Vibratory Bowl Optimization by Proper Mechanical Set-up and the Use of Chemical Accelerators to Virtually Eliminate Hand Polishing of Steel Parts

William P. Nebiolo, REM Chemicals, Inc., Southington, CT 06489

Abstract

Vibratory bowls are commonly used to deburr and reduce polishing operations on steel substrates prior to the application of a final electroplate, paint or lacquer coating. These machines are robust, time proven and a relatively inexpensive investment when compared to other automated polishing and buffing equipment. Vibratory bowls additionally offer the finishing department the cost advantage of mass finishing versus individual part handling, polishing and buffing.

It is not uncommon, however, to find that vibratory bowls are underutilized or inefficiently operated due to a lack of understanding of their mechanics. Additionally, steel components (HRC > 40) with exceptionally rough starting conditions ($R_{max} \cong 2{,}500$ µinch) cannot be finished in a practical amount of time using conventional vibratory finishing. Such parts require initial hand polishing. Traditional vibratory bowl finishing cycles require exceptionally aggressive, abrasive media and processing times in excess of 48 hours for these exceptionally rough surfaces.

Recently, however, it has become common practice, to vibratory finish such exceptionally rough steel parts in time cycles as short as four hours while virtually eliminating all hand polishing operations. Processing times can be reduced from 48 hours to 4 hours with the use of vibratory chemical accelerators.

This paper will review the basics of mechanical, vibratory bowl set-up to optimize mass rolling patterns and mass rotational speed. The correct positioning of vibratory bowl eccentric weights and weight alignment angles will be reviewed

This paper will additionally review the synergistic use of completely non-abrasive, high density media and chemical vibratory bowl accelerators that allow the finishing room to generate final R_a surface finishes in the 1 – 2 µinch level while virtually eliminating all hand polishing operations on pre and post heat treated steel parts. Examples of the reduction of vibratory processing times will be presented along with data demonstrating the virtual elimination of vibratory media attrition sludge.

For more information, contact:
William P. Nebiolo
REM Chemicals, Inc.
325 West Queen Street
Southington, CT 06489
Phone (860) 621-6755

General Vibratory Bowl Description

The vibratory bowl has the general shape of a bagel. The technical term for this shape is a toroid.[5]

A bowl consists of an O.D. wall that forms a wide diameter circle the width of the entire machine.[5] An I.D. wall forms a smaller diameter circle; the central hub, within which is housed the machine's drive shaft, eccentric weight alignment plates and on some models of vibratory bowls, the bowl's electrical motor. See Photo 1[6].

Photo 1[6]; Shows a vibratory bowl and the resulting toroid-shaped, mass rolling channel formed by the I.D. wall center hub and the O.D. wall.

The resulting toroid or bagel shape is the running channel into which the parts and the media are placed. The combination of the parts and the media is referred to as the mass.

The bowl's base is typically bolted firmly to the floor and the bowl itself sets on springs that are mounted on top of the fixtured base. The energy resulting from the revolution of the bowl's motor and the concomitant eccentric motion caused by the intentionally, unbalanced drive shaft cause the bowl to rise and fall on the springs thereby setting the mass into motion.[5]

Generic Vibratory Bowl Motion

Examination of a vibratory bowl while in operation will reveal that two planes of motion occur simultaneously. First, the mass will rise along the O.D. wall, crest in the middle of the channel and finally plunge downward at the center hub, I.D. wall. See Diagram 1[6].

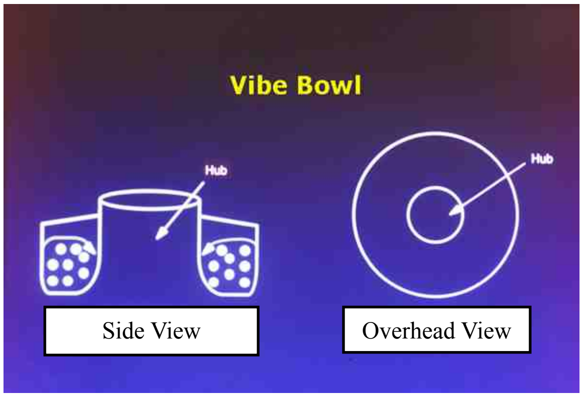

Diagram 1[6]; A cross-sectional view through a vibratory bowl on the left, shows the O.D. wall rise of the mass and its consequential plunge downward at the I.D. center hub wall. The figure on the right shows an overhead view of the bowl's bagel or toroid shape.

Simultaneously, the mass will rotate either clockwise or counter-clockwise around the center hub. (Direction is determined by the rotation of the bowl's motor and is always opposite to the motor's rotational direction.) Combining the two motions results in a spiral pattern.[5] See Diagram 2[6].

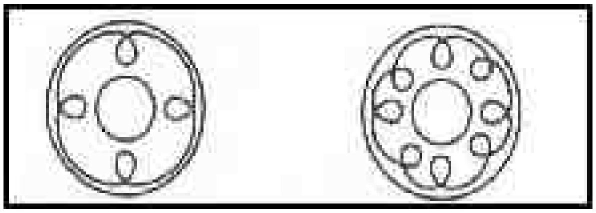

Diagram 2[6]; Shows two different spiral patterns. On the left, is a view of an open spiral whereby the mass makes only four full rolls as it simultaneously makes one lap around the central hub. The right diagram shows a more closed spiral whereby the parts will make eight full rolls while making the same single lap around the bowl.

This spiral path can be modified by adjusting the bowl's eccentric weights and weight alignment angles to effectively add or subtract spirals and thereby shorten or lengthen the path the mass takes to make one lap around the bowl's channel.[5] Again, see Diagram 2.

The tighter the spiral, the longer the mass rolling distance is per lap. Parts traveling through a tighter spiral will traverse a further distance while still making only one lap around the central hub.[5]

Inversely, a more open spiral pattern results in a shorter distance traveled per lap for the bowl mass. To optimize finishing time, it is imperative to produce the tightest spiral pattern that will finish the parts with the minimum possibility of part-on-part damage.

Part-on-part damage will occur most frequently where the parts plunge down at the center hub. This occurs because the circle that defines the center hub has a smaller diameter than the O.D. wall circle. By consequence of these geometrical size differences, parts must get closer to one another as they spiral into the center hub.[5]

Adjusting Vibratory Bowl Amplitude; the Bottom Eccentric Plate

Amplitude is a measure of the compression and expansion of the vibratory bowl's springs.[5] Since the vibratory bowl is mounted on springs, as the springs compress the vibratory bowl falls. Inversely, spring expansion results in bowl rise.

Weight segments can be added to or removed from the bottom eccentric plate to increase or decrease the bowl's amplitude.[5] See Diagram 3[6].

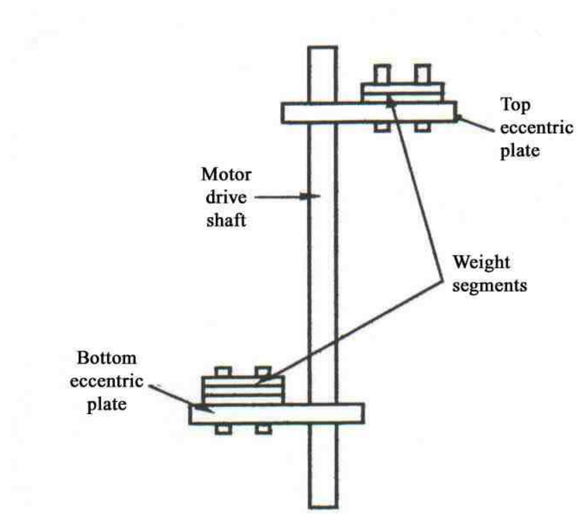

Diagram 3[6]; is a side view of the internal workings of a vibratory bowl. The diagram shows the drive shaft and weight segment eccentric plates mounted on both the top and bottom portions of the drive shaft.

Adding weights to the bottom eccentric plate increases amplitude and aggressiveness.[5] Likewise, removing weights from the bottom eccentric plate decreases amplitude making the rolling action less aggressive.[5] See Photo 2[6].

Photo 2[6]; Photo shows the bottom eccentric plate of a vibratory bowl onto which several weight segments have been added.

Typically, vibratory bowls have an amplitude range of 3.5 to 5.0 mm. Carbon steels are typically refined in this amplitude range.

Softer metals, such as aluminum and zinc die castings, would be refined better at a lower amplitude range of 2.5 to 3.5 mm, dictating that weights be removed from the bottom eccentric plate.[5]

Exceptionally soft metals, such as brass, may be damaged by amplitudes greater than 2.5 mm, and are usually finished with no weights on the bottom eccentric plate.[5]

On the other hand, exceptionally rough parts or parts where an overall cosmetically attractive final finish is not significant, can be run at higher 5.5 to 7.0 mm amplitude. Deburring an exceptionally heavy part may necessitate amplitudes of 6.5 to 7.0 mm to simply generate enough inertia to lift the part and roll it in the bowl channel. As a result 8, 9 or 10 weight segments may have to be mounted to the bottom eccentric plate in those types of finishing applications.

Adjusting Spiral, the Top Eccentric Plate

It is additionally possible to add or subtract weight segments to the top eccentric plate depending upon the number of spirals desired per lap.[5] See Photo 3[6].

Photo 3[6]; Photo shows the access hatch lifted in a vibratory bowl center hub. Visible is the top eccentric plate and stacked weight segments.

To finish parts in the shortest time, a tight spiral pattern, having a high number of spirals per channel lap, would be desirable.

Parts that can tolerate part-on-part damage, or where a cosmetically attractive final finish is not a significant concern would be good candidates for this type of motion. In practice, the spiral count is increased by decreasing the number of weight segments on the top eccentric plate.[5]

Adding weight segments to the top eccentric plate will have the opposite affect resulting in an open spiral pattern. It is possible to add sufficient weights to the top eccentric plate so that the parts may only roll once per lap. This may be an exceptionally attractive roll pattern when attempting to mass finish very delicate parts that cannot afford any part-on-part impingement damage.[5]

Adjusting Vibratory Bowl Rolling Speed

If one could look directly down from the top of the driveshaft, it would be possible to determine the angular difference between the top eccentric weight plate and the bottom plate.[5]

When adjusting a vibratory bowl for the first time or after the bowl has been recommissioned after servicing, it is imperative that the vibratory operator conduct a simple investigation of the mechanical configuration of the machine.

The traditional starting position for vibratory bowl weight segments is a 90° angle.[5] This can be determined as follows; let us assume that the vibratory bowl's motor is rotating in a clockwise direction. With the top eccentric plate positioned at the 12 o'clock position, a 90° lead angle would mean that the bottom eccentric plate would be located at 3 o'clock as viewed directly from above.[5,6] See Diagram 4[6].

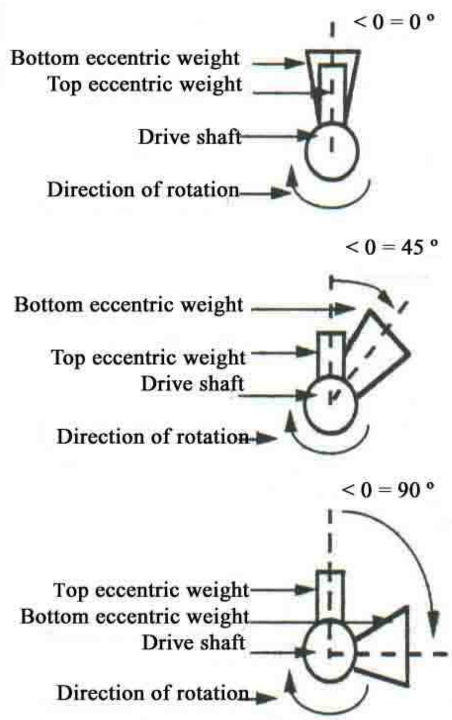

Diagram 4[6]; Shows the eccentric plate lead angle alignments in three different positions. Note, in all diagrams it is assumed that the drive shaft is rotating clockwise. Top shows a 0° alignment with both top and bottom eccentric plates in direct alignment with each other. Middle shows a 45° alignment angle with the bottom weight at 1:30 o'clock and the top weight at 12 o'clock. Bottom shows a 90° alignment angle with the bottom weight "leading" the top weight at the 3 o'clock position and the top weight at 12 o'clock.

It is possible on all vibratory bowls to adjust this angle. It is common practice to call this angle the lead angle because the bottom eccentric plate "*must always*" lead the top eccentric plate into the direction of rotation of the drive shaft.[5]

From a starting lead angle of 90°, it is possible to make the angle more acute or more obtuse to control the rolling speed of the mass. By taking this suggestion to extreme, let us assume that the lead angle can be made increasingly acute so that the bottom and top eccentric plates were directly above one another.[5] (See Diagram 4, Top image.)

As viewed from the side, a drive shaft with a 0° weight alignment would be in a maximally unbalanced rotational situation since all its possible eccentric weights are aligned to one side of the drive shaft. In this maximally unbalanced situation, as the drive shaft rotates, it transfers its unbalanced momentum to the mass, resulting in an exaggerated, aggressive rolling action.

Making the lead angle more obtuse tends to allow the eccentric weights to counterbalance each other resulting in a more balanced drive shaft rotation. When opened fully to 180°, the shaft will be fully balanced and there will be no transfer of energy to the vibratory bowl.

Obviously 0° or 180° are not normal operating conditions. Typically vibratory bowls operate in a range of 75° - 110° of lead angle.

The Cardinal Rules of Vibratory Bowl Set-Up

When setting up a vibratory bowl for the first time or when setting up a vibratory bowl that has been returned to the vibratory room after servicing, it is possible to inadvertently make some common mistakes. So, here are some basic rules to follow when setting up the vibratory bowl.

Rule No. 1 – Be certain the motor is rotating in the correct direction. All motors have a plate or sticker that shows the direction of motor rotation. It is possible with AC current to wire the motor backwards. If bowl mass motion is reversed i.e. parts rise at the hub and fall at the O.D. wall, or the mass splits in the middle of the bowl channel, the motor is wired backwards.[5]

Rule No. 2 – If the motor is rotating in the correct direction, then the mass *must* rotate in the opposite direction. The bowl mass is inert, heavy and resistant to movement. At start-up for a motor turning in the clockwise direction, the equal and opposite reaction is for the inert mass is to roll in the opposite or counterclockwise direction.[5]

Rule No. 3 – The bottom eccentric plate must always lead the top eccentric plate into the direction of rotation of the drive shaft.[5] Again, see Diagram 4[6].

The Role of Media in Vibratory Bowl Finishing

Media serves as the abrasive tool for scouring rough metal in the vibratory bowl. Media comes in two main varieties: ceramic or plastic.[5] See Photo 4[6].

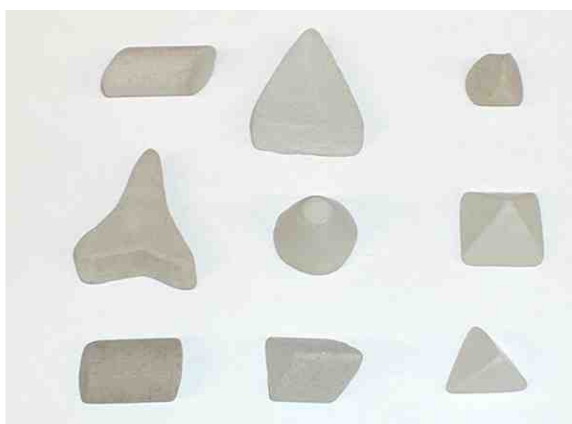

Photo 4[6]; Shows an assortment of ceramic media in a variety of pre-formed shapes such as cylinders, stars, cones, triangles and pyramids.

Ceramic Media is prepared from either river clay or porcelain. The media manufacturer adds to wetted clay; known as slip, aluminum oxide abrasive. By changing the ratio of aluminum oxide abrasive to clay or by changing the abrasive grain size, the media manufacturer can control the aggressiveness of the media.[5] See chart 1[6].

Chart 1[6]; of Typical Media Attrition Rates

Blend No.	% Clay	% Al_2O_3	δ in lbs/ft^3	Attrition in %/hr	lbs* of sludge/hr
Hi δ	100	0	130	0.02	0.2
10	92	8	90	0.13	1.3
20	85	15	85	0.35	3.5
30	75	25	80	0.75	7.5
40	65	35	75	1.20	12.0
50	55	45	70	2.00	20.0
XA	0	100	65	4.00	40.0

*1,000 lbs of media in the vibratory bowl at hour 0.

In this fashion, it is possible to chose a media blend suitable to the finishing application at hand, in the same way as you would traditionally change from an 80 grit, 120 grit, 180 grit or 220 grit piece of sand paper while polishing a piece of wood.

After blending the abrasive with the clay, the resultant putty-like mixture is extruded through a die and cut to length prior to being fired in a kiln at 1,400 – 1,600 °F. The final pre-formed shapes have a bulk density, δ = 75 to 130 lbs/ft^3, depending upon the ratio of abrasive to clay binder.

Plastic Media are similar in that the manufacturer varies the ratio of binder to abrasive content. Plastic media differ, however, because instead of clay the binder is a 2-part polyester resin and hardener that when blended together forms a pourable liquid to which the abrasive can then be added before curing.

Since plastic media are liquids prior to curing, they are formed by pouring the liquid resin into molds and allowed to cure until hardening occurs. As such, it is impossible to form extrudable shapes such as cylinders. See Photo 5[6].

Photo 5[6]; shows an assortment of plastic media in a variety of preformed shapes such as triangles, cones, stars and bow ties.

Examining Photo 5 reveals that plastic media are of a shape that can be "*dumped out of the mold*" when the resin has hardened and the mold is inverted.

Plastic media have a much lighter bulk density than ceramics with typical final density values of δ = 50 to 65 lbs per ft^3. Plastics are typically used to finish softer metals such as zinc, aluminum and brass that would ordinarily be damaged by heavier ceramics.[5]

Abrasive vs. Non-Abrasive Media

As one may expect, the more abrasive a media is, the lower the resultant surface finish or R_a value will be. This is because the larger the size of the aluminum oxide abrasive grains, the deeper the scratch pattern they will leave on the surface of the part.[5] See Chart 2.

Additionally, the higher the ratio of abrasive to clay binder, the greater will be the attrition rate of the media. In typical operation, the vibratory media is utilized similarly to a piece of sand paper. A high attrition rate media will wear rapidly thereby releasing significant quantities of free aluminum oxide abrasive into the mass to provide a significant abrading action and rapidly scour metal from a rough surface.[5]

Al_2O_3 Abrasive Comparison Table

Grit Size in inches	U.S. CAMI Grade	European FEPA Grade Equivalent	Possible Finish in µinches
0.00062"	600	P1100	5
0.00092"	40	P700	8
0.00140"	320	P385	15
0.00172"	280	P345	20
0.00257"	220	P200	25
0.00304"	180	P180	30
0.00378"	150	P160	40
0.00452"	120	P135	45
0.00749"	80	P90	100
0.01045"	60	P55	140
0.02087"	36	P33	200

Consequentially, high attrition rate media will generate copious volumes of swarf. Likewise the media level will drop rapidly and the replenishment rate will be prodigious.[5]

If media size and shape has been carefully chosen to minimize lodging in the part, a high attrition rate media will quickly decrease in size and may rapidly become a lodging problem.

This problem can be eliminated by utilizing high density, non-abrasive media. See Photo 6[6].

Photo 6[6]; Shows abrasive media on left and high temperature fired, high-density, non-abrasive ceramic media on the right.

Such media is formed in the traditional ceramic media manufacturing technique except that the media manufacturer adds no abrasive to the clay. After extrusion, the media is kiln fired at an exceptionally high temperature range of 2,200 - 2,400 °F[5]. At these temperatures the media vitrifies and becomes extremely hard, dense and durable.
As such, the media has a neglible attrition rate, and will therefore retain its size and shape for hundreds of vibratory bowl run hours.

Since this media contains no abrasive, it provides no mechanical abrasive scouring action to refine the rough surface of steel parts in a traditionally operated vibratory bowl.[2,3,4,5,7]

As a positive consequence to its operational characteristics; since this media contains no abrasive, it can generate a nearly buff like quality, R_a 1 to 2 µinch finish on steel parts.[2,3,4,5,7]

The absence of abrasive content in such media makes it impossible to refine metals using the traditional abrasive vibratory technique. However, the application of a chemical accelerator to the vibratory bowl allows this media to serve as a wiping instrument instead of a mechanical scouring abrasive.[2,3,4,5,7]

The Use of Chemical Accelerators

According to the techniques described by [4,5] rapid surface refinement occurs in a chemically accelerated vibratory finishing process. The steel parts to be refined are placed into a vibratory bowl containing the high-density, non-abrasive media[3,4,5,7]. See Photo 6.[6]

Photo 6[6]; Shows an unloading ramp equipped vibratory bowl containing high-density, non-abrasive ceramic media for the chemically accelerated vibratory finishing of steel parts.

The chemically accelerated vibratory finishing process consists of two discrete steps that are conducted sequentially in the same vibratory bowl.[4,7]

The steel parts to be finished are placed into the vibratory bowl that additionally contains high-density, non-abrasive ceramic media.[3,4,5,7] A high-magnification view of a cross section of the steel part reveals that the surface of a part; even parts that have been polished, have a micro-roughness that consists of asperity peaks and valleys.[6] See Diagram 5[6].

Original Surface

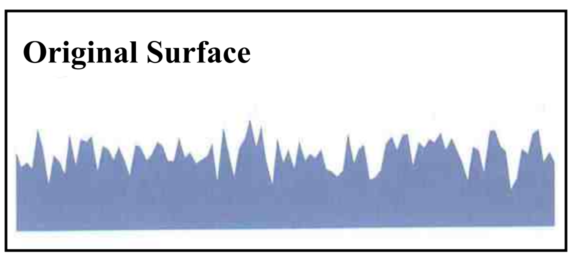

Diagram 5[6]; shows micro-roughness of polished surface with asperity peaks and valleys

During the initial or refinement step, a reactive chemistry is continuously pumped into the vibratory bowl.[2,4,5,7] Testing has shown that this chemistry does not cause hydrogen embrittlement on a heat treated steel part.[1]
The chemistry reacts with the steel parts producing a conversion coating having an approximately 1-micron thickness.[2,4,5,7] See Diagram 6[6].

Conversion Coating Formation

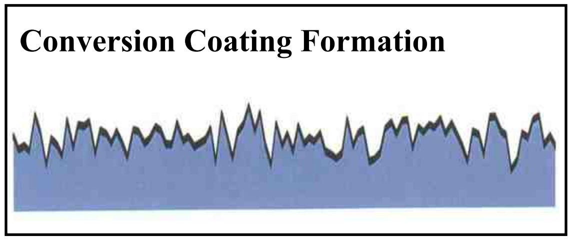

Diagram 6[6]; shows the original cross-sectional surface after the chemically accelerated conversion coating has been formed on the surface of the steel part.

The conversion coating is physically softer than the steel surface upon which it has formed.[2,3,4,5,7] As the part rolls in the vibratory bowl, the film is physically wiped from the surface of the part to expose clean metal beneath.[2,3,4,5,7]

Since the asperities are elevated, they are wiped preferentially.[2,4,5,7] The recessed valleys between the rows of polishing lines are untouched by the media, therefore the coating remains intact and the valleys remain unaffected.[2,3,4,5,7] See Diagram 7[6].

Asperities Preferentially Wiped

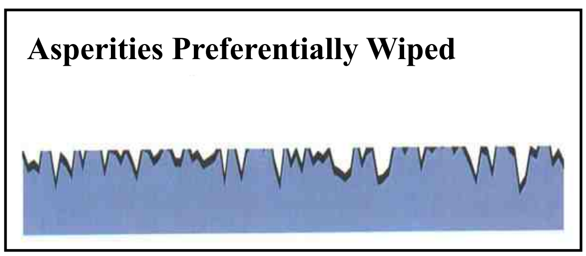

Diagram 7[6]; shows that the high-density, non-abrasive media can only contact the asperity peaks thereby preferentially beginning their leveling.

The chemical conversion coating then re-forms on the cleanly-wiped, plateau areas, that formerly were the asperity peaks.

Successive rolling and film wiping propagates asperity leveling and part refinement.[2,4,5,7] See Diagram 8[6].

Coating Reforms on Plateaus

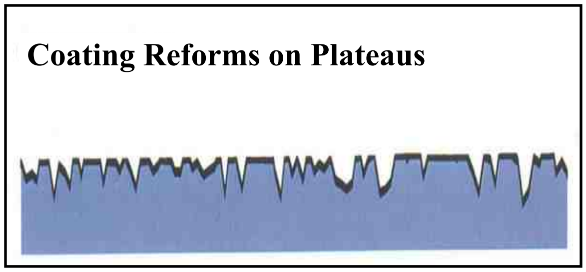

Diagram 8[6]; shows conversion coating has re-formed on partially leveled asperity peaks that are now plateaued.

As a function of vibratory bowl rolling time, the asperities are gently rubbed lower and lower, eventually leaving only the deepest valleys and generating the improved micro-finish.[2,4,5,7] See Diagram 9[6].

Surface Substantially Leveled

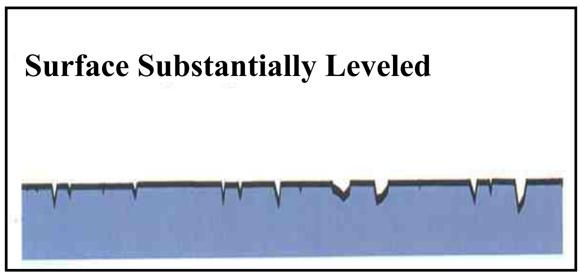

Diagram 9[6]; shows the substantially leveled asperity peaks after continued processing and the resultant improved micro-surface.

Once the required micro-finish is achieved, the second step or the burnishing process is conducted sequentially in the vibratory bowl using the same media.[2,4,5,7] A mildly alkaline, soap-like mixture is introduced[2,4,5,7] to the vibratory bowl. After a relatively short period of time, a mirror-like polished finish is achieved and any remaining conversion coating is removed.[2,4,5,7] See Diagram 10[6].

Improved Surface after Burnish

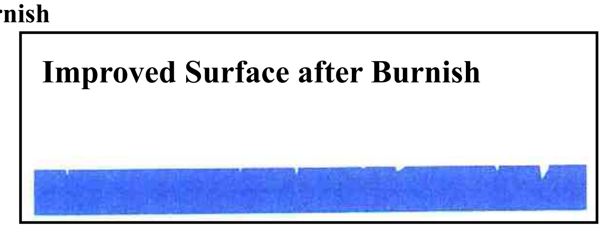

Diagram 10[6]; shows improved surface after burnishing step and conversion coating removal.

Cost savings are realized through the ability to process parts in mass, thereby, producing the superior improved finish at per piece costs lower than conventional polishing and buffing operations. See Photo 6[6].

Photo 6[6]; Shows a close-up of steel scissor halves. Note left most scissor is in a raw starting condition. Scissor in the middle has the conversion coating in place. Bottom most scissor after finishing and burnishing step.

Comparison Processing Times

As stated earlier in this paper, it is possible to greatly reduce vibratory processing times or completely eliminate hand polishing operations using this technique. See Chart 3 immediately below.

Steel Processing Comparison Chart

Starting Surface	Start Ra in µin.	Start Rmax in µin.	Run time hr/min	Final Ra in µin.	Final Rmax in µin.
forged	250	3,000	~~10~~8:00	5	60
80 grit	100	1,400	7:00	2	30
120 grit	45	520	4:00	2	30
180 grit	30	360	2:30	2	30
ground	20	240	1:30	1.5	25
honed	8	80	0:20	1	18

Conclusions

Vibratory bowls are commonly used to deburr and refine steel parts. By optimizing the rolling pattern of the parts in the bowl it is possible to shorten the processing time to a minimal level while simultaneously generating the highest quality surface condition.

The spiral rolling pattern of the mass and the speed of the mass' roll speed are controlled by adjusting the bowl's eccentric weights and the alignment angle between the top and bottom weights.

Traditionally abrasive media are used like sand paper to abrade the rough surface of a steel part to a smoother condition. The presence of the abrasive in the media results in a scratch pattern that prevents ultimate mirror-quality finishing.

Non-abrasive media produce mirror-reflective surfaces, however, their lack of abrasive does not permit finishing of rough microsurfaces.

Adding a chemical accelerator to the bowl results in the formation of a soft conversion coating on the surface of the steel parts. The soft coating is easily wiped by the non-abrasive media permitting surface refinement at a greatly accelerated rate without the requirement of an abrasive and the consequential scratch pattern.

Parts can be processed from an as forged starting condition and can be fully finished in processing times as short as 8 hours. Exceptionally advantageous is the fact that all handling, belting, and polishing operations can be eliminated and the parts processed in bulk thereby driving cost efficiency into the finishing operation.

References

1. R.D. Kane & Maldonado J., InterCorr International, Inc., Report L99825GK (1999)

2. M. Michaud, Tirendi F., Zobbi R.G.; U.S. Patent 4,491,500 (1985) "Method for Refinement of Metal Surfaces"

3. M. Michaud, U.S. Patent 4,818,333 (1989) "Metal Surface Refinement Using Dense Alumina-Based Media"

4. W.P. Nebiolo, *Proc. AESF 37th Aerospace/Airline Plating & Metal Finishing Forum;* Portland, OR (2001) "Isotropic Finishing of Helicopter and Turboprop Gearbox Components."

5. W.P. Nebiolo, *Training Manual for Vibratory Finishing;* REM Chemicals, Inc., Southington, CT (1995)

6. W.P. Nebiolo, Powerpoint Training Presentation for Vibratory Finishing; REM Chemicals, Inc.; Southington, CT (2001)

7. L. Winkelmann, Michaud M., Sroka, G., Swiglo, A.A., Mahan D.; *American Gear Manufacturers Association Meeting*, Detroit, MI, (2001) "Chemically Accelerated Vibratory Finishing for the Virtual Elimination of Wear and Pitting for Steel Gears."

