

Mirror-o-Matic Operations Manual

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Mirror-o-Matic will take most of the manual labor (some call this drudgery, some call it joy) out of mirror making. Because the mirror is rotated on a turntable, it will have a very nice figure of revolution. The chance of producing a severely astigmatic mirror is greatly reduced.

Other than these two advantages, the Mirror-o-Matic will do nothing that cannot be done by hand 'walking around the barrel'.

Although the final results should be similar, the mechanics of machine grinding and polishing can be very different from handwork. This machine should be used as described below. Although hand techniques such as full sized tools and mirror on top will work in a fashion, much better results will occur with proper machine use.

Before starting machine grinding and polishing, one should at least read several books on mirror making. Most of these books will be about hand work, but knowledge of calculating and measuring a sagitta, pouring pitch laps, building tile tools, and most importantly reading and interpreting the Ronchi and Foucault tests are extremely important. Knowing how to test a mirror and applying the proper corrections is by far the most important aspect of mirror making.

This operation manual will in no way teach you how to make a mirror. It is only a rough guide for speeds and techniques. If Mirror-o-Matic users will send details of their successes and failures, I will gladly post them on the Internet for the benefit of others.

Machine grinding and polishing is almost always done with the mirror on the bottom (MOB) and the tool on top (TOT). The tool can be another piece of glass, a tile tool or a metal tool. The tool is always smaller than the mirror if a concave mirror is desired. Tools of 50% to 80% of the mirror's diameter are normal. Tools of less than 50% diameter may cause problems while grinding, although they are valuable when figuring a parabola with a pitch lap.

Two topics that always come up in machine work are rotational speed and overarm strokes per minute. Neither is really all that critical as long as a ratio between the two is such as to prevent a repeated pattern from showing on the mirror.

Experience shows the following procedures work well.

Mirror Centering

It is important to center the mirror blank accurately on the turntable. The center of the blank must be positioned over the center of the turntable shaft. One thirty second of an inch is about the maximum acceptable offset that should be tolerated.

The center of the blank's figure of revolution will be the center of the turntable shaft. Wherever the mirror blank is positioned, the lowest spot of the mirror will be generated over the turntable shaft's center. If the mirror is offset, its low spot will not be the physical center of the blank. If the mirror is removed from the table for checking or cleaning and replaced in a slightly different location, a new center and lowest spot will be created. A whole set of hills and valleys will be created as the two figures of revolution attempt to merge.

This recontouring will occur each time that the mirror is repositioned during grinding and polishing. Hours can be added to grinding and polishing times while new radii are being generated.

If astigmatism shows with multiple spherometer readings while grinding or with Ronchi band readings while polishing, check carefully that the mirror is centered on the turntable and has no run-out. This can be checked by lightly holding a stationary pencil tip to the edge of the rotating blank and checking for a continuous line. A low cost dial indicator can also be positioned at the edge of the mirror and the run-out checked while turning the turntable by hand. .

Mirror-o-Matic uses hat sections of plywood to hold the mirror. When creating these disks, first lay out and mark the center. Then use a compass to draw a circle the same diameter as the mirror bottom. Keep in mind that the mirror may have beveled sides.

Cut and sand to the outside edge line then drill the center hole right on the center mark. Use a good quality Forstner bit with a brad point to assure accuracy.

Three or four holding blocks with slotted holes can also be attached to the turntable. Use three pronged fasteners in the bottom of the turntable and

bolt the blocks down through holes drilled through the turntable. Four blocks are preferable as three lets the carpet pad under the mirror slip away.

These can be used in lieu of taping the mirror to the hat section. Gently push these blocks against the mirror when polishing. They will cause astigmatism if set too tight.

A stationary arm can be placed over the rotating empty turntable and a pencil or marking pen can be touched to the turntable face to create a series of concentric lines on the turntable. This will make it easy to center the mirror.

Spherometers

After several years of machine grinding, I am of the opinion that it is very difficult to learn to machine fabricate mirrors without a proper spherometer.

A six-inch spherometer with a ten thousandth gauge is accurate to about 0.3 inches in radius of curvature (or 0.15 in focal length) for the typical mirrors that we create. This usually is plenty adequate. A spherometer with a thousandth gauge has one-tenth the accuracy, which is not enough.

It is my opinion that a spherometer need not be longer than half the diameter of the mirror. Many people feel that longer is better and that the best spherometer is one that is about 1/4 inch shorter than the diameter of the mirror to get the most accuracy. I feel that using a spherometer of this size reduces the usefulness of the instrument greatly.

A sub diameter spherometer can be used to measure the center area of the mirror and then the outer areas. If there is any difference, the mirror has zones. (Anytime that the ROC of the mirror is changing when grinding, you will have zones.) Polishing out a zone of even a few ten thousandths is time consuming. Take readings all over our mirror and compare them before polishing.

If readings are taken in several concentric areas of the mirror and there is any difference, you have astigmatism. Again, it's difficult to polish out. Always proceed with fine grinding until all spherometer readings are the same.

A long spherometer will only show the relative depth of the central sag verses the edge, everything between can be rippled and it will never show until you start polishing.

I have checked a lot of mirrors over the last few years. Many machine

ground mirrors have zones. It's the nature of machine grinding. Many hand ground mirrors have astigmatism. Plus zones. Again, without a small spherometer, you have no way of finding these problems until you polish and test and then you will probably tell people that you just polished a huge hole in the middle of your mirror when in fact, its been there all along.

If you are using a micrometer, you will want to make a three-legged instrument. If you are using a dial indicator, you can use a 2 or 3-legged unit. Two legged spherometers need to be tipped inwards until reading the highest and correct value.

Another advantage of small spherometers is that you can get by with a dial indicator with only 0.08 inches of travel.

MSC sells one ten thousandths micrometers for \$60 and dial indicators for about \$100.

A simple spherometer can be made without machining. Use a 6 inch or so pulley with a 3/8 inch center hole. Most micrometers have a 3/8 inch shaft. Insert the shaft in the hole and use the pulley set screw to clamp the shaft in the correct location so that the indicator reads zero when the spherometer is resting on a flat surface.

Three round headed acorn nuts can be glued to the pulley as balled feet. A locating template can be made of stiff paper. Use a compass or CAD program to layout a base circle, center hole and feet locations.

Beveling the Mirror Blank

Prior to grinding, bevel the mirror blank on both sides with a whetstone. Even a small bump to the edge of an unbeveled mirror can cause large glass breakage. An unbeveled edge can also cause severe cuts.

The bevel should be at least 1/16 inch and 1/8 inch is better. The bevel will be reduced during grinding and should be retouched occasionally.

If the bevel is made with a coarse stone, very small pieces of glass may chip off and scratch the mirror. This is not a problem when hogging, but may be during fine grinding. Use a fine grit stone to touch up the bevel when you get to the finer grinding grits

Rough Grinding

Rough grinding (hogging out) is the first stage of grinding performed on a new flat blank and tool. The purpose of rough grinding is to generate a 'dish' in the center of the mirror. This dish is deepened until the correct radius of curvature (R.O.C.) is produced.

The procedure to set up the machine for rough grinding is to first set the eccentric to zero stroke. Then set the overarm so that the toggle is directly over turntable center and set the overarm platform bolt.

With the mirror on the turntable and the tool sitting on the mirror, adjust the 5/8 inch threaded rod so that the overarm is level.

Now set the eccentric for desired stroke. You may want to tip the overarm up and remove the tool before plugging in the machine. Then after verifying that the overarm has a safe amount of stroke, stop the machine and replace the tool.

My current recommendation for rough grinding is as follows: Tool on top. The tool should be 50 to 75% of the mirror size. It must be smaller than the mirror.

Tools larger than 75% may have trouble with grit that becomes broken down before reaching the mirror center. The tool will then grind more on the edge of the mirror and less in the center and the curve will not establish or the center of the mirror curve will be flatter than the edge.

Stack between ten and 30 pounds of weight on the overarm. I use 10 pound barbell weights that have a hole in the center and stack the weight over the 5/8 inch threaded rod that sticks up through the overarm.

The turntable should turn 40 to 70 rpm depending on mirror size. Smaller mirrors can spin faster. Too fast will sling grit and water off the mirror and make a mess.

Set the eccentric so as to stroke the tool center over center edge to edge with no tool overhang on each side of the mirror. Stroke 5 to 10 strokes per minute.

Use 60 to 80 grit. Add grit and water every 2-3 minutes for 6 to 10 hours. Heavier grit causes problems by not properly distributing itself under the tool. If the slurry formed by grinding is thick and sticky, add more water with your grit. When grinding, the slurry should always be a bit on the watery side. I use a plastic drink bottle with a 1/16 hole drilled in the cap filled 1/3 with grit and 1/3 with water to apply grit and water. Shake it up with your thumb over the hole and then turn it over and give a squeeze.

Caution:

Never allow the grinding or polishing slurry to dry out. If it does, the tool and mirror blank will glue themselves together instantly. Then the motion of the turntable will cause both to be thrown from the machine, perhaps violently. You may become injured or the mirror may become destroyed.

Make sure that your machine has an overarm stop to prevent the toggle from dropping and hitting the mirror should the tool leave the machine.

I check the sag with a homebuilt 6-inch spherometer with a 1/10,000th micrometer every 20 minutes or so. Without a spherometer it is hard to tell what is happening.

An eight-inch plain glass mirror should take 3 or 4 hours to hog. A twelve-inch mirror will take about 5 hours. About one or two cubic inches of glass will be removed every hour. Pyrex may add 50% to these times. Some very hard glasses will double the times.

If I am starting with a flat mirror blank, I use a flat tile tool. They will grind spherical quickly. Tiles are soft enough to recontour and make good contact. Avoid pre-curved tile and metal tools while hogging. The curved tool surface will not allow good contact until it is worn flat. It will then be compromised for fine grinding. If you are starting with a concave blank, use the blank as a mold to pour a tile tool with the same curve. Do not use a curved tool with a flat blank or a flat tool with a curved blank.

If your strokes are too long, the mirror will stay flat. If they are way too long, the mirror may go convex. Adjust the tool overhang to produce the desired radius of curvature. Short strokes make deep curves. Long strokes flatten curves. The fastest hogging will occur when there is no overhang.

A tile tool may completely grind an 8-inch f/8 mirror without reapplying tiles. Bigger mirrors will probably need a second and third layer of tiles. It is possible to stand the tiles on edge within a form set on a Saran Wrap covered mirror and encase them in Pourstone Plaster. This will give you a full inch of tool thickness, which will definitely last throughout grinding.

A tablespoon of grit and a squirt of water will be required every 2 to 5 minutes. Listen to the sound of the grit tumbling and it will be apparent that a recharge is necessary.

Weight should be added to speed the grinding. I find about 10 to 30 pounds to be ideal. Five-pound barbell weights are only a couple of dollars and can be stacked directly on the arm over the swivel. Too much weight can deform the tool or turntable and create zones. It may also crack tile. Too much weight will cause the grit to fracture before it can reach the center of the mirror which will cause a mirror center with not enough curve.

A second method of rough grinding is to use a 55% - 70% diameter tool with a stationary overarm. Set the eccentric for zero throw. Set the arm offset so that one edge of the tool has about 1/8th inch overhang.

Add grit, water and weight as above and let the tool ride on the rotating mirror. The tool will spin on the mirror with their outside edges rotating at the same rate. Because there is little relative speed between the outside edges and a lot of relative speed at the mirror center, a sphere will be ground into the mirror and the tool will become convex. The longer that it spins, the deeper the curve gets. Move the arm out and the edge develops a chordial motion, which grinds the edge down and makes the curve shallower. Find just the right spot and the tool doesn't change the ROC. This is the place that you do all your fine grinding and the start of polishing.

This is my favorite way to grind. Without the twisting moment caused by pushing a heavy tool across the mirror, additional weight can be stacked on the arm which speeds grinding. It is easy to add grit and water since a portion of the mirror is always exposed. I recommend that you use this method on mirror blanks that have an established curve.

If you are starting with a new flat mirror blank, I would recommend that you begin with a side to side arm movement until the curve becomes established. Occasionally, the stationary arm method does not work until a shallow curve is begun. If the mirror blank or tool has any high or rough spots, you will definitely want to start with a side to side motion. Without some scrubbing motion to break in the tool, it will just spin on the high spot until it is very slowly worn down.

If the tool chatters excessively, it probably has high and low tiles. Reduce the weight or slow down the turntable until the tool grinds itself smooth. Once the tool and mirror surfaces have meshed with each other, grinding should be very smooth.

Check your progress with your spherometer. You can use this hogging period to learn what different stroke will accomplish. Do not worry if the curve is less than a perfect sphere. It likely will have a surface that varies about the same as your grit diameter.

Fine grinding

After the mirror has been rough ground to the proper sagitta, fine grinding can begin. Fine grinding will remove the pits from the previous coarser grit and will form a more exact sphere.

I have had very good results fine grinding with a side to side motion using a 75% diameter tool and allowing the tool to overhang each side of the mirror by 1/6 of the tool diameter.

I start with 120 grit and work through 240, 400, 15 micron and 9 micron. I generally spend 15 minutes with each grit. Since the machine is doing the work, some people only use 40 micron and 9 micron to fine grind. It takes a little longer, but there is less cleanup.

A freshly hogged mirror blank usually has a less than perfect sphere. The bottom of the curve will usually be flat. As you go through each grit, the curve will get better. After 9 micron, the curve should be within 0.0001 inches of perfect.

Fine grinding on Mirror-o-Matic can also be done with the stationary overarm method. The overarm does not need to swing side to side if the tool is large enough to cover half the mirror diameter when in the neutral position described below. However, if the mirror surface starts developing zones, side to side motion will average them out.

The procedure is to first set the eccentric offset to zero throw (position of the eccentric rod end bearing is at the center of the eccentric drive) and tighten the bolt. Next set the overarm offset so that the tool hangs over the edge of the mirror about 15% of the tool's diameter. The inner tool edge must extend over the center of the mirror. Tighten the bolt in the overarm offset slot.

Turntable speed can be fast or moderate. If desired, the eccentric can be hooked up at a slow speed and a very small amount (1/2" to 1") of back and forth motion can be introduced. This will blend away any tile tool marks that may appear and give a better spherical surface..

Tools should be in the 70 to 80 percent of mirror diameter range. Smaller tools can be used for fine grinding if they are swept across the mirror surface enough to grind the mirror center. Sweeping the tool will require larger tool overhangs to maintain the neutral position mentioned below. If you are swinging edge to edge, a overhang of about 22% of the tool diameter will be needed.

Tile works fine except small pieces may break off and leave very small scratches. It is best to use unbroken tiles as the edges break off easily.

I fine grind about 30 minutes with each type of smaller grit. Check for a uniform grayness all across the mirror and check for pits and scratches with a magnifying glass before moving on to the next grit.

Check the curve after the first fifteen minutes. If it is getting deeper, move the arm out a bit. If it is getting shallow, move it in. You will soon find the "sweet spot" where the curve maintains its R.O.C. This is the neutral position.

It is important to maintain the R.O.C. when fine grinding. If the R.O.C. changes during fine grinding, zones will be created which will take a long time to polish out. The neutral position uniformly removes glass across the entire mirror surface without changing the mirror's radius of curvature.

Use a spherometer of one half the mirror's diameter to check the outer portion against the inner portion of the mirror's surface. The ROC of the two must be the same. The ROC of the mirror should not be changing while in the final stages of fine grinding. If the readings are not the same or if the ROC is changing, you have created zones. Adjust the arm in or out as necessary to find the neutral position.

If you do not have a spherometer, mark the mirror face with a Sharpie felt tip pen and assure that the surface is grinding uniformly. If areas are still black after a few minutes, fine grinding is not complete and a spherical surface has not been established. It is important to maintain the neutral position for at least 30 minutes to assure that there are no zones ground into the surface.

Check the mirror surface. If the outer areas and inner areas have different pit sizes, you may have zones.

Polishing

Most polishing problems are due to improperly formed pitch laps. The pitch should have a uniform thickness of between $\frac{1}{4}$ inch and $\frac{3}{8}$ inch. Deep beveled $\frac{1}{4}$ inch wide channels should be cut in the pitch. I use a single edge razor blade to cut the channels. If you use a short stroke shaving motion, the pitch will cut nicely. Cut the pitch over a piece of newspaper or under cold running water. It can be messy.

The pitch lap must be fully pressed to conform to the mirror's sphere. Make sure that the lap's channels are uniformly cut to allow for pitch flow.

Cold press overnight and check the channels. Wavy channels are an indicator that there were high and low spots in the lap and the pitch has recontoured itself. Straight channels are an indicator that the lap is in proper contact with the mirror surface. Recut and repress if necessary.

After pressing, you may want to run hot water over the face of the lap for a few seconds and scrub the pitch with a stainless wire brush to micro-facet the surface. When the lap is working properly, a fine soft brown scum may be produced.

I have had good results with Gogolz 64 pitch. This is fairly hard pitch. Softer pitch can cause problems with excessive flow and of grabbing. Polishing should be done in a room with a uniform temperature of 70 to 75 degrees F.

It is important that the pitch lap be symmetrical about its center. A lap that is not symmetrical will not spin correctly when polishing and will drag across the glass causing zones and grooves. Do not offset the channels as you might in hand polishing laps. If the lap does not spin, verify that the toggle hole is centered in the tool.

If the tool chatters excessively, the pitch lap is either not properly formed or it has become glazed. If it is glazed, scrub it with a stainless steel wire brush while holding it under pretty warm running water. Use the corner of a razor blade to make some small scratches across each facet so the pitch can get a better bite on the glass.

A pitch lap of 70% to 80% of the mirror diameter works well for polishing. Use the same stationary overarm techniques as in grinding. It is easier on the machine than using a stroking motion. I use 60 to 70 rpm for a turntable speed. It is desirable to introduce a small amount of eccentric motion (1/2" to 1" total tool movement). Use the slowest eccentric speed (8-rpm). Good results can be had by setting the eccentric to produce an average overhang of 15% of the tool diameter when the arm is all the way in and out. Do not allow the outside edge of the lap to cross over the outside edge of the mirror when polishing. This will cause a turned down edge.

When polishing, we are looking for the neutral position as in fine grinding. If the arm is in too far, a second inner sphere with a shorter ROC will be polished into the mirror. If the arm is too far out, a shallower sphere will be overlaid on the original sphere and it will grind the edge down. Each will show as a turned down edge when testing.

If you have just finished fine grinding, you can use a pitch lap of the same diameter as the fine grinding tool and use exactly the same overarm position and stroke as in fine grinding. If the pitchlap is properly pressed, the

surface will polish to a perfect sphere quickly. This is the surest method of getting a perfect sphere.

After the first 30 minutes of polishing, check to see if the surface is taking a uniform polish. If the center is polishing faster, move the arm out. If the edge is polishing first, move the arm in.

Use the Ronchi test to check that the figure of revolution is spherical with no edge problems. The center is not as important as the edge. If it is slightly high, it will be taken down in figuring. If it is slightly low, it's part way parabolized. It is better to be slightly high.

When polishing, the lap should spin smoothly. If it is grabbing and jerking, it probably has high and low spots. It must be pressed better. Check to make sure that the channels are really clean and straight (so the pitch can flow properly) and press overnight with 5 to 10 pounds of weight. This method almost always produces perfectly straight Ronchi lines if the lap is properly pressed and the neutral grinding and polishing positions are used.

If the Ronchi test shows severe zones or a black center, you have probably ground (not polished) them in. You may want to go back to grinding with 9-micron grit until the spherometer shows equal readings.

Add 3 heaping teaspoons of quality cerium in 32 ounces of water and let set overnight to dissolve clumps that can cause scratching. You can also pass the cerium mix through a coffee filter. With a fresh pitch lap there can be quite a bit of resonance. The arm will vibrate and the machine will lightly shake. You will only be able to use five pounds of weight at first and maybe 10 pounds after the lap breaks in because of the vibration. Faster or slower rotational speeds may reduce the resonance.

The cerium mixture should be thin like milk. Anything thicker impedes the polishing process.

Polish the mirror fully before moving on to figuring. Again, the edge should be perfect before moving on. It will take 3 to 5 hours to fully polish a spherical mirror.

If you find deep scratches during polishing, you will have to determine whether to live with them or go back to fine grinding. It takes forever to remove even 220 grit scratches by polishing. It is better to go back to 15 then 9 micron fine grinding for 20 minutes to remove the scratches and to polish for another 2 hours again than to try to polish out the scratches by polishing for 10 more hours. Or you can live with the scratches. They are of no optical significance.

I do not recommend using the fine grinding tool for a pitch lap. If you find scratches, it will be difficult to go back to fine grinding without the original tool.

Figuring

Figuring is the process of changing the mirror surface from a sphere to a parabola. We do this through addition polishing of the center of the mirror while leaving the edge essentially untouched. The amount of material removed is usually measured in ten thousandths of an inch or less.

Sub diameter pitch laps are usually used (40-60 %). The polishing lap can be used for figuring by placing a ring of aluminum foil or waxed paper into the outer portion of the lap and pressing it between tool and mirror overnight. When the foil is removed, the new lap will be effectively smaller. If you wish to change the mirror surface back to a sphere, you can repress without foil and regain the area.

Slow the turntable to 7 rpm and speed up the eccentric to 16-21 rpm. This will give a proper stroke ratio (5 or 6 to 1 is about right). Slowing down the turntable will prevent the pitch lap from spinning and grinding a new sphere into the surface. The lap should still be turning, just not spinning. When figuring, we want to 'scrub' a selected portion of the surface away, not create a new sphere. The fast arm motion will cause scrubbing.

Since turning a sphere into a parabola requires deepening the center of the mirror, the pitch lap should stroke across the center of the mirror in an edge to edge fashion.. Use only a few pounds of weight and concentrate the polishing towards the center at first. Later work your way out by increasing the stroke length. This will blend the zones smoothly together.

You can use a Ronchi computer program to show what the Ronchi lines should look like for your mirror. When figuring, the more the lap rubs on a zone, the farther apart the Ronchi lines will move. Figuring is the process of deciding where to place the lap and for how long it should rub to correct the Ronchi lines.

It may be useful to slide the overarm assembly rearward to figure out zones that can appear in the outer radius of the mirror. You can also offset the arm over high zones and use small side to sidestrokes to blend them into the correct zones. Several builders have cut a 5/8-inch slot down the overarm and hinge to allow positioning the lap in the correct zone. The Mirror-o-Matic 20 has a slot cut into the overarm for this purpose.

Small laps and rose or star shaped blending laps are often used with machines. I have had good results with 60% shaped laps.

You may want to disconnect the eccentric and move the arm to the up position or remove the overarm assemble totally and just use the turntable alone for hand figuring.

It is up to you to experiment. Please pass your experience back to me, so I can share it with others.

Turntable and eccentric rotational speeds

With the recommended 1725-rpm electric motor, the following RPMs will be available.

Intermediate shaft = 258 rpm

Slow speed shaft = 38 rpm

Turntable (12" Pulley) & Medium Speed Shaft

Shaft Pulley	RPM	Belt Required
1-1/2"	32	
2"	43	
3	65	
4	86	

Turntable (12" Pulley) & Low Speed Shaft

Shaft Pulley	RPM	Belt Required
1-1/2"	4.7	
2"	6.3	
3	9.5	
4	12.6	
5	15.8	
6	19	

Eccentric (8" Pulley) & Low Speed Shaft

Shaft Pulley	RPM	Belt Required
1-1/2"	7.1	
2"	9.5	
3	14.2	
4	19	
5	23.7	
6	28.5	

Note: Belt sizes are not given due to the different combinations that can occur from varying speeds with low and intermediate shafts. Space is given for you to enter your own preferred belts. The belts called out in the parts list will be adequate for most use.