operations are departmentalized.
- Part-holding fixtures are immersed in the abrasive mass as well as the parts being finished and are subject to wear; however, in most cases fixture costs are nominal.
- Not practical, in terms of standard equipment, for parts exceeding 48 inches in diameter or weighing over 100 pounds.
- Subject to part configuration and degree of burr; has limitations for internal burr removal.

ECONOMICS OF LOOSE ABRASIVE PROCESSES

The following equation defines the items which affect loose abrasive finishing costs:

$$C = \frac{C_D + C_M + WC_P + C_E + C_C + C_W}{N} + \frac{(C_L k_1 + C_A K_2)(1 + D_O)}{N} + \frac{A(F + H + L_1 + I + G)}{H_y N}$$

where:

C = Deburring cost per part.

C_D = Depreciation cost per hour = machine cost/operating hours.

C_M = Maintenance cost per hour of operation.

C_L = Labor cost per hour to run machine.

C_P = Cost of power used (\$/kilowatt hr.).

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

C_E = Cost of media per hour = media cost x percent hourly attrition.

C_C = Cost of compound per hour.

C_w = Cost of water per hour.

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 (hr) per cycle.

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

k_1 = Percent of cycle time operator actually spends controlling deburring operation.

k_2 = Percent of cycle time operator actually spends cleaning parts.

F = Yearly floor space costs (\$/sq ft/yr).

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 barrel operation (sq ft).

To illustrate the use of this formula, assume that a barrel machine to be used is in a job shop which has to deburr a wide variety of parts in any given week. The owner of the shop wants to know what deburring is actually costing him. He is particularly interested in a part--roughly a 1-inch cube--of which he only has to make 50 pieces. The available unit is a 3-cubic foot capacity barrel machine and he estimates, for the existing burr size, that it will take 10 hours to deburr his parts. For lack of better data, he uses the media, water and related costs shown in Example 1 of Table 1.

For this particular part he estimates he will spend 20 minutes changing media, loading and unloading parts, and otherwise setting up (thus $k_1 = 20 / [10 \times 60] = 0.033$). While barrel-tumbled parts may be clean enough for normal commercial use, these parts require a subsequent ultrasonic cleaning operation which requires 15 minutes of actual operator attention (thus $k_2 = 15 / [10 \times 60] = 0.025$). Using these values from Example 1 of

Table 1. Examples of Unit Deburring Costs

Cost Item	Example 1 Barrel	Example 2 Vibratory Barrel	Example 3 Barrel	Example 4 Centrifugal Barrel	Example 5 Vibratory	Example 6 Vibratory
C_D	0.03	0.40	0.03	0.60	0.80	1.20
C_M	0.001	0.04	0.001	0.06	0.08	0.12
C_L	5.00	5.00	5.00	5.00	5.00	5.00
C_P	0.04	0.04	0.04	0.04	0.04	0.04
C_A	5.00	5.00	5.00	5.00	5.00	5.00
C_E	0.11	0.60	0.00	0.30	1.20	1.50
C_c	0.03	0.30	0.00	0.30	0.60	0.66
C_w	0.01	0.15	0.01	0.15	0.30	0.25
D_o	0.30	0.30	0.30	0.30	0.30	0.30
N	5	25	10,000	13,333	300	300
n	50	50	10,000	10,000	150	150
t	10	2	1	0.75	0.5	0.5
k_1	0.033	0.17	0.33	0.30	0.2	0.15
k_2	0.025	0.12	0.25	0.15	0	0
W	0.75	1.65	0.75	1.00	3.4	4.95
F	5.00	5.00	5.00	5.00	5.00	5.00
H	1.40	1.40	1.40	1.40	1.40	1.40
L_i	0.50	0.50	0.50	0.50	0.50	0.50

Table 1 Continued. Examples of Unit Deburring Costs

Cost Item	Example 1 Barrel	Example 2 Vibratory Barrel	Example 3 Barrel	Example 4 Centrifugal Barrel	Example 5 Vibratory	Example 6 Vibratory
I	0.10	0.10	0.10	0.10	0.10	0.10
G	1.00	1.00	1.00	1.00	1.00	1.00
H _y	4000	2000	4000	4000	4000	6000
A	300	300	300	300	300	300
Calculated C	\$0.237	\$0.186	\$0.00044	\$0.00035	\$0.017	\$0.018

Table 1 results in a deburring cost per part of just under 24 cents; or a total cost of \$11.85 for the 50 parts.

Barrel Vs. Vibratory Deburring

While 24 cents is not expensive for deburring a machined part run in a job shop situation, it is of interest to compare this cost to that of vibratory deburring. Assume Example 2 data from Table 1 represents equivalent deburring on a vibratory machine. One finds that vibratory finishing is less expensive for this example (18.6 versus 23.7 cents).

The reason for this becomes apparent from the three terms of the cost equation. The first represents the cost of expendable supplies; the second, labor costs; and the last, floor space cost of a deburring area. Comparing these three costs in the two examples will reveal that it was floor space that made barrel tumbling more expensive.

In the case of barrel tumbling, the data used results in a floor space cost of 60 cents per operating hour or \$6.00 for the 10-hour run (12 cents/part). Although the unit vibratory floor costs are much higher--\$1.20 per hour of use--only two hours were required, or a total of \$2.40 per run (less than 5 cents/part).

Cost Elements

In the previous two examples it was assumed that only 50 parts could be placed in a barrel. In most cases barrel tumbling is used to finish hundreds or thousands of parts. It is not unusual in those situations to operate without media or compounds. While this part-on-part deburring often does not remove all raised metal or all burrs, it typically removes the vast majority of undesired material at an edge.

Example 3, Table 1, presents reasonable cost data for high-volume small-diameter pins run one hour in a barrel. Here the cost of running 25 parts is only one cent (\$0.00044 per part).

One can easily deburr and burnish 10,000 pins each 0.020 inch in diameter by 0.125 inch long in 45 minutes in a 13-inch diameter centrifugal barrel 6 inches deep. As shown in Example No. 4 of Table 1, the cost per part is extremely small. Machines available today have two to six barrels, thus allowing the processing of two to six times as many parts as used in this example.

As a further example of time differentials, to achieve the 0.0002-inch diameter change shown in Table 2 required 48 hours in a small barrel, 10 hours in a vibratory machine, and 20 minutes in a centrifugal barrel machine.

Table 2. Edge Radius Produced for a Given Diameter Change*

Equipment Used	Diameter Change (Inch)/(μ m)		
	0.00005/1.3	0.0001/2.5	0.0002/5.0
Barrel (20 rpm)	Radius Produced (Inch)/(μ m)		
	0.0015/38.1	0.0025/63.5	0.0028/71.1
Centrifugal Barrel (15 g's)	0.0030/76.2	0.0045/114.3	0.0056/142.2
Vibratory Unit	0.0029/73.7	0.0037/94.0	0.0039/99.1

*Using 1/8-inch 303 stainless steel cylinders 1/2-inch long finished in 3/16-inch aluminum oxide triangles with abrasive compound.

As an example of processing a relatively large quantity of parts in a vibratory machine, consider Example 5. The cost elements would be the same as used in Example 2, with the following exceptions. First, 150 parts can be run in a 30-minute cycle. Second, no cleaning is required. Finally, equipment is run two shifts per day, five days a week.

A 6-cubic-foot machine is used with the assumption that the cost of expendables is twice that of a 3-cubic-foot machine. Total hourly cost is \$5.20; part costs are \$0.017 each. Again, it is assumed that the operator is using time profitably when not involved with the vibratory operation. If the total time were required for loading and unloading, the part cost would increase by \$0.017 per part.

Full Automation

Another finishing situation to consider is the facility which finishes the same part day after day. Generally, full automated equipment is employed. In addition, raw supplies are purchased in large volume. Again assume that a load of 150 parts requires a cycle time of 0.5 hours. However, a 10-cubic-foot vibratory machine is involved and ran on a three shift basis. Here, the cost elements shown in Example 6, Table 1 are representative. Per hour operation cost is \$5.02 or \$0.018 per part.

Expendable Elements

It is desirable to know which factors most affect cost. For the example just cited, significant costs other than labor were media, abrasive compound and depreciation.

Media

Costs are significantly affected by such factors as type of media (random chunks or preformed shapes), aggressiveness of the media, machine size, operating frequency and amplitude, amount of abrasive used and other variables such as method of media manufacture.

For example, one manufacturer recently reported that its media wore at a rate of 0.2 to 0.6 percent per hour. In other words, a 200-pound load would wear away at a rate of 0.4 to 1.2 pounds per hour. If media lodging in holes is not a problem it is possible to use the load for 200 hours or more. However, if lodging is a problem, media may be discarded after it has shrunk 50 percent. Therefore, if media costs were 68 cents per pound, the net cost per hour of media would be $\$0.68/\text{lb.} \times 200 \text{ lbs./load} \times 0.005/\text{hour loss} \times 1 \text{ hr.}$ or $\$0.68/\text{hr.}$

While media costs are generally low, there are instances where it is high. When using plastic media to deburr aluminum aircraft parts, for example, it is possible to consume \$100 worth every 24 hours in a 20 to 30-cubic-foot machine. That's an annual cost of \$20,000. Most small shops which use smaller machines will probably spend from \$300 to \$1,000 per year while deburring job shops can easily use \$3,000 to \$6,000 a year.

One often ignored and easily forgotten aspect of media wear is that, alone, it is a poor measure of effectiveness. Effectiveness is actually a ratio of wear to stock lost, burrs removed or finish produced. So a media with high wear may also produce fast results.

Media costs are also a function of volume purchased. For example, a 5/8-inch triangle in 1978 sold for \$0.67/lb. when purchased in quantities of 50 pounds. When quantities of 30,000 pounds are secured the cost drops to about \$0.57/lb.

Depreciation

Equipment costs are generally low if amortized over the actual life of a machine. Although there is a tendency to shake apart, machine lives of 10 to 15 years are not uncommon. Using a rule-of-thumb cost of \$1,000/cu. ft., a 3-cubic-foot machine costs a user about \$1.20/day over a 10-year period. If operated on a

three shift basis, the life of a machine decreases but the net cost per hour changes little if the machine is designed well.

Maintenance

Equipment costs are difficult to estimate, but it is not unrealistic to assume a rate 10 to 20 percent of hourly depreciation for vibratory equipment. Properly designed machines have few components that can go bad.

Energy Costs

Most vibratory machines require a horsepower rating of 0.75 hp per cubic foot of capacity. At a cost of \$0.04 per kilowatt hour, a 3-cubic-foot machine only uses \$0.54 worth of energy for an eight hour shift.

Compound Costs

Abrasives are another cost factor. Like media costs, some compounds are more effective than others. Large lot purchase quantities also influence the cost of the item. But unlike media, abrasive compounds are not reusable since they contain spent soap, dirt, metal particles and other objectionable constituents.

Water Costs

Work areas are usually wet because water is required during deburring cycles and for rinsing parts and media. Running a single 3-cubic-foot vibratory machine one shift per day requires 10 to 20 cubic feet of water. Since rates are in the order of \$0.01 per cubic foot, cost is minimal.

Labor Content

The second set of terms stated in the initial equation of this discussion describes labor costs. Here, it is that effort required to load/unload parts, media and compound; to separate parts from media; and to further clean parts after vibratory finishing. In this case the term k_1 denotes make-ready time as well as any additional time required in the middle of a run to verify proper operation. This is expressed as a ratio of machine run time or cycle time. The term k_2 , as previously stated, represents labor applied to cleaning after vibratory finishing.

For the values shown in Table 1, Example 2, raw materials (first term items) used in deburring cost \$0.062 per part while labor costs are \$0.075 per part. Therefore, for this set of conditions, labor and material costs are almost identical on a per part basis.

These calculations assume that an operator is gainfully using the remaining time--about 71 percent--which is not accounted for by the k factors in the example. Where several vibratory or related machines are available, an operator is usually busy.

Floor Space Requirements

The actual area in which an operation is located plus attendant heating, lighting, insurance and maintenance contribute to deburring cost and should be evaluated as such. Unfortunately, they are ignored by most users because they are fixed costs.

As an example, using the values shown in Table 1 and assuming that a vibratory operation having 300 square feet is adequate to handle the work of 200 machinists, then fixed costs would amount to \$2,400 per year. Using 2000 hours per year as a typical one shift workload, a fixed cost of \$1.20 per hour is assessed by just having a deburring area. This element adds \$0.048 per part for Example 2. When all three facets are added together a typical hourly operating cost can be obtained. In this case it amounts to \$4.64 per hour.

Rules-of-Thumb

While some guidelines do exist, as all gross estimates, they should be used judiciously. One rule-of-thumb used in 1974 was that it costs \$1.35 per hour to operate a 10-cubic-foot (0.28 cubic meter) vibratory machine and twice as much for a 20-cubic-foot machine. Another author states that operating costs other than labor are around \$0.25 per hour per cubic foot of capacity. Another author concludes that direct labor costs of loading parts and compound can be estimated at one-half minute per cycle per cubic foot of machine size.

Cost Estimating

When developing estimates it is essential to understand formulas and cost items as well as general plant working factors. No one formula or worksheet can account for all variables within all companies. As an example, some companies require that cost figures include a specific rate of return on investment. Others require values which ignore floor costs. Some users must build in after-tax considerations and others require non-uniform yearly depreciation costs.

In addition to the costs mentioned, most users must periodically screen media to eliminate undersize or broken media, metallic chips, sprues, and related contaminants. This requires pans, hoists, and separators whose costs are not explicitly shown in the equations.

Similar comments apply to the fact that media must be deglazed, parts de-magnetized, dried, and in some cases oiled or otherwise coated. Each of these factors increase the floor space costs as well as the more obvious direct cost elements.

Insolubles such as abrasives, chips and broken media which go down the drain must be removed in many plants before the effluent is released from the plant. This clarification cost as well as filter clean-out, is significant for some large users. The equipment adds additional cost. Volume users must store large amounts of media which costs something in the order of 10 percent of the purchased media cost per month in major installations.

While it is important to know what deburring costs are, they are not the only criteria by which processes are selected. Versatility, equipment life, level of training required and flow time are valid reasons for selecting a process as well as guaranteed lowest cost. Fortunately, loose abrasive finishing is not only one of the least expensive approaches, but is flexible and repeatable enough to also meet other selection requirements.

PROCESS COMPARISONS

With the advent of so many new deburring processes one has to wonder why anyone still uses barrel tumbling (the process was reportedly used in the 1600's to polish suits of armor). Although many companies have changed to vibratory finishing or other processes, approximately 23,000 barrel machines are still proving the most economical means of deburring for a large number of firms. Among the machines in use are those which will hold as little as a cup to as much as 40 cubic feet of parts. And at least 25 manufacturers today offer between 75 and 100 standard models of barrel tumbling machines.

From Table 1 data it is obvious that barrel tumbling is still a highly economical process, particularly when large volumes of small parts are involved. It also can be an economical process for large parts if floor space costs can be reduced. When only one or two different media are needed and bulky dryers, storage bins and separators are not required, floor space can be reduced to half or less of the area used in the examples--thus the costs would be directly competitive with vibratory deburring.

Advantages of Barrels

Tumbling barrels have several advantages over vibratory machines which are difficult to express in a simple formula.

- They can produce better surface finishes.
- They are easier to repair.

- Equipment cost is often less.
- Many different parts can be run at one time on a single machine which has several barrels.
- They can produce beneficial high compressive stresses.

While this process can produce finishes down to 1 μ in., it typically is not used to produce a finish better than 2 or 3 μ in. While vibratory finishing can produce finishes finer than 20 μ in., it typically is used for this purpose only on zinc die castings.

Barrel tumbling is generally considered simple and inexpensive, but in most cases initial costs are higher than many realize. As a rough rule of thumb, in 1978 one would pay \$750 to \$1,000 per cubic foot of total barrel capacity. Vibratory machines in 1978 varied in cost from \$1,000 to \$1,500 dollars per cubic foot of machine capacity.

Some small hobby type barrel units which can be used in production can be purchased for under \$50, and many companies have also fabricated their own inexpensive units. While the hobby units are not well suited to years of work, they are adequate for many small shops producing miniature parts in addition to being convenient for evaluating deburring parameters.

Multicompartmented barrels allow users to run four, five, or up to 16 different parts in the same machine at the same time. Since compartments are separated, different media can be run in each compartment. Some machines will also allow half the barrels to be run at one speed and half at another. In some machines, different size barrels can be used which also results in different tumbling speeds.

Barrel tumbling introduces compressive stresses in the outer surfaces of workpieces while improving finishes and removing burrs. These stresses are usually desirable as they increase the effective fatigue strength of the parts.

Advantages of Centrifugal Barrel Tumbling

As previously indicated, centrifugal barrel tumbling has several significant advantages. The principal advantage is that it can do a very effective job on small and miniature parts. The second most significant factor for this process is that it performs its action very quickly as a result of the G-level or speeds used in the process. As seen in Table 2, when the machine was operated such that 0.00005 inch change in diameter occurred, the conventional barrel had produced a radius of 0.0015 inch. The vibratory machine had produced a radius of 0.0029 inch, and the centrifugal

barrel machine had produced a radius of 0.0030 inch for the same size change.

As noted before, when a 0.0002 inch diameter change occurred on parts, the conventional barrel had operated for 48 hours. The vibratory machine required 10 hours to produce the same size change under the same conditions, but the centrifugal barrel machine only required 20 minutes. In this case, the centrifugal barrel machine also produced a significantly larger radius. The centrifugal barrel tumbling machine requires approximately the same labor per part as do the barrel and the vibratory deburring machines. The advantage is that so many more parts can be produced in the same time period.

The centrifugal barrel tumbling machine can also produce finishes as fine as two μ in. In most circumstances, however, parts made from stainless steel will typically have a finish of 15 to 25 μ in. after using this process.

REFERENCES

- ¹Mass Finishing Guide. Metal Finishing Suppliers Association, Birmingham, Michigan,: 1976.
- ²Clarke, P. K., "Determining Finishing Costs Accurately," Metal Finishing Journal, pp. 396-398: November, 1969.
- ³Matsunaga, M. and Haguida, Y., "Researches on Barrel Finishing," Electroplating and Metal Finishing, Vol. 20, No. 3, pp. 75-80: 1967.
- ⁴Blundell, Brian F., An Introduction to Industrial Finishing Equipment, Pergamon Press: 1965.
- ⁵Kohler, Arthur S., Barrel Finishing, 34-page booklet available from Frederick Gumm Chemical Co., Kearny, N. Y.
- ⁶"Barrel Finishing," Metals Handbook, Vol. 2 (Heat Treating, Cleaning, and Finishing), ASM, pp. 387-397: 1963.
- ⁷Gillespie, L. K., Deburring by Centrifugal Barrel Tumbling, Bendix Corporation: BDX-613-1559 (available from NTIS): June 1976.
- ⁸Kittredge, John, "The Testing of Vibratory Finishing Media." SME paper MR77-466: 1977.
- ⁹Patterson, William C. "Finishing Aluminum P/M Parts." Precision Metal, March 1971, pp. 61-63.
- ¹⁰"A Comparative Media Efficiency System," Precision Metal, May 1974, pp. 32-34.
- ¹¹Murphy, James A. (ed), Surface Preparation and Finishes for Metals, McGraw-Hill: 1971.
- ¹²Strom, Jr. R. and LaValley, D. R. "Vibratory Finishing," Automation, September 1971, pp. 74-78.
- ¹³Brandt, William "Vibratory Fixture Processing" Precision Metal Molding, June 1967, pp. 79-83.
- ¹⁴Johannesen, R. W., "The Total Deburring Cost," SME paper MR77-132: 1977.
- ¹⁵M. Matsunaga and Y. Hagiuda, "Vibratory Finishing--Fundamental Research," Metal Finishing, Vol. 63, No. 9, September, 1965, pp. 52-57; No. 10, October, 1965, pp. 88-94, 97.

¹⁶G. V. Robbins, Radius Generation in Vibratory Deburring, Bendix Corp. (Kansas City, Missouri), September, 1966 (Available from NTIS under accession Number N67-17437).

¹⁷L. K. Gillespie (ed), Deburring Capabilities and Limitations, SME, 1974.

¹⁸L. K. Gillespie (ed), Advances in Deburring, SME, 1976.

BDX-613-2382

DEBURRING: TECHNICAL CAPABILITIES AND COST-EFFECTIVE APPROACHES, LESSONS 5 AND 6, L. K. Gillespie, June 1980.

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, plant-wide approaches, burr formation, and prevention. Deburring methods described include barrel, centrifugal barrel, vibratory, spindle, manual, electrochemical, electropolish,

SPECIAL PROJECTS: Deburring

DEBURRING: TECHNICAL CAPABILITIES AND COST-EFFECTIVE APPROACHES, LESSONS 5 AND 6, L. K. Gillespie, BDX-613-2382, June 1980.

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, plant-wide approaches, burr formation, and prevention. Deburring methods described include barrel, centrifugal barrel, vibratory, spindle, manual, electrochemical, electropolish,

DEBURRING: TECHNICAL CAPABILITIES AND COST-EFFECTIVE APPROACHES, LESSONS 5 AND 6, L. K. Gillespie, BDX-613-2382, June 1980.

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, plant-wide 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 5 and 6 describe plantwide approaches to reducing costs and loose abrasive finishing processes respectively.

brush, abrasive jet, abrasive flow, water jet, thermal energy, and mechanized mechanical. Lessons 5 and 6 describe plantwide approaches to reducing costs and loose abrasive finishing processes respectively.

brush, abrasive jet, abrasive flow, water jet, thermal energy, and mechanized mechanical. Lessons 5 and 6 describe plantwide approaches to reducing costs and loose abrasive finishing processes respectively.