Chapter 10

Vibratory Finishing

Vibratory finishing is now the most popular type of mass finishing and, next to hand deburring, the most common surface conditioning method used by industry. This versatile process is used for cleaning, deburring, deflashing, descaling, edge and corner radiusing, surface finishing, and stress relieving. Workpieces in a wide variety of sizes and shapes are processed, as are all metals and many nonmetallic materials. Large quantities of parts can be run in batch or continuous process setups without handling or fixturing, thus minimizing costs.

10.1 EQUIPMENT BASICS

Vibratory equipment is made in two basic configurations: *rectangular tub* and *round bowl* types[1]. A third type, *tubular*, is made by at least one company, but is not widely used. The first tub-type vibratory finishing machine was introduced commercially in 1957, and the bowl-type about five years later. Both types use an open-top work chamber containing an aggregate of media, compound, water, and the workpieces. While the chamber is vibrated, work is performed by the media and compound's scrubbing or peening action on the workpieces. Table 10-1 provides an overview of the variety of these machines.

[1]Vibratory barrels, considered by some users to be vibratory finishing machines, are discussed in Chapter 8 rather than here because they truly are barrels and do not have the advantages of continuous processing.

10.1.1 Tub-Type Vibratory Equipment

With tub-type machines workpieces are loaded into the open top of a container holding the media, compound, and water. The rectangular tub (container) generally has a U-shaped cross-section with flat parallel ends, and is usually mounted on coil or rubber springs (see Figs.10-1 through 10-4). On some machines the containers are suspended on air bags, while certain small units employ composite or metal strips for suspension (Fig. 10-5). Processing containers other than U-shaped, such as keyhole shapes (see Fig. 10-6) and enclosed

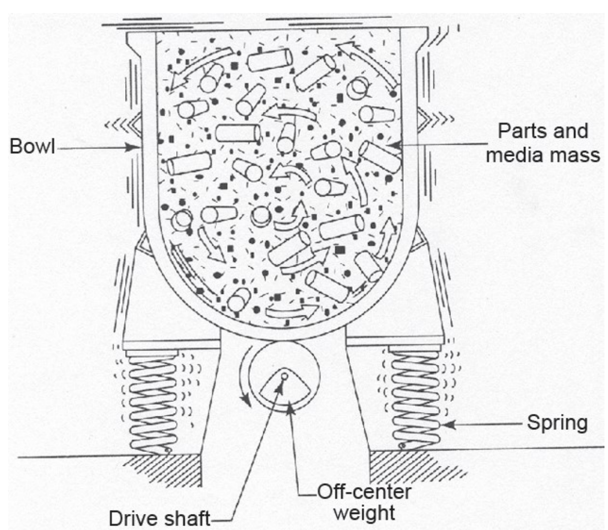


Figure 10-1. Sectional view of tub-type vibratory finishing machine (courtesy: SME)

Table 10-1. Types of vibratory deburring machines (Kittredge 1989)

Vibratory Equipment Style	Optional Configurations	Media Separation
1) Tub, batch	Compartmentalized, fixtured cryogenic, modular, bench top portable	generally none
2) Tub, continuous		with/without
3) Bowl, flat bottom	Compartmentalized, fixtured	with/without
4) Bowl with elevation		with/without
5) Bowl—big ratio*		with/without
6) Bowl—continuous		with
7) Oval		with/without

*Ratio is the diameter of the center section of a bowl divided by the channel diameter. Ratios larger than 4 are "big" ratio machines.

Figure 10-2. Simple tub machine (courtesy: C&M Cleaning Systems)

Figure 10-3. 24-cubic foot vibratory tub machines (courtesy: Deburring Equipment Manufacturing)

tubular units, are sometimes used to improve unrestricted mass movement. Tub liners, generally polyurethane, are used to prevent wear, reduce noise, and resist chemical attack. They also transmit energy to the media. Removable separators can be installed to divide the rectangular tub into a number of compartments. This permits processing workpieces individually or the use of different media to finish various parts at the same time.

Tub replacement liners are about 15–25% of the cost of a new machine. Repair kits are also available for some machines. These will add up to a year of additional life to the liner.

Vibration of the container is accomplished through several means, including the following:

- A vibratory motor having counterweights on its shaft and attached to the bottom of the

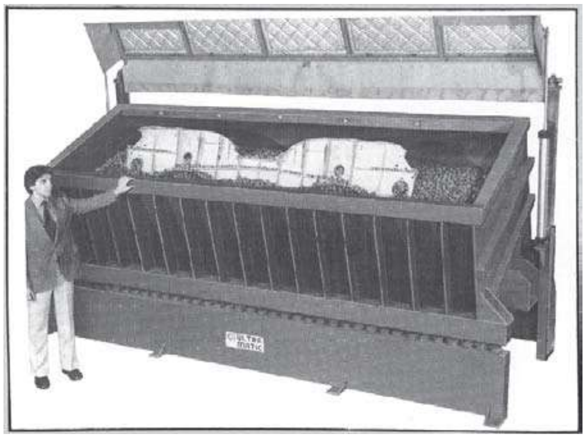


Figure 10-4. Heavy-duty 150-cu ft vibratory tub finisher (Thompson 1983)

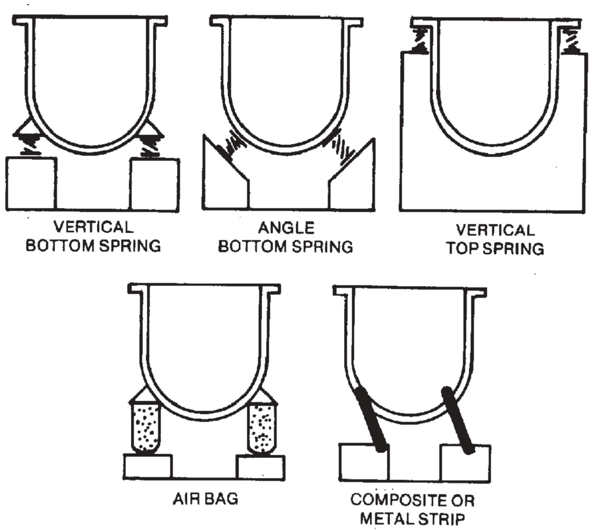


Figure 10-5. Suspension methods (Thompson 1983)

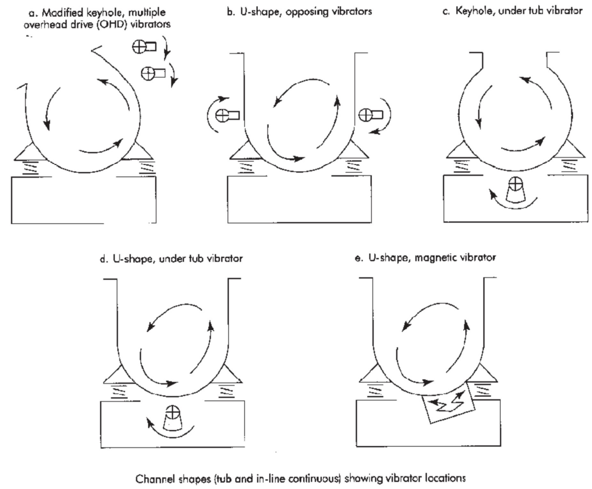


Figure 10-6. Cross-sectional view of various types of tubs and in-line continuous processing containers (Thompson 1983)

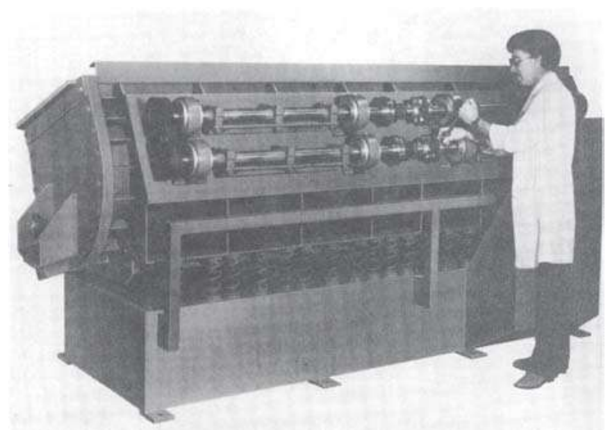


Figure 10-7. Large dual shaft vibrating tub (Thompson 1983)

container. This method is used on some bowl-type machines (Figs. 10-6c,d).

- A single shaft or twin shafts with eccentric weights driven by a standard motor (Fig. 10-6a,b).
- A system of electromagnetic vibration generators (Fig. 10-6e).

Figure 10-7 shows a large dual shaft vibratory from the back side where adjustments are made. Figure 10-8 provides a view of a different dual shaft design. Figure 10-9 illustrates the action differences within the tub when single shaft and dual shaft tubs are used. Table 10-2 provides a glimpse to the many variables in tub designs.

Machines equipped with magnetic vibrators are usually limited to less than 10 cu ft of capacity. For this type of system the vibration occurs under the machine at a constant 3600 cycles per second (cps). Increasing the voltage from the rectifier console strengthens the magnetic field, resulting in a longer pull to the armature, thus increasing the stroke. The operating principle here is that the variable stroke acts like the variable speed and

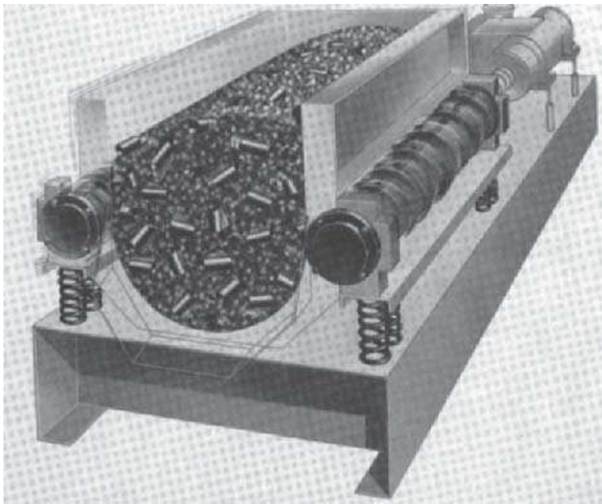


Figure 10-8. Dual shaft vibratory finisher (courtesy: SME)

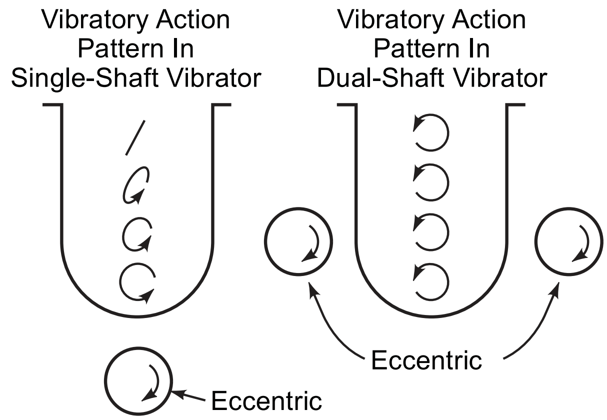


Figure 10-9. Action differences in tubs between single and dual shaft machines (Freeman 1983)

Table 10-2. Vibratory tub machine design attributes

Design Issue	Style a	Style b	Style c
Machine design type	Batch	Continuous	Compartmented
	Fixtured	Cryogenic	Modular (bench type)
Size	Less than 0.03 cu ft	More than 200 cu ft	
Chamber section	U-shape	Inverted keyhole	Semi-inverted keyhole
	Closed top		
Discharge method	End unload door	Open-end	Manual
	Tip-over		
Separation	External	Manual	Magnetic
	Built in		
Lining material	Polyurethane (variable hardness)	Rubber	
Drive	Variable speeds	Stepped speeds	Reversing
	Fixed direct	Belt	Hydraulic
	Multiple shafts	Electromagnetic	
Drive speed	1600–3400 rpm		
Eccentrics	Variable	Fixed mass	
Solution systems	Automatic	Semi-automatic	Batch
	None		
Drainage	None	Single drain	Multiple drains
	Interchangeable	In bottom of tub	In end of tub

amplitude of a mechanical vibrator without having to change weights.

Action of the media against the workpieces takes place throughout the entire load (Fig. 10-1). The media rubs against the workpieces while the entire load is turning over within the container. As a result cycle times are substantially shorter for this kind of vibratory finishing than for barrel finishing. Other advantages of tub-type vibratory finishing include the capability for in-process inspection, unloading and reloading without stopping the machine, and the possibility of automating for either batch or in-line processing. Stated differently, vibratory finishing lends itself readily to continuous processing, and hence to integration into automatic process lines.

Vibratory equipment can provide more finishing action in the recesses of workpieces than barrels, and it can process larger parts. Tub vibrators have been built to process components such as aircraft wing spars 30 ft (9 m) or more in length. Modular-type machines mounted in series can handle parts over 100 ft (30.5 m) long. Modular tub units are used to make very long tub vibrators from a series of shorter ones. Each unit must be separately driven and the units must be joined in such a way that maintains as good a vibratory action in the connection area as elsewhere.

With long tub-type vibrators, fully automated continuous processing of small parts is possible. Workpieces are loaded at one end of the tub and unloaded at the opposite end. At the unloading end the media is separated from the workpieces and is generally returned to the tub by a conveyor (see Fig. 10-10), often through reclassification systems. Post processing operations, such as rinsing and drying, can be incorporated into such continuous systems. The first 40 ft (12 m) long machine had a capacity of 200 cu ft (5.66 m^3) and was used to finish die cast parts up to 36 in. (1 m) in diameter (Anonymous 1976). Some tub machines are designed to allow both forward and reverse rotation of tub contents.

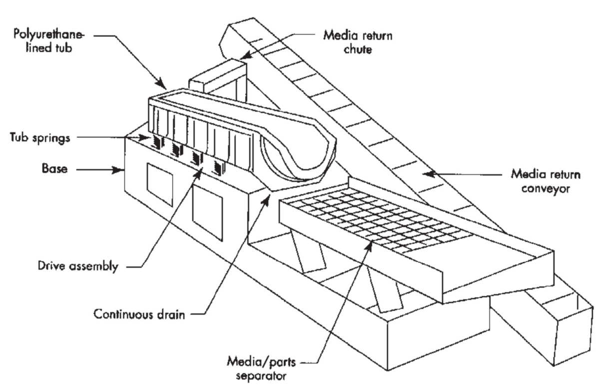


Figure 10-10. Tub-type vibrator with automatic workpiece loading conveyor and another conveyor system to return media to the tub (courtesy: SME)

10.1.2 Round Bowl Equipment

Round bowl or toroidal vibratory finishing machines have a doughnut-shaped chamber (see Figs. 10-11 through 10-18) that permits a continuous circular flow of media and workpieces. The bowls may have either flat or spiral bottoms. As with tub-type machines the chambers are provided with liners.

Vibration of the bowl is accomplished either by a vibratory motor or by an eccentric weight system mounted vertically in the center tube of the bowl (Fig. 10-18). With either method the amount

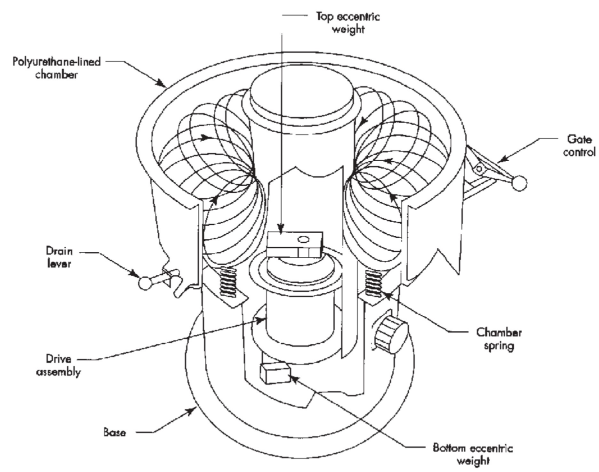


Figure 10-11. Basic configuration of a round bowl vibratory finishing machine (courtesy: SME)

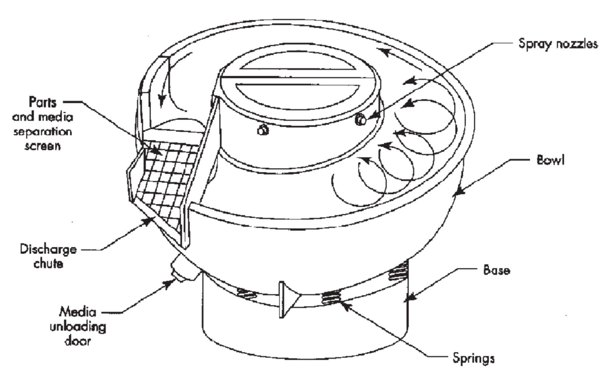


Figure 10-12. Automated continuous-feed vibratory finishing machine with screen for separating parts and media, and conveyor and chutes for returning media to the machine (courtesy: SME)

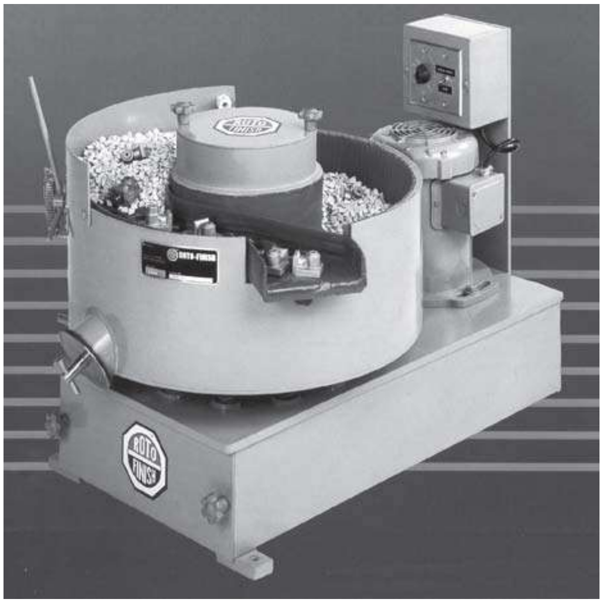


Figure 10-13. 1-cu ft bowl machine (courtesy: Roto-Finish)

Figure 10-15. Bench top bowl 0.75 cu ft vibratory finisher (courtesy: C&M Topline)

Figure 10-14. 35-cu ft bowl machine (Thompson 1981)

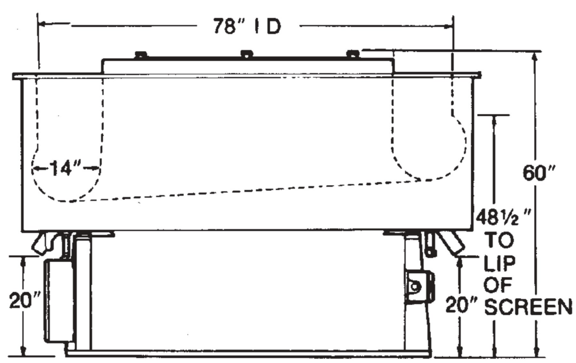


Figure 10-16. Dimensions of a 20-cu ft (6000 pound load) 20-hp bowl machine liner has 1 in. minimum thickness in high wear areas (Beck & Maudlin 1979)

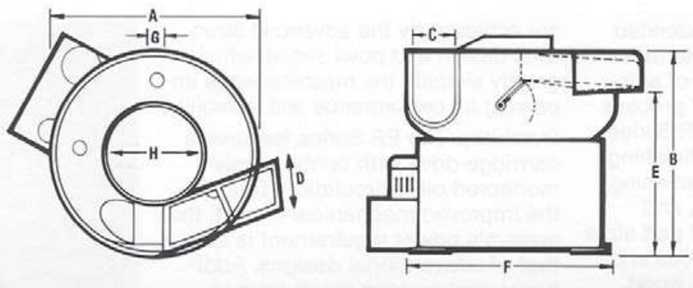
of weight placed on the top and bottom of the eccentric system and the angular displacement between the two weights control the following:

- the finishing action (the amount of media vibration against the workpieces)
- the speed at which the mass rolls over within the bowl
- the speed at which the mass rotates around the bowl.

Table 10-3 provides an overview of the many design variations that are in production for bowl machines.

10.1.3 Tubular Machines

Tubular machines come in at least two basic designs, but their overall shape looks like a large-diameter, almost horizontal tube (Fig. 10-19). One version is a continuous spiral tube similar to



MODEL	MAXIMUM WORKING CAPACITY CU.FT.	A OVERALL DIAMETER	B OVERALL HEIGHT	C PROCESS CHANNEL WIDTH	H CENTER COLUMN DIAMETER	D SCREEN DECK WIDTH	E SCREEN DECK HEIGHT	F BASE DIAMETER	G DRAIN SIZE	NUMBER OF DRAINS	MOTOR HORSE POWER	460 VOLTS AMP LOAD	230 VOLTS AMP LOAD	APPROX. SHIPPING WEIGHT
ER-0203	2.5	42.0	43.0	7.5	26.0	6.0	37.0	41.0	4.0	1.0	3.0	7.8	12.6	2,200
ER-0203D	2.5	42.0	43.0	8.7	24.0	6.0	37.0	41.0	—	—	3.0	7.8	12.6	2,200
ER-0203FB	3.0	42.0	43.0	7.5	26.0	—	—	41.0	4.0	1.0	3.0	7.8	12.6	2,200
ER-0405	5.0	48.7	46.5	10.2	26.0	8.0	39.0	47.0	4.0	3.0	3.0	7.8	12.6	3,000
ER-0405D	5.0	48.7	46.5	12.0	24.0	9.0	39.0	47.0	—	—	3.0	7.8	12.6	3,000
ER-0405FB	6.0	48.7	46.5	10.2	26.0	—	—	47.0	4.0	3.0	3.0	7.8	12.6	3,000
ER-1011	10.0	61.25	55.25	12.50	33.25	12.5	44.0	57.0	4.0	2.0	7.5	14.0	25.0	5,000
ER-1011D	10.0	60.0	52.0	15.0	30.0	11.0	40.0	57.0	—	—	7.5	14.0	25.0	5,000
ER-1011FB	11.5	60.0	52.0	13.4	32.0	—	—	57.0	4.0	3.0	7.5	14.0	25.0	5,000
ER-1516	15.0	70.0	53.0	15.0	38.0	13.0	40.0	67.0	4.0	2.0	10.0	17.0	31.0	5,500
ER-1516D	15.0	70.0	53.0	17.0	36.0	13.0	40.0	67.0	—	—	10.0	17.0	31.0	5,500
ER-1516FB	17.0	70.0	53.0	15.0	38.0	—	—	67.0	4.0	3.0	10.0	17.0	31.0	5,500
ER-1822	18.0	76.0	53.0	18.0	38.0	15.0	42.0	67.0	4.0	2.0	10.0	17.0	31.0	6,200
ER-1822D	18.0	76.0	53.0	19.5	36.0	15.0	42.0	67.0	—	—	10.0	17.0	31.0	6,200
ER-1822FB	20.0	76.0	53.0	18.0	38.0	—	—	67.0	4.0	3.0	10.0	17.0	31.0	6,200
ER-2530	26.0	80.0	63.7	20.0	38.0	17.0	52.0	66.0	4.0	3.0	10.0	17.0	31.0	6,600
ER-2530D	26.0	80.0	63.7	21.5	36.0	17.0	52.0	66.0	—	—	10.0	17.0	31.0	6,600
ER-2530FB	28.0	80.0	63.7	20.0	38.0	—	—	66.0	4.0	3.0	10.0	17.0	31.0	6,600
ER-60	51.0	108.0	80.0	22.0	61.0	19.0	58.0	104.0	4.0	3.0	30.0	43.0	83.0	12,000
ER-60FB	54.0	108.0	80.0	22.0	61.0	—	—	104.0	4.0	3.0	30.0	43.0	83.0	12,000
ER-100	82.0	120.0	86.0	27.0	61.0	24.0	62.0	104.0	4.0	6.0	30.0	43.0	83.0	20,500
ER-100FB	85.0	120.0	86.0	27.0	61.0	—	—	104.0	4.0	6.0	30.0	43.0	83.0	20,500

D - Dryer   FB - Flat Bottom

NOTE: All models other than the Dryer (D) can be either Straight Wall(S) or Curved Wall (C). Curved Wall is recommended for processes using steel media.

Continuous improvement of products is a standard policy. All specifications and designs are subject to change without notice or obligation. Prices are also subject to change and do not include taxes and freight where applicable.

Figure 10-17. Dimensions of one manufacturer's bowl machine line (courtesy: Roto-Finish)

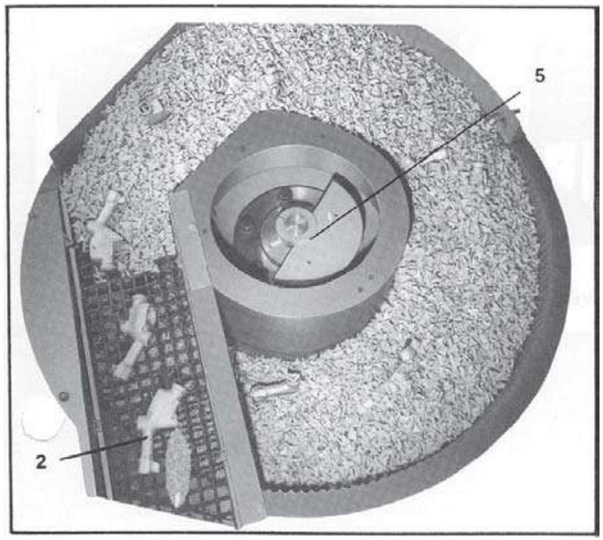


Figure 10-18. Top view showing adjustable weights on bowl machine

Table 10-3. Vibratory bowl equipment design issues (Kittredge 1987)

Design Issue	Style a	Style b	Style c
Size	Less than 0.05 cu ft.	More than 100 cu ft	
Machine type	Batch	Continuous	Elevating bottom
	Flat bottom	Dryer	Fixed compartments
	Loose compartments	Fixtured parts	Oval (bench top)
Chamber section	U-shaped	Semi-inverted keyhole	
Diameter ratios	Center section: channel of 0.5:1.0 up to 8:1		
Separation method	Internal	Built-in deflector	Insertable deflector
	External	Tip-over	Magnetic
	Manual	Electromagnetic	
Media unload method	Door in bottom	Over screen	Tip-over
	Manual		
Lining material	Polyurethane (variable hardness)	Rubber	Steel
	Polyethylene		
Drive	Fixed	Variable speed	Reversing
	Direct	Belt	Hydraulic
Drive speed	1200–2800 rpm		
Eccentrics	Both variable mass	One variable	Both fixed
	Variable angle	Fixed angle	Changeable angle
	Reversing		
Solution systems	Automatic	Semi-automatic	Batch
	None		
Drainage	None	Single drain	Multiple drains
	Fixed	Interchangeable	Vacuum

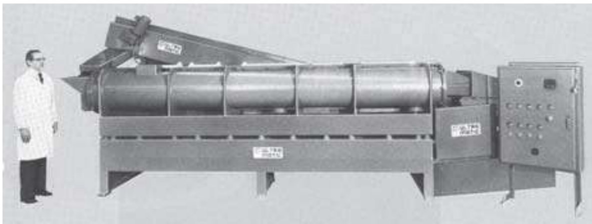


Figure 10-19. Tube machine provides long path as well as reduced noise levels (Thompson 1983)

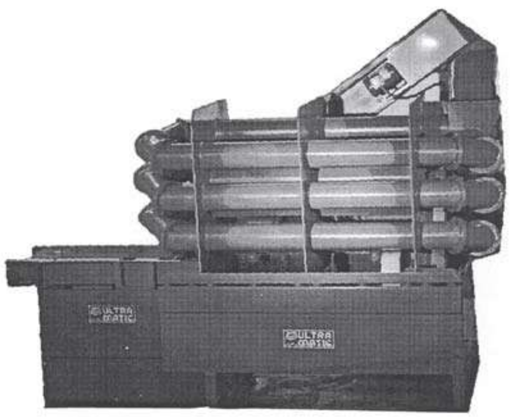


Figure 10-20. Spiral tube machine

popular amusement park water slides (Fig. 10-20). Such machines are totally enclosed except for the ends, which are open to allow automatic loading and unloading. The tube is completely lined 360° with a rubber-like liner, which usually drops the noise level by 20 dB or more compared to open designs. A single motor drives the several tubes (this is a continuous tube, actually), saving energy. The location of the motor reportedly equalizes forces within each tube, resulting in consistent media action from one end to the other. The machine drive is versatile enough to run all types of media that vary in density such as ceramic, plastic, dry polishing media, and even steel media. Typically, the space requirement for an in line flow-through system having 10 ft (3 m) of linear tub length is 7 ft wide × 20 ft long (2.13 m × 6 m). The new multiple-tube machine (called "MULTI-TUBE" by the manufacturer) allows over 70 ft (21.3 m) of linear tube length to fit in this area. The system is capable of continuous feed time cycles up to 4 hours. Russian research illustrates some conceptual variations of these designs (Babichev, Ryseva & Davydova 1995).

10.1.4 Stacks of Tub Machines

One manufacturer provides a series of tubs in a single machine much like the seats in a Ferris wheel (Fig. 10-21). This allows long parts to be placed in one tub for roughing, into another for finishing and into yet another for cleaning, all in the same basic piece of equipment. Up to five different tubs, each handling parts up to 30 in. (76 cm) long, can be placed in the machine.

10.1.5 Vibratory Shaker Mixer Deburring

Laboratory mixers have been used for deburring small parts. These tabletop machines generally produce a vibrating, figure-8 motion in a closed container to mix powders. Small parts including jewelry can be finished in them, but they are not in common usage.

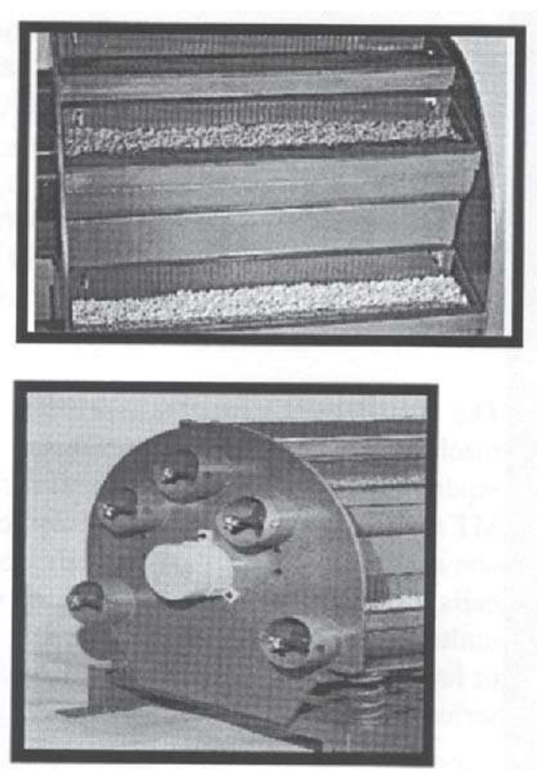


Figure 10-21. Ferris wheel style vibratory machine

10.2 MACHINE BASICS

There are probably more machines equipped with the under-tub vibrator than any other design. The introduction of tub-type vibrators in the 1950s featured this method and it continues to be used today. The vibrator is attached beneath the tub itself, having pie-shaped flyweights fitted to the shaft ends. Vibration input is upward producing a rise and fall motion to the tub, the eccentricity develops the orbital path of the mass motion opposite of the vibrator rotation. Variable speed is a desirable feature that aids in controlling any variables in mass density.

Machines equipped with magnetic vibrators are usually limited to less than 10 cu ft (0.28 m^3) in capacity. The vibration input is from the underside of the tub and operates at a constant 3600 cycles per minute. Voltage is controlled via a rectifier console. Increasing the voltage strengthens the magnetic field resulting in a longer pull to the armature, thus increasing the stroke. The theory is that variable strokes simulate the variable speed and amplitude of a mechanical vibrator without changing weights.

Round bowl vibrators are available in a number of "diameter ratios"—the ratio of the center section diameter to the channel cross-sectional diameter (Fig. 10-16). A 1:1 ratio means the processing channel has the same diameter as the center section diameter. A 4:1 ratio means the center section diameter is four times that of the channel diameter. Generally, the closer this ratio is to unity (1:1), the lower the cost of the machine.

Ratios of 1:1 are common for "non-elevating" chambers where no internal separation is expected. Higher ratios make internal separation easier—2:1 to 4:1 ratios are not uncommon for these machines when conventional ceramic and plastic media are used. Ratios up to 7:1 can be found when difficult-to-move, hardened steel media is used. When the diameter ratio is about 1:1, part retention times are quite small, generally on the order of 1/5 to 1/3 min per cu ft (0.064 to 0.1 min per m^3) of machine capacity. When the diameter ratio is increased to 5:1, retention times of 1/2 to 1 min per cu ft (0.17 to 0.34 min per m^3) can be realized (Kittredge 1992).

Special designs satisfy a great number of additional industrial requirements such as ball burnishing machines, which are designed to handle much heavier steel ball media. Some machines allow predetermined speed alternatives to maximize the type of work that is possible in a single cycle.

One major job shop user estimates life of vibratory finishers with daily use at 10 years. Life of barrels in the same facility is estimated at 20 years with the same use.

10.3 MACHINE VARIABLES

There are at least six types of batch and continuous tub vibrators: *U cross-section*, *inverted keyhole section*, *half-U cross-section, single*, *dual*, or *overhead drives* (Fig. 10-6). Batch equipment comes with or without dividers. Continuous machines may or may not have a means to control continuous process cycle time.

Round vibrators with no elevation in the chamber are of at least four types: *with dividers*, *without dividers* (discussed later), *curved outer wall*, (Fig. 10-16) or *straight outer wall* (Fig. 10-14). Round vibrators are available with or without a separation system.

Round vibrators with an elevation in the chamber (Fig. 10-16) and the big ratio designs have at least two additional variables: 1) type of separation deflector and its method of actuation, and 2) screen deck type and material.

Round continuous machines also have at least two additional variables: screen deck type and material, and a system, if any, for controlling continuous cycle time. The ratio is the diameter of the center section of a bowl divided by the channel diameter. Figure 10-16 shows a big ratio machine. Ratios greater than 4 are found in so-called "big" ratio machines.

Oval vibrators possess the variables associated with round vibrators with an elevation plus the potential additional variable of ratio of length to width. Figure 10-22 shows an oval high energy vibratory machine.

Portable tub machines can be used at the point of machining. Some of these allow recirculation of the compounds, reconstitution of the compound, filtering, and chemically recharging the effluent (Fig. 10-23). While most machines of this design are small, one manufacturer provides 3 and 5 cu ft

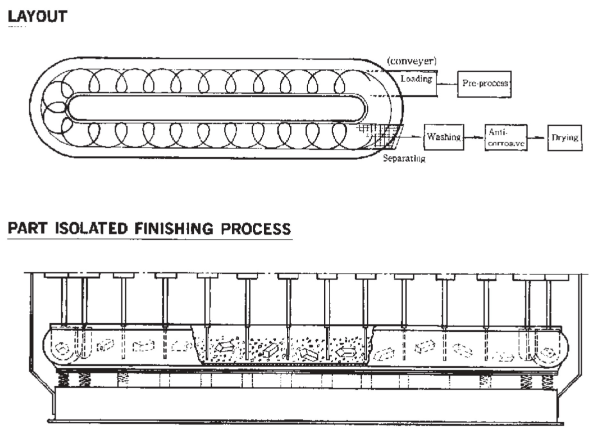


Figure 10-22. Oval vibratory machine (Kobayashi & Matsunaga 1980)

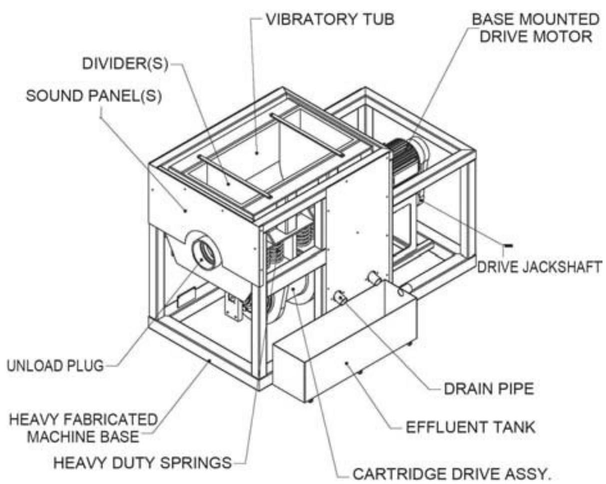


Figure 10-23. Portable vibratory machine (courtesy: Roto-Finish)

capacity portable units. The settling tank, with pump and hose, is in the base of the unit for self-contained recirculation of solution. These machines can be converted to flow-through use for optimum cleanliness.

10.3.1 Dryers

Dryers are made in round vibratory machine designs because of their simple in-and-out feed capability that gives several minutes of retention time in the machine. Ground and graded corncob is used as a drying media and is best when heated to drive off moisture. Infrared, electric contact, and hot oil heaters are used to dry the corncob material.

10.3.2 Continuous Machines

Continuous machines are popular for the deburring of parts in relatively short cycles. In these systems the separation deflector is fixed in the separation position so that media and parts are always deflected up onto the separation deck (Fig. 10-24). Media drops through the screen where new parts are loaded continuously. Cycles are generally in the 3- to 30-minute range depending on media, parts, amplitude, machine design, and size. These machines hold 10 to 20% more media than batch machines because the area under the screen where parts are loaded is filled.

Compartmented machines, like tub vibrators, are designed to make a number of small machines out of one big one (Figs. 10-25 and 10-26). The small compartments insure no part-on-part contact, but are loaded and unloaded by hand. Compartments can be fixed in place in the channel or they can be mounted on a fixture that allows them to rotate with the mass. Figure 10-25a is unique in the multitude of small compartments housed on the outer side of the machine.

Some compartmented machines separate different media or different part numbers. These may contain more than one part per compartment.

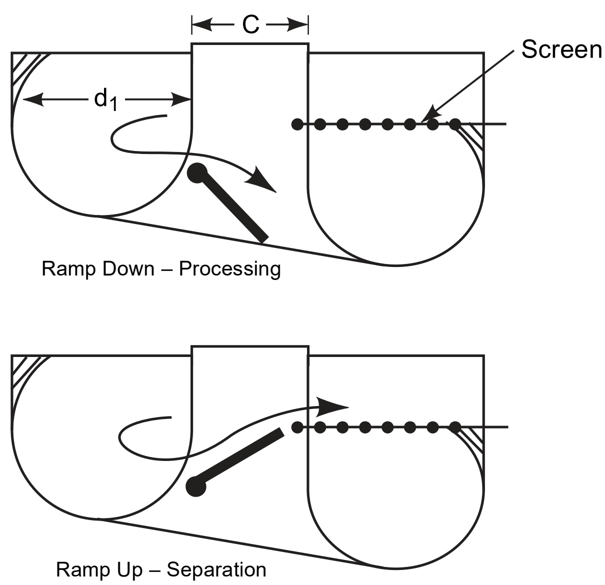


Figure 10-24. When ramp is down, media and parts continue around the bowl. When ramp is up, the parts and media climb upon the screen deck and media falls through.

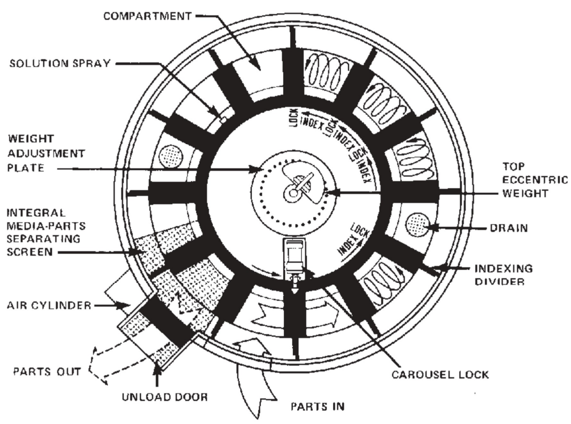


Figure 10-25a. Compartmented bowl vibrator assures that parts do not bang into each other (courtesy: SME)

Figure 10-25b. Twelve compartmented tubs surrounding bowl vibrator house 0.6 1iter each of parts and media. Note the multiple-solution feed tubes feeding from the top. (courtesy: Polyservice AG)

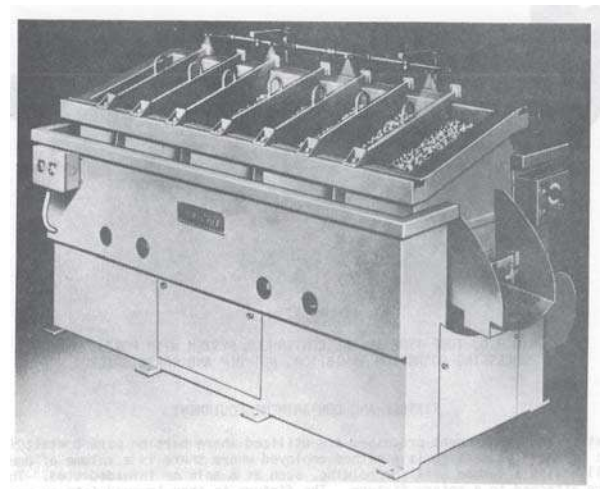


Figure 10-26. Compartmented tub machine (Thompson 1981)

Oval-shaped vibratory machines shown in Fig. 10-22 are said to offer better separation of parts from media, better control of retention times, and other advantages. They are driven by a central eccentric weight system, like the round versions. Therefore they do not offer a uniform action (i.e., media and parts close to the center do not act the same as those that are farther away). Single shaft oval machines are no longer made, but dual shaft machines (Figs. 10-7 and 10-8), which provide better action are still produced. Dual shaft design produces a true orbital motion at the center of the rotation—a centrifugal force that optimizes input energy. This gives the fastest possible speed of mass rotation for any given machine speed. This machine design can be up to five times faster than single shaft machines.

10.3.3 Multiple Pass Designs

Multiple pass machines are newer. They permit longer retention times by making the media and parts mass travel around the machine two or more times (Fig. 10-27). Alternatively, several operations can be performed on the parts, such as deburring followed by drying in one continuous operation. Two or more different types of media could be used in the same machine at the same time without mixing (media falls through separator before parts reach next channel). The narrow paths essentially prevent parts from hitting each other. When fed in at uniform spacing the parts come out at the same spacing intervals. Parts merely follow one another

Figure 10-27. Multi-pass bowl machine (courtesy: Roto-Finish)

around the bowl. Part-on-part processing is also possible if desired, but the prevention of contact is of particular benefit for many parts. Uniform part spacing occurs automatically.

10.3.4 Bench Top Units

Most (but not all) of the small bench top machines are marginally designed devices that cannot compare favorably with their grown-up fellows. In order to hold down costs manufacturers of these machines have removed several important items, such as the adjustable weight system and a good solution system. Leaving these two items alone out of the design can turn a good machine into a bad one. (There are good machines on the market, but they cost more.)

10.3.5 General Considerations

Heavy, bulky, or long parts need a tub style machine, while parts of more geometrically uniform surfaces process better in bowls. If a machine is for metal media processing the manufacturer will supply the machine set specifically to the application. Continuous equipment is more directed in its use and usually applied to high volume production.

The choice a user makes between tub and bowl is not based on personal preference but on a review of part size and anticipated production. Part size will dictate the channel requirements, while production and process time will determine the machine size, style, and number of units required. However, it is not unusual for manufacturers to purchase large bowl machines to process bulky parts that would finish quicker and more efficiently in a tub unit 1/4 the capacity of the bowl. On the other hand, the use of tubs to process larger quantities of small parts with no provision for unloading or separation is just as inefficient.

Some machines are not well designed: they will shake themselves apart after a few months of operation. The vibration can also be transmitted through the floor to other parts of the plant. One manufacturer provides an impressive display of vibration control. He does so by standing a U.S. nickel on edge on the base of his machine while it is running. The nickel does not move, fall over, or roll away. Vibrations can be controlled!

10.3.6 Channel Cross-Sections

Like the tub units, bowl channels have a curved, hemispherical bottom, and, normally, straight and parallel sides (Fig. 10-16). When small parts and small media are involved, a curve to the outer wall can be used to prevent media "back-roll." Seldom is the center section wall curved (Fig. 10-28).

Regardless of the type of machine (tub, bowl, or continuous), the processing channel shape is important. Scratches, impingement, and tangling of parts occur when the channel cavity restricts freedom of mass motion. Deep channels develop forces at the bottom area that can cause distortion to delicate pieces; in shallow channels large pieces hit the bottom and one another. It would seem that a circular channel would be the better design, but, once again, this depends upon the application. A circular channel

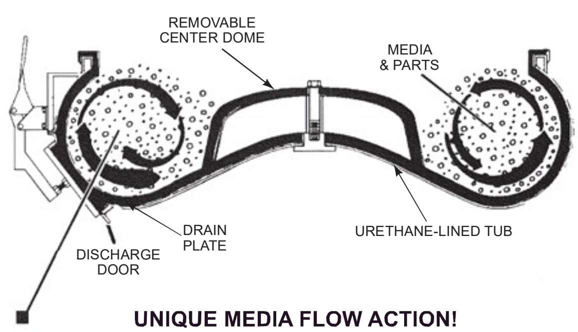


Figure 10-28. Bowl vibratory machine having curved outer walls to prevent parts from crawling out and keep media rolling (courtesy: SME)

may be too forgiving and extend cycle times for deburring applications, yet it may accept more parts, thus increasing the yield per load.

A deep narrow channel has containment. If the part size is such that the mass motion is unrestricted excellent results can be expected when utilized for deburring applications. Shallow channels will accept long objects well, while bulky items will be in constant contact with the channel lining and other workpieces.

Keyhole or modified keyhole channels (Figs. 10-6a and c) featuring curved walls allow for unrestricted mass movement. This design is popular where finish may be as important as deburring. Part geometry or bulk is not as critical. Almost anything that will fit in will run nicely.

Other popular channel configurations are manufactured. The above examples illustrate that the part size, material, volume, and process are the key factors upon which to base decisions. Operator work height and reach requirement should be carefully reviewed. Certain units may require a platform for operator convenience and ergonomic considerations.

10.3.7 Amplitude and Speed Adjustments

The use of speed and the adjustment of amplitude are often confused or misunderstood. *Amplitude* is a measure of energy input to the mass. *Speed* is the frequency of amplitude. The most common method of achieving amplitude is via the *eccentric shaft principle*. The shaft can be mounted to bearings loaded with eccentric bushings, resulting in a single lobe crankshaft. Amplitude adjustments for increasing or decreasing generated energy forces are accomplished by adding or removing weight from the shaft.

Bowl machines have an additional adjustment: the shaft mounting of bowl equipment is located vertically in the center post or donut hole area of the machine. The counterweights are located on the top and bottom of the vibrator shaft. Adding or taking away weight also controls the amplitude. However, since the processing channel is round, the mass travel is a combination of rotary motion with lineal extension, resulting in a spiral motion within the machine's circular processing channel. The dual motion or mass path is controlled by adjustment of the relationship of the top and bottom weight, resulting in a tight or open spiral of the mass path (Fig. 10-29). The addition or removal of weight to the top or bottom flyweights governs the energy input and velocity of either the rotary motion or lineal extension of the mass and the tight or open spiral of the mass path. One machine uses a weight shifter during the cycle to move the upper weight back and forth between two preset stops for just a few seconds while it is rotating. This makes the machine feed forward briefly and then dwell a few seconds. Cycles up to one or two minutes per cu ft of capacity can be obtained (Kittredge 1992).

Amplitude settings are the factor by which the mass path is governed and it is determined by:

- parts-to-media ratio
- size of part
- part weight or specific gravity differential between parts and media.

Incorrect amplitude settings can result in part impingement, poor mass motion, parts migration, parts distortion, and difficult or incomplete internal separation in bowl machines (Thompson 1981).

Speed adjustment controls the frequency of energy input as well as the speed of the mass. Simplifying the definition between amplitude weight and speed, one could say: amplitude is the size of the hammer and speed is the frequency of the use. Thus, the rapid use of a tack hammer is different from the slow deliberate blow of the

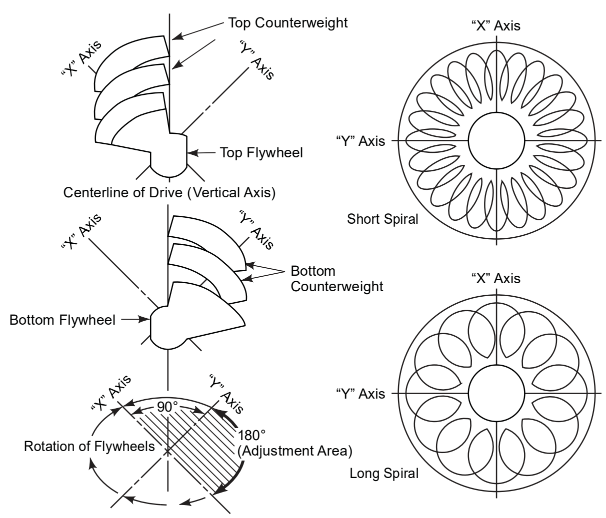


Figure 10-29. Changing the relationship of upper and lower weights changes the tightness of the path followed by the parts (Thompson 1987)

sledgehammer. Many vibratory machines have no variable speed capability while others do. Typically tub machines use frequencies of 1500 to 1900 cpm, while bowl machines use 1200 to 1500 cpm, but no physical limitation exists that prevents other frequencies.

Since amplitude is the governing factor within the mass and is adjustable to suit needs, it is seldom changed. Where surface conditions are uncertain, the flexibility of changing amplitude gives users an option. Adjustable amplitude is available on all equipment utilizing mechanical vibrators. However, variable speed is not.

10.3.8 Vibrator Details

Round bowl machine vibrators are located vertically at the center of the bowl. The vibrator shaft length and vertical location in relationship to the centerline of the processing channel vary according to the manufacturer and channel configuration.

Eccentric weights are located horizontally at either end of the vertical vibrator shaft and are adjustable relative to one another. When set within the allowable range established by the manufacturer, a spiral motion to the parts and media is produced. A change in their relationship allows adjustments of the spiral path to complement the part size or configuration. Additional weight may be added to accelerate the mass velocity to move a more dense mass.

In the case of bowl machines, the angle between the top and bottom weights affects the action of the rolling mass. The lead angle is the number of degrees the bottom weight leads the top weight as the shaft rotates. If one observes the rotation when the cover is off, usually the difference seen is 60–100 degrees. For a given amount of weight on the top and bottom, a lead angle close to 90 degrees gives the maximum travel rate around the bowl (Marcus 1994). Higher lead angles give more lift and are useful for keeping heavy parts from being damaged on the bottom of the bowl. Lower lead angles have the effect of giving more roll rate and keeping the parts submerged in the mass.

For any lead angle more top weight will increase the forward drive of the mass, also increasing pressure against the center post. More bottom weight will increase the roll weight, also increasing lift at the outer wall.

Any change to the lead angle or to any of the weights will affect the roll rate, the forward drive, the center post pressure, the angle of repose, the lift of the parts, the ability of the parts to separate with internal separation, and so on.

The *overhead drive* (OHD) vibrator is located above the centerline of the mass (Figs. 10-6 and 10-7). Its flyweight is oblong and mounted on the allowable length of the shaft between bearings. The low profile design of this type of flyweight allows clearance for multiple vibrators. Like all other eccentric weighted vibrators, the direction movement of its flyweight is opposite that of the mass. The overhead location above the tub centerline induces a pull-up motion, producing a uniform lift angle cascade to the mass.

The opposing vibrator method is to mount the vibrator shafts horizontally on both sides of the tub (Figs. 10-6b and 10-8). The shafts are synchronous and amplitude input is equal for each shaft. The theory is that this equal division of shaft amplitude input at the centerline of the processing chamber results in a more fluidized mass, creating a circular orbit to the tub and mass. Large dual-shaft tubs can finish parts weighing more than 2000 lb (Freeman 1983).

When weights are above the center of the bowl they are easy to access in machines under 10-cu ft diameter. For larger machines, operators have to crawl onto the machine to make changes.

10.3.9 Liner Material

The introduction of wear-resistant polyurethane as a work bowl liner significantly reduces the coefficient of friction between the media and bowl, thereby raising the media wear efficiency of the vibratory machines. Presently, new materials are being investigated that will have an even better coefficient of friction than polyurethane with simultaneous high creep strength.

By adjusting the ratio and type of raw materials, the resulting elastomeric lining can vary in hardness from about 50 Shore “D” to over 90. Softer linings are believed to make steel media roll easier and are considered less harmful to delicate parts, while harder materials are said to last longer.

Rubber and PVC (polyvinyl chloride) are sometimes used as lining materials. Neither have anything like the durability of polyurethane, but they are cheap and can be found in inexpensive small equipment.

10.4 METHODS OF PART AND MEDIA SEPARATION

Many methods are utilized in the separation of parts from media and the best approach is a generous application of common sense. One author notes that once media and parts are mixed together in a unit that can do the work, separation is the single most important cost consideration. Separation can cost more than the entire process if it is not designed into the system. The long radius burnisher described above solves this problem. Separation is accomplished in three areas:

- in the machine
- at the machine
- remote to the machine.

The most common separation method is to pass parts and media over a screen allowing the parts to drop through and the media to remain on top or to pass off (Fig. 10-18). Should the parts have projections that can hang up in a screen hole in the pass off method, then a bar deck would allow an uninterrupted path for the parts to pass off. Step or flip stations can provide a turnover for parts that may have dished or recessed areas that would hold media. Timing is important so that an upward facing part holding media does not turn over emptying its media into another upward facing part on the lower step.

Magnetic separators work well where ferrous parts are run with a non-ferrous media and the size relationship is such that it would be the faster method. Magnetic separation usually requires a demagnetizing operation.

In-the-machine separation involves: a) hand picking, b) manual or automatic magnet inside bowl, or c) machines equipped with an internal separator. For internal bowl separation flat bottom channels generally have vertical or near vertical dams that interrupt the mass path by blocking off the channel. The continued energy input from the vibrator directs the mass against the dam, pulling the mass up upon itself until high enough to continue over the top and across a screen deck (Figs. 10-18 and 10-24). Screens have hole sizes large enough to pass the media back through into the processing channel, yet small enough to pass the parts off the top.

Bowl machines that feature an inclined or spiral bottom (lock washer design) utilize a discharge gate located at the high point of the processing channel and, when engaged, acts as an extension of the processing incline, directing the mass to the screen deck for separation as described above. Bowl vibrators easily achieve various degrees of automation. Figure 10-12 illustrates a machine equipped with a screen for parts and media separation and a discharge chute. A gate can be raised or lowered within the bowl to act as a dam (Fig. 10-24), stopping the continuous flow of workpieces and media around the bowl when desired. When the gate is either raised or lowered a screen separates the workpieces and media—the workpieces being discharged down the chute and the media being retained in the bowl. Bowl machines with internal separation may also be fitted with a media classifier that will discharge undersized media from the machine.

At-the-machine external separation involves evacuating the mass to a separator, either magnetic or screen type. Upon completion, the media is then reintroduced into the machine by hand, a hoist system, or conveyor. External separation allows for classification of undersize media and particle fines to aid in preventing media lodging or debris collecting in part holes, corners, or crevices.

Remote-to-the-machine is the procedure of evacuating the mass into a container. The container is moved to an area for separation, either by hand separation or automatic classification.

Magnetic separators are sometimes used when finishing ferrous parts with non-ferrous media. Machines can be equipped with magnetic parts collectors and demagnetization equipment, permitting the media to remain within the bowl.

10.5 CONTINUOUS EQUIPMENT

Continuous installations are typically systems of machines working together. The first considerations are production volume and material handling requirements, i.e., the moving of products to the machine from the loading method to the separation stations, rinsing and drying, then unloading

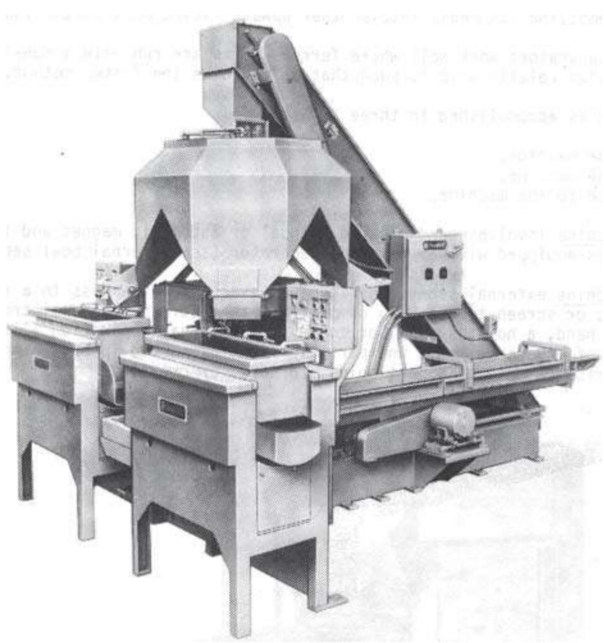


Figure 10-30. Rotary media bins, incline elevator, and screen separator (four-machine capacity, shown with two machines) (courtesy: SME)

(see Figs. 10-10 and 10-30). Other post processing operations may be included as required. If media other than steel is used a media classification area may be required to automatically discard undersize or worn media to prevent media lodging in the workpiece. Continuous equipment is usually of the in-line method, which better lends itself to in-line external automation. However, there are many applications for continuous bowl machines. Two methods of processing are available with the bowl machine. One is the conventional once around and out with the cycle time governed by the machine size and capacity—along with important part size and weight considerations. The second method, now out of date, involves a dwell system that is accomplished by shifting the top weight of the vibrator between pre-set stops, thus creating an alternating feed/dwell effect to the mass movement, resulting in a longer cycle within the processing channel.

Both bowl methods utilize the internal separation method where a dam or gate interrupts the mass travel. This method directs the mass upward where it is separated on a screen deck above the processing channel sending the parts off the top while the media passes through the screen, depositing it back in the processing channel. Multiple pass machines can duplicate the time cycles and production of all but the largest in-line machines. Some multi-pass machines have channel lengths over 75 ft (23 m).

Multi-pass equipment can either run the parts around the bowl for a longer time or perform a second operation on parts within the same piece of equipment (i.e., polish, clean, coat, etc.).

Cycle time and production volume are important considerations in the evaluation of bowl equipment. The once-around-and-out method may be too quick for deburring, but excellent for use as a parts washer or cob dryer. The second method using the dwell system may not yield sufficient production.

In-line machines have flexibility limited only by imagination; volume, part size, weight, or cycle time rarely present problems. The machine does not require excessive amplitude to elevate the mass of bulky or heavy parts up to a separation screen because the mass simply passes off onto a screen deck placed at a convenient level to the exit end of the processing channel (Fig. 10-10).

Unlike in bowl machines, the separation area in continuous equipment is independent of the processing unit, allowing for a separator speed and size compatible to the process and adequate to the task. The media is directed from the separator to a conveyor, returning it automatically into the starting point of the processing channel. Amplitude adjustments can be accomplished without the cycle time being affected, which is adjusted by varying the speed. The primary cycle adjustment is the level of the load.

Continuous equipment is not limited to small parts. Such large parts as cast utility meter housings and lawn mower decks are examples of products that may presently be batch processed and are excellent candidates for continuous equipment.

In-line equipment is available in two styles: *open top* and *tube*. Both can be equipped with a plug-type door to block the discharge end. This feature gives the added flexibility of batch operation, allowing the process cycle to be extended beyond the normal continuous mode.

Open top machines are best utilized where a duplex continuous batch operation is planned.

The open top allows manual loading/unloading of the parts during batch operation and full view of the mass during continuous cycles.

Tubular units are totally enclosed. The ends of the processing chamber feature openings engineered to the application for automated loading and discharge of the mass. The tubular equipment advantage is the processing chamber, which is enclosed and lined around its full circumference; this usually drops the operating noise by 20% or more, compared to one of the open top designs.

Regardless of the type machine selected (bowl or in-line), the diameter of the processing channel is directly related to production volume and processing time.

Machines can be placed in tandem. For example, one machine can be used for heavy deburring, discharging parts into a second machine for surface refinement or burnishing and rust inhibiting, and then discharging into a third machine for drying. Parts can automatically transfer from the dryer onto a conveyor for subsequent operations or containers (Fig. 10-38).

Load level control is possible with small vibratory hoppers to feed media into the chamber every so often. Set up on a time basis, such devices approximate the media use rate. Set up on a demand basis, media levels are held constant with little operator attention except to keep the hopper full.

10.6 FIXTURED PARTS AND COMPARTMENTED MACHINES

Fixture and compartment processes are utilized where part-on-part contact is prohibited. Fixture processing is used when many parts of the same design are needed. All parts must have a common area for holding, such as a hole or threaded stud. The parts are generally attached to a rotary fixture, but non-rotating fixtures have also been used. The fixture is then lowered into an empty tub type machine. Another choice for some parts is to bolt the fixture frame to the tub. The frame mounted with bearings allows the fixture to rotate freely, then media is added. The media motion causes the fixture to rotate. Properly designed fixtures hold the parts for equal exposure to the media. Total removal of the media is usually required prior to removal of the fixture at completion of the cycle. Obviously, this method of finishing is utilized only where necessary. The channel shape employed is usually the straight wall, U-type or modified keyhole. Both allow for ease of entry and removal of the fixture.

Material handling equipment is necessary to load and remove both the media and the fixture.

Early research noted that the position of the part within a U-shaped tub makes a significant difference in metal removal rates (Matsunaga & Hagiuda 1965b). Figure 10-31 shows a position designation that defines orientation of test samples. Figure 10-32 shows the stock removal rate for one set of conditions as a function of both angular orientation and distance from the end wall. Figure 10-33 shows the force of media hitting a force-measuring device in the tub. As seen, there the greatest abrasion forces occur at the bottom of the tub. Figure 10-34 illustrates the effect of media size and location on metal removal on fixtured parts. Not shown is the fact that metal removal rate decreases as vibration amplitude decreases.

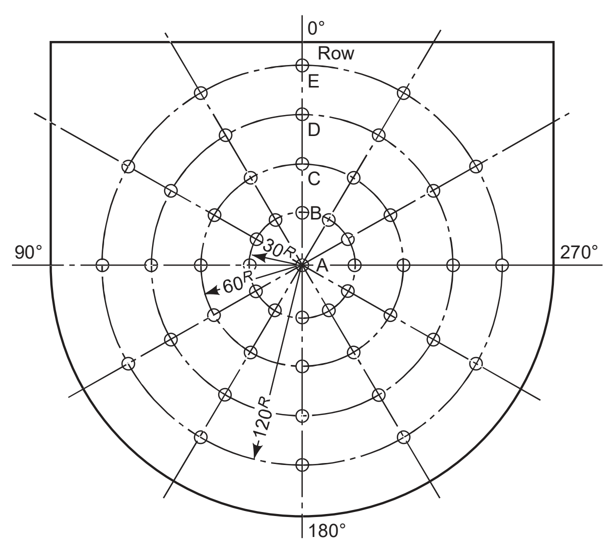


Figure 10-31. Definitions of location in vibratory tub (Matsunaga & Hagiuda 1965)

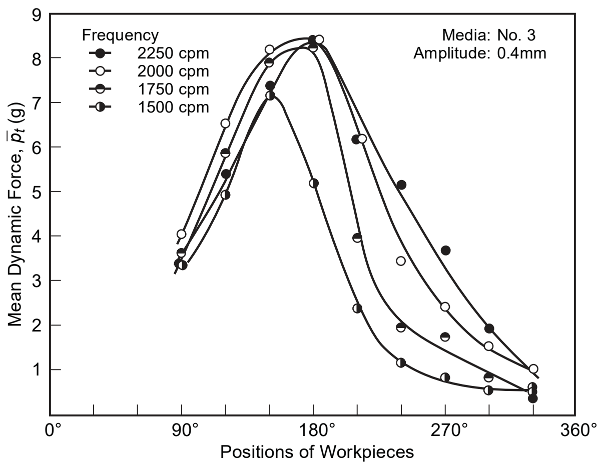


Figure 10-32. Effect of frequency and location in tub on metal removal rates (Matsunaga & Hagiuda 1965)

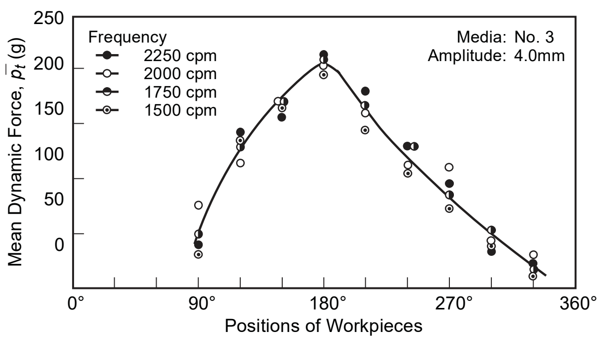


Figure 10-33. Force of media hitting part (Matsunaga & Hagiuda 1965)

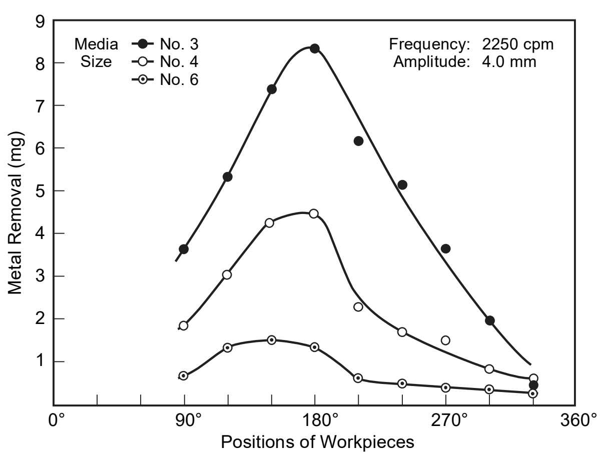


Figure 10-34. Effect of media size and location in machine on meal removal rate (Matsunaga & Hagiuda 1965)

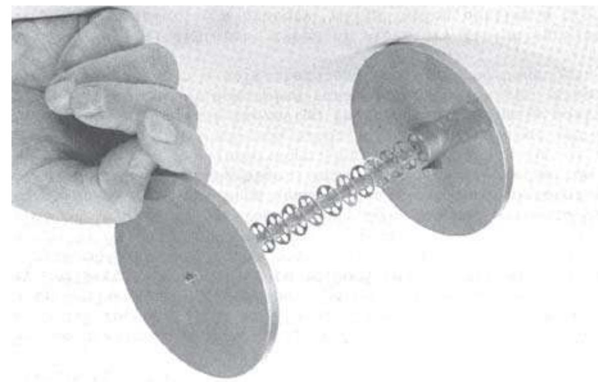


Figure 10-35. Special fixture used for deburring small gears. Rubber spacers between gears permit media to circulate freely. (H.D. Russell 1976)

10.6.1 Fixtured Parts

Fixtures are used to hold parts. They make a "big part" out of a number of smaller ones. These fixtures are then placed in the vibratory tub loosely or are bolted to it. Figures 10-35 and 10-36 illustrate results and tooling for small gears in a large machine[2]. Figure 10-37 illustrates two approaches to conventional fixturing.

Because fixtures prevent any possibility of one part touching another, they allow much higher part loading in the vibratory chamber, increasing the efficiency of the operation and offsetting some of the cost of the fixturing process. Fixtures are used for very high quality work. One of the earliest examples of fixtured parts is 12-ft long 7075-T6 aluminum wing spars for aircraft (Anonymous 1958). Flat spars are deburred in 6 minutes using only a 4-in. depth of Number 6 abrasive. In this instance the media is held in a stationary tank and only the parts vibrate (actually reciprocate) in the simple machine.

Vibratory fixture processing:

- causes faster processing
- allows more pieces per load
- produces finer finishes
- prevents part-on-part impingement (damage)
- provides more internal work in narrow passages and openings

[2]The surface texture shown in the third illustration of Fig. 10-36 is common for vibratory deburring.

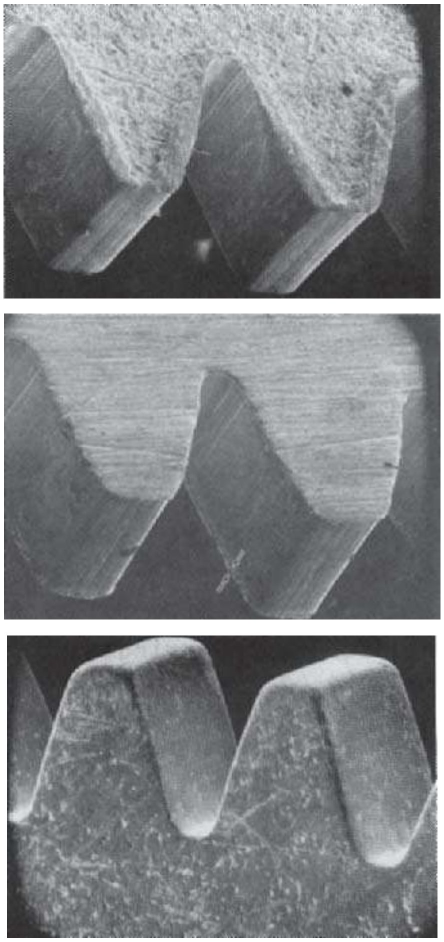


Figure 10-36. Edges of gear teeth after vibratory finishing (Russell 1976)

- allows smaller media to be more effective
- allows higher machine frequencies to be used
- prevents damage to the machine liner from sharp edged parts.

An early researcher notes that fixtured vibratory processing cuts operating time by a factor of 4, provided the fixture is attached to the lip of the container. Mounted in this manner the parts do not give when the media hits them and this results in greater pressure between parts and media, thus causing the faster action (Brandt 1967). To provide uniform action it is desirable to rotate the media in one direction, then reverse it for half the cycle. Parts should be kept 2–4 in. (50–100 mm) from the bottom of the tub and at least 2 in. (50.8 mm) below the top of the media in order to get uniform action. Tub-type vibratory

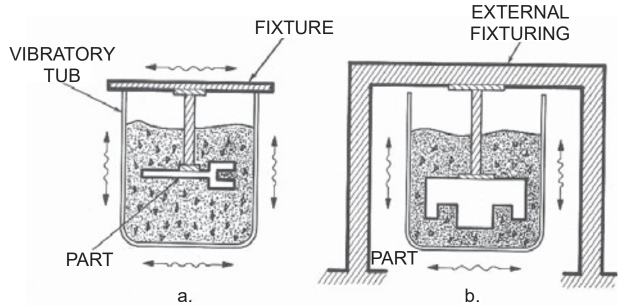


Figure 10-37. Part fixturing results in faster deburring cycles. External fixturing is used for heavy parts. (Sofronas 1976)

machines are easier to use for fixturing, but bowl-type machines can also be used. Keyhole tub designs restrict the opening and make it harder to use fixturing than do straight U-shaped tubs. If media flow cannot be reversed in direction, the fixtures can be removed and turned 180 degrees to more effectively expose the opposite side of the parts to the media. When many different part designs must be fixtured, users will want to build a universal frame to which each fixture will attach. Remember that fixture weight can load the vibratory motor above its limit. Operators should make sure that the machine would not be overloaded before investing in fixtures. Clamps on fixtures must not block media flow around parts. Therefore, clamping deserves special planning.

For faster processing, users should have two of each fixture. One is loaded and used in the machine while more parts are being loaded into the second fixture. Spring-loaded contacts or holders help minimize clamping time. Pneumatic clamping can also be faster than manual mechanical clamps. Threaded ends must be covered or they will wear quickly. Rubber coatings are not typically required on fixtures. The initial high wear rate on fixtures settles down to a slow action after a few runs.

Aluminum stator housings have been fixtured and polished to 2-µin. finishes. If part quality is not attained in normal run cycles, the part is loaded at an angle in the fixture or reversed. Impellers, for example, may not polish well when placed face on to the media, but picking the right angle makes the difference between success or frustration. Pump impellers weighing 250 lb each have been finished by fixturing for decades. New users of fixturing are encouraged to visit vibratory deburring manufacturers to see various designs for applicable fixtures. One enterprising plant faced piston rings entangling with each other because of the gap cut in the ring. This plant selected an in-line machine and took a pipe slightly smaller in diameter than the rings. Parts were continuously fed onto the pipe by flattening the end for easy access. The vibratory media dragged the rings along the 12-ft length of the pipe, deburring them as they traveled. They automatically discharged when they got to the end of the pipe—no tangled parts!

Floating fixtures are used when the purpose is to prevent part-on-part damage. These fixtures allow more parts per load than the do the permanently attached fixtures. Fixtures must be rugged to survive the constant force on parts and fixtures.

10.6.2 Compartmented Approaches

Compartments do much the same as fixtures, but are not quite as efficient. One or more bulkheads, making several smaller chambers out of one big one (Figs. 10-25 and 10-26), divide the tub or bowl chamber. Used for larger parts, one part is dropped into each compartment, insuring no part-on-part contact. Parts are normally loaded into and removed from each compartment by hand. As mentioned earlier, compartments can also be used to separate different media in the same machine. In the bowl machine shown in Fig. 10-25 the manufacturer uses the term "indexing compartments" to denote the fact that the entire insert rotates or indexes around during the cycle as part of a carousel. Another approach is to place the entire machine on a large turntable. One example of this latter approach is the use of a 50-cu ft capacity bowl machine to process 12 in. × 12 in. (0.304 m × 0.304 m) die-castings, which would be damaged by part-on-part contact. This 8.5-sec operation was shown to produce one of these very large parts out of the machine every 9.3 sec (Freeman 1983).

10.6.2.1 COMPARTMENTED EQUIPMENT

Compartmented finishing is accomplished in both tub- and bowl-type machines. Permanent or bolted-in dividers (Fig. 10-25) compartmentalize tub-type machines. Three approaches are used with bowl machines:

- The first approach is to mount dividers directly to chamber walls. The dividers have holes in them so media and solution can circulate, but not big enough holes to allow parts to escape.
- A more popular design uses a system of dividers mounted on a bearing, attached to the center section of the bowl. This creates a movable carousel of compartments, which slowly rotates with the media around the chamber as noted above.
- The third approach is the loose carousel with a set of channel dividers mounted on a frame, which can be dropped into the chamber. (Some consider this not as well designed from an engineering standpoint.) Supported entirely by the liner, the loose carousel allows compartments to be used only when desired. Inclined or spiral bottom bowl machines cannot be compartmentalized efficiently.
- The advantage of tub machines for compartment finishing is that the compartments can be more easily moved or removed to accommodate large or small parts. The tub can be manufactured with compound spray and drains for each compartment.
- The advantage of compartmentalized bowl units that cycle once around and out is their predetermined production cycle. When non-abrasive media is used, compartmentalized vibratory machines make excellent part washers for small or delicate parts that are hard to clean.
- In addition to fixtures and separators parts can also be placed in cages, which permits the media to come through and work the parts, but prevents parts from touching each other. Several cages can be put in a tub at one time (Nunn & Kenney 1964).

10.7 BALL BURNISHING EQUIPMENT CONSIDERATIONS

Because of the high bulk density of steel media coupled with its low angle of repose, vibratory equipment design concepts must be modified when using steel media (Kittredge 1979). The media will not "roll" and "feed" like other media types because of the lack of frictional characteristics between the pieces and because of the low coefficient of friction between the media and the lining of the vibratory machine. The tub lining is the source of power to the media mass and, since the media is not abrasive, the media often skids on the lining—as a bald tire would do on wet pavement.

Tub-type vibrators have not been successful in the ball burnishing market partly because of their lack of ability to roll the media mass, and also because of separation problems. Steel media flows so easily it is difficult to handle on a separating screen, which is external to the machine, and even more difficult to get back into the machine by means of a conveyor belt.

The round-type of vibratory machine, by its basic design, reduces the cross-sectional area of the steel media mass and has a built-in screen deck. The conveyorized handling of media is therefore eliminated. With steel media and its desire to flow, simplicity is an absolute must in equipment design. If the media never leaves the tub it eliminates the problem of returning it.

Most manufacturing engineers get a better appreciation for equipment design in steel burnishing applications when they go through the following considerations. This exercise is based on a 20-cu ft (566 liter) steel ball burnishing machine operating on a 12-minute continuous cycle. The size of the equipment and the cycle time are about average. With this 20-cu ft machine the goal is to handle approximately 6000 lb of steel (2700 kg) per 12-min continuous cycle. There will be 5 cycles per hr, or 30,000 lb (13,600 kg) per hr, which translates to 240,000 lb (109,000 kg) per 8-hr day, 1,200,000 lb (545,000 kg) per 5-day week, 60,000,000 lb (27,000,000 kg) per 50-week year. And that's only the first year! Automated loading and unloading equipment is a necessity when using steel media.

Long radius burnishing equipment is a further improvement in equipment design over the *standard radius* round equipment. As noted before, these long radius machines have ratios of overall tub diameter to channel diameter up to 9.5:1. In other words, they have a smaller channel diameter and bigger overall machine diameter. Figure 10-16 shows a 20-cu ft (566-liter) long radius burnisher with an overall tub diameter of 78 in. (1985 mm) and a channel diameter of 14 in. (356 mm) for a ratio of 5.6. Conventional standard radius equipment will have ratios on the order of 3 to 4. The angle of climb of the media mass in short radius machines is much too great and the high density and smooth surface of steel media causes it to slide back downhill. The long radius machines are therefore much more foolproof in their ability to move the media mass.

A final consideration in the design of equipment is the absolute necessity for ruggedness. The extremely high bulk density of steel media requires maximum structural integrity of the burnishing machine. Long radius machines are desirable for finishing with steel media. The machines have an overall tub diameter greater than normal and the load channel is reduced from standard dimensions. This results in a reduced angle of climb for the media mass, producing a more effective slide pattern. Stated differently, there are more channels in the machine than normal. Large long radius vibratory steel ball burnishing machines in the 50-cu ft (1416-liter) range, for example, are 12 ft in diameter and have an empty vibratory tub weighing over 20,000 lb (9100 kg). A machine this size will handle 15,000 or 16,000 lb (6800 or 7300 kg) of steel media, depending on whether batch or continuous cycles are used. With the high horsepower available on large eccentric weights widely separated, the forces on these tubs become extreme. Heavy-duty construction with solid welds is essential. Lightweight vibratory burnishing equipment will not last.

10.8 AUTOMATION

Well-designed equipment with easy separation capabilities allows simple, fully automatic or semi-automatic systems to be developed with ease (Figs. 10-38 and 10-39). Figure 10-40 shows a parts feeder feeding a burnisher, which, in turn, feeds a fresh water rinse and shake-off unit. Then a vibratory parts dryer filled with cob meal discharges onto an inspection belt. Systems involving the feeding of one machine from another are commonplace. If the parts must make more than one cycle around a bowl machine to provide the needed finishing, timers can raise the separator

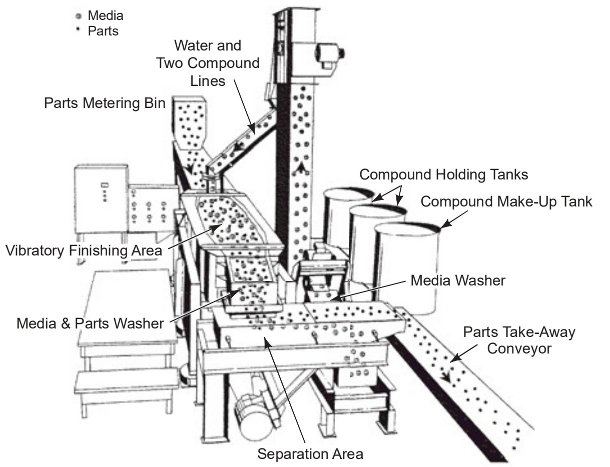


Figure 10-38. Continuous, in-line vibratory finishing (Anonymous 1963)

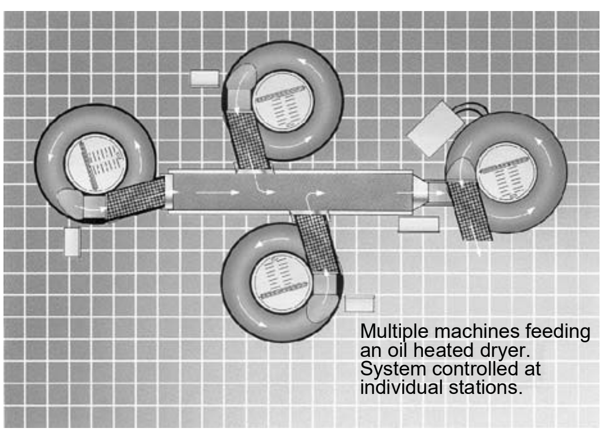


Figure 10-39. Multiple bowl machines feed an oil heated bowl dryer (courtesy: Hammond Roto-Finish)

screen at the end of the cycle. For machines producing a single part month after month, the machine can be built so that a single pass around the machine produces the desired action and the separator is always in the up position.

10.9 UNIQUE MACHINES

Several unique designs exist for vibratory applications. Some of these have already been described, but this section looks at others. As in all deburring, each machine has its own best application and no one machine fills all needs.

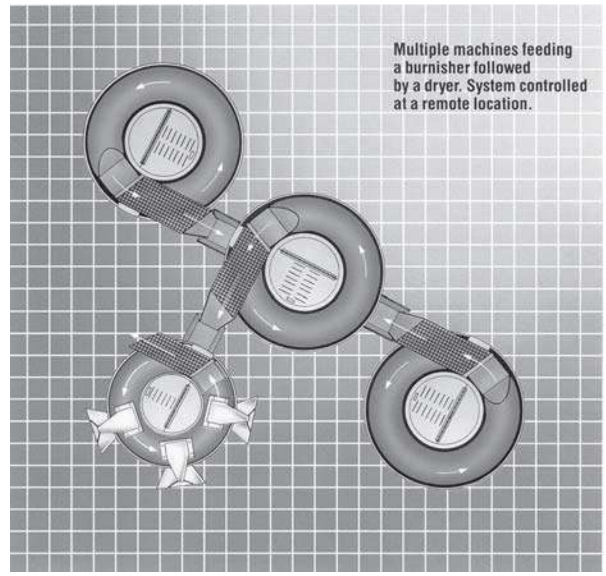


Figure 10-40. Two bowl machines feed a bowl burnisher followed by a corncob dryer (courtesy: Hammond Roto-Finish)

10.9.1 Combined Vibratory and Blasting Operations

One company produces a vibratory machine that combines shot blasting with the rolling action of normal vibratory operations. This equipment reportedly accelerates the deflashing of die castings. The machine looks like a conventional vibratory bowl, but has many blasting nozzles around the exterior. As an example of one use in the 1970s, a company vibratory-finished golf balls to provide a smooth finish and remove flash. After blasting they were painted (Poll 1978; Stauffer 1979). With this latest design they could be finished in one operation.

10.9.2 Vibratory Blasting Equipment

A recent innovation is a vibratory finishing bowl with blasting heads around the periphery[3]. The vibratory motion moves the parts without fixturing under the blasting heads. At the same time it provides some conventional vibratory scrubbing or deburring, but the manufacturer notes that

[3]Hammond Roto-Finish Spiralblast.

Figure 10-41. Blasting machine, which utilizes tumbling action (courtesy: Hammond Roto-Finish)

most of the finishing actually occurs from the blasting nozzles. Blasting machines sold in the 1960s had a similar arrangement, and, like the latest design, the primary deburring or deflashing was performed by the blasting as opposed to the tumbling (Fig. 10-41).

10.9.3 Combined Vibratory and Centrifugal Machines

In 1978 one manufacturer introduced a machine that claimed to be 30 times faster than a conventional vibratory machine (Anonymous 1978). Data for three different parts were presented. The bowl-type machine begins with a vibratory action, then the machine's rotor begins, adding the centrifugal force. When the process cycle is complete, the rotor stops, then media and parts are separated. The machine can be operated in vibratory, centrifugal, or vibratory centrifugal mode (Anonymous 1978).

10.9.4 Combined Vibratory and Spindle Finishing

One Russian researcher describes the use of a vibratory container and spindle finishing

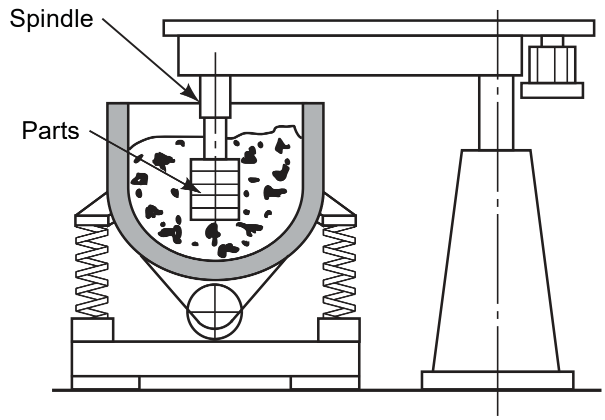


Figure 10-42. Combination vibratory and spindle machine (courtesy: Yuri Baron)

(Fig. 10-42) to finish parts (Baron 2002), but presents no results.

10.9.5 Combined Vibratory, Spindle, and Electrolytic Finishing

Russian research describes the use of a vibratory container and spindle finishing with an electrolytic solution and power supply to finish hard-to-machine parts (Baron 2002), but without data (Fig. 10-42). The original work appears to have been performed at Don State Technical University by Dr. Anatoly Babichev, a leader of vibratory technology in Russia. Japanese researchers also discussed this in 1970 (Anonymous 1970). Chapter 23 describes electrolytic mass finishing in more detail.

10.10 MEDIA SHAPE EFFECTS

Chapter 6 describes many aspects of media, but one aspect specifically related to vibratory operations is the impact of media shape on finishing. Figure 10-43 shows the change in surface roughness when cutting with media of similar hardness but different shapes on aluminum alloy AlCuMgPb (Przyklenk & Schlatter 1987). The flat part shape used is shown in the figure, as are the media shapes. Figure 10-44 shows similar data for the percent of material on the part that was abraded away after 6 hours. Figure 10-45 shows the impact of shape on part edges. Several figures in Chapter 6 also show the impact of correct media shape and size.

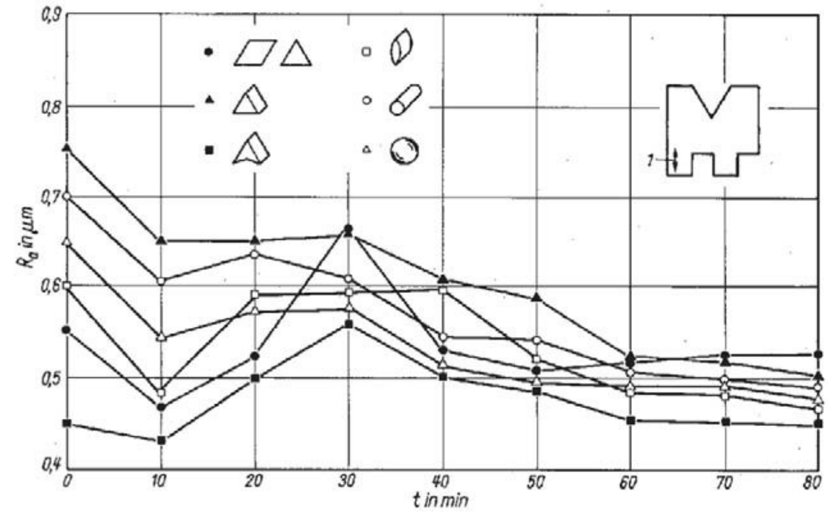


Figure 10-43. Change in surface roughness during vibratory finishing with media of different shapes, but similar hardness (Copyright Aluminum-Verlag, Marketing & Kommunikation GmbH) (Przyklenk & Schlatter 1987)

10.11 SELF-TUMBLING

When burr removal is the only key requirement of a part, vibrating parts without using media is a good solution. It is fast, inexpensive, and can be done dry or wet. Another alternative is to use some metal media. Nails, brads, or screws provide points and ridges sufficient to remove many burrs from hard to reach areas.

Parts may be run with no compounds, but for heavier cutting wet media and added abrasive compound are helpful. In about 30 minutes the compound will break down and the entire contents of the tub will begin to dry out. If the deburring is adequate then parts can be rinsed. If it is inadequate, the wetting and compound addition can be repeated and the cycle rerun. The final steps can be addition of burnishing compound or cleaner, then rinsing. Fifteen minutes may be needed to wash out all the compound. The worn abrasive compound may provide enough action to eliminate the need for burnishing compound. Lubricity may be needed if the parts do not roll well in the machine.

Part-on-part processing may require some experimentation, but if it saves compounds and time, it also reduces waste treatment and costs little or nothing to do.

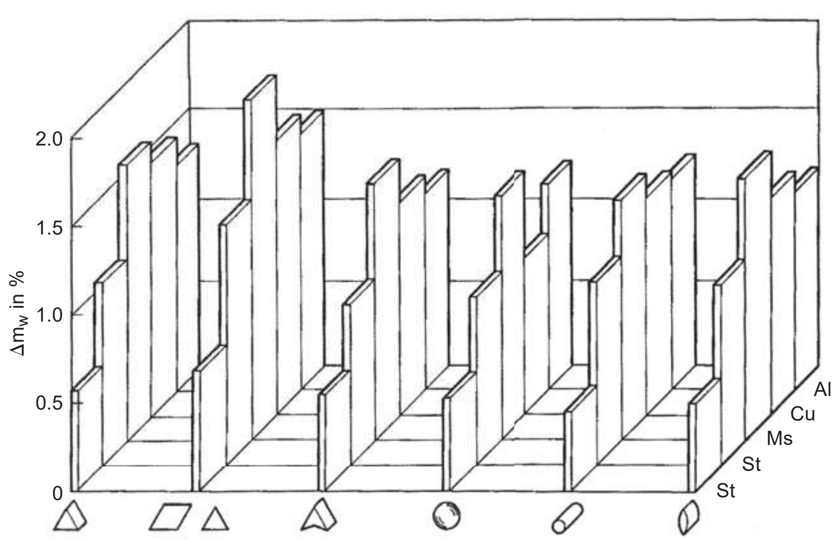


Figure 10-44. Percentage of part material abraded away using media of different shapes, but similar hardness after 6 hours (Copyright Aluminum-Verlag, Marketing & Kommunikation GmbH) (Przyklenk & Schlatter 1987)

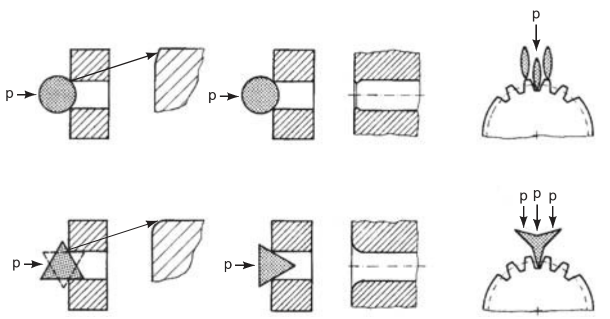


Figure 10-45. Characteristics of various deburring chips (Copyright Aluminum-Verlag, Marketing & Kommunikation GmbH) (Przyklenk & Schlatter 1987)

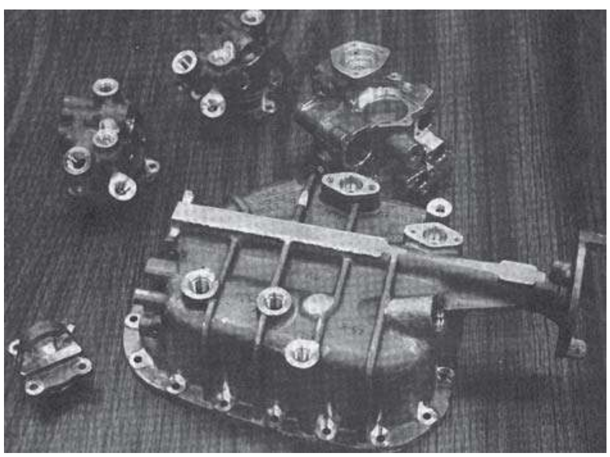


Figure 10-46. Fuel control housings finished in vibratory machine to remove burrs (Stauffer 1979)

10.12 FINISHING LARGE PARTS

The very long machines allow use on large or long parts. Typically, four or five or more tub machines are attached end to end to produce such length. Each module has its own vibratory motor mounted to the bottom of that section. Media unloading can be at one end, or more typically at the side of each section. The modules are tied together with heavy-duty polyurethane couplings.

Figure 10-46 shows aircraft fuel control housings that are vibratory finished. Preventing lodging is critical in this application. These part configurations are typically ruled out as applicable to vibratory finishing by many users, who mistakenly believe the parts will be damaged and not receive the necessary action.

As another example, a 48-in. × 144-in. (1.22 m × 3.66-m) tub machine provides a 140-cu ft (3.96 m^3) machine to radius 200-lb (90.7-kg) titanium aircraft bulkheads. The tub produces a 0.010-in. (0.254-mm) radius on all part edges in 60 minutes. Hand finishing required 60 hours. In this instance the finishing media weighs 10,000 lb.

10.13 FINISHING SMALL PARTS

Buying a single machine to process a wide variety of parts may not be the best solution for many shops. For the average cost of one 2.5-cu ft machine users can buy five 1-cu ft machines or twelve ¼-cu ft machines (Kenton 1996). This allows users to run multiple parts at the same time, or it allows users to progressively process parts with different media in each tub. This also allows each worker to have his or her own machine and process parts as they come off machining centers. This is the kind of solution that allows cellular operation.

Multiple machines also simplify maintenance problems and eliminate the problem of cross contaminations such as copper parts leaving copper on steel, or low carbon steel residues carrying across to rust stainless steel parts. Similarly, steel left on aluminum parts will cause unacceptable rust spots.

Figure 10-47 shows the unique approach one shop used when their parts were too small for their vibratory machine. While this was not the most effective way to finish these parts, it allowed the plant to immediately complete the job. The job was to deburr Ni-Span alloy disks of about 5/16 in. (7.9 mm) diameter and 1/32 to 1/8 in. (0.8 to 3.2 mm) thick. Disks of the same sizes and of the same alloy heats had to be kept in segregated groups.

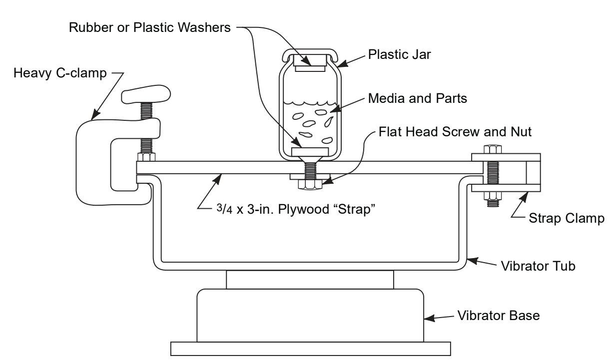


Figure 10-47. Simple vibratory setup for miniature parts (Anonymous 1988)

The job was done successfully with a large vibrator tub with three 3/4-in. (19.1-mm) wide "straps" of plywood clamped across the tub as sketched. One, two, or three 1-quart (0.946-liter) plastic jars were fastened to each plywood strap with a nut and bolt (Boer 1988). A 1/16-in. (0.4-mm) rubber disk was fitted at the bottom of the jar and under the lid. The Ni-Span parts and assorted deburring media were placed in the jars.

Two alternate methods had been tried, but proved unsuccessful (Boer 1988). In one, the loaded jars were simply allowed to float in the tub media. In the other the jars were mounted to a single plywood sheet that was fastened to the top of the tub. These two failures led the innovators to conclude that the narrow plywood straps were flexing to give the jars a more vigorous action, which provided better deburring of the parts.

10.14 DRY TUMBLING

In a dry system the predominant media, as previously mentioned, is usually a dry organic shell (apricot, walnut, etc.) or wood sawdust impregnated with liquid or wax additives. If the sawdust compounds are used, then a wood shape is also used to provide some weight and speed to the operation. Five parts of wood are used to one part of sawdust compound. This media is also used to create a variety of effects on hardwood products as well as to coat the wood parts. In a vibratory machine hardwood media and powdered abrasive can replace and automate many sanding operations (Davidson 1989).

10.15 DEFLASHING PLASTICS AND RUBBER PARTS

Phenolic parts such as electrical insulators are often deburred or deflashed in ball burnishers with cycle times as low as 9–12 min. Flash thickness must be controlled, however, to repeatably remove the flash. Chapter 19 describes the use of cryogenic deflashing, which is the more common approach for thermoplastics deflashing.

10.16 DEFLASHING CERAMIC PARTS

Ceramic parts are not normally thought of as good material for vibratory operations, yet today they are being deflashed just like rubber and plastic parts. Steel media deflashes electrical insulators. "Steel media does not change the electrical properties of the ceramic," according to one author, yet the quotation should be taken with a bit of care since steel on ceramic can leave steel coatings, which can be electrically conductive. Appropriate compounds may make the difference.

10.17 PROCESS VARIABLES

Process variables for vibratory finishing are similar to those for other mass finishing methods (Table 10-4). The process variables are shown in the following list:

Table 10-4. Variables significant in vibratory deburring

Compound	Media	Machine	Workpiece	Loading
Composition	Size	Frequency	Material	Amount of media
Grit size	Shape	Amplitude	Burr thickness	Amount of abrasive
Grit material	Material	Basic design*	Burr length	Amount of water
Emulsifying agent	Grit coarseness in media	Shape	Burr toughness	Volume of parts
		Capacity	Geometry	Weight of parts
	Composition			
	Weight		Burr location	
			Part size	
			Part weight	

*Some machines have "dead" zones in which little deburring action occurs.

- machine size and design details
- media size, shape, composition, amount, and ratio of media to parts
- compound abrasive size, material, and amount
- run time
- vibration magnitude
- vibration frequency
- position of weights (this affects part path in media).

The part-related variables include:

- part material
- part hardness
- part geometry
- part initial surface roughness
- part aesthetic requirements
- burr properties (thickness, height, hardness—different for each edge)
- part size
- part dimensional tolerances
- edge radii specifications and tolerances.

For barrel, centrifugal barrel, or vibratory equipment, the choice of the proper media must be sufficiently aggressive to remove burrs and to round edges while being sufficiently gentle to achieve desired surface finishes. The media variable generally requires the most trial-and-error testing. The size and shape of the media are also important to ensure action on all critical areas of the parts, including recessed areas of the workpieces, to prevent the media from lodging in such recesses or holes and to facilitate simple separation of workpieces from the media. If the media can pass freely through holes in the workpieces, or over the edge, radii on the hole edges will be produced.

Water can have a considerable effect on the results obtained with vibratory equipment. Too much water will substantially dampen the action by flooding. For this reason, many vibratory machines are designed for continuous flow-through of the water and compound solution. Compounds used serve the same functions in vibrators as in barrels. They enhance abrasive action, improve the color produced, inhibit corrosion, and, primarily, maintain cleanliness of the total load in the machine.

Other process variables for vibratory equipment are the amplitude of vibration, a variable provided on virtually all vibratory machines, and the frequency, which is variable on only some vibratory machines. Operational amplitudes generally range up to 0.375 in. (9.52 mm), and frequencies vary between 800 and 3600 vibrations per min. Speed of rotation equals the frequency of the transmitted vibration. Higher speeds and/or amplitudes of vibration produce faster metal removal rates but rougher surface finishes for given media and compound. Media wear rate is also increased. Vibratory tub and bowl machines are now available with high frequencies and/or amplitudes for higher energy mass finishing than previously possible. Figure 10-48 shows edge radiusing curves as a function of frequency and time in the machine for bronze parts (Russian bronze alloy KMts 3-1 weighing 20 to 40 grams) weighing 20 to 40 grams (0.044 to 0.088 lb). As shown in this figure, 40 minutes in a 30-Hz machine produces a 120-µm edge radius for the conditions cited. A 20-Hz machine requires 90 minutes to produce the same radius (Bagmet et al. 1974)[4].

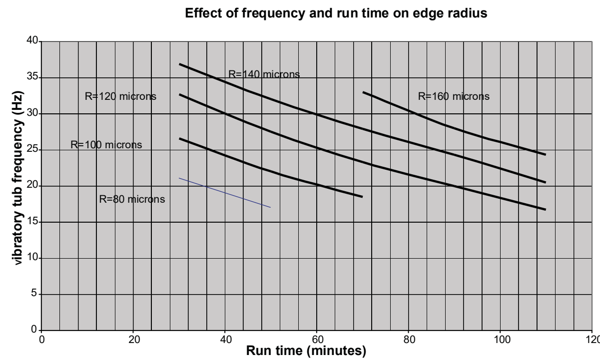


Figure 10-48. Lines of equal edge radii plotted against vibratory frequency *f* and run time with 4-mm amplitude vibration and 20–30 mm granules (Bagmet 1974)

10.18 EMPIRICAL GUIDELINES FOR CALCULATING CYCLE TIMES

From the charts shown earlier in this chapter and in previous chapters it is clear that for most situations of conventional vibratory finishing the following equations describe the process:

[4]Russian research on vibratory finishing provides many technical insights not found in other works. An extensive list of these works is found elsewhere (Gillespie 2004).

$$S = A_1 t \tag{10-1}$$

$$F(t) = (f_0 - f_\infty)e^{-t/T} + f_0 \tag{10-2}$$

$$R = A_2 t^m \tag{10-3}$$

where S is stock removal and

F = surface finish (roughness)
f_0 = roughness of part before finishing
f_∞ = roughness at time infinity for the specific finishing conditions used (Fig. 10-49)
t = time ran in vibratory equipment
T = time constant in hours (determined by plotting roughness against run time and finding time t at which roughness =

$$\begin{aligned} f_0 e^{-1} + f_\infty(1 - e^{-1}) &= 0.367 f_0 + f_\infty(1 - 0.367) \\ &= 0.367 f_0 + f_\infty - 0.367 f_\infty \\ &= 0.367 f_0 + 0.633 f_\infty \end{aligned}$$

R = radius of edge after finishing
A_1, A_2 and m = constants.

All the constants must be determined from at least one test run for a given set of conditions. Figure 10-49 shows four different starting roughness values for parts run under the same process conditions. Users can calculate the time constants T by noting that the surface roughness levels off to a value of about 0.064 µm which is the variable R_∞. If the part begins with a roughness of 0.71 µm as shown in the top curve, then T is the time at which roughness

$$\begin{aligned} f_\infty &= 0.367(0.71) + 0.667(0.064) \\ &= 0.303 \text{ hr} = 18 \text{ min.} \end{aligned}$$

If the data show the stock removal constant A_1 to be 0.05 µm per min, then in 18 min the process will have removed (0.05)(18) = 0.09 µm on a diameter or thickness. Similarly, if the radiusing constant m is 0.34 per min and the constant A_2 is 0.022 µm, then the radius after 18 min is

$$\begin{aligned} R = A_2 t^m &= (0.022)(18 \text{ min})^{0.34} \\ &= (0.022)(1.4049) = 0.031 \text{ µm.} \end{aligned}$$

The equations and calculations presented above are simple to use, and others exist (Hashimoto 1996). The issue for picking the best conditions entails that all the part requirements be met, not just surface finish. If a time of 18 minutes does not provide adequate radiusing in the above examples of finish, stock removal, and radiusing, then the process must run longer. Running longer will also increase the stock removal, improve the surface finish, and add cost. If a part has 10 different edges of concern and 3 critical dimensions to hold, some 13 different sets of data would be needed to determine the minimum run time.

Few individuals utilize the equations for non-critical parts, but the equations do allow computer calculations and provide an understanding and teaching tool to illustrate the challenge of the process on tightly toleranced parts.

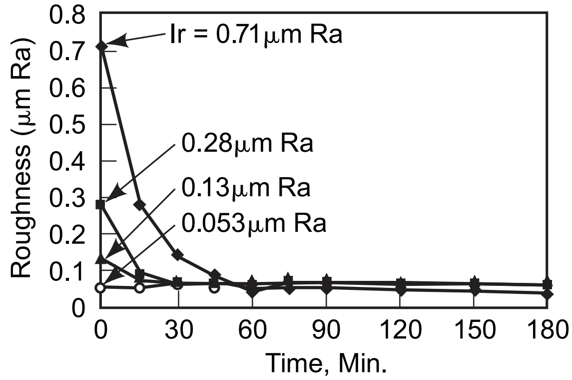


Figure 10-49. Roughness changes during vibratory finishing (Hashimoto 1996)

10.19 VIBRATORY FINISHING CAPABILITIES

As noted in previous chapters, several part attributes are affected when a part is placed in a vibratory machine or subjected to another mass finishing process. Specifically:

- burrs are removed
- edges are rounded
- surfaces are smoothed (or roughened)
- part dimensions are changed

as well as a host of other properties that can be affected (see Chapter 4).

In conventional vibratory finishing the very nature of the process makes it impossible to remove a 0.005-in. thick (127.0-µm) burr and maintain size within 0.000010 in. (0.25 µm). If this *were* possible, and if the details of how it could be done were known, then calculations of the economics would be possible. Therefore, the first question to answer is, “Will the process meet the technical requirements?” The following paragraphs describe typical changes and provide guidance for establishing similar data for the plant operation. They suggest improvements, give starting recommendations, and reference other works for continued improvement.

10.19.1 Deburring

Several excellent examples of vibratory finishing research exist as models to help the beginner. Response surface methodology is used in one early study to document the relationships between burr height reduction, edge radius, and surface finish improvement (Sofronas 1977). The researcher looked at workpiece hardness, burr thickness (width), processing time, media size, and vibration frequency as the key process variables. Since no abrasive was used in this study and the media was large the burr reduction was due to the burr being beaten over rather than it being abraded. Because most operations use abrasives, these results and implications may not agree with other studies. An earlier study gives simpler (nonmathematical) examples of deburring improvement approaches (Sofronas 1976).

10.19.1.1 ALUMINUM

In the first of the nonabrasive studies just mentioned the researcher found that the vibratory frequency is the most important variable of all studied when large aluminum castings are finished (6061, 2024, and 7075 aluminum). Higher frequencies increase effectiveness; larger media size increases actions. Processing time is the least important for this study. *Brinell hardness* (for aluminum) has insignificant impact on surface finish and edge radiusing for the conditions studied. More simply, when a constant amplitude vibratory machine is used and burr reduction and corner rounding are most important, the following guides are timely:

- Use the highest frequency possible.
- Use the largest media possible.
- Adjust the cycle time to achieve the desired result.

For this study of aluminum three basic relationships are established in equation format:

Burr height reduction H (%):

$$H = \frac{6\times 10^{-22} \times T^{0.51} \times M^{1.88} \times F^{6.13}}{B^{0.85} \times W^{1.62}} \tag{10-4}$$

Edge radius R:

$$R = 4.8 \times 10^{-11} \times T^{0.25} \times M^{0.79} \times F^{2.43} \tag{10-5}$$

Surface finish improvement S_F (%):

$$S_F = 4.2\times10^{-9} \times T^{0.15} \times M^{0.75} \times F^{2.93} \tag{10-6}$$

where H = percentage reduction in burr height
R = edge radius
S_F = percentage surface finish reduction
B = Brinell hardness (BHN)
W = burr thickness (in.)
T = processing time (min)
M = media size (in.)
F = vibratory frequency (cps).

Note that burr height starts at 0.025 in. (0.625 mm) and surface finish starts at 200 µin. (5.1 µm).

The impact can quickly be understood by looking at the value of the exponents. Exponents larger than 1 have the most impact. As seen in equation (10-4), because burr thickness W is in the denominator and has a big exponent, thicker burrs take longer time T to remove when all other variables are held constant. The advantage of these equations is that the user can optimize the operation for all three variables. As shown in the study, burr size reduction can be maximized when surface finish changes are limited to some value, while not causing the edge radius to exceed 0.010 in. The analysis can be further constrained to say cycle time must be within 30 min to 2 hr, frequency must fall within 1500 and 2000 cps, and media size must be within 5/8 and 11/8 in. (15 and 28.6 mm) ceramic triangles.

This study (Sofronas 1977) is a particularly good one for researchers of burr removal technique who rely on mathematical models and for those who need to have uniform burrs for their studies. In this instance the researcher used a *pseudo burr* (machined a cylinder to leave a thin flange that acted like a burr—see Fig. 10-50).

10.19.1.2 BURR REMOVAL TIME AS A FUNCTION OF BURR SIZE IN 303 SE STAINLESS STEEL

Another study uses simulated burrs to determine how burr size affects burr removal time (Gillespie 1975). Steel shim stock of various thickness are spot welded to 0.5-in. (12.7-mm) cubes of 303 Se stainless steel. These simulated burrs project above the top surface by varying amounts (Fig. 10-50c). After measuring burr height the parts are vibratory finished in 3/16-in. (2.1-mm) triangles and 1A-1 abrasive compound. Changes in burr height were then recorded each hour for 4 hr (Table 10-5).

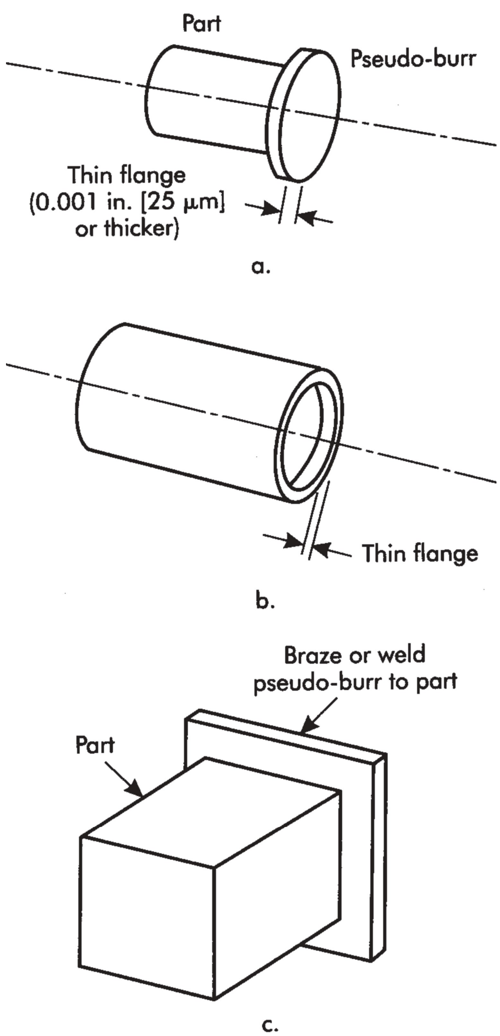


Figure 10-50. Pseudo burrs (Gillespie 1979b)

As seen in Fig. 10-51, the 0.001 in. (25.4 μm) thick simulated burrs wore more quickly than the 0.005 in. (127.0 μm) thick burrs. In fact, after about 2 hours the 0.001 in. thick burr was removed, and after 4 hours the edge had a radius of about 0.0025 in. In contrast after 4 hours the 0.005 in. (127 μm) thick burr had only been shortened to 0.0018 in. (50 μm) A regression analysis of the data indicates that the reduction in burr height (*dH*) can be expressed by

$$dH = (41.97 - 23.77b_t + 15.64t - 6.15b_t t + 4.34b_t^2 + 2.82t^2) \times 10^{-4} \qquad (10\text{-}7)$$

where b_t = burr thickness in 0.001-in. units, t = time in vibratory finisher (hr), and dH = change in burr height (in.).

Differentiating with respect to time provides an equation for the rate at which burr height decreases (in./hr):

$$H_t = \frac{dH}{dt} = (15.64 - 6.15b_t + 5.64t) \times 10^{-4} \qquad (10\text{-}8)$$

where H_t is the rate at which burr height changes (e.g., in./hr).

Figure 10-52 illustrates how a burr initially 0.005 in. (127 μm) high is affected by burr thickness. Figure 10-53 is an extrapolation of Fig. 10-51 with later data on edge radii given to illustrate how the final edge radius would be affected by

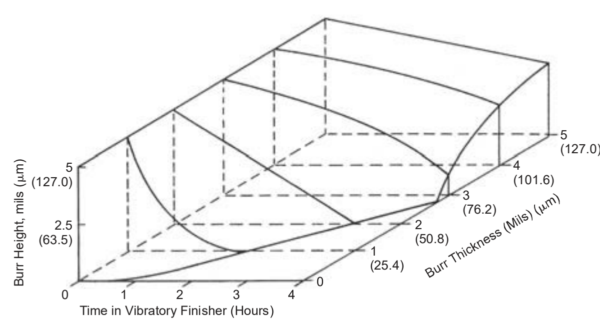


Figure 10-51. Effect of run time and burr thickness on burr height for simulated stainless steel (Gillespie 1975)

Table 10-5. Measured mean change in burr height

Mean Burr Thickness b_t in. (mm)*	Coded burr thickness X1*	Burr Height Reduction $H(t)$ (in.) after Indicated Time t (hr) in Vibratory Finisher			
		1 hr	2 hr	3 hr	4 hr
0.001 (25.4)	1	0.0035	0.0043	0.0089	0.0121
0.002 (50.8)	2	0.0020	0.0022	0.0031	0.0050
0.003 (76.2)	3	0.0018	0.0021	0.0031	0.0047
0.004 (101.6)	4	0.0014	0.0018	0.0019	0.0025
0.005 (127.0)	5	0.0008	0.0011	0.0013	0.0018
0.006 (152.4)**	6	0.0015	0.0015	0.0017	0.0022

*Value substituted into equations (10-7) and (10-8).
**Omitted from regression analysis.

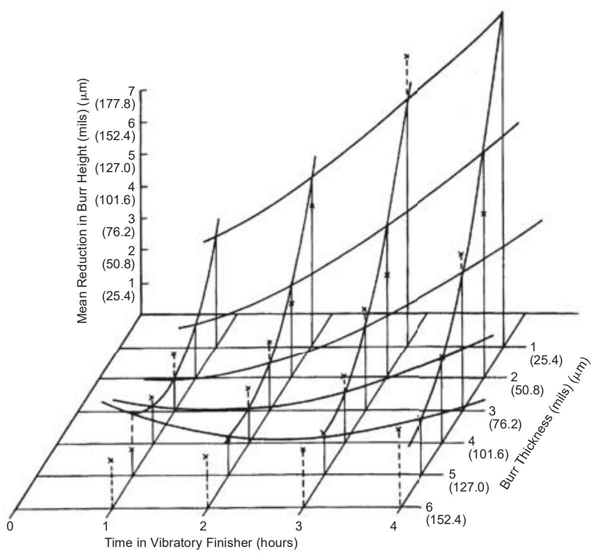


Figure 10-52. Effect of run time and burr thickness on burr height reduction for 303 Se stainless steel. (Gillespie 1975)

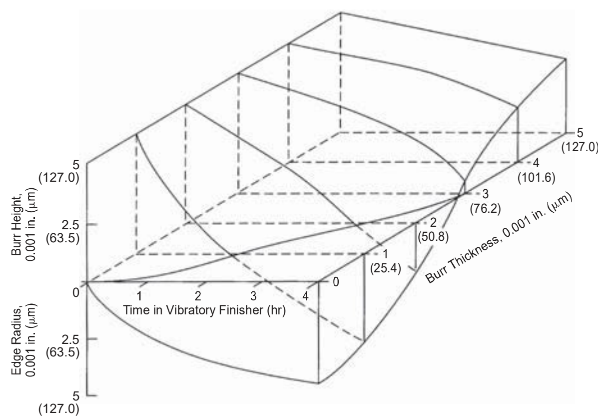


Figure 10-53. Effect of run time and burr thickness on burr height and edge radius for simulated stainless steel burrs. (Gillespie 1975)

burr thickness. In practice, the transition from a small burr to a radius would probably be a sharp discontinuity, since the radius actually begins forming on the burr (Fig. 10-54).

In viewing Fig. 10-53, it is clear that burrs 0.005 in. (127.0 μm) high and thinner than 0.001 inch (25.4 μm) wear away very quickly. Burrs which are 0.003 in. (76.2 μm) thick are not entirely worn away in 4 hours when using the 3/16-in. (4.75 mm) triangles. Little of the 0.005-in. thick burrs is removed after 4 hours.

As indicated in Fig. 10-53, when no burr is present, a 0.004-in. (101.6-μm) radius is produced after 4 hours. When a 0.001-in. thick burr, 0.005 in.

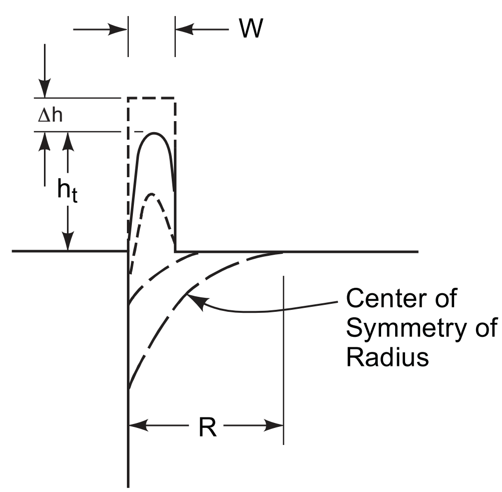


Figure 10-54. Configuration of burr as media wears it downs (Gillespie 1976)

Table 10-6. One plant's standard for permissible burr height on stamped metal parts (Ivaska 1983)

Permissible Height of Tight Burrs on Stamped Metal Parts, in. (mm)		
Material Thickness	**Continuous Burr**	**Random Burr**
Under 0.012 (0.3)	0.001 (0.025)	0.002 (0.05)
0.012–0.062 (0.3–1.57)	0.003 (0.076)	0.006 (0.152)
0.063–0.080 (1.6–2.03)	0.004 (0.101)	0.008 (0.203)
0.081–0.110 (2.06–2.79)	0.005 (0.127)	0.010 (0.25)
Over 0.110 (2.79)	0.006 (0.152)	0.012 (0.30)

high (25.4 μm × 127.0 μm) is present, the burr is gone after 1.8 hours. After 4 hours, a 0.003-in. radius exists on the edges. Four hours under these conditions would remove a burr initially 0.0027 in. (63.6 μm) thick and 0.005 in. (127.0 μm) high, but no measurable radius would occur.

Although this test utilizes simulated burrs, the results are consistent with production experience. In tests involving actual burrs 0.003 in. or thicker, some measurable stock is removed from the external surfaces before the burr is removed.

As mentioned before the key to success in mass finishing is to keep the burrs short, initially. This minimizes operation time and side effects and allows more parts to leave the plant each day. Each plant controls the size of burrs that arrives at the machine. Table 10-6 provides insight into one plant's standard for allowable burrs from the various manufacturing processes. This standard is generally aligned with sheet metal work practices, but there is no national standard covering all parts (each site or professional organization develops it own). Chapter 2 discusses edge standards in more detail.

10.19.2 Edge Radii

For a vibratory machine processing with loose media fill, the primary factors influencing material removal rates are:

- the average number of simultaneously acting abrasive grains (media particles) in contact with the workpiece at a given time
- the hardness of the abrasive media
- the velocity of flow of the processing medium
- the pressure that is put on the workpiece through the abrasive media
- the characteristics of the cutting edges of the abrasive media and how those cutting edges interact with the workpiece material
- the coefficient of friction between the media and the workpiece material
- the coefficient of friction between the processing medium and the coating of the work bowl.

All vibratory equipment have at least four variables in common: (1) single or variable speed; (2) fixed or variable adjustments for amplitude; (3) grease, recirculated oil or sealed bearings; and (4) type, number and size of drain patches, etc.

Equation (10-5) presented earlier in this chapter provides insight into the radiusing action on aluminum parts. Other materials such as bronze and stainless steel are described in the following sections.

10.19.2.1 BRONZE WORKPIECES

The impact of vibration frequency and run time on edge radiusing bronze is shown in Fig. 10-48 for one set of conditions. This chart is also summarized in a lengthy equation from a statistical factorial design, which, while not of broad industry use, does provide insight into several process effects that will apply to most materials (Bagmet 1974):

$$\begin{aligned} R_0 = {} & 38.3 - 8.5A - 9\times10^{-3} f - 0.6t - 1.62d - 0.72c \\ & + 5.4\times10^{-3} Af + 0.15At + 0.33ad + 0.15Ac \\ & + 3\times10^{-4} ft + 8.7\times10^{-4} fd + 3.8\times10^{-4} fc \\ & + 9.6\times10^{-3} td + 4.2\times10^{-3} tc \end{aligned} \tag{10-9}$$

where R_0 = edge radius (μm) at the end of the process at which the part started with a sharp edge (zero burr), A = amplitude of vibration (mm),

f = vibratory frequency (Hz), t = run time (min), d = diameter of the loose abrasive nuggets, and c = grain size within each nugget (µm).

While this equation ignores part size, it applies to parts 1 ± 0.33 oz (30 ± 10 grams) and aluminum oxide media. Amplitudes of 0.040 in. (1mm) are largely ineffective, while an amplitude of 0.200 in. (5 mm) causes rapid wear. Large nugget sizes cause considerable part damage of small parts. Nuggets of 0.200–1.20 in. (5–30 mm) are effective. Grain sizes within each nugget 0.0005–0.002 in. (12–50 µm) provide good productivity. Figure 10-48 shows the several conditions users can select to produce the same edge radius.

10.19.2.2 RADIUS GENERATION ON STAINLESS STEEL SHARP-EDGED PARTS

In the 1960s one industrial user (Robbins 1966; 1967) published 120 curves showing the edge radius produced on 0.5-in. (12.7-mm) cubes. The cubes, which initially had sharp edges (no burrs and no radius above 0.001 in. (25.4 µm) are vibratory finished in four different machines using four different media. Four workpiece materials are used. Figures 10-55 and 10-56 illustrate the results obtained on two materials using two media. Similar curves using plastic preformed media have also been reported (Gillespie 1973). Figure 10-57 shows two of these curves. Details of the tests and equipment involved are described later in this section.

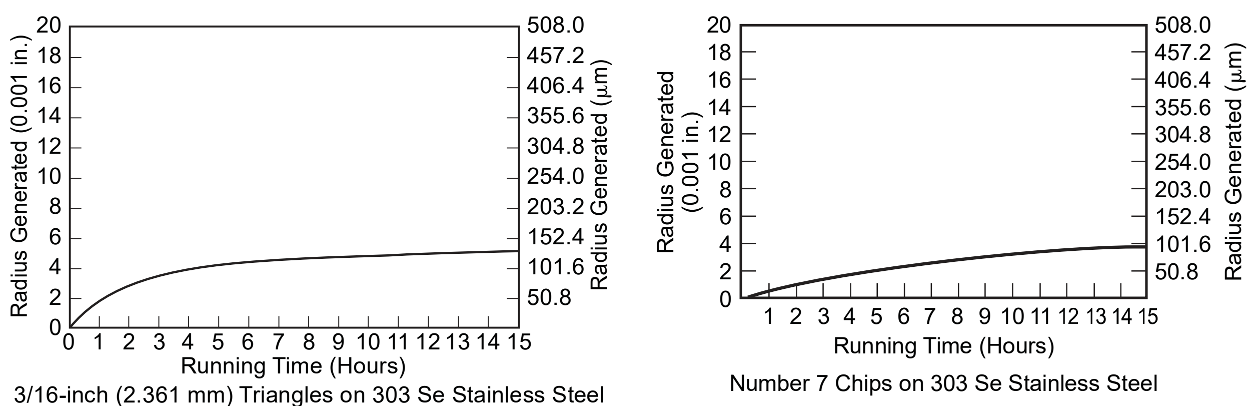


Figure 10-55. Effect of media size and shape on radii produced on stainless steel (Gillespie 1975)

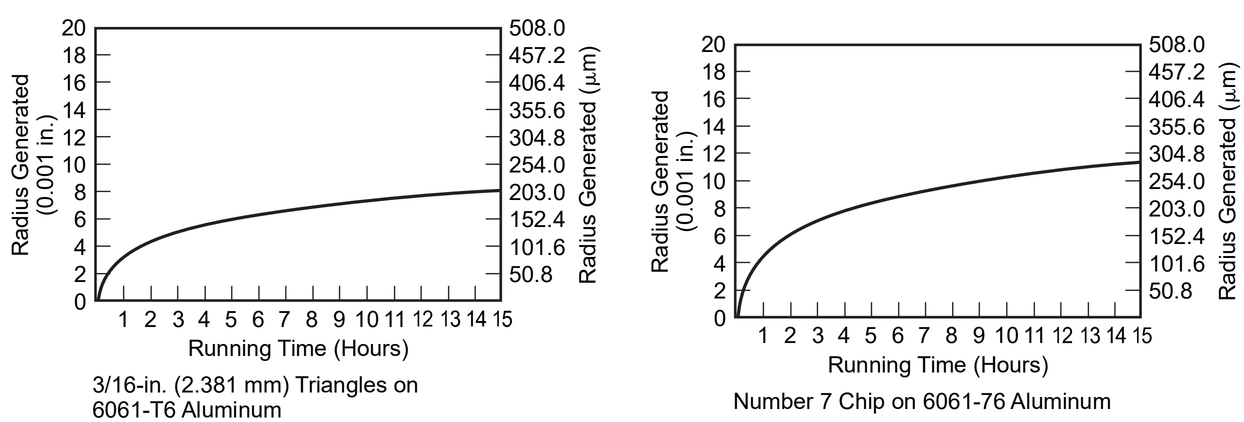


Figure 10-56. Effect of media size and shape on edge radiusing aluminum (Gillespie 1975)

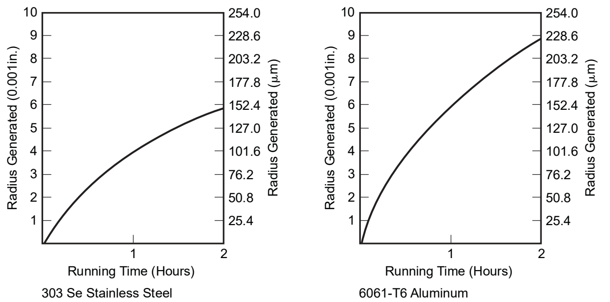


Figure 10-57. Effect of 9/16-inch plastic cones on radius for stainless steel and aluminum cubes (Gillespie 1975)

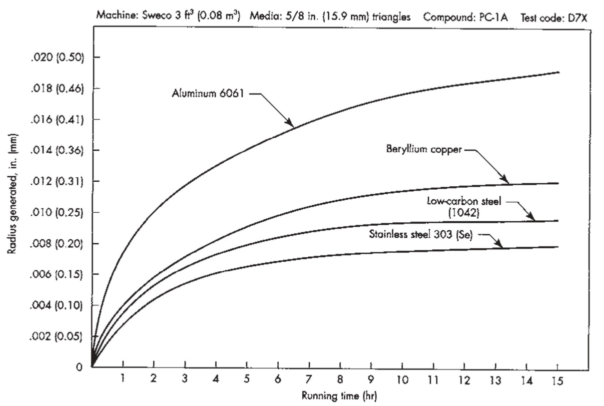


Figure 10-58. Impact of part material on edge radii when using 5/8 aluminum oxide triangles (Gillespie 1975)

As indicated in these figures, larger media produces faster radiusing than smaller media. In addition, it is impossible to achieve a radius larger than 0.004 in. (101.6 µm) in stainless steel using the N7 nuggets (roughly 1/7 in. (3.63 mm) in diameter—see Tables 4-7, 6-12, and 9-10 for actual dimensions)—in any reasonable time frame. Using the large plastic cones, however, it takes only 2 hours to produce a 0.006 in. (152.4 µm) radius. The aluminum, which is a much softer material, radiuses roughly twice as fast as the stainless steel. Figure 10-58 shows the impact of part material on edge radius taken from this same industrial study.

These curves are of the form,

$$R = Bt^{C} \tag{10-10}$$

where B and C are constants.

10.19.3 Repeatability of Edge Finishing

The test just described revealed two process limitations. First, it is not possible to generate large radii[5] through the use of small media. This is significant if small parts are involved because large media cannot be effectively used on many small parts. The second limitation (not shown in the figures) is that the repeatability of the radiusing is only ± 0.001 in. (± 25.4 µm) at best. Thus, while the average radius measured follows the curves shown, actual measurements would vary ± 0.001 in. from this value. This is true for initially burr-free parts. In additional tests involving the removal of small milling burrs using the 9/16-in. (14.35-mm) plastic cones, it is noted that radii vary within ± 0.0022 in. (55.9 µm) on aluminum specimens for the 95% probability level and ± 0.0012 in. (30.5 µm) on the stainless steel specimens (Figs. 10-59 and 10-60 and Table 10-7) (Gillespie 1973). These figures provide confidence intervals for edge radiusing of two common materials in one study. As seen there, 95% of the parts will fall within ± 0.001 to 0.002 in. of the nominal or average result. Note that the exponents of all these equations are greater than 1.0 and parts starting burr-free all have exponents smaller than 1.0.

While this is not a serious limitation in most applications, it is on small precision parts requiring ± 0.001 in. tolerances on edge radii. The process itself adds that much variability if the parts are perfect to begin with. In addition, from this insight it is unrealistic to expect the typical processes to produce radii smaller than 0.001 or 0.002 in. (25.4 or 50.8 mm).

The media used in the tests for Fig. 10-58 are AX-90 preformed Al_2O_3 triangles, 5/8 in. × 5/8 in. × 3/16 in. (15.9 mm × 15.9 mm × 4.76 mm). The abrasive compound, PC-1A is an alkaline base, long life, fast cutting, low foam compound which is compatible with the materials tested and is commonly used in vibratory deburring and centrifugal barrel finishing operations (see Chapter 9). A running time of 15 hours is selected

[5]Throughout this report it is assumed that a conventional vibratory process is used. It is possible by fixturing parts, masking surfaces, and similar approaches to obtain different results. These techniques, however, are not part of what most authorities consider normal approaches.

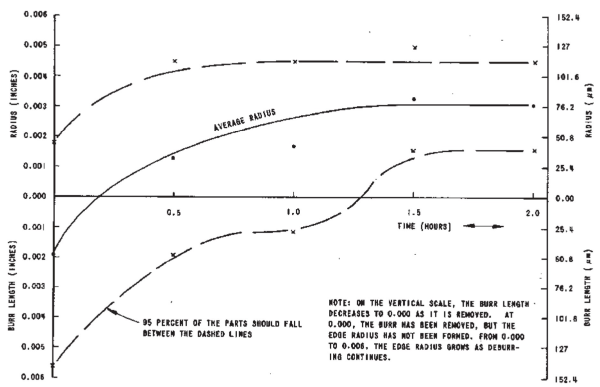


Figure 10-59. Deburring and edge radius on 303 Se stainless steel (Gillespie 1975)

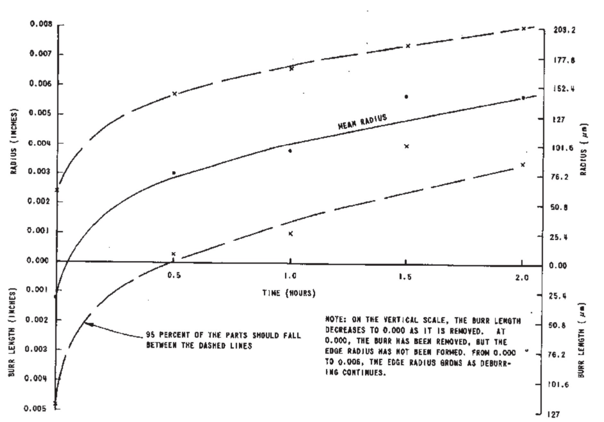


Figure 10-60. Deburring and edge radius on 6061-T6 aluminum (Gillespie 1975)

to provide a sufficient number of data distribution points for comprehensive graphical presentation. Two samples are gauged at each time interval to provide a median value for each point of curve intersection with the plotted data.

For this test the specified maximum allowable radius is 0.010 in. (25.4 µm). For the sample shown in Fig. 10-61 the limit radius generated is reached in approximately 6 hours, as shown by the dotted lines.

For a safety factor of 0.001 in. (25.4 µm) (making sure the part edges are always below the 0.010 in. limit by the amount of the safety factor shown by the dashed lines, users would have to specify a running time of 4 3/4 hours. If accuracy of the

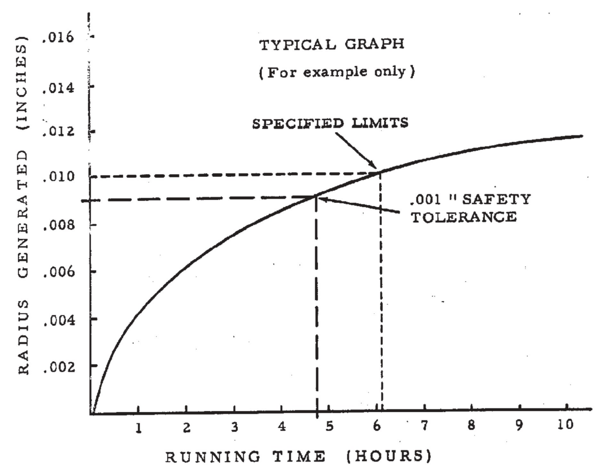


Figure 10-61. To assure that edge radii will be within tolerance select a value less than the maximum and determine what run time yields that radii (Robbins 1973)

Table 10-7. Vibratory radiusing action on typical small milling burrs on metal parts

Material	Equation $R = A_2t^m$	Results after 2 hr in 9/16 plastic cones: Edge radius R (in.) Radius std. dev. σ (in.)	Corner radii (in.)	95% of edge radii will fall within ± 2σ
Aluminum (6061-T6) (Rb 73)	$R = 0.002t^{1.58}$	$R = 0.0086$ $\sigma = 0.0011$	$R = 0.019$	$R = 0.0086 \pm .0.0022$
Stainless steel (303) (Rc 31)	$R = 0.0013t^{1.24}$	$R = 0.0031$ $\sigma = 0.0006$	$R = 0.014$	$R = 0.0031 \pm 0.0012$
Low carbon steel (SAE 1042) (Rc 16)	Not available	$R = 0.0033$ $\sigma = 0.0005$	Not measured	$R = 0.0033 \pm 0.0010$
Beryllium copper (Rc 24)	$R = 0.0017t^{1.45}$	$R = 0.0057$ $\sigma = 0.0009$	$R = 0.019$	$R = 0.0057 \pm 0.0018$

Table 10-8. Equations for several vibratory conditions

Part Material	Media	Machine	Equation (10-3) $R = A_2t^m$
303 Se stainless	9/16 plastic cones	1 qt machine	$0.00365t^{0.713}$
17-4 Ph H900 square			$0.00281t^{0.790}$
17-4 Ph H900 round			$0.002035t^{0.921}$
1042 carbon steel			$0.003745t^{0.712}$
6061 aluminum			$0.00575t^{0.897}$
303 Se stainless	1/4 random plastic	1 qt machine	$0.00304t^{0.701}$
17-4 Ph H900 square			$0.00200t^{0.913}$
17-4 Ph H900 round			$0.001965t^{0.726}$
1042 carbon steel			$0.00294t^{0.745}$
6061 aluminum			$0.00578t^{0.715}$
303 Se stainless	1/4 random plastic	1/3 cu ft machine	$0.002804t^{0.889}$
17-4 Ph H900 square			$0.00284t^{0.589}$
17-4 Ph H900 round			$0.001785t^{0.716}$
1042 carbon steel			$0.00272t^{0.817}$
6061 aluminum			$0.00472t^{0.814}$
303 Se stainless	9/16 plastic cones	1/3 cu ft machine	$0.003654t^{0.624}$
17-4 Ph H900 square			$0.00293t^{0.754}$
17-4 Ph H900 round			$0.00183t^{0.719}$
1042 carbon steel			$0.003742t^{0.727}$
6061 aluminum			$0.00596t^{0.642}$

graph used is + 0.0005 in. (12.7 μm), the maximum radius generated will be 0.0095 in. (0.24 mm) for the worst-case condition.

Table 10-8 provides data comparing radiusing results for two different machines using two media (Gillespie 1973). The machines include a 1-qt capacity tabletop tub unit and a 1/3-cu ft capacity tabletop tub. Both of these were well-used machines built in the 1970s. The data provide a relative comparison of variances between machines and media. These data can be compared with other results in this chapter for larger machines. While these specific machines may not be available today, the variances illustrate energy level or performance differences between machines used in one shop.

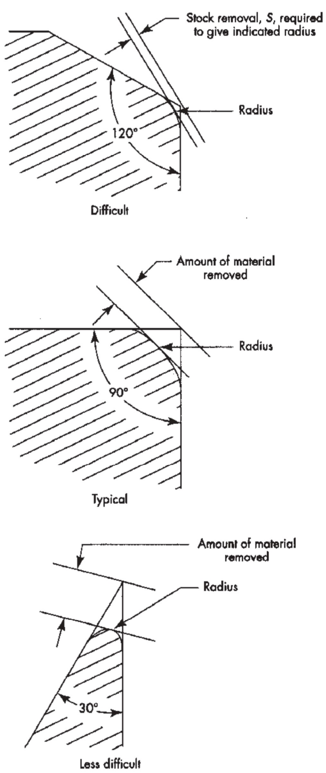
10.19.4. Corner Radii vs. Edge Radii

Figure 9-9 illustrates the difference between corner radii and edge radii. Few production parts acknowledge corner radii requirements so no data exist comparing the two. However, experience indicates that corner radii may be three times the size of edge radii on the same part.

Table 10-7 provides some comparative data for parts finished in two hours.

10.19.4.1 EDGE ANGLE EFFECTS ON RADII

From a strictly theoretical standpoint, the production of a given radius is much more difficult on a 30° included edge angle than on a 90° included edge angle. As shown in the cross-sections of Fig. 10-62, the production of a 0.002-in. (50.8 μm) radius on a 30° edge requires the removal of 0.0077 in. (195.6 μm) of material. For a 90° edge, only 0.0008 in. (20.3 μm) must be removed before this radius is produced. If the objective of finishing is to produce a 0.002 in. (50.8 μm) radius, a 30° edge will require almost 10 times the finishing time required by a 90° edge. A 120° edge will require only 3/8 the time of a 90° edge. If it is required that a workpiece with different edge



Radius in.	Radius µm	S in.	S µm
.002	50.8	.0003	7.6
.003	76.2	.0004	10.2
.005	127.0	.0007	17.8
.010	254.0	.0015	38.1
.015	381.0	.0022	55.9

Radius in.	Radius µm	S in.	S µm
.002	50.8	.0008	20.3
.003	76.2	.0012	30.5
.005	127.0	.0021	53.3
.010	254.0	.0041	104.1
.015	381.0	.0062	157.5

Radius in.	Radius µm	S in.	S µm
.002	50.8	.0077	195.6
.003	76.2	.0116	294.6
.005	127.0	.0194	492.8
.010	254.0	.0387	983.0
.015	381.0	.0581	1475.7

Figure 10-62. Effect of edge angle on edge radiusing (Gillespie 1976b)

angles have edge radii of 0.002 in. (50.8 µm) or less, the largest angle will dictate the allowable finishing time. Again edge repeatability is ± 0.001 in. (25.4 µm) (Table 10-9).

From geometrical considerations, the relationship between stock loss (S) and resulting radius (R) can be expressed by the following equation:

$$S = \frac{R[1 - \sin(\Phi / 2)]}{\sin(\Phi / 2)} \tag{10-11}$$

where Φ is the included angle of the edge.

The three materials used in the experimental study of this phenomenon are 303 Se stainless steel, phosphor bronze, and 6061-T6 aluminum. The specimens are nominally 0.75 in. (19 mm) square and 0.125 in. (3.175 mm) thick—and all have sharp, burr-free edges at the beginning of the tests. They are vibratory finished in a 3 ft^3 (8.5 dm^3) bowl-type machine (Gillespie 1975). Plastic cones 0.562 in. (14.3 mm) in diameter (Almco Supercut X) are used with 500 grams of abrasive compound (Carborundum lA-1). Radii are checked at one-hour intervals using optical equipment.

As indicated by the analysis, radii are produced faster on edges with large included angles (Fig. 10-63). The production of a 0.001-in. (25.4 µm) radius on a 30° edge in 303 Se stainless steel is almost 20 times longer than the production of the same radius on a 120° edge. This agrees closely with the theory if the assumption is made that the finishing time is proportional to the linear stock removal at the edge. Similar results occur with the other materials (Figs. 10-64 and 10-65). The magnitude of the radius produced is a function of the workpiece material; the hardest metal is radiused the slowest (Fig. 10-66).

The curves shown in Figs. 10-63 through 10-66 are of the form:

$$R = CA(1 - e^{Bt}) \tag{10-12}$$

where R = final radius, A = edge angle, B = constant, C = constant, and t = time in vibratory finisher.

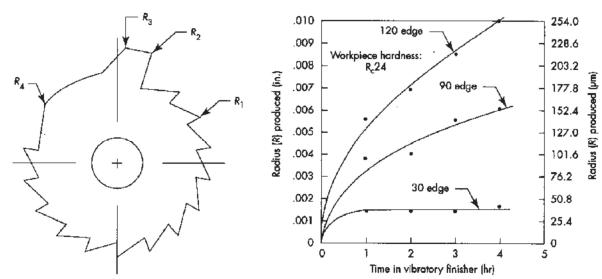


Figure 10-63. Time required to remove the burr and radius the edges of a ratchet wheel (Gillespie 1976b)

Table 10-9. Radii produced on three edges of part while maintaining tolerance of radius R_2 (see Fig. 10-63)

Radius Feature No.	Edge Angle (degrees)	Radius Produced in. (µm)
R_1	60	0.018 ±0.001 (457 ±25.4)
R_2	90	0.005 ±0.001 (127.0 ±25.4)
R_3	125	0.0113 ±0.001 (287.0 ±25.4)
R_4	140	0.0121 ±0.001 (307.3 ±25.4)

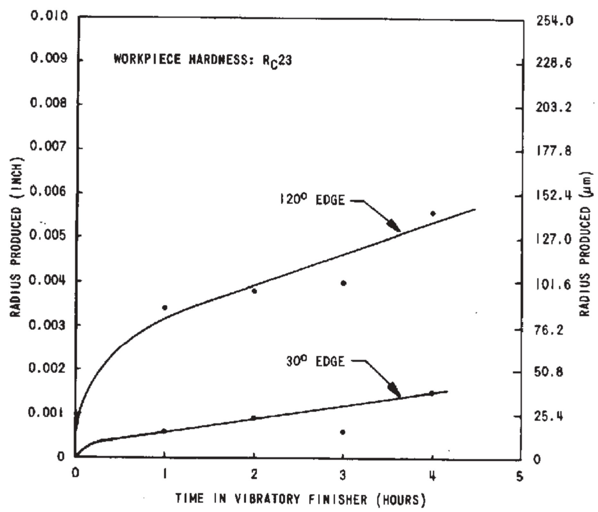


Figure 10-64. Effect of edge angle and vibration time on edge radius of 303 Se stainless steel workpiece (Gillespie 1976b)

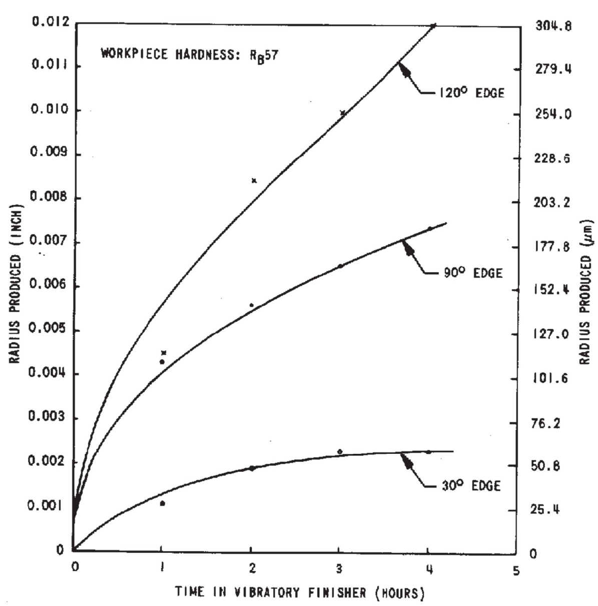


Figure 10-65. Effect of edge angle and vibration time on edge radius of 6061-T6 aluminum workpiece (Gillespie 1976b)

A regression analysis of the data from this study provides the values shown in Table 10-10 for B and C.

Equation (10-12) is valid for t between 0 and 4 hours.

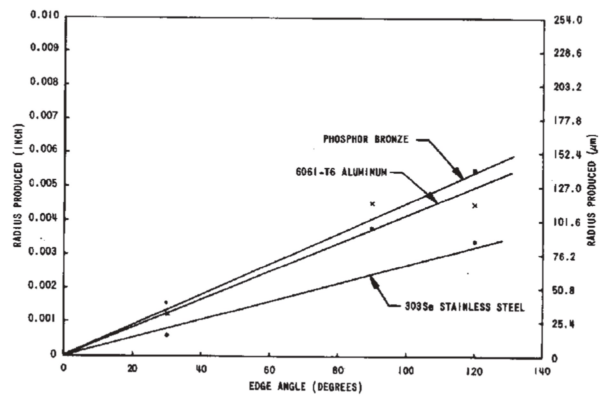


Figure 10-66. Comparison of radiusing by vibratory finishing on three materials (Gillespie 1976b)

Table 10-10. Constants for edge radiusing equation (10-12)

Workpiece Material	Constant	
	B	C
6061-T6 aluminum	–0.00107	0.0249
Phosphor bronze	–0.735	0.0000764
303 Se stainless steel	–0.00293	0.0043

Values shown in this table are for edge angle in degrees, time t in hours, and radius R in inches.

A more accurate relationship for R is given in equation (10-13), but this equation is only valid for t between 1 and 4 hours.

$$R = CA + Bt^2. \qquad (10\text{-}13)$$

A regression analysis for equation (10-13) provides the values for B and C shown in Table 10-11. An analysis of actual measurements indicates that the edge radius will vary by ± 0.001 in. (25.4 µm) from the nominal radius predicted by this equation.

Figure 10-63 shows a part having multiple edge angles. Assume that the workpiece is phosphor bronze, radius R_2 has a value of 0.005 in. (127 µm) with a tolerance of ±0.001 in. (±25.4 µm), the finishing media is the same as previously described, and the edge angle at R_2 is 90°. Then,

Table 10-11. Constants for edge radiusing equation (10-13)

Workpiece Material	Constant B	Constant C
6061-T6 aluminum	0.000107	0.0000589
Phosphor bronze	0.0000932	0.0000529
303 Se stainless steel	0.0000569	0.0000307

Values shown in this table are for edge angle in degrees, time t in hours, and radius R in inches.

in order to produce a 0.005-in. (127-μm) minimum radius on this edge:

$$0.005 = (0.0000529)\ (90) + 0.0000932\ t^2.$$

By solving this equation for the finishing time, t is found to be 1.0 hour. As just indicated, the actual radius varies within a ±0.001-in. (25.4 μm) band around the nominal. As shown in Table 10-10, a radius of 0.0111 to 0.0131 in. (282 to 333 μm) will be produced at R_4, while a radius of 0.005 ± 0.001 in. is produced at R_2; a radius of only 0.0017 to 0.0019 in. (43 to 48 μm) will be produced at R_1. Thus, if either R_1 or R_4 also has an edge radius of 0.005 ± 0.001 in., the required radius could not be produced on any two of these edges by vibratory finishing.

In production situations, the impact of varying edge radii can be more significant than already indicated. Whereas the edge angles used in these tests are initially burr-free, the burrs encountered in production parts can vary significantly between respective edges. A large burr on one edge of a part and a small burr on another edge will further limit the use of vibratory finishing on workpieces, such as that shown in Fig. 10-63, when they have precision edge-radius tolerances.

There are two solutions to the deburring/radiusing problems described:

(1) allow larger radii and larger tolerances for larger edge angles, or
(2) resort to other more expensive deburring/radiusing processes.

10.19.5 Surface Finish

Equation (10-2) defines surface roughness changes for a general population of parts in vibratory finishing. Equation (10-6) describes the surface roughness changes experienced on aluminum in a study of vibration frequency effects (Sofronas 1977). Figure 10-49 and both of these equations are indicative of the process.

The surface roughness of the many radius samples described in the radiusing section above improve only slightly on stainless steel specimens (Fig. 10-67). The aluminum specimens, which initially had a finish of 23 μin. AA (0.61 μm), become rougher when the larger media is used (Fig. 10-68). The small nuggets reduce surface roughness to 18 μin. (0.46 μm). By adding a 30-min burnishing cycle, it is possible to improve the surface finish slightly.

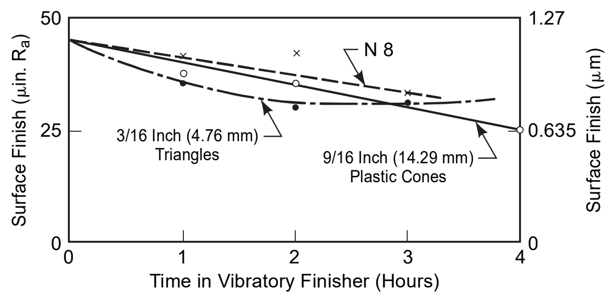


Figure 10-67. Effect of media and time on surface roughness changes for 303 Se stainless steel pins (0.490 [12.45 mm] diameter and 0.5 in. [12.7 mm] long) (Gillespie 1975)

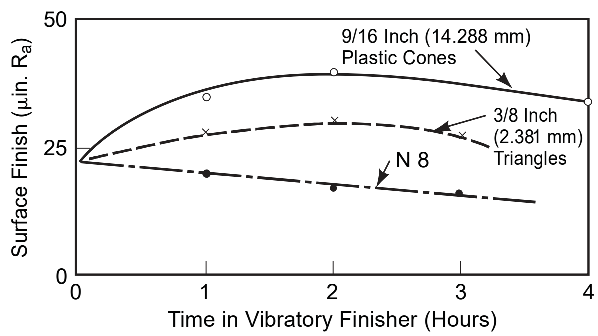


Figure 10-68. Effect of process and roughness of 6061-T6 aluminum (Gillespie 1975)

In assessing these six graphs, it is obvious that vibratory finishing removes small amounts of stock and that its effect on surface finish depends on the workpiece hardness. Although not shown here surface finish improvement depends upon the initial finish. In measuring diameter changes it appears that there is a variation of at least ± 0.000025 in. (0.635 μm) because of process variability, measurement error, or other sources. While the stock losses are extremely small, it is obvious that on ultra-precision parts with tolerances of ± 0.0001 in. (2.54 μm) this would not be a good process to remove large burrs. In addition, using weight changes to predict dimensional changes may result in noticeable errors. (Additional data on surface finish effects can be found in the literature, Kobayashi and Matsunaga 1981.)

10.19.6 Size Changes

The size of exposed surfaces changes as a result of vibratory action. The longer the time in the machine and the more aggressive the conditions, the larger the size change will be.

10.19.6.1 STAINLESS STEEL AND ALUMINUM

Weight losses and size and surface finish changes are noted over a 4-hour cycle using cylindrical specimens, each 0.490 in. (12.45 mm) in diameter and 0.5 in. (12.7 mm) long. Ten specimens of each material are weighed to the nearest milligram and measured to the nearest 0.000020 in. (0.51 μm). Three groups of these specimens are used to compare the results of three media. To assure initial uniformity, the parts are centerless ground to a tolerance of ± 0.0001 in. (2.54 μm), and ultrasonically cleaned in warm detergent before weighing and measuring.

The weight losses are small (Figs. 10-69 and 10-70). After 3 hours the stainless steel specimens each lose 0.0007 oz (2 mg) of material. An aluminum sample, which has a density one-third that of steel, loses 0.00035 oz (1 mg). As in edge radiusing, the large media produces the fastest cutting.

The results of measuring the diameter change are considerably different from those of the weight changes (Figs. 10-71 and 10-72). Some of this is the result of measuring errors and out-of-roundness of the workpieces. A 0.0001 in. (2.54 μm) out-of-roundness, for example, would be half the total loss shown. Some of this is the natural variability of the process. After 4 hours, the maximum loss measured is 0.0002 in. (5.08 μm). Media size makes little difference in this case.

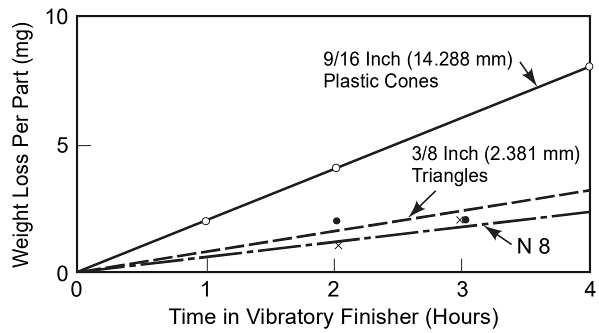


Figure 10-69. Weight loss on 303 Se stainless steel (Rc 20)(Gillespie 1975)

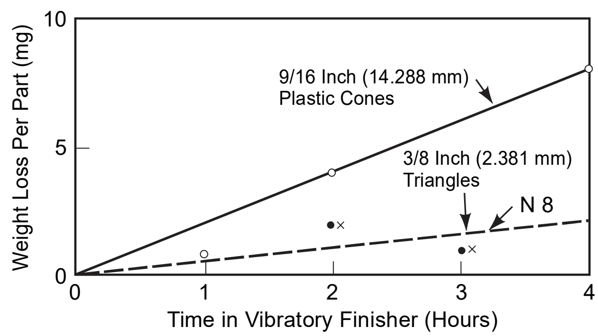


Figure 10-70. Weight loss on 6061-T6 aluminum (Rb 61) (Gillespie 1975)

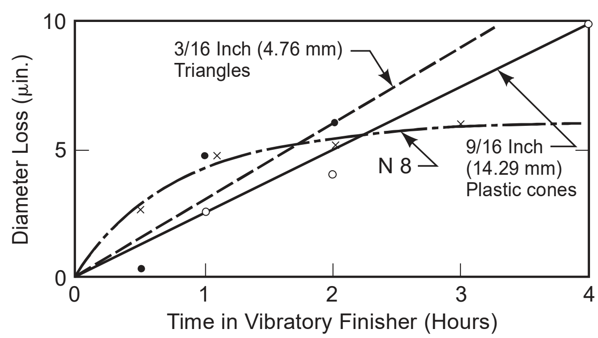


Figure 10-71 Effect of media and time on diameter change for 303 Se stainless steel pins (.490[12.45mm] diameter and 0.5 in. [12.7 mm] long) (Gillespie 1975)

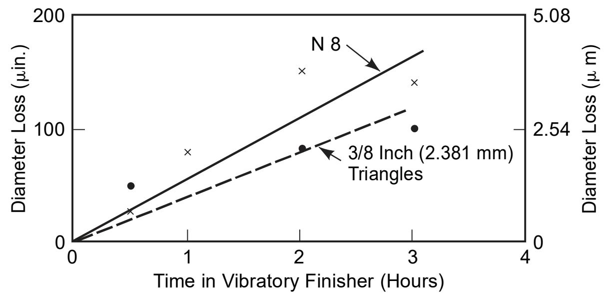


Figure 10-72. Diameter change as function of time on aluminum (Gillespie 1975)

Because of geometry, one would have expected the diameter change to be directly proportional to the weight loss. However, if the following equation for the surface area of a material is used, the observed change does not agree with the calculated value:

$$\Delta W = \frac{\pi \times D^2}{2} + \pi D \times L \times \rho \times \Delta t_p \qquad (10\text{-}14)$$

thus,

$$\Delta t_p = \frac{\Delta W}{\rho \times \pi \times D\left(D/2 + L\right)} \qquad (10\text{-}15)$$

where ΔW = change in weight of the part, D = diameter, L = length of the cylinder, Δt_p = change in part size per surface (i.e., half of the diameter change or half the length change), and ρ = part material density.

The 9/16-in. plastic cones remove 0.0028 oz (8 mg) after 4 hours. The diameter of the parts (D) is 0.490 in. (12.45 mm), and they are 0.5 in. (12.7 mm) long (L). The density (ρ) of steel is 0.29 lb/in^3 (8024 kg/m^3) and 1 lb equals 454 grams. Using equation (10-15) this weight change should have resulted in a diameter change of 0.00010 in. (2.54 μm), yet the measured change is two times larger than this.

10.19.6.2 BRASS PARTS

Figure 10-31 provides a view of locations within a tub vibrator. As seen here and described earlier in this chapter the tub is defined as angular positions and radial positions. Figure 10-32 illustrates the effect of vibratory tub frequency on 70/30 brass disk samples. For this study the samples are 0.5 in. (12.7 mm) in diameter and 0.091 in. (2.3 mm) thick. A 0.394–0.472 in (10–12 mm) diameter propriety media is used in a U-shaped tub (Matsunaga & Hagiuda 1965). As seen at the position of 210 degrees, when the tub vibrates at a speed or frequency of 2250 cycles per minute the metal removal rate is almost three times greater than if it vibrated at only 1500 cpm. More metal is removed per load when the tub is filled to 2/3 of total capacity or higher—in part just because the tub has more parts in it when it is almost full. Figure 10-34 shows that the larger media (smaller grit size number) removes metal quicker than small media and, again, the fastest cutting occurs at the bottom of the tub (Matsunaga & Hagiuda 1965, 1965b). Figure 10-73 shows that doubling

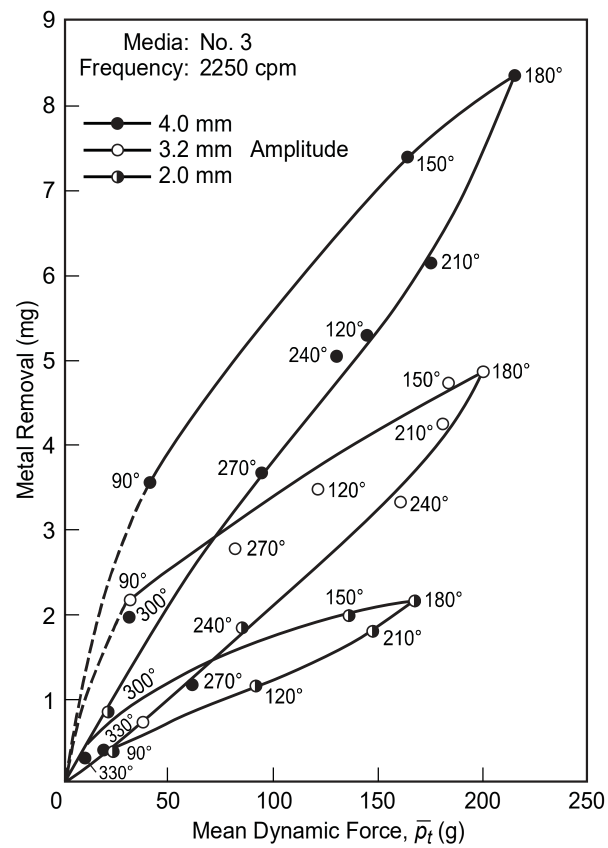


Figure 10-73. Relation between metal removal rate and effect of amplitude for row E in the vibratory tub (Matsunaga & Hagiuda 1965)

the amplitude of vibration from 0.080 to 0.160 in. (2.0 mm to 4.0 mm) at the 180-degree position increases metal removal from 0.007 oz to over 0.028 oz (2 mg to over 8 mg) in the same time period.

10.19.6.3 OTHER MATERIALS AND MODELS

Sofronas and Hashimoto provide other models on stock loss. The model for aluminum is presented in equation (10-4). All of these predict a linear model for stock loss assuming that the same abrasive concentration is maintained in the tub (Sofronas 1977; Hashimoto 1996).

10.20 CASE HISTORIES

The following case histories provide additional insight into vibratory actions.

10.20.1 Turbine Engine Blades

Figure 10-74 illustrates the geometry of turbine engine blades. As seen here, several features are critical to usage and acceptance. Each of these features change different amounts in a mass finishing operation. To meet the final requirements of these parts users have to perform a series of experiments to document the changes from the process, then adjust either the incoming dimensions or the process. Figures 10-75 through 10-76 illustrate the variety of configurations that are possible, but they are not all acceptable for this application. Table 10-12 illustrates the data collection form used for these parts to establish the final process and initial part needs. In this instance the manufacturer increases the initial blade chord width to allow adequate dimensions

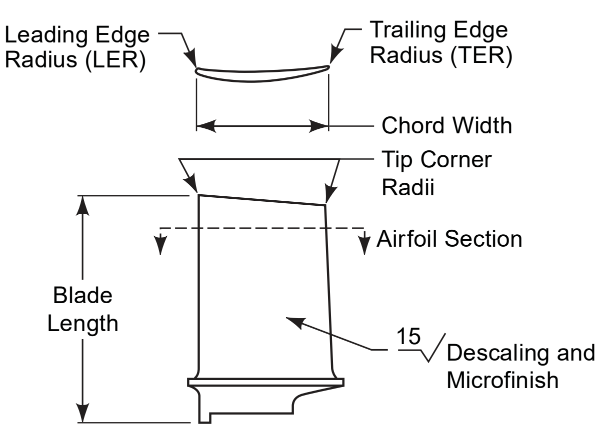


Figure 10-74. Airfoil configuration (Neal 1981)

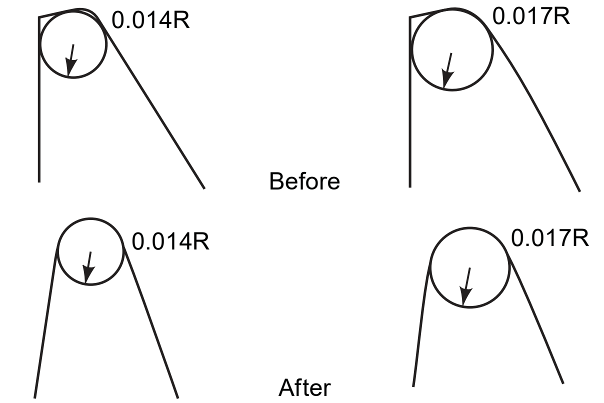


Figure 10-75. Radius generated on sheared edge of airfoil (Neal 1981)

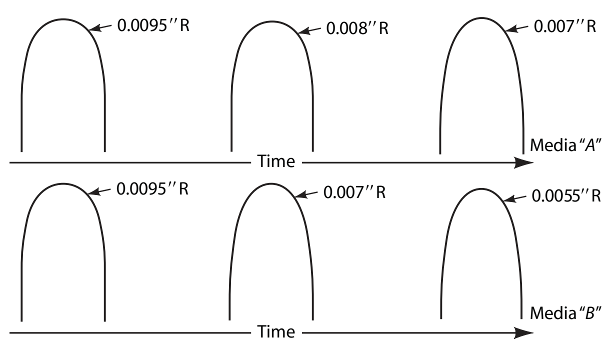


Figure 10-76. Progression of edge radii size and shape (Neal 1981)

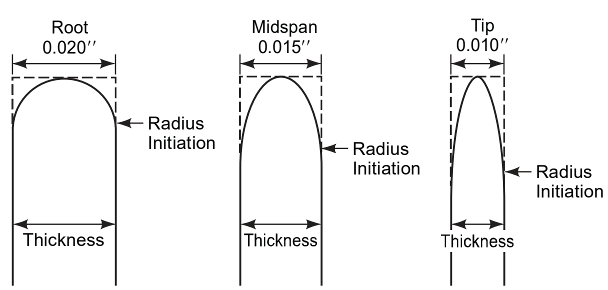


Figure 10-77. Possible edge conditions from vibratory finishing (Neal 1981)

Table 10-12. Media finishing development for blade edge (Neal 1981)

Media Finishing Development Blade Inspection Sheet

Blade No. ________________________ Date __________________

P/N/ _____________________________ Test No. _______________

Compound ________________________ Media __________________

Machine, Model, and Setup Parameters ___________________________________

Characteristic		Time (hrs)														
		0	½	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7
Chord width	A															
	B/C															
	D/E															
LE thickness	A															
	B/C															
	D/E															
TE thickness	A															
	B/C															
	D/E															
Blade length																
LE tip radius																
TE tip radius																
Tip burr present (Yes or No) (if No, measure radius)																

Comments: Include notes on elimination of grinding marks, millmarks, oxide, burrs, etc. Also include visual evaluation of LER and TER after each run.

after deburring. This study is performed on every blade size and shape in order to assure quality control.

10.20.2 Milled Slots

Figure 10-78 illustrates a milling burr bent under one of the stainless tabs. Although the sharp pointed, small diameter angle cut cylinders are the best choice for this part, they are not adequate to ensure complete burr removal. The addition of small pins would take this light burr off, but it also increases the chance for cross contamination of a non-stainless steel media on a stainless steel that does not normally rust when exposed to light moisture.

10.20.3 Smudges

Figure 10-79 shows an L-shaped 416 stainless steel part that is ground on the bottom, but has a milled L-shape on the top. The same aluminum oxide ceramic cylinder is used on the top of the part in Fig. 10-78. As seen in the illustration dark smudges appear along tangency points where the media rides in the inner surfaces. Wiping a clean white cloth along this area can validate this smudge, but typical ultrasonic cleaning cannot remove it. An abrasive cutting compound has also been used with aluminum oxide ceramic cylinders. When media having flat surfaces and square corners are used, the smudges disappear.

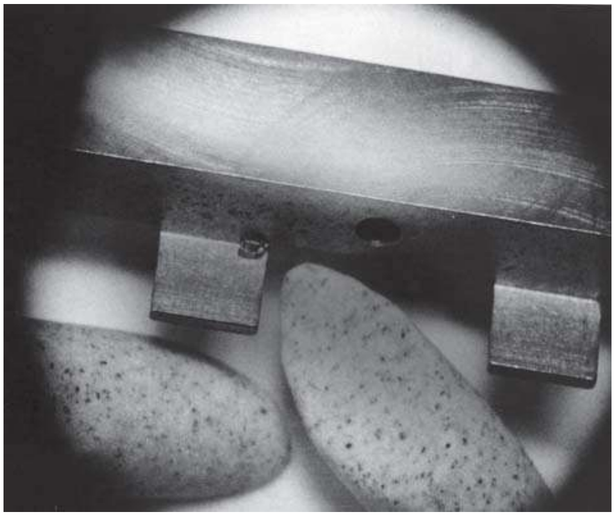


Figure 10-78. Angle cut cylinders cannot reach small curled burr under a tab

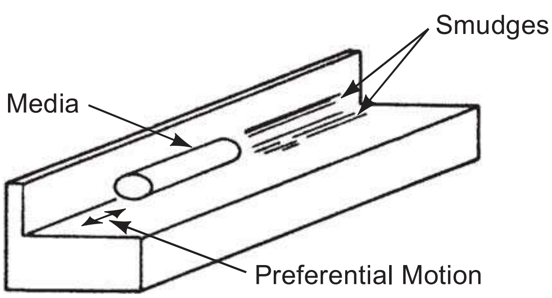


Figure 10-79. Black streaks caused by preferential rubbing

As a side note other vibratory users note that garnet and quartz fines are preferred for processing the light metals because the other abrasives leave a smudge that is difficult to remove. That may be true for rock-like media, but it probably is not the case for plastic media, which is not known to cause this smudge issue.

A second user notes: Smut conditions promoted by aluminum oxide media is apparently not prevalent in silicon bonded media, which is, therefore, used where cleanliness is of utmost importance (Mosher 1969).

10.20.4 Flatness Changes

Figure 10-80 shows the flatness change on the "L"-shaped bar illustrated above. When the L-shaped part is machined the grinding operation leaves tensile stresses in the bottom surface. The milling operation produces different stresses in the top surface. As a result the part comes off the last operation somewhat bowed. Since vibratory operations reduce tensile stresses, the engineer decided to straighten the part by masking the top surface with masking tape, then subjecting it to a 7-hour vibratory finishing operation. As seen in Fig. 10-80 the part flatness improves by 0.0005 in. Any attempt to bend the part by other mechanical means would leave "kinks" in the part or wide variances in the stresses that, over time, could provide problems with strength and corrosion.

10.20.5 A General Quantitative Approach For Defining Deburring Capabilities

The data presented thus far are for an almost unlimited range of vibratory finishing combinations. As indicated in Tables 10-1 through 10-4, a large number of variables exist, in addition to a near limitless range within variables. Despite the immensity and complexity of interactions between these variables, it is possible to draw some basic process conclusions.

The size, shape, and composition of the media determine its aggressiveness (that is, the time required to produce given conditions). Machine parameters such as frequency, amplitude, bowl size, and bowl shape also influence aggressiveness.

By the nature of the process a specified level of burr removal or edge radiusing results in a given amount of stock loss on a part. For an external edge in a specific material, any two combinations of media and machine parameters that remove the

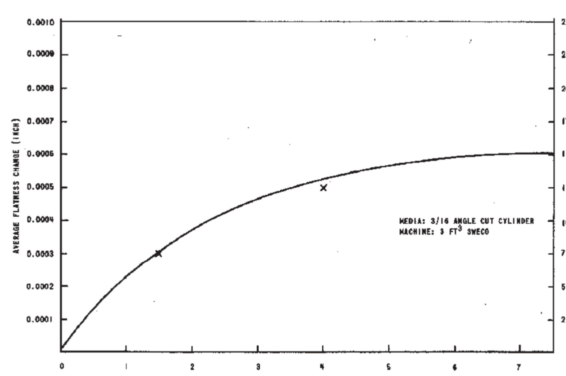


Figure 10-80. Flatness improvement from vibratory finishing

burr and produce the same edge radius should remove equal amounts of stock from the workpiece.

If only media size and composition affect edge radiusing and stock loss disproportionately[6], then a knowledge of burr size, desired edge radius, allowable stock loss, and final surface finish limits can help one determine if vibratory finishing will produce these conditions.

Table 10-13 shows information used by the author to determine some of the conditions needed to produce final parts. The key is that real data are used to make the table, but it is only applicable to one range of surface roughness. As seen in the table, if the parts have a burr only 0.0001 in. (2.54 μm) thick (burr height for this example is not important), a radius of 0.002 in. (50.8 μm) (the maximum that the part drawing allows), and if part size can change up to 0.0001 in. (2.54 μm), then a vibratory process will work.

If, on the other hand, the burr is 0.005 in. thick and 0.005 in. (127 × 127 μm) tall, can have no more than 0.002 in. (50.8 μm) edge radii and not lose more than 0.0001 in. (2.54 μm) from diameters, then no vibratory combinations will work.

If the part must also have a surface roughness of 4 μin. or less, then the data in this table do not apply. Another table must be constructed.

By evaluating three or four examples like this, it is possible to construct other tables such as that shown which reflect all the plant's typical working conditions. Since surface finish is more affected by media used than by material removed from the workpiece, tables have to be constructed for various levels of surface finishes (that is, for 8, 16, 32, and 64 μin. (0.2, 0.4, 0.8, and 1.6 μm). Because material hardness affects all measured variables, tables would have to be constructed for at least two levels of hardness. Aluminum and steel represent two logical choices.

It is apparent that large media produces large radii but is not significantly more aggressive in removing stock from the workpiece. By the nature of the process it is logical to assume that the machine parameters should affect both stock removal and edge radiusing proportionately, whereas media size affects one more than the other. If this assumption is true, then one can ignore machine parameters in preparing tables of physical process capabilities. Thus, the machine parameters only indicate the length of time required to reach the desired capabilities.

Is it worth all this effort to quantify capabilities? The answer, of course, depends upon who is using the data. The novice in vibratory deburring needs this kind of analysis in order to be effective immediately. The departmental manager needs easy to read facts to make decisions on equipment and general processing capabilities. The engineer responsible for high precision, job shop runs needs the data. Being wrong means unacceptable delays and scrap charges. Even individuals who do not fall into these categories would use the information if it were available because there is always a part or workpiece for which they need to know immediately whether a process will work. Unfortunately, this information is often not available or is not easy to access.

10.21 THE MATHEMATICS OF VIBRATORY CAPACITY

Chapters 1 and 9 describe how to estimate parts per load. The following provides the same information for vibratory finishing. The process is as follows:

1. Determine the cubic volume of the part or the volume of a box that would contain the part.
2. Divide 1728 cu in. per cu ft by the part volume to obtain the number of parts that will fit in a cu ft.
3. Calculate the actual volume that can normally be run in the vibratory machine (90% of total tub volume, for example).
4. Determine the ratio of parts-to-media to be run (3:1 is typical—that means ¼ of the load (3 + 1 = 4) is parts).
5. Determine the volume of parts that can be run by dividing the actual load volume (from step 3) by the ratio of parts to media (¼, for example, in step 4).

To get parts per load divide the volume of parts (in step 5) by the number of parts in a cu ft (from step 2).

[6]Knowing the final edge radius is not sufficient to predict size changes. As evident in the previous figures, media size greatly affected radii but only slightly influenced stock loss.

Table 10-13. Estimated capabilities of vibratory finishing steel alloys with surface roughness of 32 μin. (0.813 μm) or better and low-loss conditions. X indicates process can maintain the indicated size loss and edge radius while burrs of size shown are removed. A dash indicates the process is not capable of maintaining both of these features while removing the indicated burr size. A blank indicates it is not possible to produce this condition for the burr size indicated without using additional processes.

Removable burr size thickness, in. (μm) × length in. (μm)	**Allowable thickness or diametrical loss, in. (μm)**			
	0.0001 (2.54)	**0.0005 (12.7)**	**0.0010 (25.4)**	**0.0050 (127)**
Maximum edge radius allowed, in. (μm)				
0.0001 (2.54) × any length				
0.002 (50.8)	X	X	X	X
0.005 (127)	X	X	X	X
0.010 (254)	X	X	X	X
0.015 (381)	X	X	X	X
0.0005 (12.7) × 0.0005 (12.7)				
0.002 (50.8)	X	X	X	X
0.005 (127)	X	X	X	X
0.010 (254)	X	X	X	X
0.015 (381)	X	X	X	X
0.005 (127) × 0.003 (76.2)				
0.002 (50.8)	–	–	–	–
0.005 (127)	–	X	X	X
0.010 (254)	–	X	X	X
0.015 (381)	–	X	X	X
0.005 (127) × 0.005 (127)				
0.002 (50.8)				
0.005 (127)			X	X
0.010 (254)			X	X
0.015 (381)			X	X

As an example, use the data in Table 1-17 and the same considerations used for the part in barrel tumbling (Chapter 9). Assume the part is 4.6 in. × 3.7 in. × 2.6 in. (117 mm × 94 mm × 66 mm). The total box size it would take to hold the part would be this product, or at least 44.25 cu in. (0.72 L) volume. Since there are 1728 cu in. per 1 cu ft, only 1728/44.25 or 39 parts could fit in a cu ft. If we had a 10.8-cu ft (0.31-m^3) vibratory machine and could only load it to 90% of capacity the actual workload would be 0.9 × 10.8 or 9.72 cu ft (0.28 m^3)[7]. If we decide to use three times as much media as we did parts (3:1 ratio),

[7]There is no industry standard as to what the word "capacity" means. Some users believe that machine capacity means the volume of an absolutely full machine even though it cannot be operated at that load. To others, a 3-cu ft machine implies a machine that, when operated at the normal load, contains 3 cu ft of media and parts. One should clarify this point before ordering equipment because the equipment reveived may require a larger footprint or more power than one designed for the other definition.

then 3 portions media plus 1 portion parts = 4 portions per load. Thus, our parts represent only ¼ of the load, or ¼ of 9.72 cu ft, that is 2.43 cu ft (0.07 m^3). Since 39 parts can fit in 1 cu ft, we can only load 39 × 2.43 = 95 parts in the load. Note that this is 50% more parts per load (150% of original load) than the barrel, and this is because in vibratory finishing we can load to 90% rather than 60% of volume. Vibratory will also be three to four times faster in cycle time, so the net output if four times faster would be 4 × 150% = 600% or 6 times more productive than the barrel.

In 1983 one company developed a computer program to make the calculations for recommending machine size and operating conditions from the answers to ten simple questions (Freeman 1983). Another provided costs as well as common machine needs (Balz 1983; Kittredge 1985). Also, a Japanese program provides details for many deburring processes including mass finishing (Ioi 1985).

10.22 OPERATIONAL COSTS

One manufacturer provides data on typical part cycle times as indicated in Table 10-14 (Schaeffer 2003). The data are valid for a manual operation of a large machine in which media may have to be exchanged for different sizes. However, the unload time is not consistent with many of today's operations. When operators have to provide further cleaning, sorting, and inspection in manual operation, the 25-minute unload is appropriate, but it is more than the "unload" stated. Table 10-15 provides comparative data for tub and bowl costs. As seen in the latter table, reducing costs requires concentrating on labor and consumables. When compared to the barrel operation described in Chapter 8, vibratory costs are lower. In turn, the bowl is cheaper to operate than a tub because of the internal separation. A $7 per hour difference is very significant!

Table 10-14. Vibratory cycle time (Schaeffer 2003)

Operational Step	Typical Time (minutes) Tub machine	Typical Time (minutes) Bowl machine
Load	5	3
Run process	30	45
Unload	25	10
Transition	3	2
Total	63	60

10.23 HOW TO GET STARTED

The first need is to determine the appropriate process and equipment. Generally, that requires numerous discussions with equipment vendors and other users, but it all must begin with a completed form similar to that shown in Table 9.1, which provides the technical and economic data for comparisons and decisions. It also provides a description of the media and compounds used for the first product(s). Table 10-16 shows the simplified form used by one plant (Johannesen 1977, 1981).

Making decisions after the equipment is available requires some additional considerations, which are presented below. While these considerations are given for vibratory deburring, they are generally similar in barrel, centrifugal barrel, and centrifugal disk operations. However, the exact values of time, radii, and finish will be different.

10.23.1 Process Steps in Vibratory Finishing—Part Needs

- Determine the required degree of burr removal.
- Determine the required edge break.
- Determine the allowable size change by reviewing piece part tolerance.
- Estimate or measure the starting burr size (if operator is experienced, this is not required).
- Determine the diameter of an equivalent part having diameter equal to length.
- Determine the required surface finish.
- Determine the starting surface finish.
- Determine the required operational cost target.
- Determine the required cycle time needs for production.
- Select an appropriate media size for the part size.

Table 10-15. Vibratory finishing operating costs (Schaeffer 2003)

Cost Element	Tub Design		Bowl Design	
	Cost ($/hr)	% of Cost	Cost ($/hr)	% of Cost
Equipment depreciation	10.00	34	7.50	33
Labor	10.00	34	5.60	25
Media attrition	8.00	27	8.00	36
Waste water	1.05	4	1.25	6
Power	0.05	1	0.05	0
Total	29.10		22.40	

The costs shown here are based on US rates, equipment payback of 2000 hr, electrical costs of $0.05/hp/hr, water costs of $0.040/cu ft, media costs of $1.00/lb, labor of $20.00/hr, and a 3-to-1 ratio of media working on parts that are 1 cu in. in size. Production rate is 3024 parts/hr for a 1-hr cycle and hand unloading for tub and internal machine unloading for the bowl.

Table 10-16. Typical vibratory finishing process Sheet (Johannesen 1977)

Company XYZ Finishing Process Sheet

Customer's Name ______________________________ Our job no. ____________________

Part name ______________________________ Part no. ____________________

PCS/Cycle ______________________________ Material ____________________

Results desired ______________________________ Date ____________________

Processing Data	Operation 1	Operation 2	Operation 3
Machine no.			
Workload no. pieces			
Amount, type, size of media			
Amount, type of comp.			
Amount of water			
Angle, weights, rotations			
Time cycle required			

Additional operations or
procedures:____

____

____

____

Special handling ____

Seperation ____

Processed by ____

Approved by ____

Screen size ____

- Verify the media will not lodge in part features (Chapter 4).
- Determine what subsequent operation might be affected by the media or compound choice (welding, soldering, plating, contact loop resistance on electrical contacts, etc.; see Chapter 4).
- Determine any unique requirements and manufacturing restraints.
- Calculate the operating time that produces the allowable stock loss (from plant equations or graphs; see Fig. 10-81).
- Determine if burr is removed in the time allowed for stock loss (equation (10-1)).
- Calculate the expected edge radius, which occurs for the time calculated in the previous step (from plant equations or graphs).
- Calculate change in burr height expected for the indicated time in the machine (equation (10-4)).
- If the radii from the calculation above for expected radii is too large, then:

  – use smaller media
  – use a non-cutting or slow-cutting media,
  – use a non-abrasive compound, or
  – use a shorter cycle time.

  Equations (10-3), (10-9), (10-12), or (10-13), as well as any of the curves shown in this chapter, can be used to determine the cycle time required to produce a given radius.
- If the radius is too small or if the calculated burr height reduction is not sufficient to remove the burr, then

  – partially remove the burr before finishing, or
  – allow a larger change in diameter.

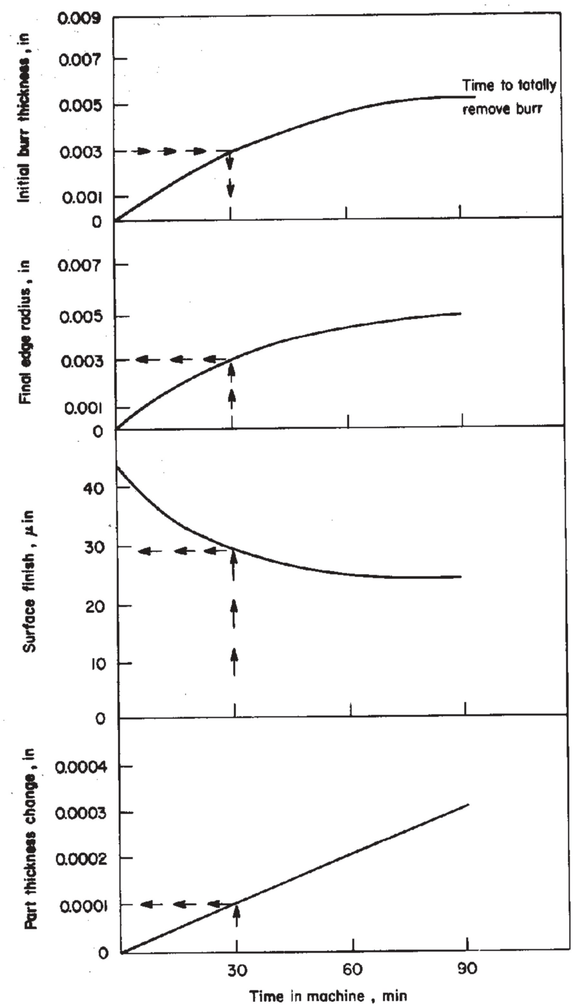


Figure 10-81. Users must evaluate impact of burr size, surface roughness, size change, and edge radii to pick proper conditions (Gillespie 1979a)

10.23.2 During Operation

During the operating cycle operators should:

- Verify that parts on hand and work instructions match.
- Validate that media is not likely to lodge in small crevices or holes.
- Verify that burrs are normal—if not, inform manager.
- Operate equipment per instructions on operations sheet.
- Clean parts.
- Rinse media.
- Verify that finished parts meet requirements sheet.
- Sign off paperwork.
- Move parts as indicated.

10.24 TROUBLESHOOTING

Because there are so many variables in mass finishing (equipment operating parameters, workpiece materials, media, compound solution, desired results, etc.), this section cannot discuss all possible problems that may be encountered. Four major problems are: 1) unacceptable results, 2) excessively long cycle times, 3) high media compound costs, and 4) media lodging in the workpieces. Table 10-17 provides a framework for solving some common deburring related problems.

10.24.1 Unacceptable Results

When unsatisfactory finishes, incorrect corner radii, incomplete burr removal, or other problems arise in mass finishing they are probably the result of using improper equipment, media, compound solution, or workpieces. Improper operating parameters for the machines, incorrect concentrations of compounds in solutions, and attempting to finish workpieces that have differences in quality all contribute to poor results.

In vibratory finishing a grit size of less than 14 is useless because the media will not move. Sand, for example, might appear to be a good media for small parts. But, because of the small grain size, it packs together rather than moving freely. Yet, size 14 media can be very effective in centrifugal machines.

10.24.1.1 LONG CYCLE TIMES

There are many reasons for excessively long cycle times. The time can sometimes be shortened by changing the compound solution used to reduce glazing of the media and improve the cutting action. The media itself may be the problem: It may be too large, impeding separation from the workpieces. Changing to a different shape and/or faster cutting media often reduces cycle times. Machines that are not kept in good condition and operated at proper speeds may lengthen cycle times.

In some cases long cycle times are the result of over-finishing parts. Specifications for actual requirements should be checked, then a shorter cycle tried to see if the requirements are met. Sometimes changing the preprocessing operations performed on the parts can reduce the amount of finishing needed. Attempts should be made to increase the uniformity of quality and cleanliness of the workpieces to be finished in order to reduce cycle times.

Five or six different parts can run in the same tubs at the same time. Not only does this save on setup and loading, it also reduces operator time. As an example of the possible speed of output, large aluminum die castings can be finished in vibratory machines at a rate of one part every five seconds.

Slow processing may be the result of the motor running backward. If the problem is continuous it may be necessary to verify that the motor on bowl machines is running in the correct direction. It can be set up wrong or reversed during maintenance repairs. Machine manuals tell users which direction to run the motor. Not all run the same direction. The motor in a bowl machine runs opposite to that of the media and parts. If media is pushing the parts up out of the mass or just along the outside of the bowl, parts will be in the working mass only a portion of the normal time. Another clue to wrong motor direction is if the rolling action is not smooth. Make sure when reversing motors that other equipment the motor drives is not affected. Some machines have oil pumps for automatic lubricators or conveyer motors controlled by the master panel (Marcus 1997).

One author (Brandt 1959) notes that vibratory finishers actually use less media and compound than tumbling barrels. A 23-hour cutdown was required for one part using a barrel. With vibratory finishing more parts per tub were loaded and they experienced only 1/6 the media wear (see Chapter 11 for more process comparisons).

10.24.1.2 PARTS STICK TO THE WALLS OF THE MACHINE

Most modern machines use a bowl or tub liner that has large grooves or ribs. When sheet metal parts rub against the bottom of the tub, the soap solution causes them to stick to the walls. As the load circulates up, the ribbed walls break the bond to the rubber lining and allow the parts to fall back into the mass. If the machine has a sticking problem, a ribbed coating can be requested of the vendor. Figures 10-16 and 10-28 show the effect of curved walls on a bowl unit. Curved and ribbed walls keep parts from crawling out of the machine while at the same time keeping them mixing better with media. This type of machine has a removable center dome to handle bigger parts.

Table 10-17. Troubleshooting Guide (Sofronas 1977)

Solution / problem area	Plug, mask and/or deburr critical area by hand	Change machining conditions or revise tool changeout program	Change size or shape of media	Use a compound	Change machining direction or sequence	Try shorter deburr time or hot water wash	Deburr more parts per cycle or fixture part	Is removal of burr necessary if not ado note
Precision bore damagex	x							
Roll-over burrs generated	x	x	x		x			x
lodging of media	x		x			x		
scratching of surface	x		x	x				
Excessive burr size	x	x			x			x
Intersecting passage burrs not removed	x							x
Not cost effective due to excessive deburring time	x	x	x		x		x	

10.24.2 Change the Sequence of Machining and Deburring

One author notes (Kramer 1971) that when drilling burrs were too stubborn to come off in normal vibratory finishing times, he had the shop change the sequence of manufacturing operations. In normal processing the shop drilled the hole (which exited in a slot, masking the burr from tumbling action), vibratory deburred it, and then tapped the hole. If the hole is tapped, tapping before vibratory operations, the tap cuts off much of the drill burr at its root, allowing media to effectively remove the thin remaining burr.

10.24.3 Corrosion on Parts

As mentioned above, when media is used on aluminum, copper, and steel parts, it can carry small particles to the other materials and that can cause visible corrosion or spotting. If this is a problem, media specific to the material should be used. Corrosion and spotting can happen when a single machine processes several materials. The materials impregnate the liners and slowly leach out. Use different machines for each material if this is the source of a problem.

10.24.4 Media Lodging

Chapter 6 presents several solutions to media lodging. Effective solutions start with the operator making careful considerations before running parts.

10.25 DOCUMENT OPERATIONS AND RESULTS

Speed, amplitude, weigh settings, as well as compound types, rates, media, and run times should all be recorded so users can repeat a process accurately months and years later. A device called an Ampli ✓ Check[8], as shown in Figure 10-82, records vibration amplitude. When subjected to vibration even with the oval patterns set up in the round vibratory equipment, the circles will form the same pattern. Big circles form a kind of blurred

[8]©Minnesota Mining and Manufacturing Co.

figure 8 with a “cat eye” between top and bottom. Read to the left, or toward the smaller circles, until the cat eye just disappears. The amplitude is the number where the circles just intersect. In Fig. 10-82 the amplitude is 5 mm (0.197 in.). The diameter of the inside of that circle is the amplitude of the machine. These devices are calibrated in either 32nds of an inch or in millimeters (1 mm = 0.0394 in.) (Kittredge 1981; Schaeffer 2003).

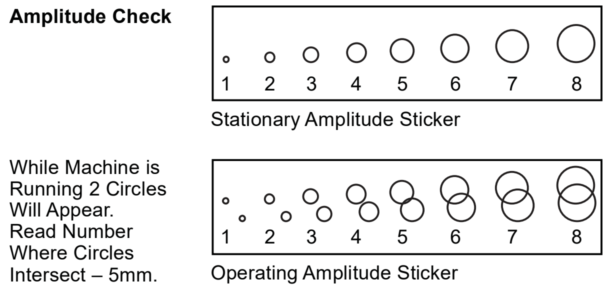


Figure 10-82. 3M Ampli ✓ Check measures vibratory amplitude (Schaeffer 2003)

10.26 MEDIA STORAGE

One of the features available to automate is a multiple media system vibrator that allows different media for each process. Overhead or container storage of media is used after the media has been separated from the parts (Fig. 10-30). Another type, size, and shape media can be used for the next cycle. These bins are available for tub and bowl machines.

Overhead storage hoppers may have a rotating carousel with four or more compartments to handle that many types of media. A slow cut plastic media process can be followed by a fast cut ceramic. The operator rotates the storage hopper until the proper product is over the machine then pulls the lever to dump media into the vibrator. Several vibratory tubs can be serviced by a common separation and overhead storage system. Contamination of one type of media by another can occur if care is not exercised.

10.27 MAINTENANCE

The vibratory source and shafts need maintenance. This may involve occasional greasing of shafts in bearings or keeping oil systems full. Oil and seal changes may be required periodically. Some use recirculating oil and others use oil-cooling devices. Because of contamination from the process, oil changing can be an important attribute of long life. Grease systems also come in both manual and automatic systems.

10.27.1 Ask Before Purchasing

Users should inquire about maintenance before buying a system and, once equipment is installed, put the manufacturer’s recommendations in place. To learn about the ease of maintenance the user should look at equipment prior to purchase. For example, maintenance that can only be done if a person crawls under the machine may be undesirable.

10.27.2 Check the Liner

When liners wear through it may be months before replacements can be procured, so the operator should keep track of wear. No one can afford to shut down production because of this oversight. When the new machine or new liner comes in, pick a place on the machine and measure the thickness. Record the location and thickness. The measurement has to be repeated every three months and checked at the same place each time. An ice pick and hammer can be used if necessary to drive the pick to the metal on the other side of the liner. The pick can be coated after it is fully in (a crayon can be used) so when withdrawn the depth of the liner is evident. A crayon works when measuring in water. Ink or dycum is used for other situations. Highest wear will always be at the bottom of tub or bowl. It is measured at the bottom near the discharge door and little media have to be removed (Girouard 1979). Record the result and the number of hours run in the service manual or other permanent machine record. An hour meter on the machine is used to record time run. Order a replacement liner when worn down to 1/4 or 1/8 in. thickness at the thinnest point. Blisters are signs of imminent failure.

10.28 ENVIRONMENTAL, HEALTH, AND SAFETY

Vibratory operations used around the world daily by all size of shops and in a wide variety of operating conditions have several safety and health considerations.

First the operations are typically performed wet and the water dries out skin, and that in turn causes rashes or other skin issues. Rubber boots, bibs, and gloves minimize this issue, but they may be hot. The soaps in the compounds exacerbate the issue and they may contain allergenic ingredients.

Some operators are allergic to copper or other metals and this may not be obvious.

In China, under conditions of 95 degree and 90% humidity, the author observed a vibratory operator was clothed in a parka in order to keep the soap suds that were literally billowing to the roof from touching his skin. Water, as well as soap, introduce slipping hazards that must be considered.

Noise from the operation can exceed allowable limits. Noise dampening covers for preventing hearing damage are available for many machines.

The loads being put into or removed from tubs may exceed normal weight limits or ergonomic standards, especially considering the amount of hand and arm motion involved when operators work with hundreds of parts day after day.

Some metals are known health hazards. Beryllium and its compounds and alloys are of this type. Nickel dust is a suspected carcinogen. Others, if run dry, like magnesium and even aluminum, which generates aluminum fines, can be the source of intense fires. If fine dust is present explosions may occur. What minimizes this issue is that most vibratory operations are wet operations.

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