Priručnik za izgradnju teleskopa

Izvori:

1. The San Francisco Sidewalk Astronomers (USA)
2. Victor's Telescope Making (USA)
3. ATM – amaterska izrada teleskopa (Hrvatska)

The San Francisco Sidewalk Astronomers

Victor's Telescope Making

Plans for Building a Dobsonian Telescope

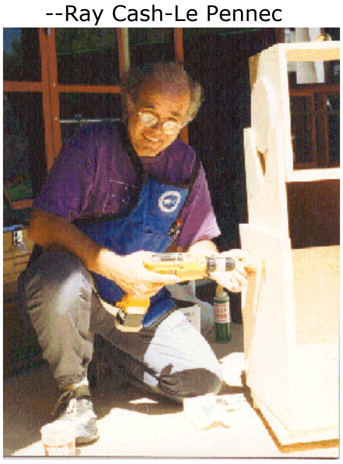
brought to you by: The San Francisco Sidewalk Astronomers

Yes, it "looks like a cannon," but the above is really a ten-inch (measured by the diameter of the objective) Newtonian telescope that almost *anybody* can build. Here you will find plans to build this telescope, or a smaller one--either a six-inch, or an eight-inch--of identical design. These plans are only slightly modified from the plans *The Sidewalk Astronomers* have been sending to interested parties for a mere $2.00 via snail-mail. I have kept as close to this design as possible: One, because this is--hands down--the cheapest and easiest way to make a quality telescope; and two, because I walk in the shadow of John Dobson, who invented many of these designs which have revolutionized amateur and professional astronomy alike... Besides, *Los Angeles Sidewalk Astronomer*, Pam Reid, did most of the work by writing and typing the procedures, as well as gathering the drawings--which, by the way, were done by Earl Jungians (from photographs of John at work by Molly Lusignan). Most of my "work" consisted of scanning and re-typing Pam's work... though I do interject my two-cents here and there.

In the category of "the left hand not knowing what the right hand is doing," another Webpage, supported by NASA's ***Telescopes in Education Project,*** also have these plans online. Here you will find the original plans--images and text scanned together, without my minor meddling--which includes, by the way: the Six-inch plans, the Sun Telescope construction tips page, a Links page, and a real person to E-mail your questions to. Regardless, it is a beautiful page, and I recommend you check it out; especially if you have any problems printing the plans from this page.

If you would like to grind, polish and figure your own mirror, I suggest Victor's Telescope Making page as well as the late Sam Brown's book , **All About Telescopes**, which may be ordered from Orion Telescope and Binocular Center.

--Ray Cash-Le Pennec



Introduction

The plans you will find on these pages, are, by and large, the result of years of trial and error on the part of John Dobson, one of the founders of The San Francisco Sidewalk Astronomers and a prolific telescope maker. John has, quite literally, helped thousands of people make telescopes of this design! Only in the past few years have commercial telescope manufacturers adopted the *Dobsonian* approach to make affordable, alt-azimuth Newtonian telescopes... However, the three top manufacturers (henceforth referred to as: "The Big Three"), Celestron, Meade, and Orion, continue to fall short mechanically of the simple designs found on these pages. All of The Big Three, for example, use *Melamine*; a kind of coated particle board, which is heavy, not durable, in short; not as strong or light as plywood, which, of course, *we* recommend. All of The Big Three have undersized pivot bolts, do not use *Teflon* as bearing surfaces (there is no substitute!), and have shoddy mirror cells (tailgates). The list goes on... They do look "pretty," especially in photos; I'll give them that. If you happen to own one of these scopes; you might well peruse these pages to find ways to tinker and fix up your mass-produced Dob: you can only *improve* what you got! It ain't rocket science!

The designs you find on these pages are also open to improvement by *you*: the builder. Not only will you discover the ins and outs of Newtonian / Dobsonian telescope design, but you are encouraged to come up with your own modifications. We include plans to make your own Primary Mirror Cell (we call it a "Tailgate"), Secondary Diagonal Mirror Holder and "Spider," and Eyepiece Holder/Focuser. These are items even the most seasoned TM (telescope-maker) usually buys from small telescope part manufacturers: you may opt to do the same (although John's designs are perfectly functional--some ingenious--and *very* inexpensive to fabricate). Contact your local astronomy club, there are usually at least a handful of TM's that can help you out. Also, check my Sources page for materials and accessories you will need, or, might want, to purchase.

I think you will find these plans pretty clear, simple, and straightforward. If not, let me know.

Have fun!

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Frequently Asked Questions (FAQ's)

Q: How much is this going to cost?

You can research this as well as I can. The primary mirror will be your greatest expense, followed by eyepiece(s), accessories (like a 1-power finder), and your diagonal mirror. Some prices (as of 1/26/99) are as follows (prices do not include shipping):

Mirrors (Primary + Diagonal--from Coulter, as an example):

- 6" $134.95+$29.95
- 8" $189.95+$39.95
- 10" $329.95+$52.95

Eyepieces (from Orion):

- 26mm Plossl= $49.95
- 10mm Plossl= $49.95

One-Power Finder (from Rigel Systems):

- QuikFinder= $39.95

Sonotube and other miscellaneous parts from these plans are incredibly inexpensive. A sheet of plywood will cost about $30 (but you will use less than 1/2 a sheet if you make a six-incher... maybe you can scrounge scrap material from a local cabinetmaker?

Remember: ***The San Francisco Sidewalk Astronomers*** have a long, proud tradition of helping folks make the least expensive/scrounged materials quality telescopes in the world!

There is nothing preventing you from spending more on your scope, however. A good commercial focuser can cost upwards of $100; a diagonal mirror holder and spider can cost $50, a commercial mirror cell can cost $30...

Q: Is a ten-inch scope that much better than a six or eight?

Size does matter, but as is often said: the best telescope is one that is used the most often... A smaller telescope is easier to handle, to transport, and will (generally) be used more often. I very much like six-inch f/8 or f/10 scopes for use in light polluted cities: images of the planets and the Moon are stunning through quality scopes of this aperture. Eight-inchers of faster focal ratios (say f/5.6) are also very manageable with ordinary vehicles, and often visually outperform similar aperture commercial Schmidt-Cassegrains costing upwards of $2000! For ten-inchers, their aperture really comes into play at dark sites and with "deep-sky" objects. For this reason, especially if this is your first telescope, I recommend the smaller sizes unless you have ready access to dark skies, or know yourself to be a fanatic about this hobby already!

Q: How far away can I see with this size telescope?

The Sun is eight light minutes away; Jupiter a few hours; Saturn twice that distance; star clusters within our Milky Way are typically hundreds to thousands of light years away; galaxies are millions of light years distant, some billions... However, "How far away can I see?" is not really the question: The naked eye, for example, can see the Andromeda Galaxy which is 2.9 million light years away! Sure, any telescope will make the Andromeda clearer, and that is more to the point: The larger the diameter of the telescope, the more ***resolving power*** one has available to your eye/brain. Just as expensive computer monitors have more lines of ***resolution***, and therefore display a more detailed image, a larger telescope mirror will collect more light and is therefore capable of higher magnification and higher resolution; enabling us to detect more detail in celestial objects.

Q: Will I be able to see color... anything like the beautiful space photographs I have seen?

No. We have all been spoiled by the Hubble Space Telescope, NASA, *Star Trek* and other beautiful space images--real or imagined. However, there is no substitute for seing the Universe as it really is through a telescope that you have made! I strongly suggest you attend a public "star party" in your locale and look through as many telescopes as you can. Go to http://www.skypub.com/ for an extensive listing of astronomy clubs--to find one in your area.

Q: Can I take photographs through this telescope?

No. Dobsonians can be made to track with computers or equatorial platforms, (see my Dobsonian Evolution links page) but at quite an expense... Even so, these set-ups are generally for visual use, not photographic. For photographing the sky through a telescope, I suggest a different kind of telescope, with a different kind of mount. Be prepared to spend at least $2000 on the telescope and another $2000 on photographic accessories. In short, you are on the wrong Webpage<g>.

Q: How long will it take me to make this telescope?

Oh, about two weekends, I would guess. I think you will find most of your time spent at the beginning and end if your project: the gathering of the materials; and the final sanding, painting and finishing--everything else goes pretty fast--and is quite satisfying.

Q: Even the six-inch scope in your plans is a bit ambitious for me and my young child--is there someone that makes a kit in a smaller size?

Yes! I recommend *Stargazer Steve.* Steve sells very affordable kits in various sizes.

Q: Where can I get a printed copy of these plans?

If you can't print--for whatever reason--from these pages, I suggest you contact the Los Angeles Sidewalk Astronomers; last I heard, they are still sending out hard copies for $2.00 from this address:

The Sidewalk Astronomers
1946 Vedanta Place
Hollywood, CA. 90068

If you are requesting these plans be mailed to another country, the price may be higher.

I do not send any plans through the mail, nor do I have any infuence over those that do.

Some not-too-technical advice before you begin...

This Webpage contains complete instructions for constructing a Sidewalk (Dobsonian) telescope using a six, eight, or ten inch (diameter) purchased objective mirror. If you are interested in grinding and polishing your own mirror, we suggest you pick up John Dobson's video (listed under "Sources" below) as a start. Also, Victor's Telescope Making Page has step by step instructions for mirror making. **All About Telescopes**, by Sam Brown (found at Orion Telescope and Binocular Center) also has good instructions on this art.

How much is this going to cost? Well... an 8" f/7 mirror from Coulter with diagonal costs $219.95, plus $15.00 for shipping. If you can build an 8" scope for twice the cost of this, consider yourself lucky! You *can* buy a "Big Three" scope for only a little more; you can also buy used for less... Something else must be motivating you to "build your own." This Webpage is for you... and your daughter and/or son!

You will need to purchase one objective ("primary") mirror and one diagonal flat, ("secondary) mirror, in order to build the telescope. Mirrors may be purchased from mail-order telescope supply houses. Coulter Optical is an excellent, dependable source for good-quality, inexpensive mirrors, so we have included their address in the "Sources" list below. Orion Telescope and Binocular Center also sell mirrors, as well as alot of other stuff.

What we describe as a Sidewalk Telescope, or Dobsonian Telescope, is a simple Newtonian reflecting telescope in a sturdy, wooden, alt-azimuth mount or rocker. The telescope consists of a concave (actually *parabolic*) objective (or Primary) mirror, which is mounted in the bottom of the tube. This objective gathers light from the object under observation and brings the light to a focus; forming an image of the object in what is called the *focal plane* or image plane, at the upper end of the tube.

A small, flat, front-surface mirror called the diagonal (or secondary) mirror is mounted inside the telescope tube near the front end. This mirror is mounted at a 45 degree angle to the tube's axis—hence its name. It deflects light from the objective to the side of the tube where the image may be more easily examined with an eyepiece.

A Word About Focal Length and Focal Ratio

The focal ratio of the mirror you select determines how long your telescope will be. A 10" objective mirror with an f/7 focal ratio will give you a telescope with a 70" focal length. (Multiply the "f-number" by the diameter of the objective mirror to get the focal length.) Your tube will need to be cut to the length of the focal length, so you would have a 70" long tube. An 8" objective mirror with an f/7 focal ratio would have a 56" focal length, and a 56" long tube.

(John Dobson recommends a focal ratio around f/6 or f/7)

FOCAL RATIO (f-number) x MIRROR DIAMETER = FOCAL LENGTH = LENGTH OF TUBE

SOURCES

Sources for "Ready Made" Telescope Mirrors and Telescope Eyepieces:

- **Coulter Optical, Inc** -- now part of: Murnaghan Instruments

1781 Primrose Ln.

W. Palm Beach, FL

We recommend Coulter's mirrors: quality products at **very** reasonable prices. Call or write for catalog and price list.

- **Orion Telescope and Binocular Center**

2540 - 17th Avenue, P. O. Box 1158

Santa Cruz, CA 95061-1158

In California (800) 443-1001

Outside California (800) 447-1001

Call toll free number for free color catalog.

- **Paul Rini** sells *very* inexpensive eyepieces at $17.50 apiece plus $4 shipping.

P. O. Box 224 Main St.

Maple Shade, NJ 08052-0224

- You may also check the "previously owned" market at: http://www.astromart.com/.

Other Accessories, and Miscellaneous Parts:

- http://www.crazyedoptical.com/ is a great source for *Teflon* and hard to find parts to "gussy up" your scope.
- The ATM Resource List. The *definitive*, up-to-date list for the Amateur Telescope Maker. If you can't find it here, I can't help you!

If you want to make your own mirror, may we suggest:

- **John Dobson's Telescope-Building Video**

  This 90 minute, full color video is John Dobson's personal guide to making astronomical telescopes—8 inch to 16 inch apertures and larger. Especially strong in the mirror making department and for large (read 16" Dobsonians). Free color flier available on request.

  Price per tape: $39.95

  Shipping per tape: $3.50

  CA residents add $3.40 sales tax.

Total per tape (except CA) $43.45

Total per tape (CA only) $46.85

Make check or money order payable to: Dobson Astro Initiatives

Remember to include your shipping address!

Mail to: Dobson Astro Initiatives

P. O. Box 460915

San Francisco, CA 94146-0915

Sources for Mirror Kits and other Mirror Making Supplies:

Willmann-Bell; P.O. Box 35025; Richmond, VA 23235

(804) 320-7016

$1 Catalog

Newport Glass Works, LTD; 2044-D Placienta Ave; Costa Mesa, CA 92627

(714) 642-9980

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Hollywood, CA. 90068

If you are requesting these plans be mailed to another country, the price may be higher.

The plans on this Webpage are much improved from the ones the LA folks send out--I recommend you try to print the plans from these pages.

I do not send any plans through the mail, nor do I have any control over those that do (concerning promptness--or anything else, that is)!

A Final Note:

If you are new to the world of astronomy, the Internet is a great resource! (But don't forget your local Library, either)!

Here are a few WebPages devoted to helping the beginner:

- Absolute Beginner's Astronomy Page
- Kevin Daly's Astro-Nuts Page

- Bill Ferris' Cosmic Voyage
- Don't forget Yahoo!'s Astronomy Links

To join **The Sidewalk Astronomers** and receive our quarterly newsletter, send $15 to:

The Sidewalk Astronomers

1946 Vedanta Place

Hollywood, CA 90068

Mirror making

The following information is based on my own, and other Club -members' experience in making, or helping make, test and finish about 50 or so mirrors over the last fiteen years. No guarantee is given that this information will enable you to make a perfect mirror, but is intended simply to share our knowledge of the subject in order to help those who have no experience - and are making a mirror for the first time:

If you have never made a mirror or a telescope before - one of the best things you can do is search for a local Astronomy Club. In many clubs you will find members who have already made telescopes - either from 'kits' which contain all the necessary parts - or 'from scratch' using the least expensive materials and methods. Most telescope makers are quite proud of their efforts and very willing to pass on their experience and knowledge to others. Another (most essential, in my opinion) is the acquisition of a good BOOK on telescope making. Both the above can make life much easier - even for the experienced mirror and telescope builder.

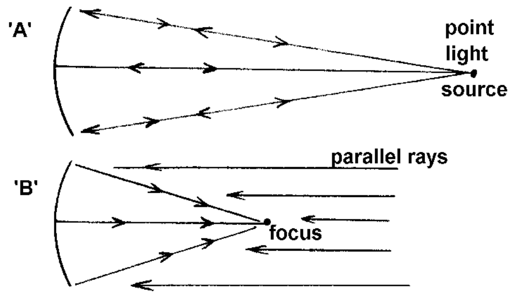
Before we start - a bit about the shape of a reflector-type telescope mirror

The primary mirror in a Newtonian type reflecting telescope is a 'concave mirror.' It is of course usually a round mirror and thus is shaped as though it were a 'slice' cut out from a sphere, or a round ball. So that across any diameter of the mirror the curve in its surface is a section of a circle. This is normally the shape that is automatically formed by the process which is described in the following text. (In practice though, this does not give perfect images when parallel light rays coming from very distant objects are reflected to its focus point. So, in practice, we have to shape it so that its cross-section across any diameter becomes a cross-section of a parabola, rather than a cross-section of a circle. This is what is referred to as 'parabolising' the mirror. The reasons for this are explained further in the following text, and **the process of 'parabolising' is done after the mirror is ground, polished and tested.)**

TO START OFF - a bit about optics

Figure 1 (A) shows light coming from a point source located at the center of curvature of a concave spherical mirror. This would form an image of the source superimposed on the source - as all the rays are reflected back to the source, as they all meet the mirror's surface at a 90 degree angle.

Figure 1.
Reflection from a curved mirror



If we moved the point source slightly to one side the image would move slightly to the opposite side and could be seen by placing a screen at that point. Below is shown the same mirror (B) but with **parallel light rays** coming to the mirror surface from distant objects - stars, planets etc. In this case the light rays meet the mirror surface at differing angles from edge to edge of the mirror. They are bent further inward and form an image at what is termed the FOCUS of the mirror. Once the source of incoming rays is a few miles away - the rays are effectively parallel, and they will meet at the 'focus' of the mirror. This point will be a point halfway between the mirror and the center of curvature of the mirror's surface.

Note:the numbers given in the following are in inches...if you are used to metric numbers 1 inch = 25.4 millimeters, So an 8" mirror would have a 203 mm diameter in metric measurement.

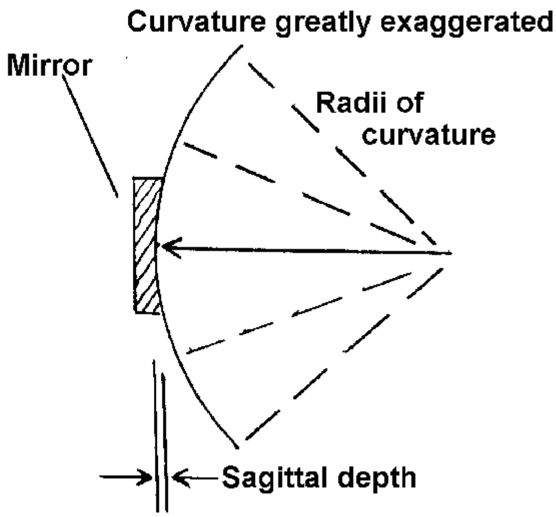
From the foregoing you will see that if a mirror is to have a 'focal-length' of let's say 40 inches - the radius of the curve in the mirror's surface will be 80 inches. Therefore if we want to make a 6 inch mirror and have a 36 inch focus - the "radius of curvature" will be 72 inches. We would refer to this mirror 6" diameter, 36" focal-length as an "F-6" mirror.

This is simply the ratio between the mirror's diameter and the focal-length. So an "F-8 " mirror of 8" diameter would focus at 64 inches (and would have a radius of curve in the mirror surface of 128 inches.)

O.K . NOW HOW DO WE GRIND THE MIRROR - and how do we figure out how to get the depth of curve that we want?

The details that follow apply equally to any size and any f-ratio mirror --(within the ranges up to 20" and F5 to F10 - if you're planning to make a 30" F-3, you're either nuts! or you've had a ton of previous experience)

We will start with the decision that we are going to make an **F-8, 8 inch mirror:** This means that our radius of 'c' will be 128 inches. The sectional curve in the mirror is really part of a complete circle, and we can visualise that our cross-section is a small slice from this circle which has a radius of 128"



The depth of this 'sagitta' as it is called is calculated by multiplying the radius of the mirror by itself and dividing the result by twice the radius of 'c'.. that is, in this case 4 x 4/256 = .0625" a mere 62 thousandths of an inch! (It just happens that this is 1/16th of an inch, which is much easier to remember!)

Mirror kit

Now we have decided how deep the curve in our mirror will be - we can move on to the really messy stuff - **rough grinding:**

I assume that you are starting with a mirror-kit, from one of the suppliers of kits and materials:

Some suppliers will send you a 'pyrex' mirror disc along with a ceramic disc which will be used as the tool, some still supply two 'pyrex' discs and you should pick the better one to become the mirror

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We have cut expense a couple of times - by buying a kit containing two pyrex 'blanks' (along with the necessary grit etc.,) and using **both** pyrex blanks to make **two mirrors**. To do this we have bought 1/4" or 3/8" thick glass discs from a local glass shop - cut the same size as the mirror - glued these to 3/4" plywood discs (with epoxy glue - be sure to **spread the glue evenly** right to the edges of the surface of the ply-disc) Bevel the edge of the glass and then paint the plywood base to seal it - so that grit cannot hide in any cracks. **If necessary repaint the edge between grit sizes.** Make absolutely sure that the disc is evenly glued to the glass, and that it **cannot flex** due to spaces between the glass and the plywood backing disc.

As the depth of curve in the average 6 or 8 inch mirror is usually less than 1/10", these tools work fine. (the plate-glass wears down a little more than the pyrex but not enough to cause a problem) The kit also usually contains enough grit etc., to make at least two mirrors. The **other** expense-cutter has been to buy a few port-hole glass discs. 9" or 10" diameter from marine suppliers. About five or six of our members have successfully made mirrors with these. Again using a thinner glass disc on plywood as the tool for grinding them

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The grit sizes supplied with most kits are #80, #120, #220, #320, #500, then 12, or 15-micron, 5, or 8-micron. The last of these are often Aluminum Oxide rather than the Carborundun or Emery grits. The numbered grits are finer as the numbers **increase** and the micron sizes are finer as the micron-size **decreases.**

These should be kept in separate containers and , if stored together - should **always** be kept with the finer grits above the coarser ones if they are ever stacked one above the other.

The pitch usually supplied is quite hard, and may need softening by adding a little bit of turpentine, and possibly a small amount of beeswax, the wax is usually supplied as part of the kit. Some suppliers will provide an already softened pitch. You do not want the pitch to be too soft, it should appear hard - but strong pressure for 20 or 30 seconds with your finger should make a definite impression on a square. You can pour a bit of your melted pitch - before you fill the mold, and after it is completely cooled - a few hours later, test it and adjust your mix if you think it is too hard - or too soft.

A word about polish. In most mirror-kits the polish supplied is Cerium Oxide. This is a very fine pinkish colored powder which polishes faster than the Optical Rouge which was used in the past.

Rouge although the best of all polishes is extremely messy and stains everything it contacts. Very few people use it today. An alternative, which is somewhere between the polishing speed of rouge and Cerium Oxide is a product called **Zirconium Oxide**. It is available from many suppliers of kits and is a clean white powder - and is the polish we recommend.

An important note here: The disc - from whatever source it comes should be of even thickness all the way around. There should not be any significant difference in thickness (less than perhaps 1/2 millimeter - (10 thousandths of an inch)) Also the back surface should be **quite flat** and even - some discs are cut from sheets of glass and may have either noticable corrugations or other unevenness. These discs should be **ground flat** before starting to grind the mirror.

Note the two discs are both flat discs to start with. It is the type of offset stroke which produces the curvature in both the mirror disc and the tool disc. The mirror disc is used on top of the tool disc. This produces a concave curvature in the mirror, and the tool disc becomes convex. If the correct strokes are used then they both develop an almost perfect 'spherical' curvature.

Note also that you should bevel **both edges** of the mirror and the tool at a 45 degree angle - or sharp edges will develop during grinding - and a sharp edge will 'splinter' very easily if it happens to hit the edge of the tool or any other hard surface. Use a sharpening stone or a fine sanding wheel and be sure to do this by grinding the edge in a direction away from the surface of the disc.

You now need to find a place to work - where the temperature is as even as possible - and also the area should be dust-free. You also need a **sturdy and stable** small bench - preferably one which you can walk around. You also need a bucket of water or a nearby sink in which to wash the discs, and a few small sponges 3 or 4 inches square for wiping things off. We have frequently bought a packet of cellulose sponges - about 4 x 8" and cut them in half.

During the grinding and polishing process - if you have any concern about 'dust' or breathing problems - I would recommend wearing a mask, or tying a large handkerchief around your mouth and nose. In the finer stages of grinding and polishing microscopic bits of the powders, or polish and glass particles could be inhaled as they are present in the air around your bench, especially as the 'wets' start to dry out.

During the initial grinding we are going to be applying **fairly heavy pressure between these discs.** (The grit works best at cutting the glass under strong pressure) So we need 3 small wooden 'cleats' less than the height of the disc - fastened to the bench with screws. This will prevent the lower disc from moving around. The cleats should be positioned close to the disc, at 3 points close to but not quite touching it, so that we can turn it as necessary.

Summary of grinding and polishing

1.) First of all **Rough grinding** is used to 'cut out' the glass and produce a concave curve in to the mirror's surface. During this period one uses the 'chordal' stroke and applies pressure to ensure that the grit cuts away glass. One also offsets the mirror about one-third to half of its diameter (taking care not to allow it to 'tip' over the edge of the tool.) This is done around successive 'chords' of the mirror and tool by 'walking round' the grinding table (or by turning the tool and mirror if working on a bench,) so that the grinding is spread evenly all the way around both mirror and tool. When the depth of curve is very close to that required - the stroke is changed to a 'W' stroke. This improves the accuracy of the curvature during the last stages of grinding to the required depth.

2.) During the next process, which is **smoothing** the mirror - the pressure is simply the weight of the mirror and the hands resting gently on top, to guide the mirror through its 'W' strokes. In this process which consists of using gradually finer grades of grit, the purpose is to 'let the grit' do the work. The aim is to get the surface of the mirror smooth enough to finally polish it, so that even with no coating applied it will reflect light - like any highly polished surface. When really smoothed the surface should show reflections of bright objects at a shallow angle. Also at the start of smoothing it is best to adjust (if necessary) the depth of curve as accurately as possible this can be done by reversing the discs and working with either the mirror on top (to increase the depth) or using the tool on top (to reduce the depth.)

3.) **Polishing** - this is a different process again from the previous grinding and smoothing. A polishing 'lap' is made by applying pitch squares to the tool and 'wet-pressing' it against the mirror. This makes the pitchcovered surface adopt the exact shape of the finely smoothed mirror's surface. Then an optical grade polish mixed with water is used (usually Cerium Oxide or Zirconium Oxide.) Polishing a telescope mirror calls for patience and many hours of work. To properly polish even a 6 inch diameter disc can take from 8 to 10 hours, and a 10 or 12 inch disc may need 15 hours or more.

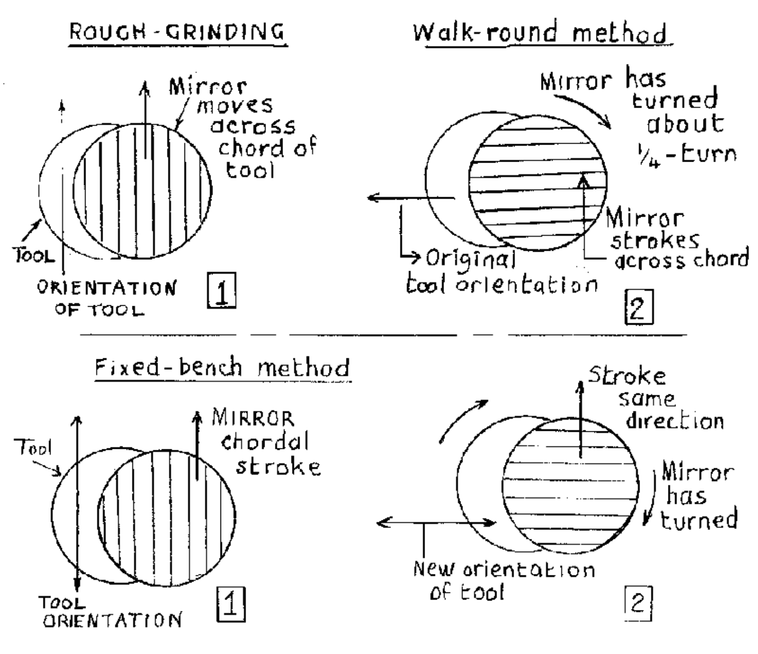
Rough grinding

In the **rough grinding** process - we place the tool disc on the bench - and then apply a small amount of the abrasive grit (number 80 grit) with enough water to form a creamy paste spread around the surface - we place the **mirror disc on top;** then swirl the discs around gently to evenly spread the mixture. See below for details on applying the grit.

For an 8" disc we would apply about a half to one teaspoonful of #80 grit and sprinkle it around the surface. (NOTE: for 4" 5" or 6" discs we would recommend using #120 grit for the rough grinding -this of course works less quickly, but you need a certain **minimum** number of strokes in the rough-grinding process to ensure that the 'spherical figure' is obtained) Then apply a small amount of water and spread the mix with our finger to make a reasonably good mix of water and grit. If the mix is too dry, then the discs will tend to bind and be hard to move - if so - we add a little more water and try again. If it is too wet the grit will wash out over the edges of the tool . With a little practice you will soon get to know the right amount to use. When grinding - if the mixture is good you will be able to tell by the loud grating noise as you rub the discs together.

Then we off-set the mirror about half its diameter - but not enough that it will tip over the edge of the tool as we move it backwards and forwards across a 'chord' of the tool. We use pressure as we stroke the mirror disc across a chord of the tool - making about 10 or 12 double strokes. -- but not counting exactly the same number of strokes each time. Then we turn the mirror disc about a quarter turn (on average - but not exactly a quarter turn - we are relying on the law of averages to even out the grinding process) We also step around the bench a little in one direction (left or right - but once you decide which - you must always go the same way) and we stroke across a different chord of the mirror - and, as we have stepped around a little way we are also stroking across a different chord of the tool. You should try to make about eight or ten small steps around as you do this - so that you gradually work your way around the lower disc. This ensures that the discs are ground out evenly and ensure that the surface becomes spherical. In this way as we **keep grinding and turning around the mirror** we will gradually cover the complete surfaces of both so that they will become ground **evenly.** (See diagram below)**Don't forget to turn after every 10 or 12 strokes !**

If you have to work on a bench which does not allow you to walk around - then to work around the mirror evenly you need to turn **both** the mirror disc and the tool disc about a quarter turn (but not exactly a quarter turn each time) so that you will grind across a different chord of each. You will in effect "walk around the tool" by turning it - but you will make your strokes across the bench in the same direction all the time. When you turn the discs - try to do this methodically. Center them first, then turn **both** discs together, now turn the top disc only. This way you will have turned each of them about a quarter turn. Then you off-set the top one and continue with the next set of strokes. (Remember to vary this 'quarter turn' - as we want this turning to average out so that both discs become ground out evenly across their whole surfaces.)



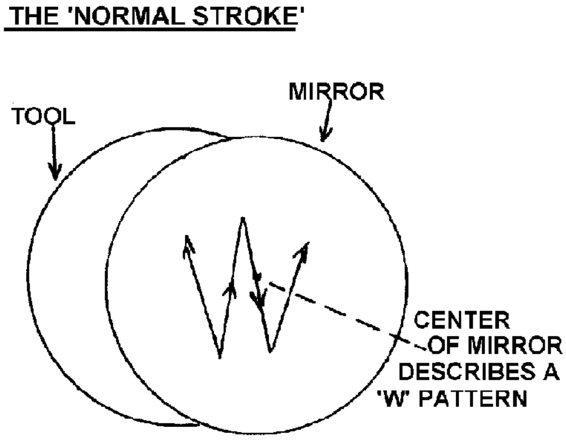
We continue with the off-set stroke constantly working our way around the mirror . The mix dries out after just a few minutes of work - (2 to 4 minutes) and the loud grinding sound dies away. The discs get harder to move and tend to bind together. As the grit mixture dries out, we stop - clean off both discs and add a fresh mix of grit and water. This few minutes of work, after which we clean and recharge the mix, is referred to as a **"Wet".**

Depending on the size of the mirror and the depth which we need in the mirror's curvature, after an hour or two we need to check the depth. The easiest way to do this is with a good straight-edge, a steel rule or other such item laid across the mirror from edge to edge and across the centre. Using a feeler gauge or small drill bits of known size we can measure the clearence between the rule and surface at the center of the mirror. If we are not yet close, we continue with the grinding until our measurement is **reasonably close** to the depth we require. Once we reach this point we can stop the rough-grinding and begin to consider the next steps.

FINISHING ROUGH GRINDING

Now that our depth is about right we need to change to a different type of stroke. We also now **reduce the pressure used previously** using only the weight of the mirror disc.

The stroke which we will use now - and for **all** of the smoothing and polishing of the mirror, is going to be a stroke in which the discs will be approximately **centered** and the pressure used is just enough to keep good contact between the tool and mirror.



As you can see from the drawing - the stroke is more over the center of the mirror and moves only about 1and 1/4 inches to each side (for an 8" disc) and the vertical stroke is about 2 and 3/4 inches. The center of the mirror therefore, describes a letter "W" shape.

When pushing the disc back and forth across the mirror - be sure that you don't 'rock' or turn the disc during or at the end of a stroke. This can be a common mistake, the disc between your hands should remain oriented in the direction in which you are moving it.

You must not allow it to twist between your hands as it goes back and forth - whatever direction you may be pushing it. **Remember to turn both discs frequently as before.**

You still keep turning the mirror (between each series of back and forth 'W' strokes) when using this new W - stroke ..its just that you should avoid twisting the disc when doing the back and forth stroke.

After a number of strokes you then turn the mirror a little as you walk around the bench so that you keep stroking across different diameters as you apply the strokes (about 10 or twelve double strokes at a time.)

If you can't walk around the bench you need to turn **both the tool and mirror** (in opposite directions) approximately 30 to 40 degrees of turn. This ensures that your smoothing action smooths the whole surface of the mirror evenly as you work.

For any size of mirror the sideways motion should be **no more than a quarter of the mirror's diameter** (this is the total sideways motion - about an eighth of the mirror's diameter on each side, about 1 inch overhang on each side for an 8 inch mirror) - and the back and forth motion should be **about a quarter to a third of its diameter in total.** This can and should **vary a little bit,** but not by much. Again the law of averages works in our favour. (When lenses and mirrors are made by machine, this variation has to be deliberately introduced or 'cyclic' effects will cause errors in the final surface figure.)

For the final part of our rough grinding we will grind the mirror for perhaps a couple of dozen or more 'wets' using this 'normal stroke'. Also we **no longer** apply weight to the mirror - we let the weight of the mirror apply the **only pressure needed.** Now we simply guide the mirror during our strokes. **If the depth in the center starts to get too deep** - we simply **reverse the tool and mirror** - and continue with the tool grinding on top of the mirror. This reduces the depth of curve in the mirror. It is also one of the reasons that we don't have to be too precise in attaining our depth exactly to a thousandth of an inch during rough grinding. As we start to use the finer grit sizes to smooth out the surface we can adjust the depth more exactly.

After perhaps another hour or so using the centered stroke we can check that our depth is close to what we want, and, if so we can call a end to the rough grinding process.

**Note - If the depth is more than the depth required, you can reduce the depth by doing a number of 'wets' with the tool on top. If it is not yet deep enough, you continue with the mirror on top.*

At this point - if you have done everything right - you now have a rough-ground mirror of very nearly the correct depth of curvature. The surface figure should be almost perfectly spherical and you can look forward to smoothing it out and polishing it.

Now you have reached the most IMPORTANT part of the whole process:

The bench, mirror, tool and bucket (if used) and anything else that has come into contact with the #80 grit must be thoroughly cleaned. You need to wash your hands - including scrubbing your fingernails, to be sure that not even a single grain of the #80 grit remains. The cleats which held the tool on the bench should preferably be discarded - along with the sponge , and new cleats and a new sponge used for the next grit size (which will probably be # 120.)

This 'thorough clean-up' must be done when each session with any grit size is completed. If for example, you were to smooth out the mirror and get down to using a #400 grit size, and one single grain of 120 or 80 grit 'got into the works' you would wind up with a very obvious 'scratch' - which you will either have to live with, or go back two or three grit sizes and start over, to remove it.! In any case you would have to stop - and clean everything up again before you could continue. So you might as well do it the first time and avoid such disasters.

SMOOTHING the MIRROR

SMOOTH GRINDING - or smoothing as we will call it from here on, is quite similar to the final stage of the rough-grind. Here again we do not use any more pressure **other than the weight of the mirror disc or tool.**The tool is again set on the desk with the mirror disc on top - a mix of water and the next size grit (usually the #120, is applied and using the 'Normal' W-stroke we do a series of 'wets' (for perhaps about an hour and a half.)

During this time do **about 15 minutes with the mirror on top** of the tool. Then, **for the next 15 minutes - change positions of the discs** - putting the mirror on the bench, and the tool on top. Continue to use the same stroke and keep **interchanging the position of the mirror and tool at 15 minute intervals.** This will ensure that the curvature remains the same. Then we clean off the mirror, dry it off and examine the surface carefully under a good light - with a hand magnifier if available, to see if the surface looks evenly pitted.

If there are a number of larger pits scattered around the surface, continue with more wets with the 120 grit, (or the next finer grit if making a smaller mirror - such as a 4 to 6 inch size, where you may start the grinding with 120 grit.) until the surface appears to be smooth and even, and the pits in the surface are all the same size. Pay special attention to the outer edge of the mirror - it seems always to be the last part to smooth out. Check that the pits are the same size all over and that the pits in the glass are all of the same, finer size than those of the previous grit that was used. (You need to check this smoothness after each size of grit used.)

Once the surface is properly smoothed, take 'time-out' to check the center of curvature and the resulting focal length. This can be done a few different ways: Firstly if you have a sunny day (always the optimist) you can take it outside, and dip it into a bucket of water to wet the surface. Then you reflect the image of the Sun's disc onto a white card or similar 'screen' and adjust the distance to get the best focussed image of the sun. This will directly give you a measurement of the Focal-length! You simply have to measure the distance between the mirror and Sun's image on the screen. You probably need someone to hold the screen and do the measuring for you.

A word of caution If you are doing this **in the sun** - be sure not to aim the mirror towards anyone's eyes, **even the uncoated mirror gives a very bright reflection which can damage one's eyes.**

Another method is to take a good flashlight, and some type of white card to make a vertical screen. Set the flashlight and card next to each other on a table. Then, again using a bucket of water or a spray-bottle wet the mirror surface and from about the distance you expect the radius of curvature to be, try to reflect an image of the flashlight back on to the screen. Move back and forth to get the best focussed image on the screen, if necessary wetting the mirror again

Try to keep the flashlight at the edge of the card and focus the image as close to that edge as possible, so that the distance between the reflected image at the edge of the card is within a couple of inches only to the side of the flashlight.You are looking for an image of the front end of the flashlight., which should be placed with its face level with the card. The distance between the card and the mirror will be the measure of the Radius of Curvature, and half that distance will be the Focal-length.

If you are not close enough to the required radius, you can then continue using the 120 grit and either reduce the curve (using the tool on top) or you can deepen the curve (using the mirror on top) depending on whether your focus measured too long, or too short.

This 'optical' way of measuring should allow you to attain the desired focus to within an inch or so. In any case it is more accurate than any mechanical means of measuring the depth of curve of the mirror disc. The focus can still be 'trimmed ' even during the finer stages of fine-grinding if you want to be within a fraction of an inch of the true 64 inch focus which this particular mirror is supposed to have.

If you are happy with the measured radius. You can now repeat the 'cleanup' process again. Remove the mirror and tool, the cleats and throw away the new sponge which you used for the

120 grit. This will be a **standard procedure** every time you finish with one size of grit and start on the next finer size.

Now you are ready to start again - but this time with the next finer grit size (220) You will continue this way, until you finally reach the finest grit size. When you finish with the 220 size grit, **re-check your focus** and use it with either the tool on top (to increase the focal-length) or with the mirror on top (to reduce the focal length) After this step - you continue with the finer grits - changing the position of the tool and mirror every fifteen minutes or so, during all the next finer grit sizes to preserve the curvature of the mirror's surface.

The time required to remove the pits left by the previous grit will vary, usually becoming less time needed as the grit sizes decrease. For the 220 grit you may need less than a couple of hours work, and as the grit size reduces the time spent will become even less. The best guide though - is to examine the surface very carefully - to be sure that all the deeper pits from the previous grit are ground out. It is better to do a little too much than not enough. Above all else - be sure to really clean up perfectly after each grit session is completed, before starting the next one.

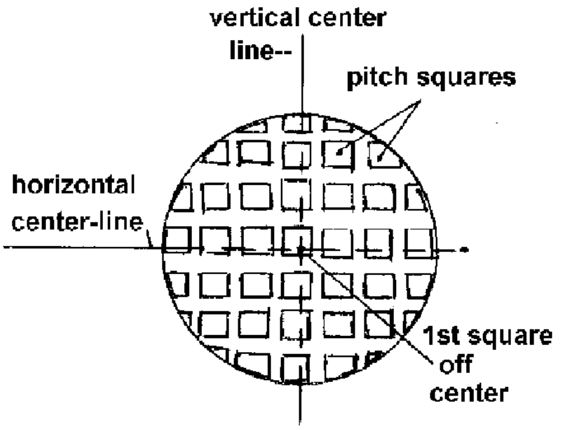
When you start to use the finer grit sizes - such as the 500, and especially the 12 micron or 5 micron, you must mix the grit and water carefully and make sure that the mix is evenly spread and does not contain 'clumps' of powder which can act as a much larger size grit and produce 'scratches' After applying and spreading the mix, place the tool or mirror in position and move it around carefully, this should 'spread' the mix evenly before you continue with the normal stroke.You should not hear any 'scratchy' sound nor should you feel the discs trying to bind together.

Once you have finished with the finest grit size, and are sure that the surface is evenly smooth over the mirror - you have reached the point at which the next step is POLISHING - "Oh Boy !! "

And - by the way - CONGRATULATIONS !

POLISHING the Mirror

To polish the mirror - we must build a new type of tool - using the existing tool-disc. But now the tool has to be covered with a number of pitch squares, evenly distributed over its surface. The pitch squares need to be placed **slightly off-center,** across both diameters of the tool. If they are precisely centered they can lead to 'periodic' patterns on the final polished surface. Between Each row of pitch squares is a channel - about 3/16" wide to allow water and polish to circulate, and to allow for spreading when pressed on the mirror.



There are many ways of making the lap - One way is to use a specially designed 'mat' obtainable from kit makers, this is placed on the tool and the pitch poured over the surface. When it has set, the mat is peeled off leaving a series of channels between the squares. In some designs the 'squares' are either circular or perhaps hexagonal. In other cases a layer of pitch is poured, allowed to set, and then channels are cut very carefully (with an old saw)

The consistency of the pitch is important. Pitch normally supplied is quite hard and extremely brittle - I usually mix in a little linseed oil (a small bottle from artists supplies can last for a long time) I use perhaps about 5 milliliters for each pound of pitch, then also I add about half a cubic inch of beeswax (about 1/2 ounce.) These two together soften the pitch and also make it less brittle. Before making up a batch of strips - I pour a small amount into a mold - about 1" by 2" and about 1/4" deep. Allow it to set and cool to room temperature. It snaps in two when bent quickly, but will bend if gentle pressure is slowly applied with both hands. The pitch should not be too soft, but must be soft enough to 'flow' when polishing. **See additional notes below**

A few additional notes:

The pitch should be heated slowly and not made too hot or it will lose some of the natural solvents it contains. A fairly thick creamy consistency is best - fluid enough to pour easily but not too 'runny' Be sure to have the mold ready before the pitch is melted and ready to pour. The sooner it is poured and cooled the less solvents will be lost.

The last time I made a pitch lap - I cast a 'block' of pitch, This was made a little softer than the formula above (I had a deeper mirror to polish) I added about 1 ounce of beeswax and about 8 to 9 milliliters of linseed oil to 1 lb. of pitch. The 'block' I cast was about 10" long by 4-1/2" wide and 5/16" thick. This was heated in a tub of water at 95 degrees F. for about 5 minutes. It was then possible to cut 3 or 4 strips 3/4" wide x 4-1/2" across before re-warming the block again to cut more strips.

Afterwards the strips were cut into squares (3/4" x 3/4") in both cases I did this with a cold knife, without the pitch breaking. This seemed to me to save a lot of time. The squares were then fixed to the tool in the normal way: before applying the squares the tool was coated with a ***very thin*** *layer of turpentine, then the squares were heated, one by one, with a candle flame untill the bottom of the square was 'wet' and then they were applied to the tool and gently pressed to ensure good adhesion.*

Our preference has always been to apply the squares individually. We cast a number of pitch strips - about 3/4" wide and perhaps 8 or 10 inches long. This is done by making a wooden mold, with thin wood strips, about 3/8" thick, to form a mold with 6 or 8 long channels into which the molten pitch is poured. The wood strips and the base of the mold are first given a good coat of varnish, and on the top of the base a layer of aluminum foil is placed. The varnish prevents the pitch from 'glueing' itself to the base and the varnished strips are lightly nailed on top with the nails sticking up so they can easily be removed. When set and completely cooled the wood strips are removed, and then the strips of pitch are cut into squares. This will provide about 70 or more squares of pitch 3/4" square and about 1/4" thick. This is done starting with the outer strips, by twisting them sharply after the nails are removed, and the pitch is quite cold.

If need be we put the mold in the fridge to really cool it. The strips of pitch can be peeled off the foil- covered base plate quite easily. The finished strips are cut using a hot knife. With the right amount of heating the knife will cut 5 or 6 squares, before having to re-heat it. The resulting squares are stuck to the tool's surface. Before doing this a very light thin layer of pure turpentine is applied to its surface. This ensures good adhesion of the squares. The squares are heated with a match or small torch until the bottom side is just beginning to melt - and then quickly applied to the tool's surface.

As shown in the diagram above the columns of squares should be applied so they are off-set slightly from the center of the tool disc. A pattern can be drawn on the tool first with a pencil to act as a guide.

Once the pitch squares are cut and applied to the tool's surface - **the outer squares must be trimmed off.** (You can do this with a chisel or an old knife) A sharp tap with a light hammer or even your hand will shear off the pitch squares efficiently. Trim them to just inside the edge of the disc.

Following this the whole tool complete with the new pitch squares in place was heated in the 95 deg. water for a few minutes. Then with a layer of Aluminum foil placed on top of the mirror, the warmed tool (or lap) was pressed firmly on top until the squares were all evenly pressed to the shape of the mirror - this needs to be done carefully - so that the squares don't get compressed too much and run together. It is better to do it two or three times - applying more gentle pressure each time until they appear properly pressed. Wetting the back of the tool also allows one to see the squares underneath, so that the degree of pressing of the squares can be seen.

When you are sure that things are o.k. lift off the tool and gently peel off the Aluminum foil. The pattern on the foil may also give a good indication that the tool is correctly pressed. After this 'cold pressing' can be done. (see below)

When the lap is finished it needs to be 'pressed' against the mirror. To do this - take a quantity of polish and water and apply it to the mirror's surface. Then the lap is placed and on top, and swished around to ensure that the polish and water is covering both surfaces of the mirror and tool. Now center the two discs and apply a weight - about 10 to 15 lbs for an 8" mirror.

Allow them to press for maybe 20 minutes to perhaps an hour or more, depending on the hardness of the pitch. During this time you **must** check that the polish does not dry out - **this is very important** - or they may stick together as if you had glued them. Every ten or fifteen minutes you must remove the weight and move the mirror around to ensure that it has not stuck. If necessary - add more water and polish. Then continue the pressing. Sometimes the mirror disc or the lap may need warming if the pitch is too hard. This can be done by immersing one or the other first into tepid water and carefully stirring in hotter water until the temperature is about 90 to 95 degrees F.

Once the pressing is complete, check that the squares have not closed together too much and that the channels between them are clear and at least an1/8th inch wide. If the edge squares have pressed out and overlap the edge of the tool, cut them back again **so that they do not overhang the edge.** Press the mirror again for ten minutes after this - and then you can start to polish.

Note : During the polishing - if you are not able to do at least an hour of polishing continuously, don't start! *You will do better to lay the tool aside, and come back to it when you do have the time.*

NOW FOR THE BAD NEWS: To completely polish an 8" mirror requires some 12 to 15 hours of polishing time! If possible you need to be able to do 2 or 3 hours work at a time. During polishing, as the tool and mirror reach a 'working temperature' and bed down into complete contact with each other, the polishing becomes much more effective and the whole surface of the mirror polishes most evenly. So never do less than at least an hour at a time. Here we are talking of the actual polishing-time on the mirror, not counting the initial 20 minutes to half hour needed to again press the discs together before starting, nor the time spent cleaning up afterwards.

At the start of polishing - after the discs have been pressed - you apply a mix of water and polish, **not much polish is needed,** and enough water to make a thin 'milky' mix spread across the surface of the tool or mirror. Polishing - like all the previous 'wets' is done with the NORMAL "W" stroke, but, unlike the 'wets' used in smoothing, this is a **continuous** process. As the polish starts to dry out - (after perhaps 3 to 5 minutes) you simply add a little more water and polish, swish the discs around and then continue polishing. You still need to rotate the discs about a quarter-turn every 15 or 20 minutes to ensure that the mirror is evenly polished. Apart from that the work is a continuous polishing, stopping now and then to add more polish and water, and to turn the discs.

At the start of polishing, you may feel that the mirror (assuming that you start with the mirror on top) feels 'sticky' and not very smooth. If this happens, try pressing again for another 15 minutes and try again. If it still feels 'sticky' then persist for a few minutes, stroking fairly slowly, and applying a bit of pressure on the center of the mirror until they begin to feel smoother. Then continue **without pressure** letting the mirror's weight and the weight of your hands be the only force applied between tool and mirror. Also try to move the mirror in its w-stroke without letting your fingers hang over the edge of the mirror. Believe it or not! this can cause local areas of the mirror disc to become heated and 'expand' enough to cause local wear around the outer edge of the mirror during polishing. (Remember that when finished the surface of the mirror should be accurately ground and polished to within a few millionths of an inch - or better!)

About every hour of polishing - you can interchange the mirror and tool positions - this helps them polish evenly from the center to the edge. This is similar to the effect of deepening or lessening the depth during the grinding process. It has little or no effect on the curvature - but does allow a more even polish.

Don't skimp on the polishing - even after a few hour's work the mirror will start to look polished - but don't go by first appearances. It takes a lot of hours to properly polish the mirror, and you cannot really polish it too much.

After about an hour of polishing, take a look at the pitch squares on the tool. If they are beginning to flatten out and spread a little, this is a good indication that the pitch is about the right hardness. If they are flattening out too much then you must trim them to ensure that the channels between them do not disappear. If they have not deformed at all, your pitch may be too hard. They should also appear evenly impregnated with the polish - a sign that they are making the proper contact with the mirror's surface. If some squares are shiny and don't have any sign of polish, then you should press the tool again.

If things get too messy during polishing, you can rinse off the 'muddy' mix of polish and water, from both the tool and the mirror. Just rinse - don't wipe them with anything - let them dry out a bit. Re-press for a few minutes and then continue.

When you finish a session of polishing - simply clean off the mirror and put it aside. Wipe the tool (lap) gently and set it aside separately also. **Never** leave them together on the bench, one on top of the other - or again they may stick together as if you'd glued them. This is also the reason that you must press them again before starting another session. The pitch, seemingly solid, is really an extremely viscous fluid! and will gradually settle when left face-up on the bench between sessions. If you are a few days between each session of polishing, you may have to press them for at least a half-hour. You will be able to tell, when you start polishing - if they slip or tend to stick - you may need to press some more

When completely polished you won't be able to see any surface characteristics even under a strong magnifier (It is possible that you may see a number of 'scattered' pits around the surface, probably left over from the fine-grinding stages. However, if there are not too many of them, they will make very little difference to the performance, and they cannot be removed by polishing.

A final word about accuracy - The median wavelength of visible light is about 22 millionths of an inch. Thus a quarter-wavelength, which is given as the required accuracy for the images reflected from a good mirror - is a mere 5.5 millionths of an inch. However, the surface of the mirror has to be better than that by a factor of two.

This is because a ray of light reflected from a mirror is reflected at the same 'angle-of-incidence' but in the opposite direction to its approach angle. Therfore any errors on the mirror's surface will double upon reflection. So now the required accuracy for a 'good' mirror means that it must be accurate to a little under 3 millionths of an inch ! or - to an eighth wavelength.

Don't let this scare you ! If you have done everything right , the grinding and smoothing and polishing stroke tends to form a mirror with this kind of surface accuracy naturally. Surprising that a hand-process can produce such a result !!! But the most accurately made mirrors are **all hand-finished !** See my comment below about testing.

Once you are sure that you have done enough hours of polishing (or done so many that you used up all the polish supplied with the kit- which is probably enough to do more than one, and maybe two!) **then you can give yourself a good pat on the back, sit back awhile and savour the feeling of accomplishment!!**

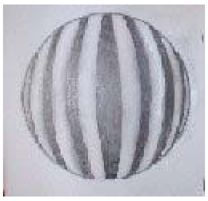
Now that you've celebrated a while - and are getting the urge to have it coated and put it into a Telescope - !! A bit of testing is necessary to ensure that it really did come out right!! Recall that at the start of this text I mentioned that a 'pefect mirror' should have a 'parabolic' cross-section. So some testing is needed to ensure that you have ground and polished your mirror accurately and to something very close to the right shape.

The Ronchi grating

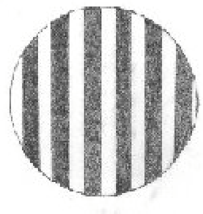
A a simple non-mathematical way to test your mirror using the Ronchi grating:

The Ronchi test for checking the 'profile' of a spherical or parabolised mirror uses a precisely ruled 'grating.' The grating which is usually a film with 'ruled' parallel lines and spaces of equal width, generally about 2 to 5 lines per millimeter. This is interposed between the mirror, (which is illuminated by a narrow slit light source,) and the reflected wavefront from the mirror. It is placed close to and a short distance inside the focus of the reflected beam near the center of curvature.

In theory - the lines will have, for a **paraboloid,** a moderate outward curvature each side of center see image at left. The shorter the desired focal length, the deeper the curve in the mirror, and the more the ronchi lines curve outward from each side of center. If the grating is too close to the focus point the lines will be fewer and more curved so you should have at least five or six lines showing across the face of the mirror during this test. The curved lines should be smoothly curved, any pronounced defects in the 'figure' of the mirror will show as variations in the smoothness of the curvature in these lines. See the image at the left below"



For a **spherical** mirror the lines should be perfectly sraight, again variations in the straightness of the lines, or bends at the top and bottom of the lines will show a 'turned up' or a ' turned down' edge for example. See image at right below:



In order to do this test you need a simple 'tester' - a light source with a narrow vertical slit. This could be made as a basic 'light-box' similar to the tester shown on my "testing" page, but just simply containing the 'light-box part.

Some suppliers can send you (for a parabolic mirror) a special 'grating' which has the lines curved the opposite way (according to the measurements of your mirror) and then you have to try to figure the contour of the mirror to make the lines appear straight when this grating is placed at a measured point close to the center of curvature. When this is accomplished the mirror should be correctly 'figured' to a parabolic profile.

So to a degree it can be a 'quantitative' measurement..although accurate figuring then depends on the tester's ability to decide when the lines at the center of curvature are really straight. It also depends on the accuracy in positioning the grating at exactly the right place inside the focus of the reflected rays at this point. So in my humble opinion - it could be a fairly accurate test, or it could be somewhat 'rough and ready' depending on the experience of the person using this test. At least, if you are not happy with using all the mathematics involved with the Foucault, or other more complicated tests with care and experience you can produce a satisfactory mirror.

Even though I don't use the Ronchi grating as a quantitative test for the shape of mirrors. I do use it frequently as a qualitative check on the shape of the mirror during figuring. The lines can show if there are noticable irregularities in the overall surface of the mirror, and if there are any major high and low areas, as the gentle curve of the lines are consequently affected.

The test method of my choice is the Foucault knife-edge test using a narrow slit source with Couder screens, as described in the "Testing" section of my web-page. Also I check the shadows seen without a mask in place, to check the smoothness of transition between the various radii of the mirror. Still, along with these observations I rely mostly on the quantitative measurements taken in the Foucault test for the final evaluation of a mirror.

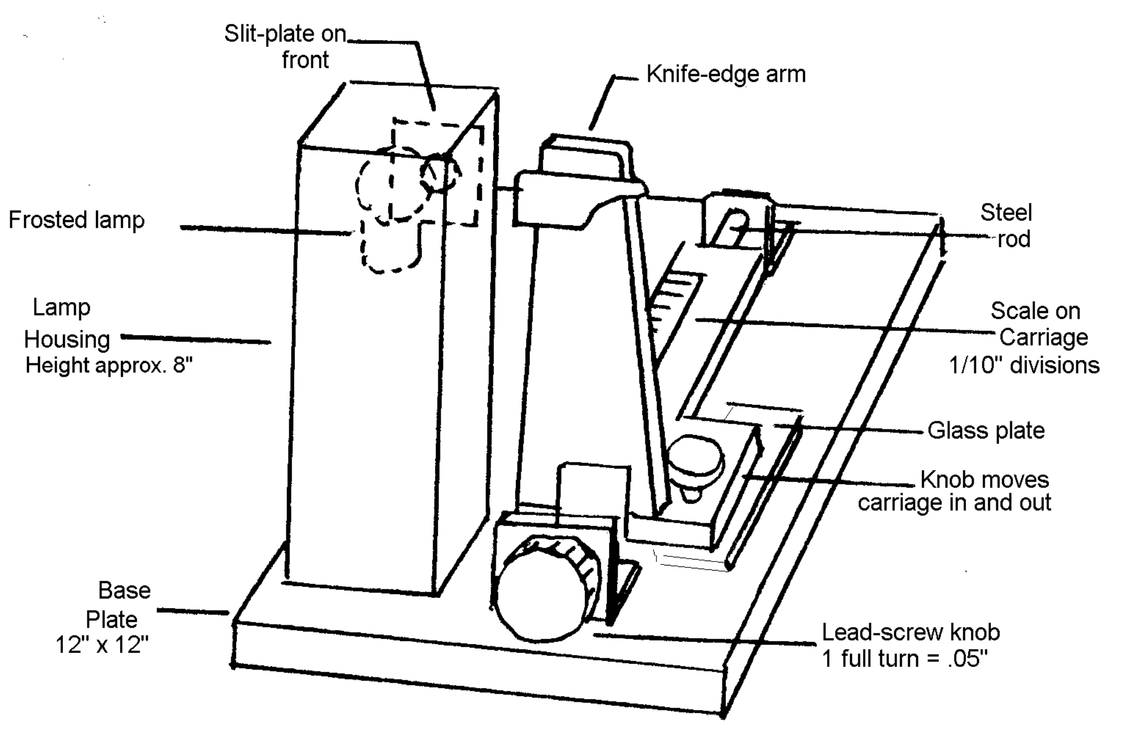
A Knife-edge Tester

An overall view and diagram of details

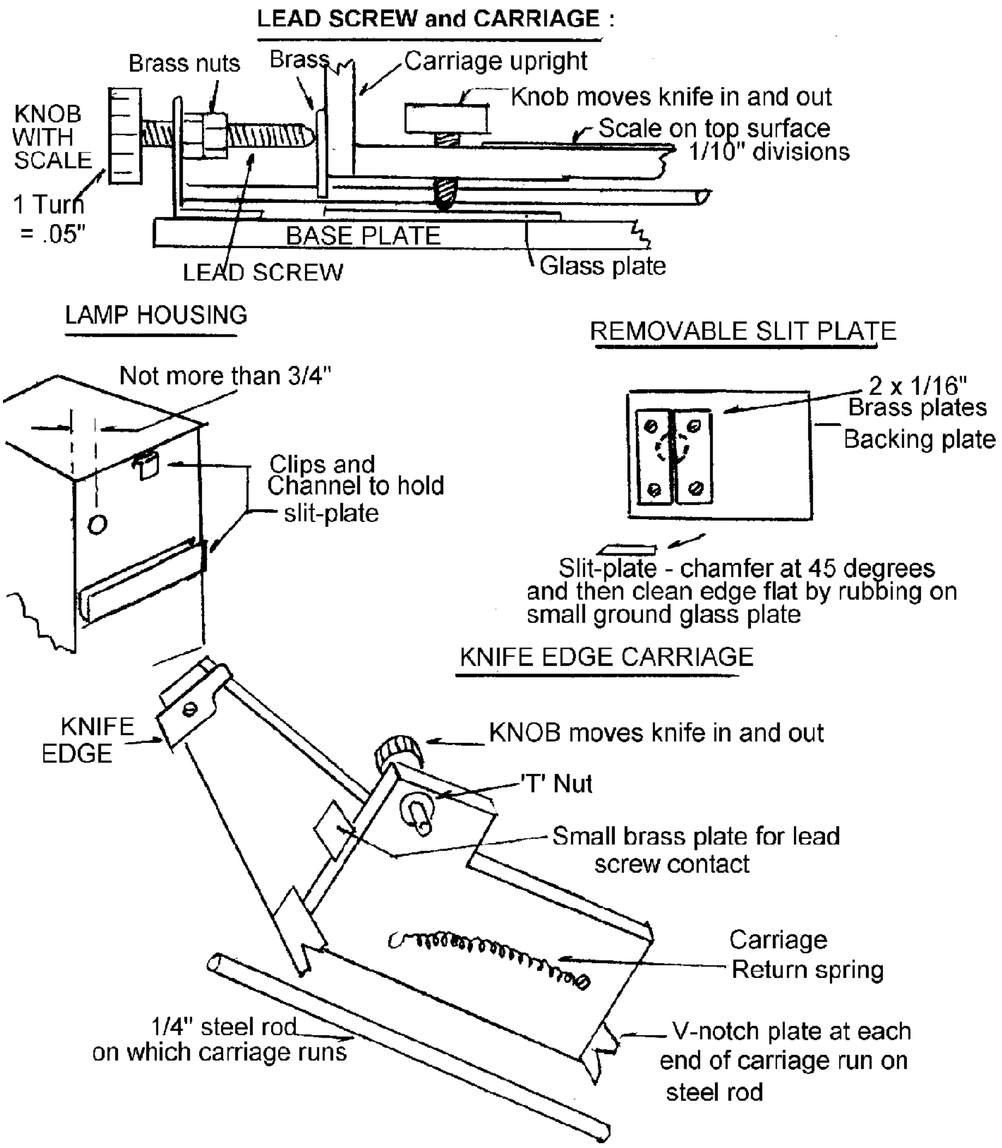
This is based on a design suggested in "How To Make a Telescope" By Jean Texereau, published by Willman-Bell,Inc. -

Parts required:

1. A 6v.or 12v. auto lamp bulb - frosted by rubbing with emery cloth.
2. Transformer for the lamp. Use a 1 amp. fuse in the primary.
3. A slit-plate - brass, see details for making it in the second drawing.
4. Plywood base and knife edge carriage (can be made of metal or plastic if desired)
5. A round steel rod about 1/4" diameter 10" long.
6. Small thin glass plate on base for the carriage adjusting screw to run on -about 1" wide x 2" long.
7. A 1/4 x 20 screw about 2 1/2" long, for the lead-screw to drive the carriage along the steel runner.
8. 2 or three 1/4 x 20 brass nuts for the lead screw to run through. These are tightened enough to allow the lead screw to turn without back-lash. They are soldered to a brass support plate and provide very smooth running of the knife-edge carriage.
9. Lead-screw knob about 1 1/4" diameter.
10. Knob about 1" diameter, to drive the knife edge carriage sideways to move the knife in and out of the reflected beam from the mirror.
11. Assorted hardware and screws to complete construction.



The next page shows the details of the way I made the tester that I use.



Important notes below

Usually the scale on the tester is marked off in **10th's of an inch** and the knob (if you are using a 1/4 x 20 thread screw) is marked in intervals to represent **thousandths of an inch.** A pointer of some kind should be made to read the scale on the knob's circumferernce. Generally you can divide the circumference of the knob into divisions each equalling 5/1000th's of an inch and then guestimate the distances in between to the nearest thou.(One full turn of a 1/4 x 20 screw = 50 thousandths of an inch) so the marks on the knob scale would go from **'0' to '50'.** Two full turns of the knob should move your longitudinal scale by **1/10th inch.** So your pointer for the knob should be set so that when the other scale is at a 1/10th position, the scale reading on the knob is set at zero.

So you would (for example) start at a position where the longitudinal scale read 0.1 inch and then add (say) 12 thou read off the side of the knob...which would give 0.112 as your reading. The next window in the Couder screeen after moving the knife-edge further away from the mirror might be 0.1 plus 75 thou read off the knob scale...giving you 0.175. etc. **It is best** if the longitudinal scale is marked with the numbers (.1 .2 .3 etc.) going away from the mirror...so that your total readings increase as you move the knife-edge away from the mirror. The absolute value of the numbers does not matter - what you are after is the relative spacing between each reading as the knife-edge is moved towards or away from the mirror for the darking position at each window of the Couder screen.

If you are using metric measurements, then make your scales accordingly. The 'coarse' scale on the carriage can be marked in millimeters. The lead screw for the in and out movement of the knife-edge carriage can be a metric screw with threads of 1mm. Then the scale on your drive-knob for the carriage can be marked with 10ths of a millimeter on its circumference, as one complete turn will give you one millimeter of movement. You could also 'estimate' the third decimal (100th's mm) by estimating between the 10 marks on the edge of the drive-knob.

The hole in the slit-plate (behind the slit) should be about 1/4 inch diameter. Also the hole in the lamp housing which coincides with the one behind the slit when it is set in place can be made slightly larger (perhaps 3/8 inch to make it easier to find and position the reflected image (slit-plate removed) when setting up, prior to making measurements.

Afew extra notes - The slit width used should be set as close as possible to about **3 to 5 thousandths of an inch,** although the unit will work with a wider slit the narrower the slit the better! The two plates forming the slit should also be parallel as closely as you can make them. A couple of strips of typewriter paper can be used to help in this respect. When setting up for a test the slit-plate is taken off temporarily so that you can find the reflected image more easily, and then after aligning the reflected image between the knife-edge and the lamp housing, the slit-plate is replaced for making the tests.

The knife-edge attached to the top of the carriage upright, is made in the same way as the two pieces on the slit-plate. It is a piece of brass fastened to the carriage by a single screw and nut, so that it can be tilted to align the knife-edge parallel to the reflected image of the slit. The edge is chamfered with a small file and then the edge is made flat and even by rubbing against a flat piece of ground-glass. This can produce an edge which is almost optically flat...and is much preferred to using a razor-blade or other piece of metal - the edge of which may not be quite as accurately flat.

Testing

Testing your mirror with a 'knife-edge' type of tester:

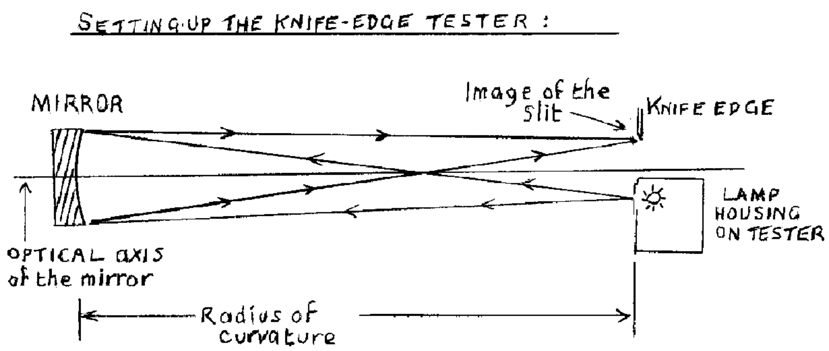
NOTE: This section is based on the use of a tester as described in the "Knife-edge tester section" This tester uses a **fixed light source** and a moving knife-edge (see note below)

NOTE: *There is another type of knife-edge tester on which the light-source and knife-edge are mounted together on the movable carriage. If you buy (or Build) this type of tester then the calculation of the different positions at which the reflected rays cross the axis - (the relative spacings) would be calculated using the formula **hm^2 / 2R ,.....** that is : they will be half the spacings when compared to the type of tester described here. That type of tester and the system of graphing results is fully explained in Richard Berry's book "Build your own Telescope" published by Willman-Bell. You could use the tester described by Richard Berry with the system described here as long as you remember to adjust the readings you obtain for the knife-edge positions and multiply them by a factor of 2. All of the following calculations would remain valid - but your knife-edge readings each would have to be adjusted as noted above. (by a factor of two.)*

If you find this method of testing too complicated, you could use the "Ronchi test" - this uses a lined 'screen' placed into the path of the reflected image from the mirror to evaluate its form.

The diagram below shows the slit in the tester's lamp housing is set at the distance of the radius of the mirror, but is offset a small distance to one side of the mirror's axis. An image of the slit will appear at the same distance, but will be offset in the opposite direction.

This is the principle used in most of the popular tests which can easily be afforded by the amateur. This type of tester is easy to make and use - and can give results with enough accuracy to satisfy the need to attain a 'perfect' mirror. With practice, careful measuring can allow one to determine the profile of the mirror to better than a millionth of an inch.

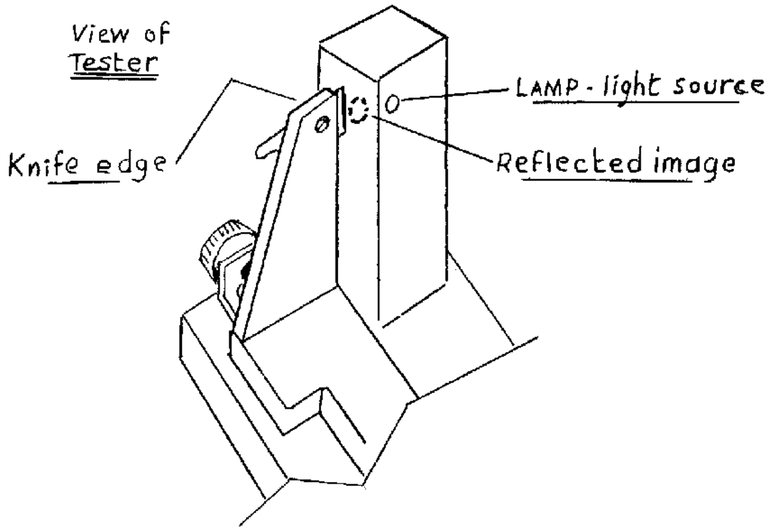


Using the **tester described in this web-page,** the tester and mirror are to be set up a distance apart equal to the radius, previously measured. They should be set so that the center of the mirror is at the same height from the floor as the illuminated slit in the testers lamp-housing. The mirror needs to be supported on some type of stand which allows it to stand vertically and can be adjusted in tilt so as to project the reflected image of the source to a point close to the knife-edge.

The setting up needs to be done in a darkened, or dimly lit room. When the mirror and tester are placed in position - the slit-plate should be removed. This allows the larger 3/16" hole in the lamp housing to provide a larger, brighter image.

Set the knife-edge carriage about half-way along its travel with the lead-screw.Place a letter-sized card in the area of the knife edge and try to find the reflected image of the light-source. Unless the mirror is exactly perpendicular to the source it could be above, below, or to either side of the tester.

This is the reason for having an adjustable support for the mirror. Once you have located the image you can then move the mirror to bring the image close to the knife-edge position at the edge of the lamp housing. The image should be between the housing and level with the center of the knife-edge. You may also need to move the tester or the mirror closer together, or further apart until the image appears the same size as the hole in front of the lamp.

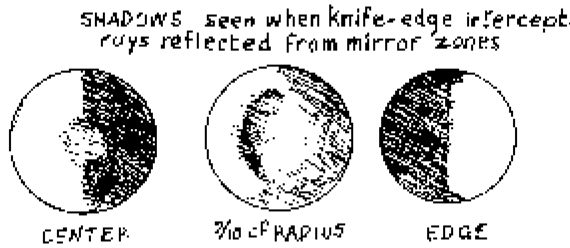


Once they are set up, replace the slit-plate. Now look at the mirror, with your eye aligned with the edge of the knife, from behind the tester. You will be looking along the edge of the lamp-housing - in the space between it and the knife-edge. Your eye should be very close to the lamp housing. You should see the mirror disc illuminated across its surface.

Now adjust the position of the knife edge towards the lamp-housing. The mirror should start to darken, until with the knife completely across the image, the mirror will darken and appear black. Backing off the knife again should make the image reappear and the mirror brighten again. You may see a vertical shadow of the knife-edge move across the disc, and as the knife moves across the mirror you may see various kinds of 'shadows' form on the mirror's surface.

NOTE: If you see only shadows across the mirror -then push the knife-edge carriage further towards the mirror, so that when you bring in the knife-edge you see a **vertical** shadow crossing the mirror - this is the dark edge of the knife, and it should be vertical upand down the mirror when it is positioned so that the edge is exactly half-way across the mirror. If it is not vertical adjust the knife-edge orientation until it is vertical. It is important that the knife-edge is parallel to the reflected image of the vertical slit on the lamp housing. If this is not so, then the readings you get may not be accurate.

If you only see the shadow of the knife cross the mirror, then you should move the knife carriage closer to, or further from, the mirror until you reach a point where shadows appear on the mirror - as if it was moulded in relief.



These shadows appear whether the mirror is 'parabolic,' ' hyperbolic,' ' elliptical ' or anything other than perfectly spherical in cross-section. If it is perfectly spherical, the whole surface of the mirror will darken uniformly when the knife- edge crosses the point at which all the reflected rays cross the axis. Inside and outside of that point the mirror will appear to darken first at one side or the other. (This will be a gradual darkening and not the same as seeing a sharp shadow of the knife crossing the mirror.) The density or 'contrast' of these shadows will vary with the 'F-number' of the mirror (an F6 will give darker shadows than an F8.) and with the degree of deviation from a true spherical surface.

If you were to draw a cross-section of these shapes you would have 1-an upside-down soup bowl, 2- a 'doughnut' shape but with the hole filled in a bit, and 3- a shallow dish, The shadows are interesting to see - and give a general idea of where the rays from various radii of the mirror cross the optical axis. They appear at different longitudinal positions of the knife-edge as it moves towards or away from the mirror. But they do not give you a clear idea of the accuracy of the mirror's figure.

The distance that the knife-edge travels to go from one to the other can be calculated - but without a better way of 'pinning' down the exact position of the knife at the center and edge, they only provide a general idea of its accuracy. To do this requires a better method, which we shall now explain. It is also the reason that we have placed scales on the tester's carriage and on the lead-screw knob.

Note IF YOU ARE USING METRIC NUMBERS - all the measurements you make should be made in millimeters. This includes the diameter of the mirror, the focal length and radius of curvature. Also the spacing of the windows in the Couder screen etc. All the calculations, and formulae such as hm^2/R remain the same....but you will just have metric numbers. Also note - the wavelength of light is **0.56 microns** (in metric) so 1/4 wave will be 0.14 microns, you will need to remember this when assessing your graph using metric numbers.]

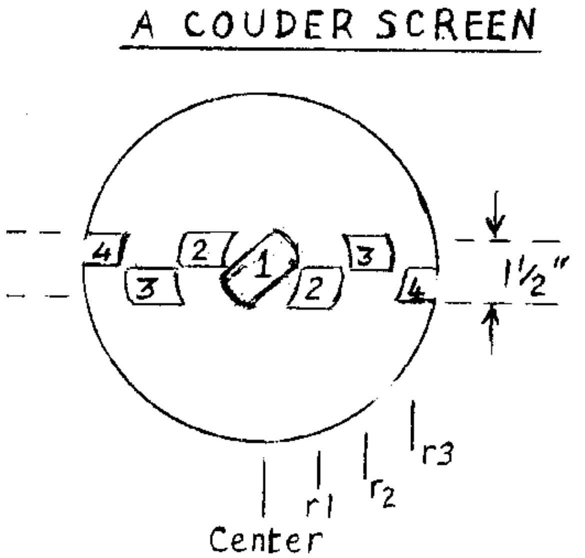
MEASURING

Some Math and a bit more optics: The principle of testing is to use a method which can allow us to determine where the rays from each part of the mirror are crossing the axis, and to calculate whether they are doing so at the correct point along the axis. If they do not, we need to know how large the errors of position are and thereby be able to make corrections to the mirror surface to eliminate such errors.

A simple way to do this is to make some type of 'mask' or 'screen' which covers the mirror, with 'windows' cut into it at various radii of the mirror, on each side of center.

This will allow us to find the point at which the knife-edge causes an **even darkening** of each pair of windows, thereby allowing us to find exactly the point along the axis where this occurs. By doing this **for at least 4 or 5 points** across the diameter of the mirror - we can obtain a measurement of the spacing of these points along the axis and compare them with the calculated spacing which an accurately 'figured' mirror should have.

The screen which we use follows a design that was suggested (a long time ago) by A. Couder, and is called appropriately enough - a Couder screen ! A thick paper or thin card circle is cut, the exact size of the mirror and 'windows' are drawn in a horizontal band about 1- 1/2" deep across the mask. Into this at intervals are cut pairs of windows on each side of center. They are 'staggered' above and below the center line of the horizontal band - so that we can easily identify them when looking from behind the tester, at a distance of some 10 feet from the mirror. There is a nice formula for calculating the width and position of these windows, based on the fact that the parabola (which is the shape we want for the mirror cross-section) deviates most from a sphere as we approach the outer areas of the disc.



In practice we select the width and the position of the windows so that none are too large nor too small to see easily and compare when performing our test. The outer window should be made about 3/4" wide to be easily seen, with the next inner window being perhap 1" the next 1-1/8" leaving 1-1/8" each side of center - giving 2-1/4" - for the central window. These are typical dimensions for an 8" disc, and would be easily viewed from behind the knife-edge. (For larger mirrors you can use 5 or 6 windows for a more accurate profile.)

The outer windows on this mask would give us readings at about 42%, 70%, and 92% of the mirror's radius - where the deviation from a sphere is greatest.

(In some cases you can if necessary make two masks - one with windows covering the inner half of the mirror with say two or three pairs of windows and another with perhaps 3 or 4 windows covering the outer radii of the mirror. When measuring you would use one mask and read the relative knife-edge positions. Then carefully changing over to the second mask make the readings for the outer zones. This needs to be done carefuly without disturbing the relative positions of the mirror and tester. Usually it is better to try to do this test with a single mask - 4 or 5 good readings made with a single mask are better than 6 or 7 doubtful readings made on two different masks if the set-up is even slightly disturbed during the switch from one mask to the other.)

MAKING THE TEST

The screen is placed on the front of the mirror, once the tester is set-up and the slit-plate has been replaced. A little masking-tape holds the top of the screen to the top edge of the mirror, but we try not to touch the mirror itself as our fingers will cause 'local heating' at its edge.

Now we look at the windows in the mask (screen) some of which will be shaded as we insert the knife edge towards the lamp housing. What we are looking for is to find a longitudinal position of the knife edge which will cause only the center window to darken evenly as the knife edge cuts off the rays reflected from that part of the mirror.

Do this a number of times - until you are sure that you have found the exact longitudinal position at which the window darkens evenly. Once you are sure - note the position of the knife edge from the scales on the top of the carriage (in tenths of an inch) and the position of the pointer against the edge scale on the lead-screw knob (in thousandths of an inch) - Recall that one complete turn of the knob represents 50 thousandths of an inch. From these two observations you should be able to establish a (relative) reading of - for example - something like .328" which is noted down.

Now you repeat the same process but this time looking at the second window at each side of the central window. You now need to establish a reading at which the knife edge causes these two windows to darken at the same time as the knife-edge cuts across the axis of the reflected rays. To get an accurate reading - the knife- edge needs to be inserted **very gradually** the best reading is taken when the windows are just beginning to darken, as they start to become grey, rather than blacked out completely. Try to compare the center of each window so that they both appear to have the same shade of greyness.

The longitudinal position of the knife-edge is recorded for each pair of windows. They will then be compared with the **calculated** relative positions to determine if they are correct. The results can be drawn out as a graph - showing the 'profile' of the mirror surface. From this you will be able to decide what kind of correction may be required to reduce any errors to an acceptable level.

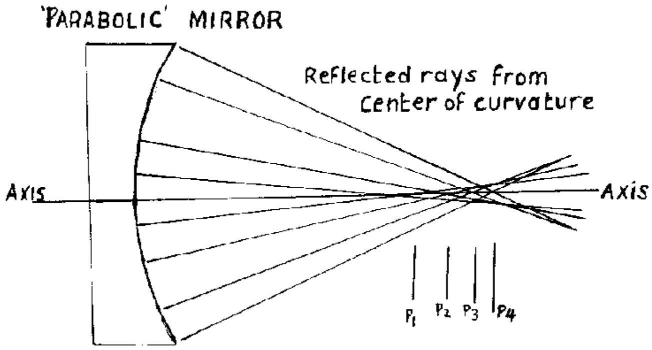
Calculations: The math involved

Now for the numbers and stuff: When you make the mask and have cut out the windows, you need to make careful measurements (within a half-millimeter or 64th of an inch of the diameters of the inside and outside) of each pair of windows. The center window's inside diameter is, of course zero. Measure its outside diam, and divide it by 2. List this on the mask as hx1. Do the same with the 2nd windows, and the 3rd and 4th, dividing each by 2.(These numbers are of course the radius of the outside of each window.)List them on the mask as hx2, hx3, and hx4.(and h5, H6, H7 etc., if using 5 or more windows)

Then by adding the **inside and outside** diameter of each pair of windows(#1, #2, #3, and #4 (and #5 etc., if used)) dividing the result by 4 you will arrive at a radius of the mirror which coincides with the 'center' of each window. These will be listed as hm1, hm2, hm3, and hm4.etc. When testing it is most natural to compare the centers of the windows for shading.

As noted earlier, light coming from a source at the center of curvature of a spherical mirror, will reflect directly back to the source. When the source is at a very long distance the rays become parallel. They then meet at the 'focus' of the mirror where they will form what is termed a 'circle of confusion'. The image under these conditions will be fuzzy due to the longitudinal spreading of the reflected rays.

To correct this situation we need to change the mirror's cross section to that of a parabola. However - when using our tester - with the light source at the mirror's radius, if our section is **parabolic** the light reaching the mirror will be diverging and not parallel. **This causes a "circle of confusion" once again** where the image is formed close to our knife-edge.The diagram shows this effect but greatly exaggerated for illustration.



This is where our tester with its mask tells us whether we have the correct parabolic shape. If we do - then the degree of shift along the axis for rays coming from various radii of the mirror must agree with the positions (relative spacing along the axis) which we have **calculated.** Although this all may sound complicated - in practice it is not very hard to do. Once you have gone through the process it will not seem nearly as difficult as reading these details.

Calculations

Note - in computerese the symbol (^) stands for 'to the power of' - so 2^2 means two-squared , 2^3 means two cubed etc., and of course 2/6 means two divided by 6. (- I hope this doesn't sound too basic but some people are not very conversant with math symbols.)

The point at which rays from each 'zone' (centers of each pair of windows) should cross the axis, is found using the following formula : p= (hm^2 /R + {hm^4 /2R^3}) The 2nd term in this can be ignored, for mirrors of moderate size and depth the difference is not measurable.

So in our case using the simpler formula (p = hm^2 /R) where 'p' stands for the position where the rays converge, we will have for zone #1. (.5625)^2 /128 = .0025 : zone #2. (1.687)^2 /128 = .0222 : zone #3 (2.531)^2 /128 = .0590 and for zone #4 (3.625)^2 /128 = .1027

Let us assume that our measurements for each zone were : #1 = .302, #2 = .352, #3 = .372, and #4 = .425 Then we tabulate the results and check the errors by comparison to the calculated values. By subtracting a suitable constant from each of our numbers we can arrive at numbers closer to those given by our calculation, without changing their relative spacing.

How to find a suitable 'constant'

*To arrive at a 'constant' which will make the measured numbers come closer to the calculated **(hm^2/R)** numbers, try the following:*

*In this example the **hm^2/R** values for the four zones were calculated to be as follows:*

zone 1	*zone 2*	*zone 3*	*zone 4*
0.0025	*0.0229*	*0.0590*	*0.1109*

*The numbers taken from the 4 zones of the mask used **during testing** gave the following result*

zone 1	*zone 2*	*zone 3*	*zone 4*
0.152	*0.172*	*0.209*	*0.260*

Take the reading from the 3rd 'window' in the mask (zone 3))which is usually the most accurate of the readings you will make. (If you have say 5 zones then take the 4th zone as being the most accurately read measurement.)

*So you take the third reading number and subtract the hm^2 number calculated for the third window which let us say is **0.059** then subtract it from the reading number three**(0.209)** this gives you a 'constant' of **0.150** If you now subtract this same number **0.150** from all the readings you will get the following:*

zone 1	*zone 2*	*zone 3*	*zone 4*
0.0020	*0.0220*	*0.0590*	*0.1100*

*Note that the third reading is exactly the same as the calculated number: **(0.059)** whilst the other zone numbers are very close to the required value. This makes comparison of the readings with the calculated values much easier. Once the differences become less than about 10 or 12 thousandths of an inch then the accuracy of the mirror's 'figure' becomes very close to the ideal.*

As long as you subtract the same 'constant' number from each of the readings - you will still maintain the difference of relative spacing between them, but they become easier to compare with the calculated numbers taken from the hm^2/R value for each window.

	zone 1	zone 2	zone 3	zone 4
Measured readings	.302	.352	.372	.425
Subtract constant -.315	-.0130	.0370	.0570	.1100
hm^2 / R calculated	.0025	.0222	.0590	.1027
Error	- .0155	+ .0148	- .0020	+ .0073

If our mirror surface had a perfectly parabolic cross-section we would not measure any errors. The readings would agree almost exactly with the points which we had calculated. (depending of course on the accuracy of our measurements) Our first try at doing these may not be accurate enough to be very exact. With practice they should improve, and we may be able to 'pin down' the readings to within a few thousandths of an inch. We can also repeat our measurements three or four times and average the results. This can help improve our accuracy. In any case if we can be fairly sure that we are within 3 or 4 thousandths, we can get an excellent evaluation of the mirror's curvature.

After we have determined the errors - we can now calculate what they mean in terms of the mirror 'profile.' We have been measuring the errors in the profile at a point **where they show the greatest effect.** A reflected ray doubles the longitudinal error at the center of curvature- but when the mirror is in use, the errors we measure here will be **reduced by a fourth at the focus, and the lateral errors even more.** (Consider the triangle made by the lateral error and the radius of curvature of the mirror -for an idea of how tiny the lateral errors could be.) So by making our measurement of longitudinal error at the point where the ray crosses the axis with our diverging light from the tester at the center of curvature (which is twice the focal-length) we are measuring errors which can be in the thousandths of an inch or even hundredths of an inch, even though at the surface of the mirror the errors are only millionths of an inch.

We can imagine the curve across the mirror to be made up of hundreds of 'flat' sections which follow the parabolic curve. Each of these has a specific 'slope' which coincides with the ideal parabola. These errors of 'slope' which are perhaps going towards the mirror's true curve, or may be sloping away from it, can be described as depressions or rises in the mirror profile.

Now for the math involved to turn these error readings into 'errors of slope' back on the mirror's surface:

First of all - these longitudinal errors which we have measured will be reduced to a quarter when we view distant objects at the **focus** rather than at the center of curvature. Also, the errors which interest us most will be the **lateral** errors at the focus. These errors are also going to be those **in the reflected wavefront** focussed by the mirror.

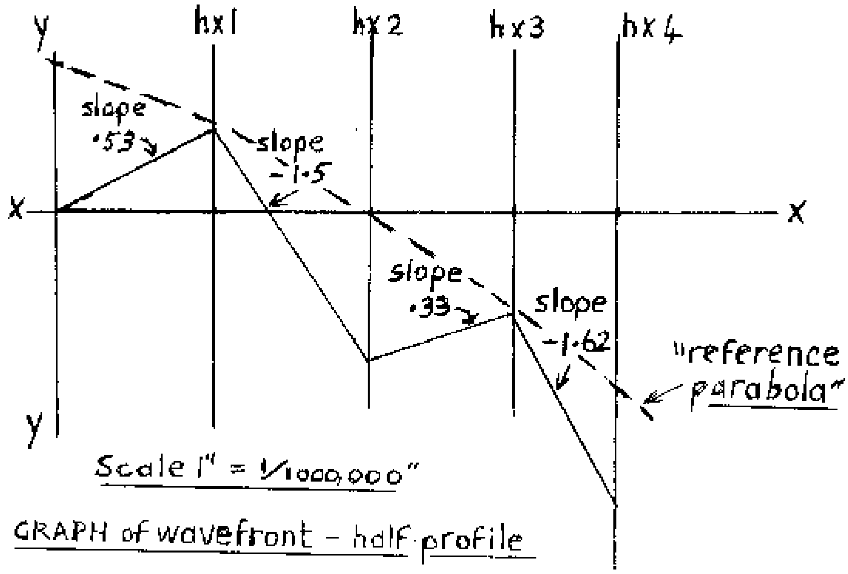
So our system measures the actual wavefront errors - the errors on the mirror will be only half as much. So we want our measured errors to be less than 5- 1/2 millionths of an inch - if we want our mirror to be "diffraction limited" (And half as much at the mirror's surface)That is, no error in our reflected image is going to exceed 1/4 wave.This is sometimes referred to as the 'Rayleigh tolerance.' If possible we would like to do much better than that. Well - let's see how our measured numbers turn out:

Before doing this, we should point out that errors in reflections from close to the center of the mirror are not as important as those of reflections from the outer areas of the mirror. We therefore need to be as accurate as possible when measuring the outer zones of the mirror.

Taking our measured errors - we multiply them by what we term a 'zone factor.' (This factor is hm divided by 4 times the focal length, for each zone) This gives us the transverse aberration at the focus. This we multiply by a large factor 10^5 (100,000) Then we divide the answer by the focal length (64") and then multiply by 10 to arrive at our final figure for the 'slope of the mirror segment' (i.e. the center of the mask window) of each zone. We also change the 'sign' of the resultant answer. See table below:

	zone1	zone 2	zone 3	zone 4
Error	- .0155	+ .0148	- .0020	+ .0073
zone factor = hm/4f	.0022	.0066	.0107	.0142
error x zone factor x 10^5	- 3.41	+9.77	- 2.14	+10.37
-mu (slope) = (error /64) x 10.	+ .53	- 1.5	+ .33	-1.62

These finally, are the slopes in the wavefront which we would find at the focus of the mirror when in use. We can draw a graph of these - even though we have only 4 line segments to show the 'half profile' of the wavefront, as long as the shadows on the mirror show a smooth transition between our selected zones, we can have a useful measurement of the mirror's surface.(and that of the reflected rays)



The graph shows us the profile of the wave-front (and effectively also the shape of the mirror's surface) from the center to the edge. If we copy this on the opposite side, with the same slopes we would have an overall picture of the surface of the mirror. This shows us that the mirror slopes down from the center to the edges, with a couple of 'humps' or raised areas between zones 1 and 2, and also between zones 3 and 4. This would tell us exactly which areas of the mirror need to be polished down, locally, to correct the surface figure. A 'perfect mirror profile,' having no measured errors would follow the reference line 'x' - 'x' As it happens, in this case, if we consider the **scale** at which the graph is drawn these 'raised areas' are only some 1/18th of a wavelength high.

Despite the fact that the graph shows a gradual slope downwards, when in use we would focus on the point of the best image ! This would be represented on our graph, by another parabola of slightly different focus. Instead of the straight line representing our ideal parabola, this would be represented by a different line, a parabola starting at the center and crossing the highest points of the graph (this is illustrated as the 'reference parabola') in the diagram. If we compare the largest deviations of our graph from this line we see that the peaks are no more than 1.2 millionths of an inch or so - this would translate to about an eighteenth-wave accuracy.

This graph of only four lines may seem a little "crude" but it does show the slopes of the mirror. Obviously the jagged peaks and valleys (we hope) don't appear on the mirror's surface. They most certainly 'roll' into each other, so at least this is a very conservative measurement. Still, the actual slopes of these four 'zones' of the mirror profile are valid indications of the variations in the curve of its surface as one goes from the center to the edge.

A FEW FINAL WORDS

If this seems too complex and you prefer a simpler check : The length of the 'segment' of overlapping rays at the knife-edge position is a good indicator of how close the mirror is to being correct. You could make a mask with simply a central window - about 1 1/2" diam. and two windows about 3/4" wide at the edges. Make measurements of these two points of the radius, and from the length of this segment you can compare it with the length calculated - still using the formula - hm^2 /R - for the radius at say 3/8" and at 7 5/8" to get the length that the segment should be for the mirror to have the right curve. If according to the shadows seen (without any mask) the mirror appears to have a smooth curve, without any obvious raised or depressed zones, then this could suffice as a basic test.

Another suggestion - when testing and graphing the results the first time - you can scale your graph at 10^-5, rather than the 10^-6 shown above. When making the last calculation for the 'slopes' don't multiply the result by 10, just divide the adjusted errors by the focal length (64" in this case only.) This will 'keep the graph' on the page if the errors are fairly large.

Following your initial graph of results you do not need to graph the result after every 'figuring' (selective zonal polishing step) you need only compare the new knife-edge readings with the previous readings to see if you are going in the right direction. Only when the knife-edge readings appear to be very close to the calculated ideal numbers do you need to once again graph the results to assure yourself that the mirror profile is accurate enough. One further item : after even a short session of polishing - you must allow the mirror (especially Pyrex) to cool for several hours before measuring. The glass surface becomes locally heated during polishing and can take a few hours at least to settle to its final surface shape. So do not try to 'rush the process' patience is amongst the best tools available to the experienced mirror-maker.

AND - FINALLY: **GOOD LUCK and happy stargazing.**

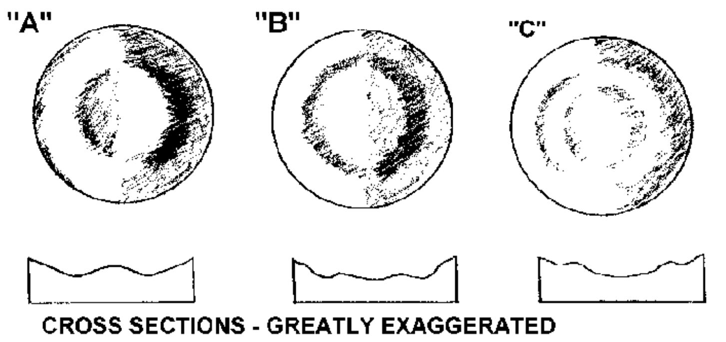
CORRECTING the polished mirror

Oh -Oh - it didn't come out right ! So this is real life ??

Well, these things happen - but unless your mirror is so far away from being a reasonable curve, whether it is too deep, has a raised hump in the center, or a deep 'hole' in the center, a couple of concentric 'ridges' or a turned down edge, you may be able to correct it by selective polishing !

These things are of course only visible if you are looking at the mirror with some kind of tester. If the knife edge position is set at the **center of curvature,** a perfect sphere will darken across its whole face as the knife edge enters the reflected rays of light. If it is elliptical it will show some form of an 'upside down dish shape," and if it has zonal ridges or depressions they will show as lighter or darker 'rings' which are concentric to the circumference of the mirror disc.

Making a complete measurement, using a Couder screen and plotting the result will show you where your mirror departs from a perfect sphere. You may even get very lucky and find that it is already close to being a parabola. (If you need a 'refresher' on this - see the section on Testing, back at "home-page")



In the diagram - **'A'** represents the kind of shadow you would see with the knife-edge cutting the rays from the edge of the mirror.**(Assuming that the light is coming from the left side across the mirror)** Underneath is a 'profile' of the defect - greatly exaggerated. In **'A'** the defect is a **raised central bump.** In **'B'** the drawing shows a mirror with a **depressed channel** a little over half-way out from center. This is one of the worst defects you could find ! If it is fairly shallow it is probably best to check your polishing lap first - it could have oversize squares in some area, or perhaps was not properly pressed. Another possible cause is applying (unconsciously) pressure on one side of the lap or mirror during the polishing stroke. Whatever the cause - firstly try about an hour of polishing again - check the squares of pitch on the lap for evenness and that no squares are contacting any other, that the channels between them are clear, make sure the tool is really well-pressed, and check your polishing stroke carefully. If this doesn't fix it - then your only possibility is to make a small lap (about 4") diameter and try to polish the areas inside and around the channel. Not a very nice problem to solve. Perhaps the best answer is to build a new lap (full size) make sure it's pressed and polish for two or three hours.

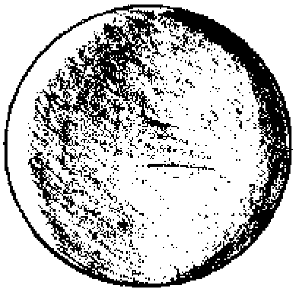
Well - after that - the next problem, a raised ridge as shown at **'C'** is a 'piece of cake' !! Any **raised ridge** can be reduced by centering the tool (lap) over the point on the radius where the ridge is, and using a short chordal stroke, work around the mirror for an **even number of turns.** Once again - do this only for a few minutes, and then check the effect. Make sure that you are blending the action into the rest of the mirror surface by moving the stroke a little to each side. And once again wait for a few hours before making a new measurement. Any polishing - even for a few minutes can heat the surface of the mirror where the polishing action has been applied. If you test it too soon, it may appear to have done nothing - but a few hours later a careful measurment will show some difference. If you do it too quickly you may repeat the action and then later, find that you have done too much.

Experience is the best guide to making corrections, and patience is always needed to ensure the best results. Also the action of the lap for a short period of time can be a little unpredictable. The action may vary quite a bit - it may be dependent on the way you hold the tool or mirror and how much pressure you may apply during the strokes when polishing for a few minutes, and it can vary in effect from person to person using the "same" stroke.

If you find more than one defect - for example a central hump and a raised zone further out : The best way to approach this kind of fault is to attack the center hump first. Then you can deal with the raised ridge after the central area is corrected. If you try to do both at the same time you can make things more complicated. The action of the lap when used for just a few minutes can give varied results and you could wind up with three areas to correct afterwards. It is better to correct one part of the mirror first, then move on to the next. You may also, after making a correction of a raised ridge - find that you need to use the normal polishing stroke for a maybe a half-hour to 'blend' things together and smooth the surface.

Depressed zones, provided that they are not deep (that is they are not grooves) and are fairly wide can be corrected by reducing the zones on either side of the depressed one. Then the whole surface can be 'blended' again by the use of the normal polishing stroke. Sometimes this kind of defect may require the use of a small lap - perhaps only 2 1/2" to 3" in diameter. Some defects just have to be dealt with this way. Although the action of a small lap is fairly predictable - and certainly only affects a small area of the mirror on which it is used - over-use can cause more problems than just going back to 'square one' and using the full lap to polish for a couple of hours. (making sure that it is pressed and in good contact, and that your stroke is carefully done.

Almost all the people I have talked to about mirror-making mention the **'dreaded turned-down edge'** Why this is so I really don't know. I don't think it happens to everyone - I've certainly seen lots of mirrors **without** turned edges.



A turned- down edge

With the knife cutting the edge rays of the mirror - this shows as a dark ridge on the right side of the mirror, with the rest of the disc having the appearance of a 'satellite dish' or a hollow 'salad dish.' The best indicator is the graph of your readings from the tester. To correct this you can try polishing with the lap centered about an inch to inch and a quarter inside the edge, using the chordal stroke. This, if the turn down is not too serious, will have the effect of 'blending' the edge into the rest of the 'figure' and will change the focus very slightly. Causes of a t.d. edge can be either too soft a pitch or maybe too wide a polishing stroke, or again possibly unconscious pressure over the edge of the mirror during polishing, or even too high a temperature in the work area.

In the end - **experience** is the main requirement, along with lots of patience if your mirror turns out to have any serious zonal defects. The only way to get experience is to persist - and spend the time necessary to find out what works for you ! If you have defects other than zonal ridges or depressions - such as astigmatism, where defects appear at different cross-sections of the mirror, your only choice is to go back to polishing for a few hours. Check the condition of the lap and the arrangement of the pitch squares. If all else fails - build a new lap and try again.

If you are reading this because you are making your own mirror - or intend to do so - I wish you lots of success.

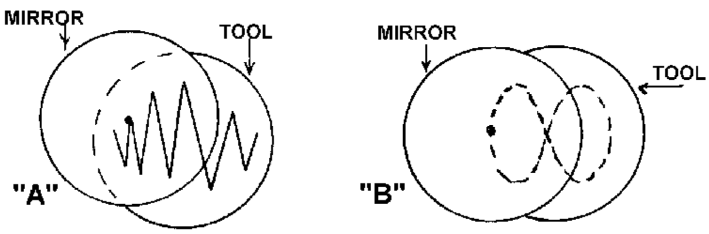
PARABOLISING the polished mirror

If you are amongst the lucky people who find that the finished mirror is almost spherical to start with, and has no major 'zonal' ridges or depressions - well, what can I say !? "Good for you! "

The difference in cross-section, for the average amateur mirror of 6 or 8 inch diameter is only a few millionths of an inch when the sphere and parabola are compared at the edge. In the case of the 8" F8 mirror discussed in this page's 'mirror' section the difference at the edge of the mirror is about 15 millionths of an inch. (15 x 10^-6) If they are compared by making the centers tangent and the edges intersect, the difference can be even less (about 4 x 10^-6 .)

The difference between the two curves is that the parabola is a little 'flatter' at the edges and a little deeper in the center. So we can **selectively polish these two areas to 'parabolise' the sphere by using a different polishing stroke.**

It should be obvious that to determine what action is necessary, you must be able to **measure** the existing profile of the mirror. Then if it is close to a sphere you can apply the modified stroke **("A" in the diagram) which is normally used to make it into a parabola.**



This stroke is like two or three letter W's together - WW(W) - and is wider and longer than the normal stroke, and is done **with the mirror on top.** Starting at one side with the mirror on top of the tool and offset perhaps 3" or more, you push the mirror about 3" or so up and down at the edge - gradually increasing the length of the stroke as you cross the center - up to perhaps a little over 6" and then reducing it again as you move to the other side. The long stroke across the center tends to deepen the center and the wide sideways motion works more on the edge of the mirror to reduce the edge.

Before starting, the mirror and tool should be **properly pressed** to ensure good contact, and the polish should be **mixed a little thicker** than for normal polishing. **Any correction**, either parabolising, or fixing some zonal defect, should be done by degrees - the action of the tool is **sometimes not** what you expect it to be ! So do only a few minutes at first, then if all is going the right way, you can simply do some more until a good parabola is obtained.

When doing this you should mark a point on the edge of the mirror, so that you know where you start. After about a minute - turn only about a 5th or 6th of the circumference of the mirror, so that you do five or six steps to make one complete turn. Usually it is best to make only two or three turns and take about ten or 15 minutes total time polishing, for the first attempt at parabolising. At the end of the last turn stop a little way short of where you started so that you do not overlap a section which you have already done.

The time for doing this should be short - only about 10 to 15 minutes for the first session, and the mirror must make **an even number of turns.** Then let the mirror settle for at least 8 hours (for pyrex) - (possibly 5 or 6 for plate glass) and check the result. The mirror surface is heated during even 10 or 15 minutes of polishing and will take a long time to settle properly. If you check it too soon - it may seem that nothing has changed and you will perhaps work it some more. Then when it has finally settled you will find that it was overdone. So be sure to give it lots of time to settle - possibly 6 to 8 hours after each 'figuring' session. It is better to wait longer to ensure a correct measurement than to rush this process.

Another method - which some people may find harder to do **(if so, stick with the 'w' stroke)** - is to use a wide "lazy-eight' stroke, which is a figure 8 stroke but lying on its side, as in "B" in the diagram. **The normal 'w' type stroke shown in "A" is generally easier to use.** In each case the jagged line shows the track made **by the center of the mirror.**

Another method is to modify the pitch lap, by cutting the outer squares to form a 'star' pattern. We have never tried this method - so I do not know how well it works. Modifying the tool is not always a good thing - the full lap is not something to be lightly altered. It can be very necessary for blending defects in the mirror - and smoothing it out again if previous actions have caused a problem. The other possible method is to make a smaller lap (using a plywood disc as the base) - making it about half the normal diameter of the mirror. This can be used selectively to deepen the center first, using a long stroke with some two or three inch sideways motion, and then again to reduce the edge with a shorter chordal stroke across the edge, again using some 'spreading motion' so as not to 'dig a channel', until a good parabola is obtained. In this case - the mirror may be on the bench - and the small lap used on top - but an even number of turns around the mirror should be made.

The use of a small lap has some dangers - it can very easily produce grooves in the mirror - especially if used too long, and without adequate sideways motion to blend into the other areas of the mirror. If you are determined to make a mirror accurate to a 1/5th wave, or better, you may have to take the risk. Frequently - after using the small lap you may need to smooth things out again overall with the full-size lap. Too much use of the small lap can produce a rough appearance to the surface, and re-polishing for an hour or more may be required afterwards.

The choice of which method to use is up to the mirror-maker. There are probably yet more ways to do the job - but the above should provide a couple of ways that you can try. The small tool is often the method of choice with larger and much shorter focus mirrors, where it can depart from a sphere by a large amount (such as the 20" F5 mirror we made for our Club, edge difference= about 150 millionths")

The process of accurately 'figuring' the mirror can be time-consuming and requires lots of patience. The final guide to accuracy will be the time spent testing and graphing the results of each step you make in getting the correct shape. If all goes well, with patience and perseverence you'll wind up with a smoothly parabolised mirror of a quality which would cost you dearly if ordered from a company who will guarantee an 'observatory' or 'research grade' mirror, which would require hand-finishing and careful measuring to ensure the best of quality.

This is probably the main reason, apart from the challenge of learning a new 'craft,' for making your own mirror. There is always also the feeling of satisfaction - especially when looking through the finished telescope, of having accomplished something (which although a 'simple' process can present quite a challenge to complete successfully) There are many finished mirrors available at reasonable cost from various suppliers today. Careful attention to the various aspects of making, testing and finishing your own mirror though is still likely to cost less - and you have first-hand assurance of its quality if you are successful.

I hope the above helps you make a really fine mirror and GOOD LUCK

Materials List

- **Telescope Objective Mirror (1):** See "A word concerning focal ratio.." and "Sources".

When you get your mirror, the focal ratio may be exactly what you ordered, or it may be a little more, or a little less. So don't cut your tube till you receive your mirror. To measure your focal length exactly, have a friend help you: Take your mirror, a tape measure, and a piece of paper outside on any clear night and catch the light of a bright star or the Moon with your mirror and reflect it back in that direction. Using that piece of paper find where the star, or Moon forms the smallest image. Measure that distance as accurately as you can. (Instead of a piece of paper, it is often easier to reflect onto a fixed surface, such as a garage door jamb or header). Write this measurement down! This determines the length of your telescope tube, as well as where you cut a hole for your focuser.

- **Telescope Diagonal Mirror (1):** Order when primary f/ratio is decided upon.

The size of the diagonal mirror is dependent on the size and focal ratio of the objective mirror. So, when you order your mirrors, make sure to ask your supplier to tell you the correct size diagonal mirror to order. Specify that you will be using a low-profile focuser. To determine more accurately the size of the diagonal, peruse the following email correspondence:

balzaccom@aol.com (Paul Balzac) writes:

>By the way, I tried to find the equation you mentioned in the archives, but
>couldn't. Anyone help?

The equation is found in Richard Berry's **Build Your Own Telescope**, pgs 26-28. However, there are a couple of errors on those pages: "E" on page 27 should be changed to "D" (this makes more sense with the drawing). Also, in the final example he uses, the "6" and "8" are transposed; switch them around, in other words.

But to cut to the chase, the formula is:

d = df +([D-df]/F) X Lde

Where **"d"** is the minor axis of the diagonal,

"df" is the focal length of your primary multiplied by: the result of the amount of fully illuminated field you want divided by 57.3 (radians in a degree). In other words, **F X (x/57.3)** where **"F"** is focal length and **"x"** is the amount of fully illuminated field you desire. *("df," is, in fact, the amount of fully illuminated field).*

"D" is the diameter of your primary,

"F" is the focal length of your primary,

"Lde" is the distance between the diagonal and the field stop of your eyepiece.

A self-serving example: I recieved my 8" f/7.06 mirror from Coulter yesterday. The common rule of thumb is to have a half (.5) degree of "fully illuminated field" for visual use. (But I will also plug in a .25 fully illuminated field, just to see how much smaller my diagonal will be...). The telescope will use a 10.5" outside diameter Sonotube, have a low profile focuser (say 2.125 inches high), and I will add 3/4 of an inch to be sure all my eyepieces will focus with
a variety of eyeballs: So my "Lde" will be: 8.125 inches: 5.25 (radius of 10" tube) + 2.125 + .75.

"df" is then,
for a .5 degree fully illuminated field: 56.5 X (.5/57.3) = .493
for a .25degree fully illuminated field: 56.5 X (.25/57.3) = .247

So lets plug these numbers in:

The formula, again is: **d = df +([D-df]/F) X Lde** (be sure to multiply BEFORE you add)

.493 + .133 X 8.125 = 1.57 inches. So, a 1.57" minor axis diagonal will fully illuminate a half a degree at the eyepiece.

.247 + .137 X 8.125 = 1.36 inches. So, if I want only a .25 degree fully illuminated field to produce more contrast on the planets... I would go with a diagonal this size. Diagonal mirrors do not come in the above sizes, of course; but one can round off--in either direction--your preference!

--Ray

- **Eyepiece (1):** Eyepieces may be purchased from telescope supply houses (see "Sources"), or you can salvage one out of an old pair of 7 x 35 binoculars (binoculars should be labeled "fully coated optics").

Q: What eyepiece(s) should I get, and what power will I get from them?

I recommend Plossl eyepieces like the Orion ones above--good eyepieces, not too expensive. Power is determined by dividing eyepiece focal length into the telescopes' focal length--in millimeters. Let's take a six inch f/8 telescope, for example: 6 X 25.4 (the number of millimeters per inch)=152.4mm. Multiply this by your focal ratio (f/8, for example)=1,219.2 mm. Divide a 26mm eyepiece into this and you get 46.89 power. Divide the same 1,219.2 mm by an eyepiece with a 10mm focal length and you get 121.9 power, right? These are good focal length eyepieces to start out with; one low power, and one medium power... You may want to add to your collection later.

Q: What will I be able to see?

Jupiter and Saturn will probably be smaller than you like (at the 121x example given above), but you will be surprised at how much detail you can see: Many cloud bands on Jupiter, not to mention the four Galilean moons, as well as the great Red Spot (which is more pale yellow nowadays); cloud bands on Saturn as well as its glorious rings and (most likely) Cassini's division--the most notable gap in the rings. The Moon will be extremely detailed. Star clusters, nebulae, and galaxies (invisible to the naked eye) will vary considerably in their glory and appearance. Do not forget to allow your scope to come to ambient temperature ("cool-down")--this is extremely important! Otherwise, excess turbulence within your scope will produce nothing but "blobs" at the eyepiece! Allow at least an hour for cool-down time. Sometimes, the "seeing" (upper atmosphere turbulence) never settles down, and you will be frustrated with the views all night... nothing to do but try another night!

The key thing to remember is that you want this formed image (called the *focal plane*), to hover in the same plane as the field stop of your eyepiece. If you opt for a commercial focuser, you will undoubtedly have to cut your focuser hole in a different place than these plans call for! Do you have your eyepiece(s) yet? If that's a "yes," good: Look into your eyepiece and put your pinky finger in the other end--slowly and carefully--can you see where your finger comes into a magnified focus? Usually there is a black ring (called a *field stop*) at this point around the inside of the eyepiece; and usually this corresponds to where--on the outside of the eyepiece--the chrome barrel ends and the rest of the eyepiece body begins. This means this is where the eyepiece "bottoms out" when inserted into a commercial focuser. But, you don't want your commercial focuser to bottom out when focusing! Individual eyes and eyepieces are different! Always allow at least 3/4" "**in travel**" for your commercial focuser, when doing the arithmetic to determine where to cut your focuser hole! More is said on this subject in "Section A" of these plans online.

- **Cardboard tube ("Sonotube") (1):**

TUBE DIAMETER

The telescope tube should be about 2 inches wider in diameter than your objective:
A ten-inch diameter objective mirror requires a twelve-inch diameter tube.
An eight-inch diameter objective mirror requires a ten-inch diameter tube.
A six-inch diameter objective mirror requires an eight inch diameter tube.

Q: Can I use a PVC (plastic) tube instead of a Sonutube (cardboard concrete forming tube)?

It has *been done; but it is not recommended, for several reasons: PVC warps with heat (like in the back seat of a car on a hot day); PVC also warps with weight, adding to collimation problems. PVC is also quite heavy.*

Construction, specifically concrete construction supply houses usually carry these tubes, which are used for forming concrete columns. Get the supply house to cut your tube rough, that is, longer than you need by, let's say, six inches or so. To "finish cut" your tube square: Tape several 8-1/2" x 11" pieces of paper together end for end--enough to wrap around the circumference of the tube, and do just that... Make the ends come together squarely; and mark the edge you want to cut. Proceed with a hand saw or Jigsaw...

- **Exterior grade plywood:** 4' x 8' x 3/4" thick. For an eight or ten inch telescope, one sheet will be plenty. An alternative to "exterior grade plywood" would be "shop grade"; not much more expensive, a MUCH smoother finish is possible.

The plywood cutout patterns on the next few pages are for the construction of telescopes with six, eight, and ten inch objective mirrors, but you can use the same design for smaller telescopes (4.5", for example) or larger telescopes with objective mirrors of up to 15" in diameter. Just remember that the tube of your telescope needs to be at least 1-1/2" wider than the diameter of the objective mirror. Then increase (or decrease) the tube box and rocker dimensions proportionately. THE DIAMETER OF YOUR TUBE DETERMINES ALL OTHER DIMENSIONS.

For telescopes with mirror diameters 16" and larger, a different tube box design and mirror support system is necessary. (Again, John Dobson's telescope-making video—listed in "Sources" shows the construction of a 16" telescope with this modified tube box and support system). A more popular method of construction nowadays for large Dobs is the truss design, which allows the telescope to be "broken down" for transport and storage. See my Vanity Page for examples I have built; recommendations, and resources.

- (Optional) **Six-Eight feet of Douglas Fir 2"X 2"**: Cut these into small lengths and glue to inside of Rocker Box and Tube Box corners--this will strengthen these joints considerably.

- **Cedar Shim Shingles:** Three pieces, about 1-1/2" to 2" wide. Shingles break easily, so it's a good idea to keep a few extra shingles on hand.

- **Wooden Dowel:** One piece, about 3" long. Usually sold as "closet pole" or "hand rail stock"— Approximately 1-3/4" in diameter.

- **Masonite:** One rectangle of 1/8" thick Masonite board about 3" x 4" (1/4" thick is also O.K.) with a 1-1/2" hole drilled in the center; **and** three pieces about 1" square.

- **Cardboard "Mailing" Tube:** One piece, 1-1/2" inside diameter, about 2" long (Grocery stores have this tube in the produce department—used for dispensing plastic bags.)

- **Cardboard:** The back of a cardboard breakfast cereal box works nicely.

- **Chrome-plated Brass Tubing:** Washbasin drainline trap—1-1/2" outside diameter: We 'll need two pieces: one about 1-1/2" long, for the eyepiece holder, and one about 6" long, for the aligning tube. (Available from a plumber's scrap bin.)

- **Sheet Metal Screws:** Panhead, size #8, 3/4" long. Get at least a dozen.

- **Nails**: Assorted sizes. Hot-dipped galvanized box nails work well.

- **Machine Bolts (3):** Three bolts, 1" long; 3/8" in diameter.

- **Lag Screw with matching washer (1):** One lag screw, 3" long; 1/2" in diameter.

- **Thumbtacks (3)**

- **Furring nails (4)** If you can't find furring nails, don't fret; I like to use rubber furniture glides (the kind you just nail in--this serves the same purpose as the furring nails: namely preventing our primary mirror from falling forward.

- **Teflon:** 7 pieces, approximately 1" x 1" square, and 1/4" thick. Three pieces will be used for the lower Rocker Box bearings and four for the Cradle Board bearings.Try a local electronics surplus house; otherwise call Crazy Ed Optical, under "Sources."

- **Record (1):** One phonograph record—33-1/3 LP rpm size (A "used" record is fine.) Or visit your local cabinetmaker for some free "scrap" Plastic Laminate ("Formica" is a brand of Plastic Laminate)--you won't need much--just enough to cover the bottom of your Rocker Box (see Section "C" of these plans) and line the outside edges of your Altitude Bearings. Do not use "gloss" Plastic Laminate, however--just the rougher surfaced stuff. You may also want to contact http://www.crazyedoptical.com/ for inexpensive "kits" of Plastic Laminate and Teflon.

- **Leather Scrap:** Three small pieces—about 1/2" square. Old belt leather works fine.

- **Sticker or Decal (1):** About 1/2" in diameter. I like to use "hole reinforcements" stickers, for three-ring notebook paper. A "gold star" also works well. Visit your stationary store.

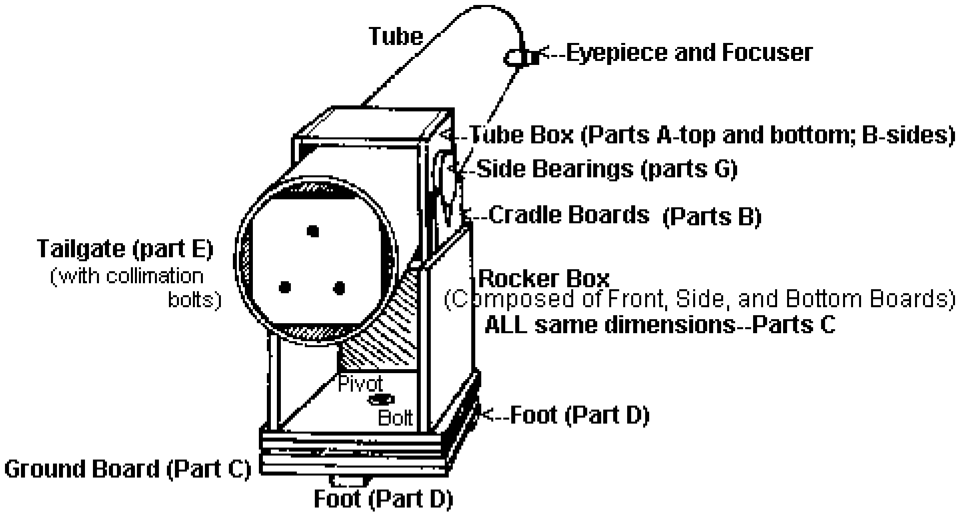
- **Paint and painting supplies:** Flat black for inside the tube; any dark color is fine for the outside of the tube. White is not recommended--it takes longer for a white tube to cool down to ambient (outside temperature).

- **Glue:** White glue works fine. In addition, I like to use 100% black silicone glue on selected parts (like focuser construction and diagonal mirror to diagonal holder adhesion.

Tools Needed

- Drill and 1/4", 7/16",1/2",and 3/32" Drill Bits, in particular.
- Saw (Table Saw, and/or Jigsaw is/are helpful but not essential).
- Screwdrivers
- Crescent (adjustable end) Wrench
- Awl
- Hole Cutter or 1-1/2" diameter doorhandle drill bit.
- Hammer
- Nail Set
- Carpenter's Framing Square (helpful but not essential); Combination Square
- Compass
- Tape Measure

Six-inch Telescope Overview with Plywood Cut Pattern



3/4" thick plywood—cut to these sizes:

Parts A (2 pieces--top and bottom of Tube Box) 8-1/2"x 8-1/2"

Parts B (4 pieces) (sides-tube box; Cradle Boards) 8-1/2"x 10"

Parts C (7 pieces--(Rocker Box, Ground Board) 12-1/2"x 13-3/4"

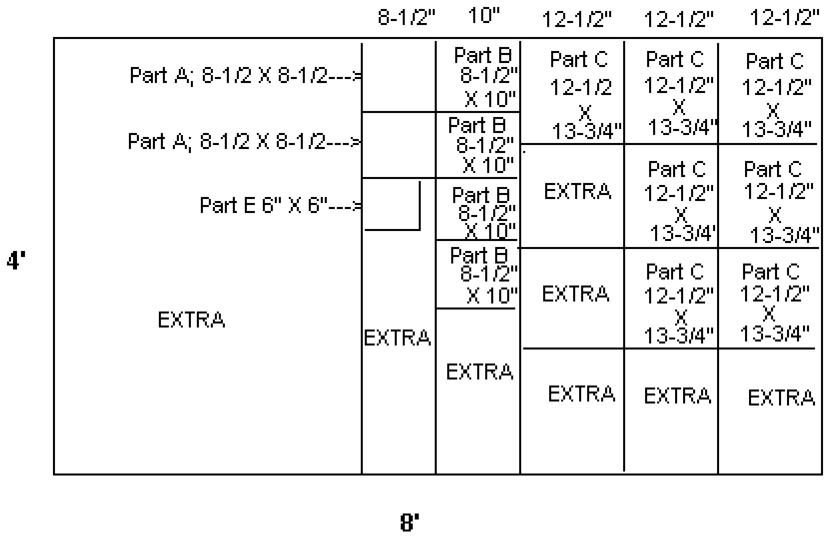
Parts D (3 pieces--Feet) 1-1/2"x 1-1/2"

Part E (1piece--tailgate) 6"x 6"

Parts F (4 pieces) 1"x 4" (Mirror Blocks--*not shown*)

Parts G (2 pieces--5" diameter circles; Altitude Bearings) Not shown below--cut from "extra."

PLYWOOD CUT PATTERN FOR A TELESCOPE WITH A 6" MIRROR:



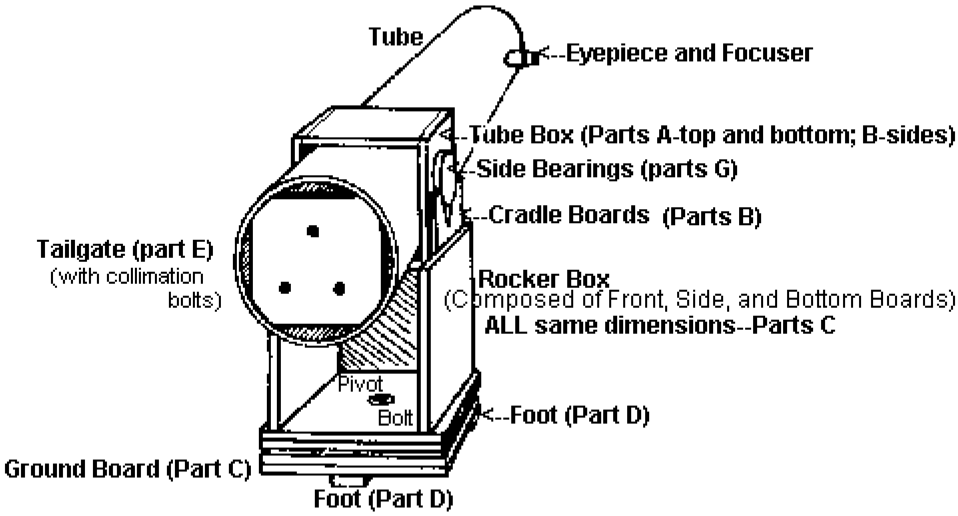
Notes:

You can make your job easier by having the lumberyard pre-cut your plywood on their panel saw. Most stores give you two free cuts and charge (50 cents?) for each additional cut. (They can only do the vertical cuts above.) Then cut the pre-cut pieces into the necessary sizes at home. Note that for a six-inch scope, you will be using less than a half-sheet of plywood; perhaps you and a friend can make two?

Make sure you tell the salesperson cutting the wood for you that these sizes are for the finished (cut) pieces of wood. Allowance will have to be made before cutting for the width of the saw blade ! ! ! (You lose about 1/8" of an inch for each cut, usually.) The wood sizes given should be the actual sizes of the cut pieces of wood.

Refer to the above drawing and plywood "cut pattern" throughout the following step-by-step instructions. Label all pieces (in pencil, chalk, or crayon) as they are cut! We will build our telescope from the "inside out," beginning with the tube.

Eight-inch Telescope Overview with Plywood Cut Pattern



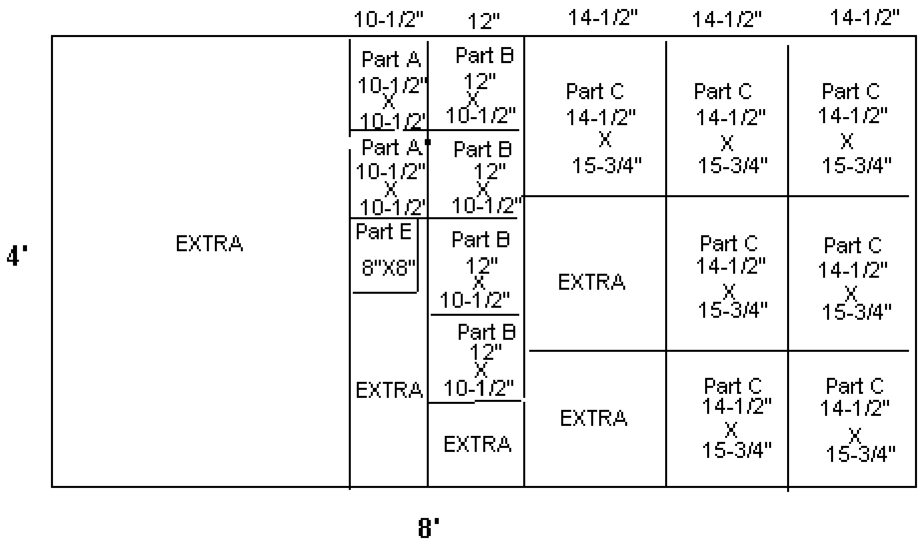
3/4" thick plywood—cut to these sizes:
Parts D (3 pieces--Feet) 2"x 2"

Parts A (2 pieces--top and bottom of Tube Box) 10-1/2"x 10-1/2"
Part E (1piece--tailgate) 8"x 8"

Parts B (4 pieces) (sides-tube box; Cradle Boards) 10-1/2"x 12"
Parts F (4 pieces) 1"x 4" (Mirror Blocks--*not shown*)

Parts C (7 pieces--(Rocker Box, Ground Board) 14-1/2"x 15-3/4"
Parts G (2 pieces--6" diameter circles; Altitude Bearings) Not shown below--cut from "extra."

PLYWOOD CUT PATTERN FOR A TELESCOPE WITH AN 8" MIRROR:



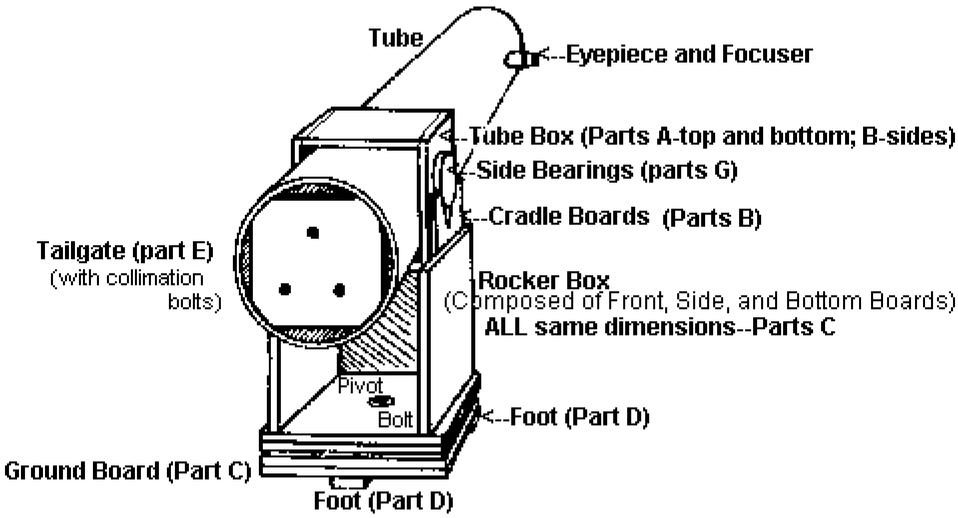
Notes:

You can make your job easier by having the lumberyard pre-cut your plywood on their panel saw. Most stores give you two free cuts and charge 25c for each additional cut. (They can only do the vertical cuts above.) Then cut the pre-cut pieces into the necessary sizes at home.

Make sure you tell the salesperson cutting the wood for you that these sizes are for the finished (cut) pieces of wood. Allowance will have to be made before cutting for the width of the saw blade ! ! ! (You lose about 1/8" of an inch for each cut, usually.) The wood sizes given should be the actual sizes of the cut pieces of wood.

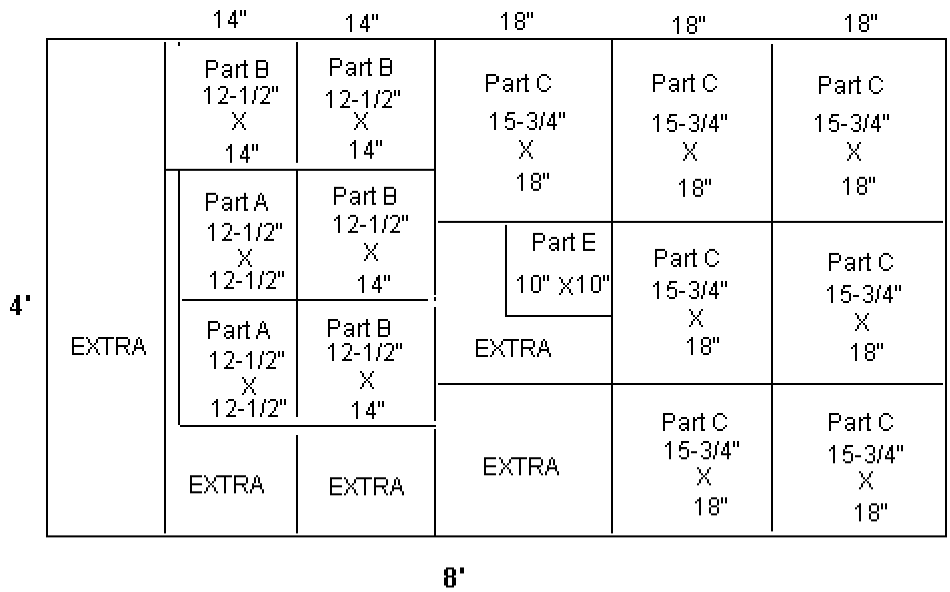
Refer to the above drawing and plywood "cut pattern" throughout the following step-by-step instructions. Label all pieces (in pencil, chalk, or crayon) as they are cut! We will build our telescope from the "inside out," beginning with the tube.

Ten-inch Telescope Overview with Plywood Cut Pattern



3/4" *thick plywood—cut to these sizes:*	**Parts A** (2 pieces--top and bottom of Tube Box) 12-1/2" x 12-1/2"	**Parts B** (4 pieces--sides of Tube box, Cradle Boards) 12-1/2" x 14"	**Parts C** (7 pieces-Rocker Box, Ground Board) 15-3/4" x 18"
Parts D (3 pieces--Feet) 2" x 2"	**Part E** (1 piece) 10" x 10" (Tailgate)	**Parts F** (4 pieces) 1" x 4" (Mirror Blocks--*not shown*)	**Parts G** (2 pieces--Altitude Bearings--6" diameter circles). Not shown below--cut from "extra."

PLYWOOD CUT PATTERN FOR A TELESCOPE WITH A 10" MIRROR:



Notes:

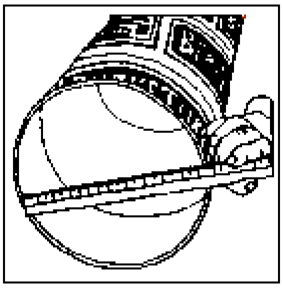
You can make your job easier by having the lumberyard pre-cut your plywood on their panel saw. Most stores give you two free cuts and charge a nominal fee (50 cents?) for each additional cut. (They can only do the vertical cuts above). Then cut the pre-cut pieces into the necessary sizes at home.

Make sure you tell the salesperson cutting the wood for you that these sizes are for the finished (cut) pieces of wood. Allowance will have to be made before cutting for the width of the saw blade ! ! ! (You lose about 1/8" of an inch for each cut, usually.) The wood sizes given should be the actual sizes of the cut pieces of wood.

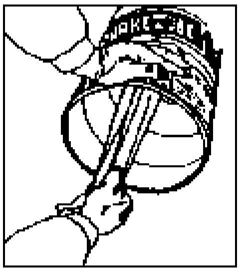
Refer to the above drawing and plywood "cut pattern" throughout the following step-by-step instructions. Label all pieces (in pencil, chalk, or crayon) as they are cut! We will build our telescope from the "inside out," beginning with the tube.

Section"A" of <u>Making a Dobsonian Telescope</u>

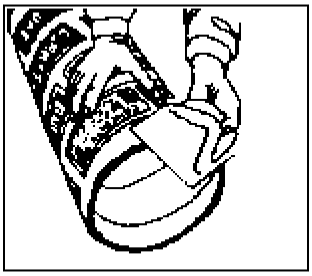
PREPARING THE TUBE



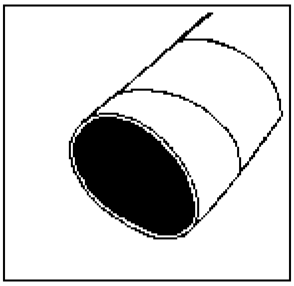
The diameter of the telescope tube should be about 2" larger in diameter than the diameter of the objective mirror



The plastic liner may be carefully peeled out of the <u>inside</u> of the tube.Slow, careful peeling helps keep the liner in one piece and makes it easier to remove.

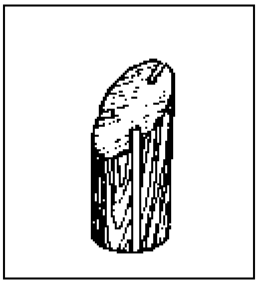


Some tubes are waxed outside. If you plan to paint the outside of the tube, a light sanding will remove some of the wax and make painting easier.



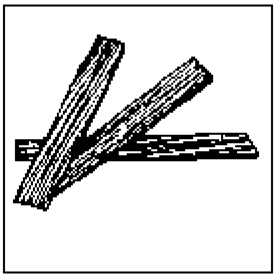
The inside of the tube may be painted black. Tape your paint brush on a broomstick handle if your tube is longer than your arm reach.

MAKING THE SECONDARY MIRROR MOUNT ("SPIDER")

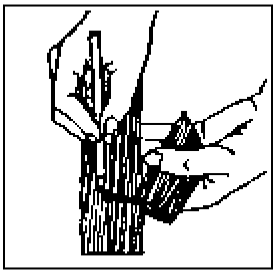


Dowel (closet pole, or handrail stock) with one end cut at a 45 degree angle. Three grooves should be cut (with a thin blade) at equal (120 degree) intervals (about 1/4" deep) as shown.

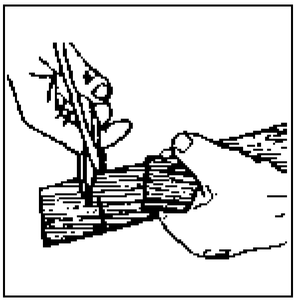
Note: *How does one cut a cylinder at 45 degrees? Cut a strip of paper long enough to wrap around your "closet pole." cut both ends (of the paper strip) at 45 degrees so that you make a trapezoidal shape... wrap this piece of paper around the dowel so that the ends come together (trail and error cutting may be required here). The paper will* ***not*** *lay flat! Now trace the outline the edge of the paper makes. Cut close with a hand saw. Sand or file to line.*



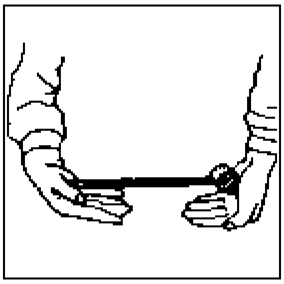
We will need three pieces of cedar shingle, each about 1 1/4" wide.



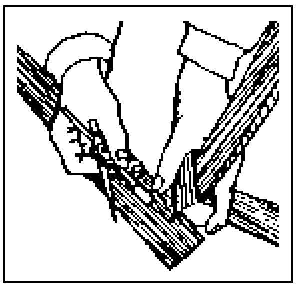
Marking the thin ends of the shingles where they fit snugly into the grooves in the dowel.



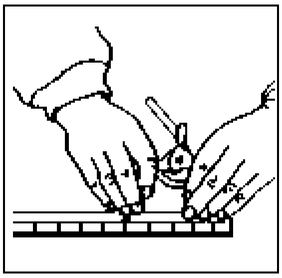
If the shingles are cut slightly concave (so they won't rock back and forth in the dowel and will fit snugly) they won't have to be glued in. Replacement will then be easy. If you do decide to glue them in, use black, 100% silicone adhesive.



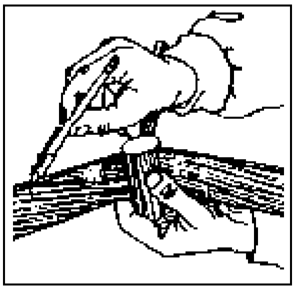
Shoving a shingle into the groove in the dowel.



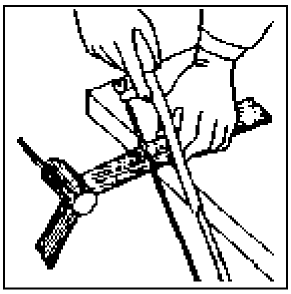
Doing the same with the other two shingles.



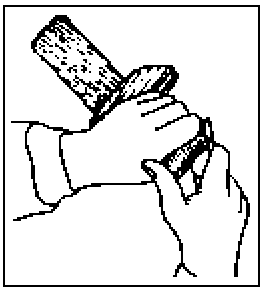
The compass should be set to the radius of the *inside* of the telescope tube.



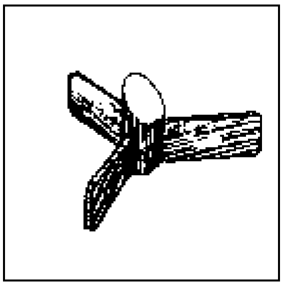
Placing the point of the compass at the center of the dowel, mark all three shingles.



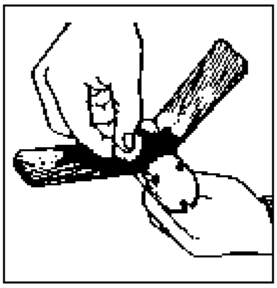
Sawing off the ends of the shingles at the marks.



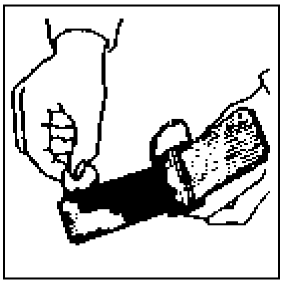
Beveling the corners so the shingles won’t split when the position of the spider is adjusted in the tube.



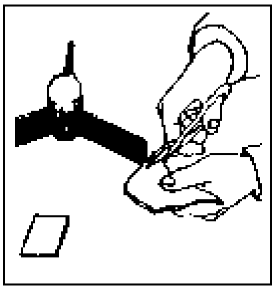
All corners beveled...



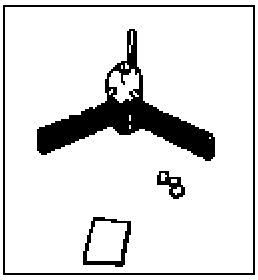
We may paint the spider black, or simply blacken the surfaces facing the eyepiece tube.



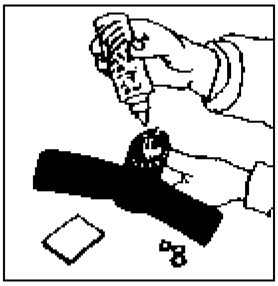
The slant-cut end should be left unpainted (to accept glue). If spray paint is used, be sure to cover the slant-cut end with masking tape while spraying



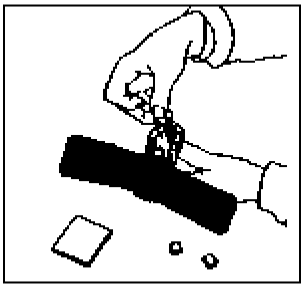
Cutting leather scrap. We will need three pieces about 1/2" square.



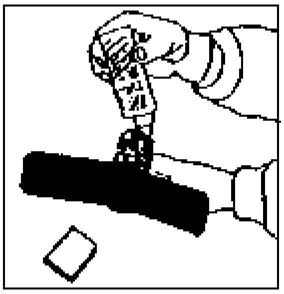
The secondary mirror (flat front-surface mirror). This mirror is also called a "diagonal." (Secondary mirrors are *usually* elliptical in shape; not rectangular like the one above).



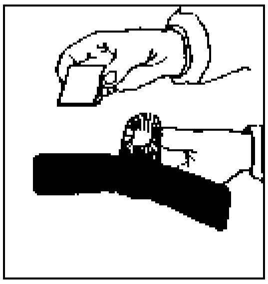
Applying glue at three points on the slant cut end of the dowel. (If masking tape was used, remove it first!). Leather pieces should be glued directly to the wood. *An alternative to leather and white glue is to use three dabs of 100% silicone adhesive--you might want to drill three small, shallow holes in the "slant cut" to accept the silicone better.*



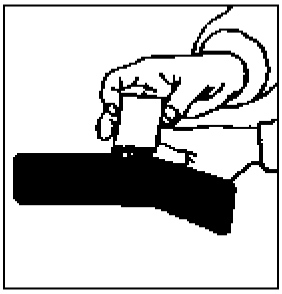
Leather pieces should be spaced evenly between the grooves. Be sure the leather gets good and wet with the glue.



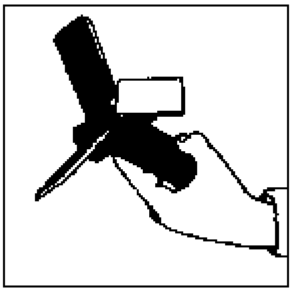
After the leather pads are glued to the dowel, we apply glue to the tops of the leather pads...



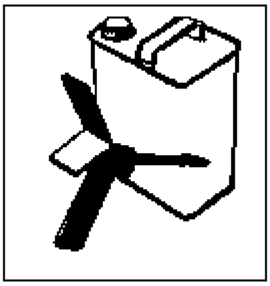
...and glue the mirror onto the pads.



Make sure the mirror is evenly centered over the dowel.



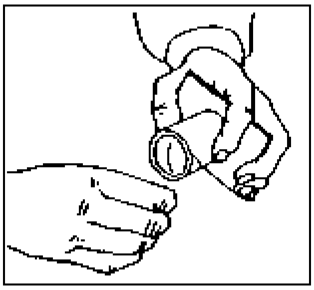
The mirror should be kept level while the glue dries.



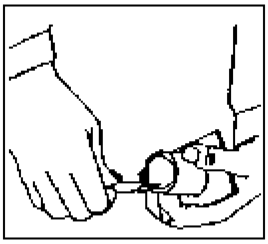
Propping up the spider while the glue sets.

MAKING AND INSTALLING THE EYEPIECE TUBE

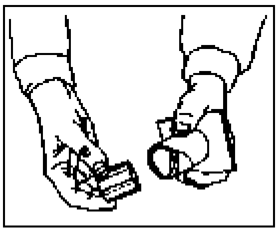
***NOTE:** Above, a close-up photo of my **Dobsonian Sun scope**: An inexpensive alternative to constructing an eyepiece tube from a cardboard tube and masonite (below) is to order--and attach--a* **2-inch to 1-1/4-inch adapter** *from a telescope mail order house like Lumicon, Orion, or Crazy Ed Optical. This $20 item is used in expensive, low-profile focusers to adapt from eyepieces with a 2" barrel to ones with the more common 1-1/4". You will have to drill a couple of holes through the metal (usually aluminum) to accept the small through bolts, and shim the flat bottom equally in two places (since you are attaching the thing to a cylindrical surface)... It adds a little more weight "up top," requires two hands to focus (one to operate the knurled stop screw, and one to push-pull focus); but you will end up with a sturdier, low-profile focuser than the one described below. Be sure to drill only an 1-1/4" hole in the tube, instead of the 1-1/2" hole as per the instructions below.*



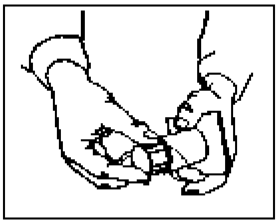
Gluing the cardboard eyepiece to a 3" x 4" piece of Masonite with a 1 1/2" hole cut in its center. Make sure to get the cardboard wet with the glue.



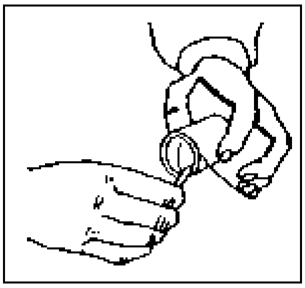
Beveling the inner edge of the tube with a pen knife so that the brass will fit in easily.



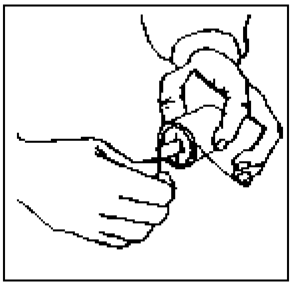
The brass tube should fit snugly inside the cardboard tube...



...and slide back and forth fairly easily.

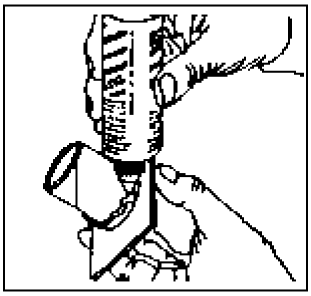


If the fit is too tight, we may peel out a thin layer of the cardboard on the inside of the eyepiece tube.

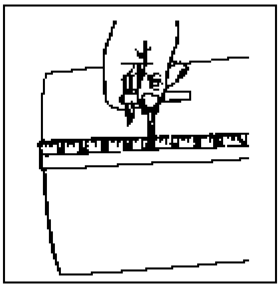


If the fit is too loose, we may glue in a strip of cardboard lengthwise down the inside of the eyepiece tube and let the end of the strip hang down over the end of the tube. (The strip should be glued down over the lip of the tube.)

Gary Morris (glmorris@jps.net) came up with an elegant solution to attain the correct amout of "focusing friction": He simply uses a hose clamp (see photo at left)... He writes that it is a onetime affair to tighten the hose clamp around the cardboard focusing tube just enough to provide the necessary friction around the sink drain tube.(This would replace the need to "peel" or "glue in a strip of cardboard" in the two previous steps)



Running a thin bead of glue (100% silicone glue works well here) around the cardboard tube where it meets the Masonite.



Finding the location for the eyepiece hole. See note—below:

Note: Cut the telescope tube the same length as the focal length of your mirror. Then cut the eyepiece hole back from the front end of the telescope tube by the radius of the tube. That is, for a 10" diameter tube, cut the eyepiece hole 5" from the front end; for a 12" diameter tube, cut the eyepiece hole 6" from the front end. These distances are for mirrors about 1" thick. If you have a thick mirror (i. e. 2"+) the hole should be moved up toward the front end of the tube an extra 1" to compensate. (i. e., a 12" tube with a 2" thick mirror would put the hole 5" from the front end; a 10" tube with a 2" thick mirror would put the hole 4" from the front end.

A more important Note: Now, the above *note* ONLY works if you make the homemade focuser AND follow all the details of tailgate construction, use Sonotube, etc in these plans. If you don't, you will have to do some simple arithmetic. Folks: it is extremely easy to drill your focuser hole in the wrong place! Please read the following email and my response:

> I just built a Dob with an 8" f/6 primary mirror, 48" length tube and
> centered the focuser 5" from the end of the tube. I can see the moon really
> clearly, but when I look at distant stars, I can see their light, but in the
> eyepiece, I can only see the primary mirror--the star doesn't come into
> focus. I have a Crayford R&P focuser and a zoom eyepiece (7-20MM).

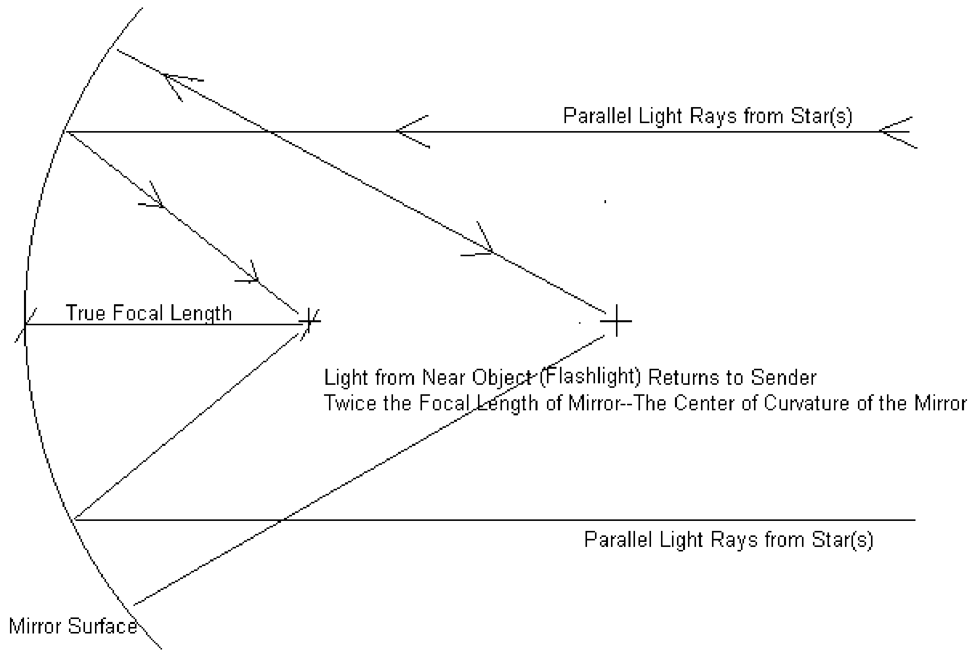
Hi Daj,

This is a most common problem. I must rewrite that section on the plans!

You did what the plans told you to do; however, you used a commercial focuser, which does not have as much "in travel" as the homemade one in the plans. You need to re-position your diagonal closer to the main mirror and re-drill your focuser hole.

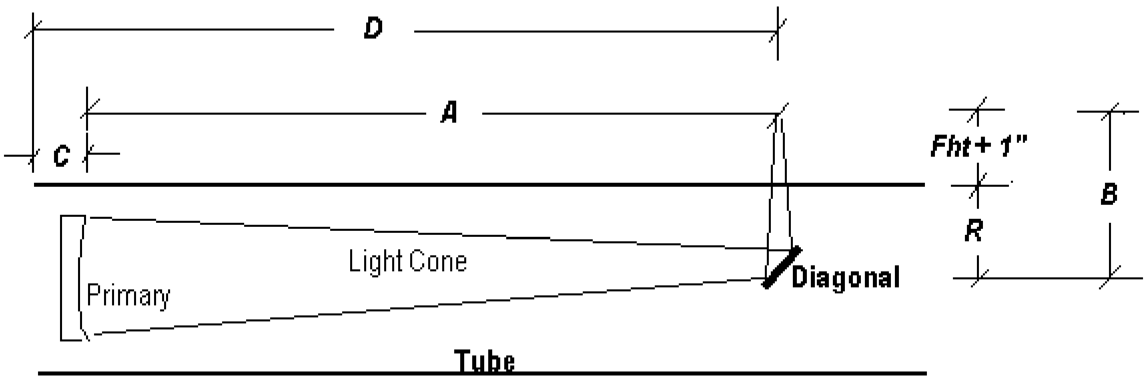
Here's how to figure out where EXACTLY:

Number One: Find out the exact focal length of your primary mirror (even if it is supposed to be 48"--for example--this may vary by an inch or more in either direction). To do this, the safest way is to bring your primary indoors, prop it up at the end of the hall, and then, with a piece of paper and a flashlight, start at about TWICE the distance of the (supposed) focal length, shine the flashlight at the primary and look for a formed image on the piece of paper (that you are holding in your other hand). IMPORTANT: The flashlight filament and piece of paper MUST be in the same plane, facing the mirror. Focus the image on the filament. Mark your floor with a piece of tape, or something. Measure carefully the distance from the face of your mirror to your mark. DIVIDE BY TWO. This is the focal length of your mirror. Write it down!



You can, of course, double check this dimension (the True Focal Length), outside at night, using the Moon or bright Jupiter as a target--don't forget to bring a friend and a tape measure to help you! And catch the image of Jupiter or the Moon bouncing back in the same direction!

Now, your telescope, when set up properly, will have a celestial image formed at the field stop of your eyepiece(s). Look at your eyepiece(s). Specifically, look down the "wrong end," the open end. Usually you can find a small black ring encircling the inside of your eyepiece, usually this ring corresponds to where the chrome barrel ends on the outside of the eyepiece, and where the eyepiece bottoms out when inserting into focuser. Find it? Now, look into your eyepiece (normally now, through the right end) and place a pinky finger in the wrong end at the field stop. See how your finger is magnified? Understand the dynamics of the telescope-to-eyepiece relationship better now? I am not familiar with zoom eyepieces; do determine where the field stop is--or its average place in relation to the outside of the eyepiece is, though. What I am trying to say is: the field stop generally corresponds to where the eyepiece bottoms out in the focuser, but maybe not in the case of a zoom eyepiece.



Refer to the above diagram, fill in your own values, if you will:

A + B = your true focal length

C = back of telescope tube to face of mirror

D = back of telescope tube to center of focuser hole

R = radius of tube

Fht + 1" = your focuser height (fully racked in) plus one inch.

(A and/or D is what we are going to determine).

Okay: it is just simple arithmetic to determine where to drill your focuser hole and place your diagonal directly below it:

***Fht + 1"**: Let's say you have a commercial focuser, which, when racked all the way in is 1-5/8" high (sitting 1-5/8" above the tube). First of all, <u>you do not want your focuser racked all the way in</u>; you need some "play"; not all eyes focus the same; not all eyepieces focus the same. Add one inch to this minimalist equation (2-5/8", in other words). You want the telescopic image to hover 2-5/8" above your tube, in other words, before being magnified by an eyepiece.*

You know all the other factors: The TRUE focal length of your mirror, where the mirror face is sitting in relation to the <u>back</u> of your tube, and the radius of your tube.

So, as an example, let's say the true focal length of your mirror is 48".

And your mirror face is sitting 2" from the back of your tube (assuming you have 3/4" plywood tailgate + 1/4" masonite collimation pads + a 1" thick mirror = 2")

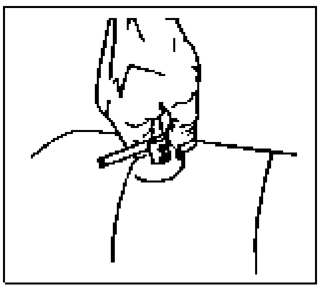
And the radius of your tube is 5".

So: add 5" + 2-5/8" = 7-5/8"

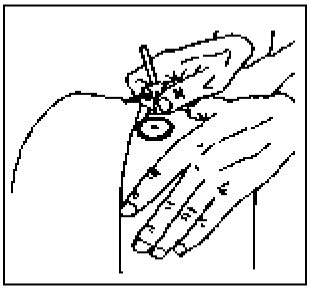
Subtract 7-5/8" from 48" = 40-3/8" This will be the distance from the face of your mirror to your focuser hole, and the diagonal.

If you add the 2" (the face of mirror to back of tube dimension), you can measure from the back of the tube 42-3/8"

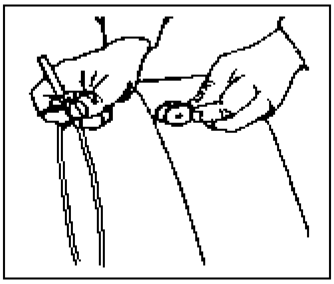
I drilled my focuser hole in the wrong place on my first homebuilt telescope; it is simple enough to fix. Did you save the piece you drilled out? Good. you can use "Bondo" (automotive body filler) to patch it back in--use masking tape to hold it in until the Bondo sets up (about ten minutes). Simply rotate your tube and redrill hole--of course you will have to reposition your diagonal, too.



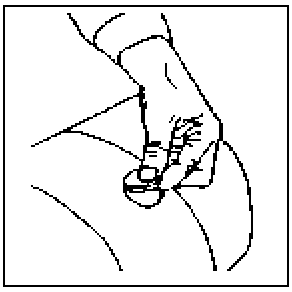
The distance we have measured is for the <u>center</u> of the hole. We may cut the hole to the outside diameter of the cardboard eyepiece tube.



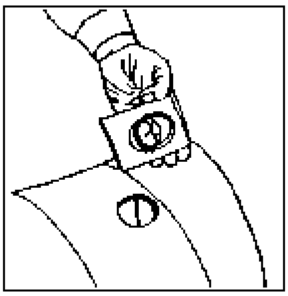
If a hole-cutter is unavailable, a mat knife may be used.



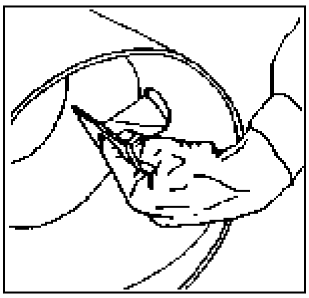
We may peel off layers of cardboard as we gradually cut through the tube.



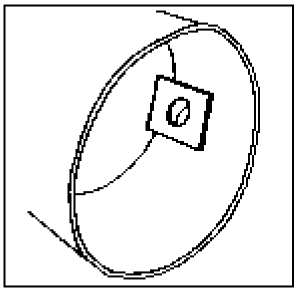
Mission accomplished! **Hint:** *Save this piece, just in case you made a boo-boo here! It will be much easier to patch up, if necessary, with this piece still around!*



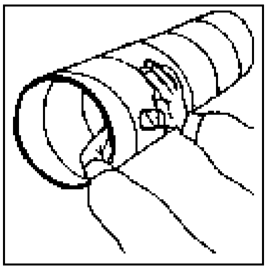
We are ready to install the eyepiece tube.



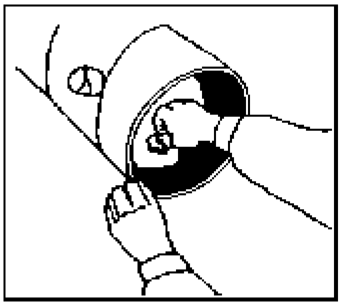
The cardboard eyepiece tube should fit snugly through the hole. If it is too tight, file or pare the hole a little bigger.



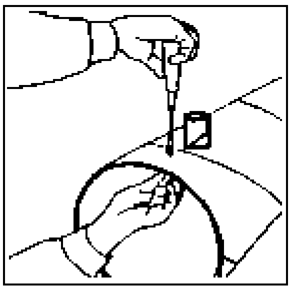
Eyepiece tube in place.



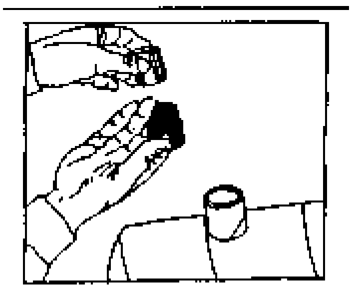
View from the outside of the telescope tube.



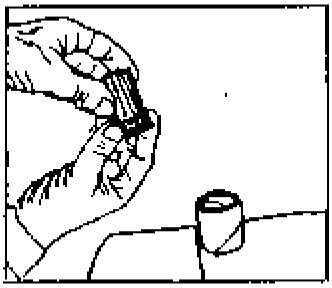
If we have not already painted the inside of the telescope tube, we now need to paint at least the section visible through the eyepiece tube black .



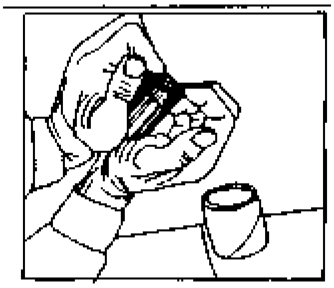
Two sheet metal screws (one on either side of the eyepiece tube) may be used to draw the Masonite rectangle snugly up against the inside of the telescope tube wall.



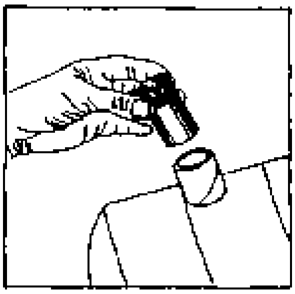
Fitting the eyepiece inside the brass tube. You can purchase an eyepiece, or salvage the eyepieces out of an old pair of binoculars.



If the eyepiece is too small to fit snugly in the brass tube, wrap it in a layer of two of corrugated cardboard.



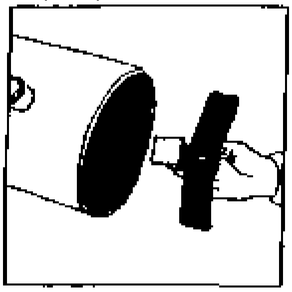
Adjust the amount of cardboard as needed so that the fit of the eyepiece in the brass tube is snug.



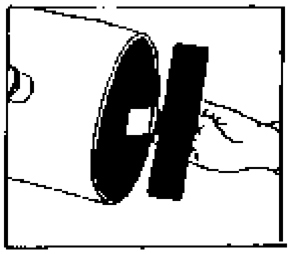
The eyepiece is ready for use!

Please Note: *<u>It is very easy to whack your eyepiece holder as you move your telescope tube around: Be especially mindful of doorjambs and car loading/unloading!</u>*

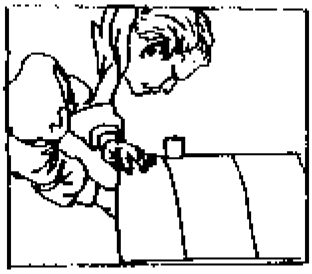
INSTALLATION & ADJUSTMENT OF THE SPIDER



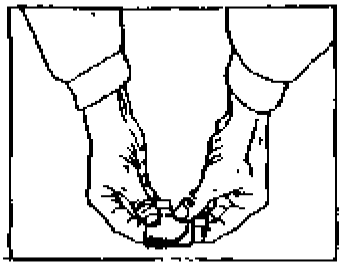
Trying out the fit of the spider in the telescope tube.



Adjust the spider so that the diagonal mirror is in front of the eyepiece hole. (The diagonal mirror should be facing the hole).

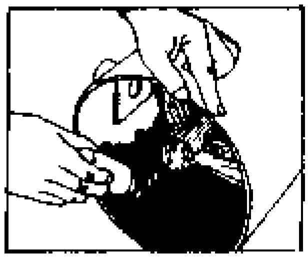


When we look through the eyepiece hole we should be able to see the reflection of the (open) bottom end of the telescope tube in the diagonal mirror.



If the fit of the spider is too loose, we may tighten the fit with cardboard folded to the necessary thickness...

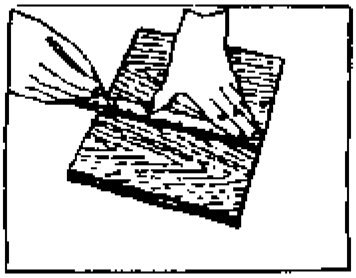
Fitting cardboard under one shingle (the shingle opposite the eyepiece hole). Readjust the spider as needed after fitting the cardboard.



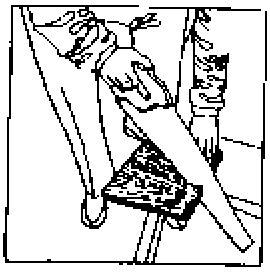
When installed, the whole objective mirror will need to be visible in the diagonal when we look into the eyepiece hole. Do not glue the spider to the tube until final adjustments are made on the alignment.

Section "B" of Making a Dobsonian Telescope

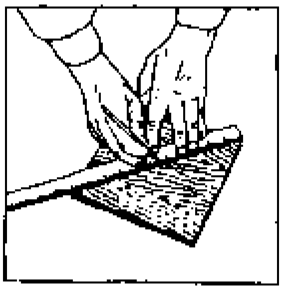
MAKING THE TAILGATE



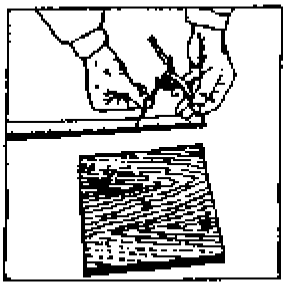
The tailgate should be a square with the same width as the objective mirror. (e. g. a 10" mirror in a 12" tube gets a 10" square tailgate--you will soon "lop off" the corners.)



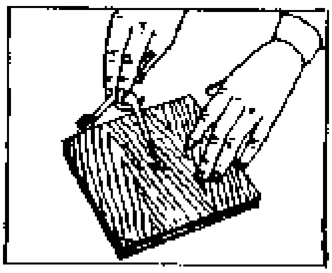
Cutting out the tailgate.



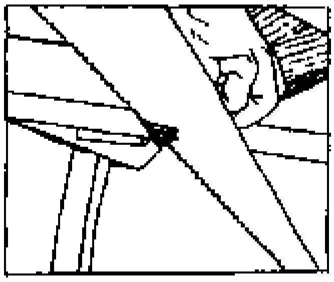
Finding the center of the tailgate.



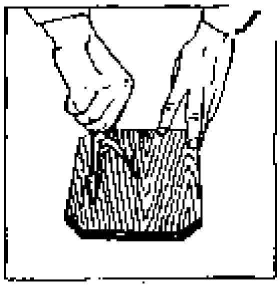
Set the compass for the radius OF THE INSIDE OF THE TUBE. (Not the radius of the mirror.)



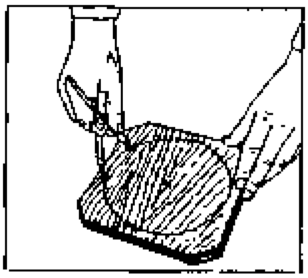
Drawing a circle with the compass point at the center of the tailgate. Only the very corners of the wood will be touched by the pencil.



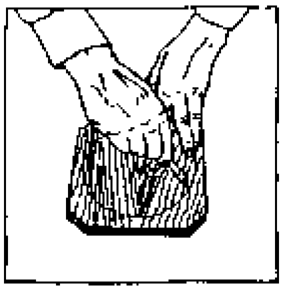
Sawing off the corners of the tailgate at the pencil marks. Now the tailgate should fit inside the telescope tube. (Plane or sand to fit if necessary.)



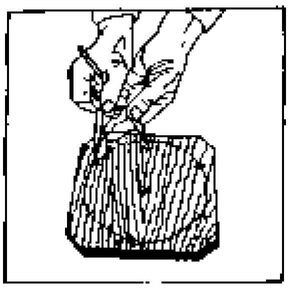
Drawing a second circle for the placement of the tailgate bolts.



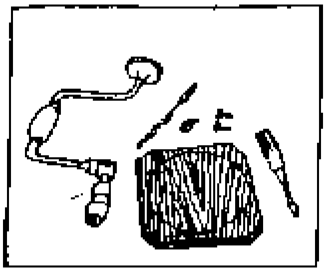
This circle should be 2" smaller than the diameter of the objective mirror. (e. g. for a 10" mirror, we need an 8" diameter circle.)



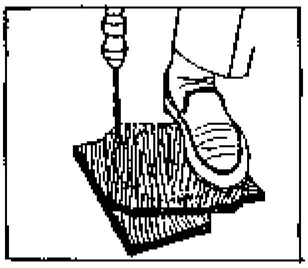
Dividing the circle into six equal segments (the radius of the circle you just drew).



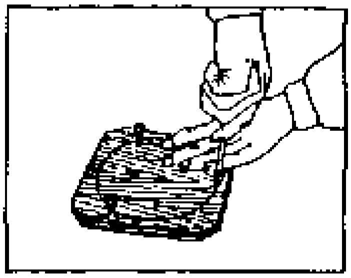
Marking the circle at each of the six points.



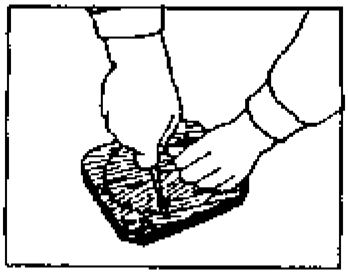
Of the six marks on the circle, we choose three (every other one) for our equilateral triangle. *We want two of our three marks to be towards two of our "cut-off" corners.* One bolt is placed at each of the three angles.



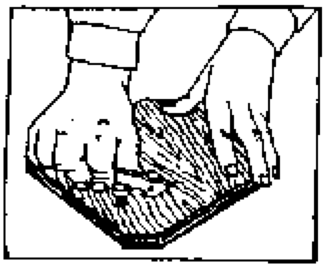
Drilling bolt holes. (A power drill also works well, if available).



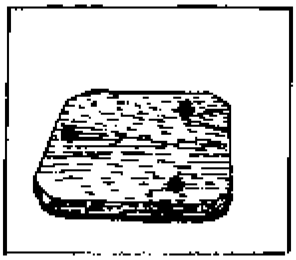
The bolt holes should be one sixteenth of an inch smaller than the bolts (5/16"), so that the bolts will fit snugly.



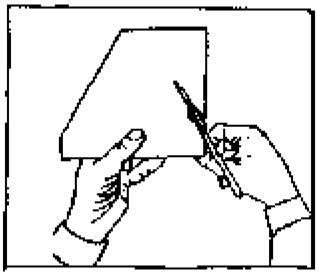
Screwing in the tailgate bolts. The bolts should be threaded right through the wood.



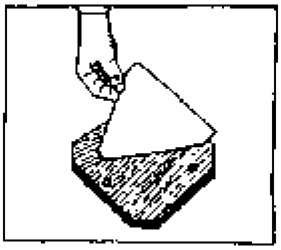
The bolts should be quite snug and difficult to turn.



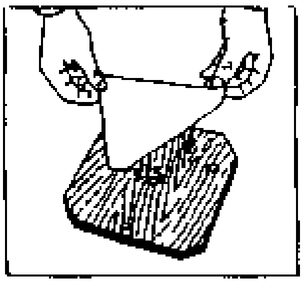
The view from the other side: tailgate bolts poking through the wood.



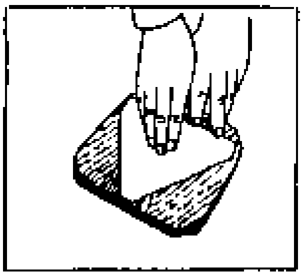
Now we cut a piece of thin (e. g. cereal box) cardboard into a triangle which will cover the protruding bolts.



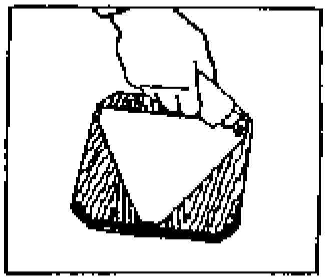
The cardboard should cover all three of the bolts where they come through the wood.



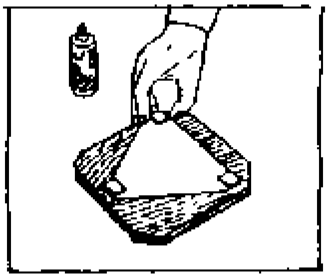
Gluing the cardboard in place. (Apply glue at the center of the cardboard only!!!)



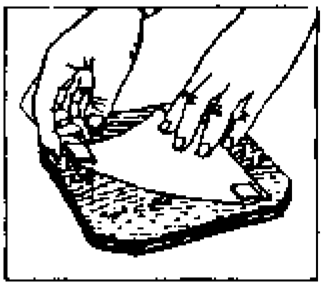
Letting the glue set.



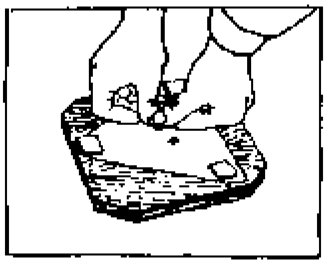
Now we apply glue to the cardboard at the three places where the bolts poke through the wood...



...and glue the squares of Masonite (about 1" square) onto the cardboard directly over the protruding bolts.

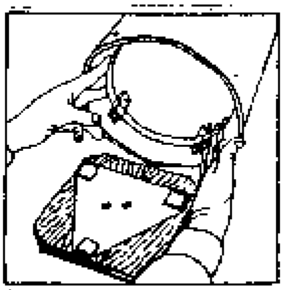


This cardboard protects the mirror from the tailgate bolts if the telescope is dropped on its end. This cardboard must be floppy so as to allow alignment of the objective.

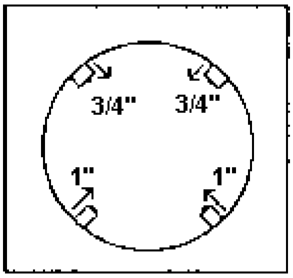


Fixing the position of the cardboard with two thumbtacks. (Double-check first to make sure each Masonite square covers its protruding bolt!)

MOUNTING THE MIRROR IN THE TUBE



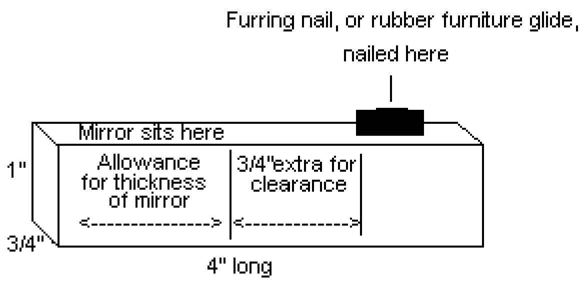
We use four mounting blocks to mount the mirror in the telescope tube. When the mirror is installed, it should rest on the two bottom blocks, but clear the two top blocks. Furring nails, or rubber furniture glides, are placed at the ends of each of the mounting blocks to prevent the mirror from rolling out of the front end of the tube. After you have installed the mounting blocks and the mirror, check to make sure that the mirror cannot get past the furring nails, or furniture glides. If it does, you will have to increase the height of the mounting blocks as necessary.



The mirror mounting blocks are designated PART F in the plywood cutting plans.

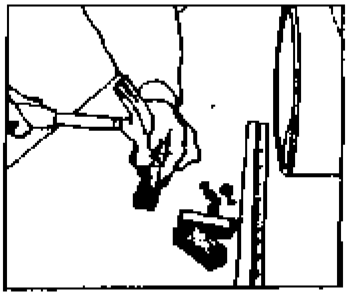
The mounting blocks are screwed in place inside the telescope tube. The mirror sits on the two bottom blocks and should just clear the top blocks—under no circumstances should the mirror be pinched or squeezed between the blocks.

If the blocks are cut from 3/4" plywood and are 1" wide (they should be about 4" long), we will probably have to place two blocks with the 3/4" side "up" and two blocks with the 1" side "up" in order for the mirror to fit nicely (see diagram above).

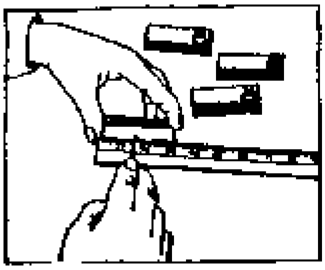


Wood Mounting Block

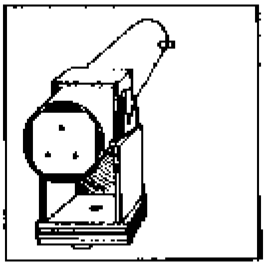
A furring nail (or rubber furniture glide), is hammered into each block before the blocks are screwed into the telescope tube. The furring nails prevent the mirror from rolling out the front end of the telescope tube. To determine the placement of the furring nail, allow room on the block for the width of the mirror, plus an extra 3/4" for clearance. Please note: the drawing above is for bottom blocks (1" high); for top blocks, they should be turned 90-degrees and only be 3/4" high before nailing furring nails or rubber furniture glides on.



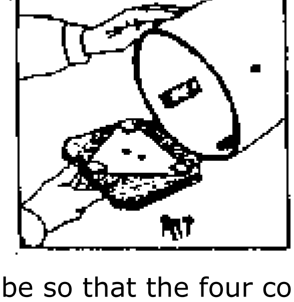
A furring nail should be hammered into one end of each of the mounting blocks (allow necessary clearance—see previous figure above) before the blocks are screwed into the tube.



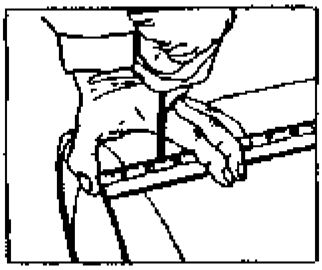
Preparing the blocks for installation in the telescope tube. A pilot hole for the screw may be made in each block (on the side of the block without the furring nail). 2" from the end (i. e. the end without the furring nail).



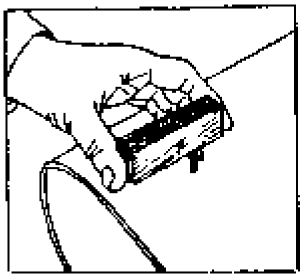
It is convenient to have the eyepiece hole on either the right side (shown), or the left side, depending on which of your eyes is "dominant." To determine which eye is dominant, simply hold your fist up to your eye and imagine this to be an eyepiece--which eye do you instinctively use? If it is your left eye, mount your tailgate so the eyepiece hole is on the right; vice-versa if it is the right eye. This will be more comfortable if, in the future, you decide to mount a Telrad, Quikfinder (1X finding aids), or a finder scope. The eyepiece may be positioned horizontal (as depicted), or canted down about 30-45-degrees; the latter helps insure your eyepiece doesn't fall out accidentally, and usually lends itself to more comfortable viewing.



Mounting blocks are screwed into the tube so that the four corners of the tailgate (when installed) will butt up against all four blocks. Please see previous note to determine where you want your eyepiece to be positioned. You also want two collimating bolts to be at the bottom; one on top--as illustrated above and previous.

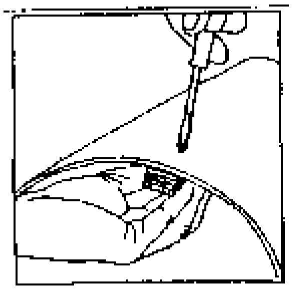


Preparing to screw the mounting blocks into the tube. Pilot holes for each of the screws may be made in the main tube 3" from the rear end.

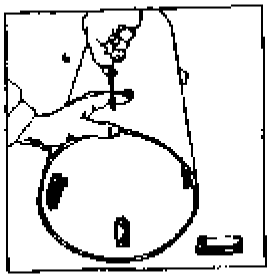


This gives the ends of the blocks 1" clearance from the rear end of the telescope tube, and leaves adequate space for installing the tailgate.

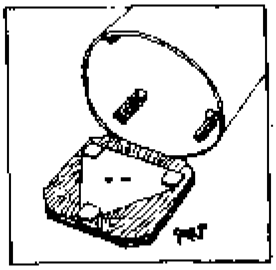
INSTALLING THE TAILGATE



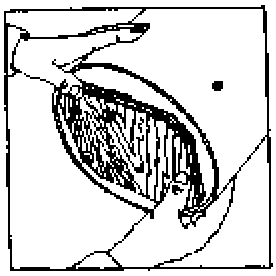
Screwing one of the mounting blocks securely in place.



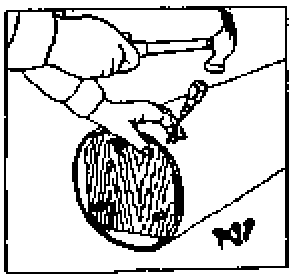
Screwing in the other three blocks.



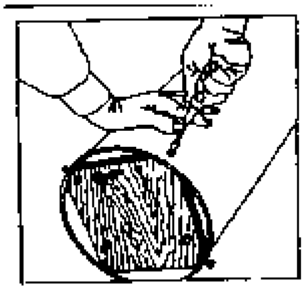
All four blocks are installed. Time to put in the tailgate.



The tailgate should butt snugly against all four blocks so that it won't rock when pushed alternately on opposite corners. If it does rock; try gluing cardboard to the end of the offending block.

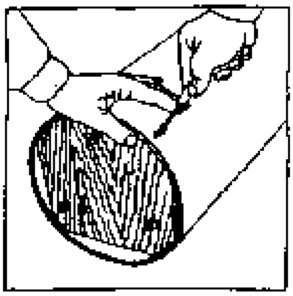


Making pilot holes for the four tailgate screws. The screws go through the cardboard tube and into the wood.



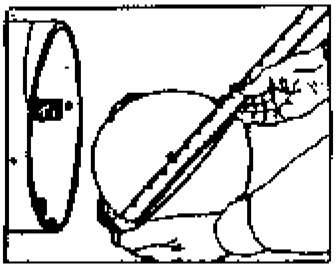
Screwing in the tailgate at all four corners. (Check the fit of the tailgate before installing the mirror).

INSTALLING THE MIRROR

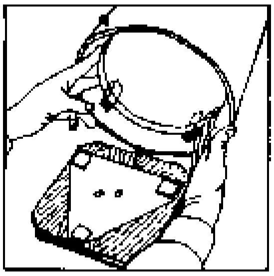


When the tailgate is snug, we are ready to install the mirror. (Of course, you will have to remove the tailgate again).

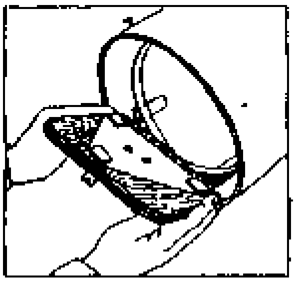
CAUTION: HANDLE YOUR MIRROR INDOORS OR IN THE SHADE!!!



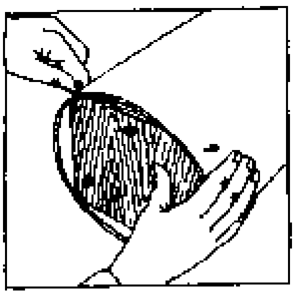
Carefully place a sticker or decal at the exact center of the mirror. This sticker will be used later to align both the diagonal mirror and the objective mirror.



Installing the mirror--very carefully!



After installing the mirror, close up the tailgate...



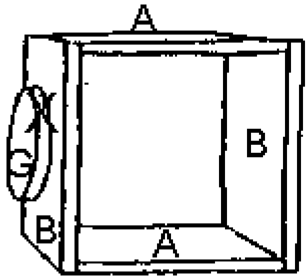
...and screw the tailgate in.

Now we are ready to build the tube box and rocker.

Section "C" of <u>Making a Dobsonian Telescope</u>

ASSEMBLING THE TUBE BOX

1) Glue and nail the **Tube Box** together as shown.



2) Nail the two **Side Bearings** (circles) onto the sides of the **Tube Box** as shown. **Side Bearings** should be centered. Side bearings do not have to be 6" in diameter, by the way. Many folks use circular plumbing parts, which are much smaller. You may also want to put side bearings on ALL four surfaces--this way, you can rotate your scope 90-degrees for a more comfortable viewing position when desired--especially useful if you have a short (fast focal ratio) tube scope.You might opt to have your circles cut out with a router, by your local, friendly cabinetmaker. While, he/she is at it, ask him to band the edge with plastic laminate ("Formica"); use a screw and a finish washer at the plastic joint. When mounting your side bearings, make sure this screw and washer is mounted at the top when your telescope is pointed at 45 degrees above the horizon ("X"--in the illustration at right)--this insures that they will not interfere with your Teflon bearing surfaces.

3) Slide the telescope tube into the **Tube Box**. If the tube is too loose in the **Tube Box**, the fit can be tightened by placing a board or boards (Masonite works well) of the necessary thickness between the tube and the **Tube Box**. After the telescope is fully assembled and balanced, a screw can be screwed through the tube into the **Tube Box** from inside the tube to make sure the tube "stays put."

VERY IMPORTANT NOTE!

Read This Before Assembling The Rocker Box On The Next Page!

◆ ◆ ◆

POSITIONING THE SIDE BOARDS

One of the TRICKIEST parts of assembling the **Rocker Box** is getting the right amount of clearance between the **Side Boards**. This is how to determine the clearance:

1) Measure the width of the **Tube Box**—<u>but do NOT include the width of the **Side Bearings** (circles) in this measurement!</u>

2) The **Tube Box** needs to fit inside the **Rocker Box**, with clearance for two **Cradle Boards**, i.e., Part B (in which the **Side Bearings** sit): PLUS an extra 1/8" clearance on each side.

<u>FORMULA FOR DETERMINING THE SPACE BETWEEN THE SIDE BOARDS:</u>

Width of Tube Box PLUS width of (2) 3/4" Cradle Boards PLUS 1/4" clearance.

Example # 1 (for 6" Dob)	
Tube Box..	10"
Plus 3/4" each for 2 Cradle boards	1-1/2"
Plus 1/4" clearance (1/8" on each side)...........	1/4"
Distance between Side Boards =................	11-3/4"

Example #2 (for 8" Dob)	
Tube Box 12" wide	12"
Plus 3/4" each for 2 Cradle Boards...........	1-1/2"
Plus 1/4" clearance (1/8" each side).............	1/4"
Distance Between Side Boards =...........	13-3/4"

Example #3(for 10" Dob)	
Tube Box 14" wide..................................	14"
Plus 3/4" each for 2 Cradle Boards........	1-1/2"
Plus 1/4" clearance (1/8" each side)..........	1/4"
Distance Between Side Boards =.........	15-3/4"

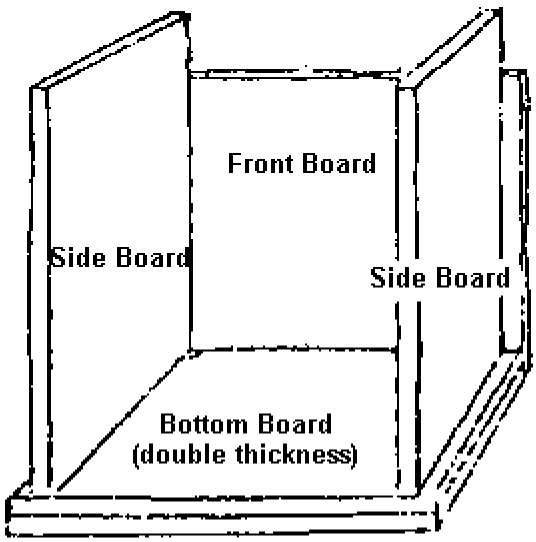
NOTE: All of the plywood sizes for the Tube Box and Rocker Box of a Dobsonian telescope are determined by the <u>width of the tube</u>. By using the above formula, you can calculate the sizes of the plywood for <u>any</u> size Dobsonian telescope.

ASSEMBLING THE ROCKER BOX

1) Glue and nail two PART C pieces together for the **Bottom Board,** this will be the base of your soon-to-be **Rocker Box.** (i. e. make it DOUBLE THICKNESS for added stability and extra "meat" for the lag screw--your pivot bolt--to rotate around).

2) Glue and nail the bottom ends of the **Side Boards** (Part C) to the top surface of the **Bottom Board** the correct distance apart (use formula above for correct spacing between **Side Boards**).Be sure that the front edges of the **Side Boards** are even with the front edge of the **Bottom Board**, because we will need an even surface on which to glue and nail the **Front Board**.

(***Note****: The* ***Side Boards*** *are attached to the top surface of the* ***Bottom Board*** *"long side" up. The* ***Front Board*** *is attached to the front edge of the* ***Bottom Board*** *"short side" up and should cover the front edge of the* ***Bottom Board****.)*

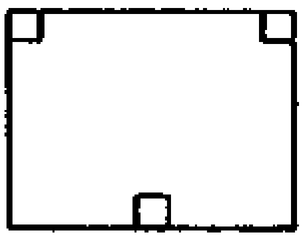


3) After the **Side Boards** are glued and nailed, set the **Front Board** in place to see how far up the front edges the glue needs to go. Then glue and nail the **Front Board** to the front edge of the **Bottom Board**. Check to make sure that the spacing between the **Side Boards** is correct (see above) before nailing the **Front Board** to them.

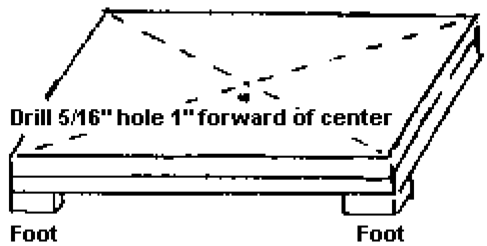
4) Glue and nail together the two remaining Part C pieces to make the **Ground Board**. (As with the **Bottom Board**, the wood is doubled for added stability and extra "meat" to which our very important lag screw will be affixed to).

5) Find and mark the center of the **Ground Board**. Then turn the **Ground Board** upside down and glue and nail the three **Feet** (part D—three pieces) in place as shown (the TWO feet go in FRONT--on one of the longer edges, that is):

Front edge of **Ground Board** (upside down, "plan view")--one foot at each corner:



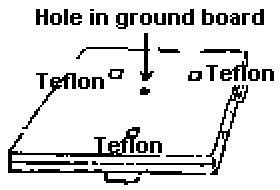
Back edge of **Ground Board** with foot centered



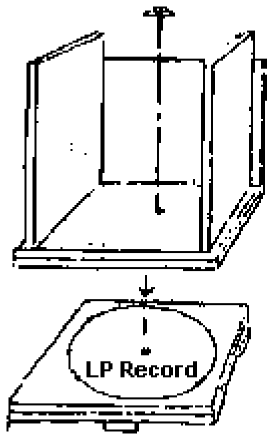
The Ground Board
(double thickness)

6) Now turn the **Ground Board** right-side-up. Make a mark one inch forward (toward the TWO front feet) of the center. *(Do NOT let this* ***1" forward*** *confuse you; this is just an approximation of the center of the triangle the three feet make. The three sides of this triangle are not equal--the front side of the triangle--the one with a foot in each corner is longer than the other two sides pointing back to the other foot. A more accurate way to determine this center is to find the midpoint of each side of the triangle and draw a line at a right angle to each side toward the center; the intersection of the three lines is the true center of the triangle formed by the feet.)* Drill a hole on this mark for the lag screw. This hole should be three sixteenths of an inch smaller in diameter than the lag screw (5/16") to insure a tight, threaded fit. Be careful to drill this hole as square as possible (have a friend "sight" for you as you drill).

7) Turn the **Rocker Box** upside down. Place the **Ground Board** (which you just drilled a 5/16" hole near the center of) on top of the upside down **Rocker Box**. Orient so all sides are flush (even) with each other.(Actually, the **Front Board** will "hang over" the **Ground Board** 3/4"--"split the difference," if you like). Using your 5/16" drill bit and the **Ground Board** as a *template*, drill through the bottom of the **Rocker Box** (the **Bottom Board**). Now use a 1/2" drill bit to make this hole (the one in the **Rocker Box** ONLY) larger--1/2" is the diameter of your lag screw/pivot bolt. Always drill as square as possible--you might have a friend "sight" for you as you drill. Leave the **Ground Board's** hole at 5/16"!



Note: *The hole in the LP record will not be big enough for the lag screw to fit through, so you will have to enlarge it with the drill--might as well do it now while you have the 1/2" drill bit in the drill!. Use the same bit you used to drill the hole in the **Rocker Box**, i. e., the same size as the diameter of the lag screw (1/2"). (CAUTION: Have someone hold down the record for you while you drill it or it will madly ride up on the bit).*



8) On the **Ground Board** (which should be right side up, i. e. with the feet on the ground), nail or screw three squares of Teflon in a circle at three angles of an equilateral triangle about half way between the "center" hole and the feet. (The phonograph record will ride on these Teflon squares, so check to make sure the squares don't extend past the edge of the record).

Note: Plastic Laminate ("Formica" is a brand of Plastic Laminate) can be used instead of an LP record, and may be easier to find nowadays--try your local cabinetmaker--they usually have tons of scrap they will let you have for free, or try http://www.crazyedoptical.com/ for inexpensive Teflon and Plastic Laminate "kits." Do not use the "gloss" kind of PL, the rougher the surface, the less the friction--Wilson Art's *Ebony Star* is generally considered the best. Some **Home Depots** sells *Ebony Star* in less-than-full-sheet amounts. Plastic Laminate can be cut with tin snips and then filed flush if you do not have access to a router. Glue your Plastic Laminate down with contact cement like 3M's *Spray 90.* Of course, if your plastic laminate is cut circular (like an LP record) there is no need to glue it to the **Bottom Board** (the base of the **Rocker Box**).

Use finish nails (small heads) to nail the Teflon onto the **Ground Board**, and use a nail set to inset the nail heads. If you opt to attach the Teflon with screws, use only flat-headed wood screws and countersink the screws so the screw head is "buried" beneath the top surface of the Teflon.(The record must ride smoothly on the Teflon and not be scraped by the nail or screw heads).

9) Now we are ready to assemble the **Rocker Box**, LP (or Plastic Laminate), and **Ground Board** in a sandwich like manner: Place the record (or Plastic Laminate) over the **Ground Board** and the **Rocker Box** over the record on the **Ground Board**, so that all the holes are lined up. Insert the lag screw (with its washer) and screw it in. (Be vigilant as you do this to make sure that the lag screw goes in straight, not at an angle). Tighten the screw until it is snug and then back off a bit--an 1/8 of a turn, let's say. The **Rocker Box** should swivel smoothly on the **Ground Board**. Voila: Our azimuth motion!

10) Now we are ready to balance the telescope and attach the **Cradle Boards** (Part B).

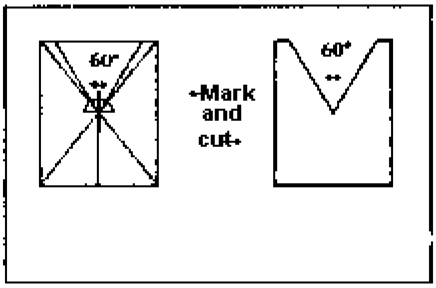
CUTTING THE CRADLE BOARDS AND BALANCING THE TUBE

CUTTING THE CRADLE BOARDS

1) Use the two remaining pieces of Part B for the **Cradle Boards**.

2) The **Cradle Boards** need to be cut to hold the **Side Bearings** (circles). (Note: Cutting a V-shape is the simplest way to cut the **Cradle Boards** and is very satisfactory, but some people prefer to cut a semicircle for aesthetic reasons. (The V-shape can be easily cut with a handsaw.)

3) To cut the V-shape, find and mark the center of one of the boards (Part B). The angle of the "V" should be about 60 degrees. **Note:** *Lay your Side Bearings and Teflon onto the surface of your Cradle Boards to insure you cut away enough material so that your Side Bearings nestle nicely into the Cradle Boards.* Use a protractor to mark the "V" and cut it out with a hand saw (see below). Do both **Cradle Boards** the same way.



Cradle Boards (Part B)

BALANCING THE TUBE

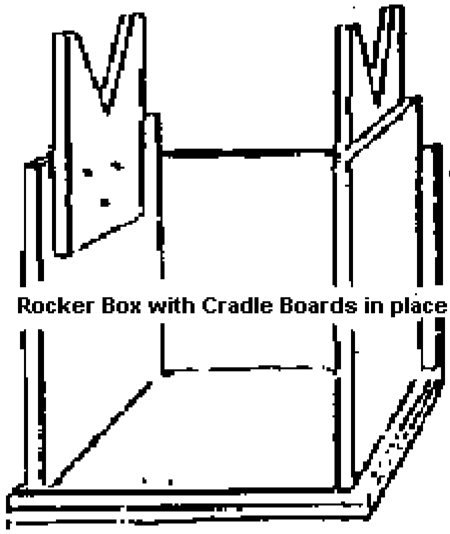
1) To balance the tube we will need to install the primary mirror, the spider with the diagonal mirror in the telescope tube, an eyepiece, as well as any 1X finder or normal finder that you plan on using with your telescope. Remember: **HANDLE MIRRORS WITH CAUTION!!!**

2) Slide the telescope tube into the **Tube Box**. The fit of the tube should be snug in the **Tube Box.** If the fit is much too loose, a piece of masonite or thin plywood, or shim shingles (the kind you used for the spider) may be glued inside the **Tube Box** to tighten the fit as needed.

3) Slide the **Tube Box** along the tube to the spot where the weight of the telescope is *balanced* at the middle of the **Tube Box**. Use a broom stick handle to aid you in finding this balance point. Knowing this "balance point" will aid you in determining where (how high) to attach your **Cradle Boards**.

ATTACHING THE CRADLE BOARDS

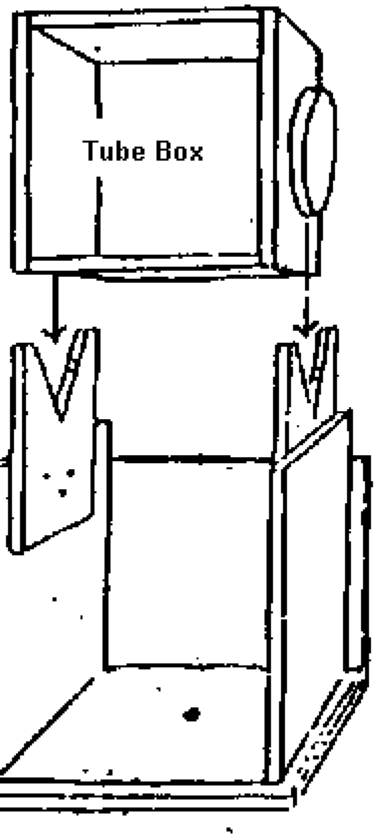
1) The telescope's **Side Bearings** (the circles on the **Tube Box**) sit in the V-shaped notches in the **Cradle Boards**, allowing the telescope to be moved up and down easily. Position the **Cradle Boards** so that there will be <u>at least 1" clearance</u> between the lower end of the telescope tube (i. e. the tailgate end) and the <u>Bottom Board</u> of the **Rocker Box** when the telescope is sitting <u>vertically</u> in the Cradle Boards. The telescope must also be able to move forward into a nearly horizontal position without interference by the **Front Board**.



2) The **Cradle Boards**, when properly positioned, may be nailed or screwed to the **Side Boards** as shown, <u>slightly forward of center</u> (in line with the bottom pivot bolt below). The **Cradle Boards** must be far enough back from the **Front Board** to allow the telescope to stand straight up in the rocker.

***Note**: Since the **Cradle Boards** may have to be moved around a few times to get the placement just right, it is a good idea to "tack" them in place with just a couple of nails while you are making adjustments. Glue and nail--or screw--them firmly in place later.*

***Another note: Cradle Boards** are not found on any commercial "Dobs," and few homemade ones, anymore. Most just incorporate these "altitude bearing holders" into the Side Boards. The advantage of Cradle Boards (other than being simple to design and manufacture) is that they stiffen up the side boards a bit, as well as widen the "footprint" of our base ("Ground Board"); thereby adding stability and rigidity: This is a good thing.*

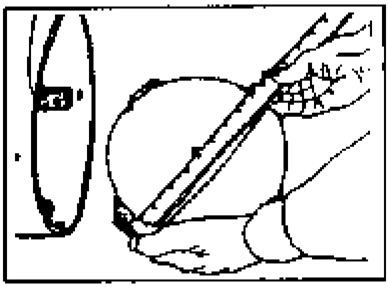


*[We will henceforth refer to the **Tube Box**-and-tube assembly (with mirrors installed) as the **"telescope."** The mount in which the telescope sits will be referred to as the **"rocker"**].*

3) To enable the telescope to move smoothly in the up-and-down direction, we nail small pieces of Teflon at the points where the **Side Bearings** contact the **Cradle Boards**. Place the telescope in the rocker. Make a mark on the wood of each of the V-shaped notches at the two points where the **Side Bearings** make contact.

4) Nail a small piece of Teflon at each of the four marked contact spots (two on each side). Let the Teflon protrude a little over the inside edge of the **Cradle Boards** to keep the **Tube box** away from the **Cradle Boards**. Use finish nails and set the nails with a nail set. Place the telescope back in the rocker. The **Side Bearings** should glide smoothly on the Teflon.

ALIGNING THE DIAGONAL



As mentioned earlier, a small sticker or decal should be placed at the exact center of your primary mirror. Visit your local stationary store--I like to use a "hole reinforcement" or a "gold star." This sticker is used to help in the alignment of both the objective and the diagonal. Don't worry: this does not harm your telescope in any way--this sticker is well inside the shadow your diagonal mirror casts.

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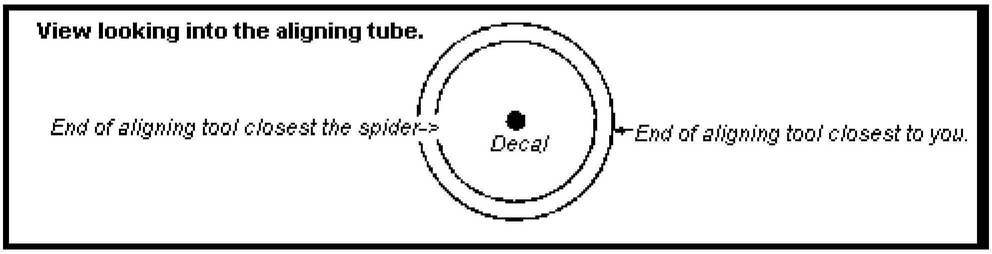
1) Set up the telescope (i. e. place the telescope with the spider and objective installed, in the rocker).

(Note: <u>Before</u> installing the spider you may wish to screw a small eye-hook dead-center into the 90 degree cut end of the wood block that supports the diagonal. After the spider is installed, another eye-hook may be screwed into the telescope tube, and a string may be tied between the two eye-hooks. This will protect the objective mirror if the spider is accidentally knocked out).

2) Adjust the spider in the tube in such a way that you can see the entire objective mirror reflected in the diagonal mirror. You should be able to see the ENTIRE OBJECTIVE MIRROR, not just a part of it. Be sure your eye is centered over your eyepiece tube.

3) Place a piece of metal tubing (about 6" long—the same width as the piece in which your eyepiece is nestled) inside the cardboard eyepiece tube, so that it protrudes out several inches. Now think of the two ends of this metal tube as CIRCLES.

4) When you look down the metal tube, the CIRCLES (i. e. the two ends of the tube) SHOULD APPEAR CONCENTRIC, AND THE DECAL ON THE MIRROR SHOULD BE EXACTLY IN THE CENTER OF THESE CONCENTRIC CIRCLES. You will see the three legs (shingles) of the spider reflected in the objective, <u>but for now, ignore them.</u>



The way to get the alignment perfect is by fiddling with the position of the spider in the tube. When you have it just right, you can glue the spider in place. Apply a line of glue on either side of each shingle where it contacts the tube--100% black silicone glue works well here.

ALIGNING THE OBJECTIVE

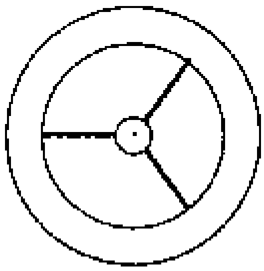
Remember: Do this indoors or in the shade!

We have come now to the final step: aligning the objective mirror.
(We won't need the aligning tube anymore).

To align the objective mirror, we turn the tailgate bolts till the reflection of the eye moves under the decal.

NOTE: If the alignment must be done in the dark, you may have to shine a light on your mirror face in order to see the reflection of your eye in the objective.

Through the eyepiece hole, it should look something like this:



Keep the mirror pulled back against the tailgate during alignment.

Note: *If you have a friend turn the bolts, you can watch which way the mirror moves--it is more difficult if you are doing it by yourself. Call the bolts "yours," "mine," and "ours": representing the furthest bolt from you; the nearest bolt; and the middle bolt (top) one, respectively. ;-)*

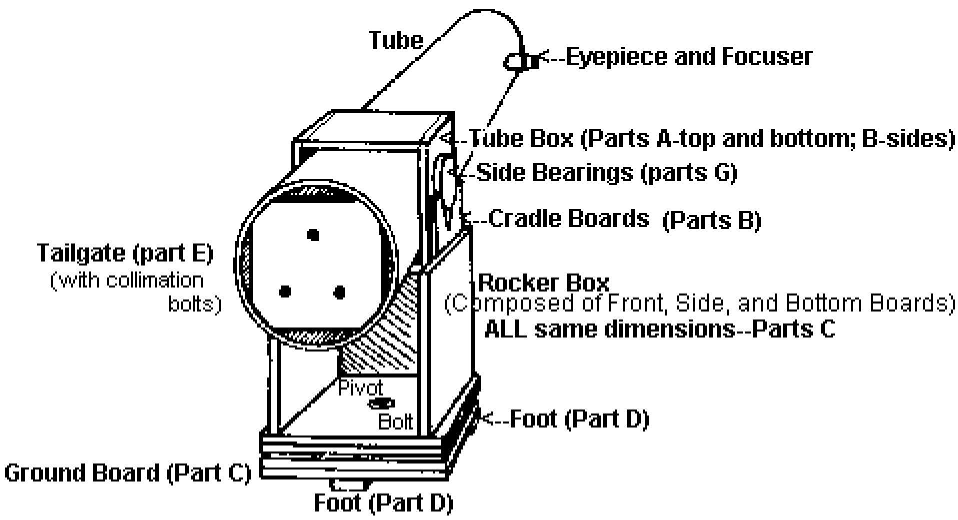
Go use your scope! ...After you *know* everything works well, you can paint and finish to your desire!

A Few Finishing Tips

Eighty-percent of a good finish is preparation. Fill any glaring holes or gaps in your plywood mount with putty or spackle (the latter only if you plan to paint it an opaque color). Take the extra time to sand your mount, especially "breaking the edges"--rounding them, if you will; so that no loose splinters come to harm anyone. If you plan to stain your mount, first experiment on a piece of scrap plywood--not all woods (birch and fir, come to mind), take stain well. Use a weatherproof paint; or varnish, or polyurethane as a final coat over stain. Be sure to seal any raw edges, including the cardboard tube, which is particularly sensitive to moisture.

Some folks use sticky-backed shelf paper to wrap their telescope tubes in. I use *Monocoat* or *Ultracoat,* found at your local hobby store: it is used to wrap model wooden airplane wings and fuselages. It is a little pricey; but it "shrink wraps" with the aid of an iron into a beautiful, glossy, weatherproof finish for your tube. Comes in lots of colors, too!

Again, you might peruse what http://www.crazyedoptical.com/ offers to gussy up your scope. He sells things like "tube rings" and one-power sights, which most people find useful: Otherwise sight down an edge of your Tube Box; that's how you aim the thing!



The completed telescope

Care Instructions

REMEMBER! TELESCOPE MIRRORS ARE POWERFUL CONCENTRATORS OF LIGHT.

Sunlight reflected off the face of a telescope mirror can cause BLINDNESS or **START A FIRE!** Always handle your mirror indoors or in the shade! The telescope described in these plans is for **NIGHT USE ONLY. NEVER** set up your telescope in a location where it may be reached by sunlight, and:

NEVER LOOK AT THE SUN THROUGH YOUR TELESCOPE!

Do not store your scope outside. If you don't have a large closet or garage, put a lampshade on your scope and store it in your living room!

Remember: Door jambs destroy homemade focusers!

Cover your scope when not in use--dust and moisture--are the enemies! Plastic garbage bags, at both ends, work fine.

Despite your best efforts; your mirror will accumulate dust, and will require cleaning from time to time... Remember: this is a "first surface" mirror--a very fine deposit of aluminum is deposited on the surface--you do NOT want to introduce any "micro scratches" here! You can remove most of the dust with a rubber air blower (found at your local pharmacy store). Once or twice (at most) a year you should wash your primary. Here's how I do it:

First, you will need:

1) A suitable, clean tub.
2) A drop or two of mild (ivory) dishwashing soap.
3) A box of sterile cotton balls.
4) A gallon (or less) of distilled water.

1) Wash your sink, *Rubbermaid* tub, whatever, thoroughly.

2) Fill sink, whatever, with *room temperature* tap water (to avoid thermal shock between the layer of aluminum and the glass--this could help loosen the adhesion between the two surfaces--use only room temperature water throughout these steps); add one or two drops (ONLY) of dishwashing soap.

3) Submerse mirror in water. Swish around. Let soak.

4) Replace soapy water with fresh soapy water. Do not hold mirror under a running tap--some people do; I don't recommend it (localizing the "thermal shock" possibility, plus the danger of overdoing it with too much pressure).

5) With STERILE cotton balls wipe your mirror--from the center out--while mirror is still submersed. Be liberal in your use of the cotton balls (change frequently). *Roll* the cotton while swiping. Do not apply much pressure.

6) Replace soapy water with room temperature tap water to rinse away any soap.

7) With bottled, *distilled* water, rinse your mirror for a final time. (This removes any harmful salts that might be in your tap water). This is an important step--do not forget it!

8) Set mirror on edge to dry. Check on it in twenty minutes, or so. Any residual water droplets (usually just one or two) can be soaked up with any cotton balls you have left.

Build a Solar Filter for your Telescope

Step-by-step instructions for building a filter for daytime Sun viewing with your Dobsonian telescope. By Michael Portuesi.

You can build a solar filter for a large aperture scope for less than $40, including the solar filter film. This is a great project to build with your kids, or perhaps as part of a classroom activity.

I describe how I built a solar filter for my 10" F/7 Dobsonian scope, but you can easily adapt these instructions for other scopes.

For daytime use, we build an off-axis filter smaller than the scope's full aperture. For convenience sake, an off-axis mask on a large Newtonian is easy to make, takes less material and the off-axis size is often more than enough given the daytime seeing.

Required Materials

- Baader Astrosolar safety film. An A4 (7.9 by 11.4 inch) sized sheet is $29 not including shipping. A 1 meter by 1/2 meter sheet is $69. It is available from one of these dealers:

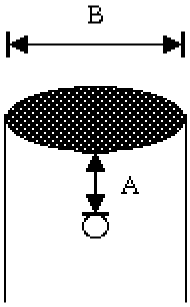
Adirondack Video Astronomy
26 Graves Street
Glens Falls, NY 12801 USA
Phone: 1-518-812-0025
Orders: 1-877-348-8433
Fax : 1-518-745-4114

Astro-Physics, Inc.
11250 Forest Hills Road
Rockford, IL 61115 USA
Phone: 1-815-282-1513
Fax: 1-815-282-9847

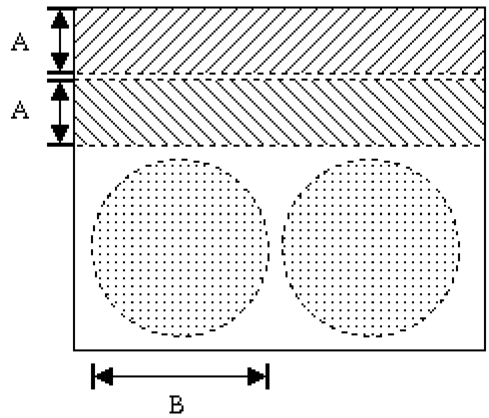
- Heavy posterboard, 20 x 30 inches
- Newsprint or tissue paper
- Fine sandpaper
- Clear packing tape
- Duct tape
- Scotch tape
- Pencil
- Ruler
- Drawing compass
- Scissors, razor and/or x-acto knife

Procedure

1. Measure the distance from the focuser to the end of your telescope tube. Draw out two long rectangles on the poster board, whose height is the distance you measured.



Measurements. A = distance from focuser to end of tube; B=diameter of tube.



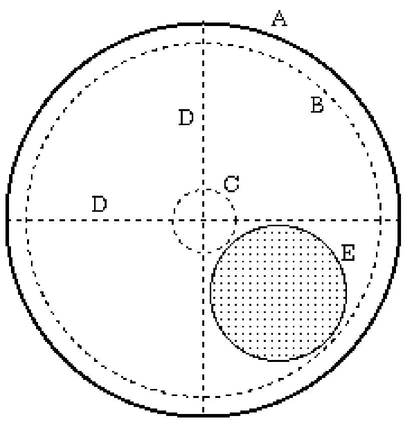
Draw strips and circles on the posterboard.

2. Cut out the strips of cardboard. These two strips double up to form the sidewalls of the filter.

3. Using a compass, measure out two circles the diameter of the telescope tube on the posterboard.

4. On one of the circles, use the ruler to draw out lines indicating the vanes of your spider assembly. Then use the compass to draw a circle in the center representing your diagonal. Finally, draw a large circle the diameter of your mirror.

5. Using the compass, draw an off-axis circle within the diagonal, spider vane and mirror lines. For my 10-inch scope with a four vane spider and a 1.85" diagonal, a 3.5-inch off-axis aperture fits perfectly.

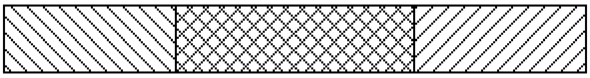


Cutting the aperture hole. A = diameter of tube. B = diameter of mirror. C = diameter of center mirror. D = spider vanes. E = aperture hole for solar filter film.

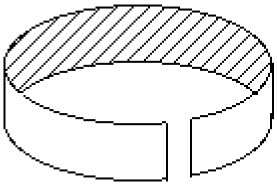
6. Cut both circles from the posterboard. Cut out the inside of the aperture hole from the one circle. Sharp scissors and/or a sturdy razor blade are useful to cut through the heavy posterboard.

7. Place the circle with the aperture hole atop the other circle. Trace out the aperture hole outline onto the other circle. Cut the second aperture hole. You may need to smooth out the edges of both aperture holes with some fine sandpaper.

8. Take the strips of cardboard, and arrange them into a circular collar the same circumference as one of the circles. At one end where the strips overlap, join them with tape into one long strip. Temporarily tack the other side of the collar so that it forms a cylinder.



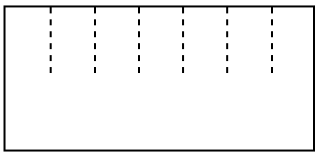
Join strips together, so the length is the circumference of the telescope tube.



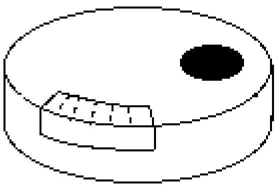
Join remaining ends into a cylinder.

9. Test fit the collar against your telescope tube. Adjust the diameter of the collar for a snug fit. Then seal the other end of the collar with packing tape, to permanently form the cylinder.

10. Attach one of the large circles to one end of the collar. Cut duct tape into six-inch strips, then cut notches about every 3/4 to 1 inch along the tape. Cut the notch halfway across the width of the tape.



Cut notches halfway through the tape.



Fold the tabs of tape to match the curvature of the filter collar.

11. Place the uncut end of the tape along the edge of the collar, then fold the tabs over the circle to follow the curve of the top.

12. Hold the cap up to a bright light, and check for small pinpoints where light may be showing through the tape. Cover any holes with small patches of duct tape.

13. Take the remaining circle, and place it inside the cap. You may need to trim or sandpaper it a bit to get it to just fit within the cap. Line up the aperture holes of the two circles. On both the sidewall of the cap and the circle, make some alignment marks and label them A, B, C, D, E.

14. Arrange the newspaper or tissue paper on a table. Cut out a square of solar film with sharp scissors or a razor, carefully following the instructions which came with the film. You do not want to scratch the film or create pinholes.

15. Take the free circle, and use Scotch tape to attach the solar film over the aperture hole. Do this on the side opposite the alignment marks. Do not stretch the solar film tight; this will ruin its optical properties. It should be loose and maybe a little billowy.

16. Insert the free circle into the filter, and realign the alignment marks. Seal into place with packing tape.

17. Hold the filter up to a bright light to look for pinholes in the film. Dot the pinholes with a black or blue permanent marker. You can use a halogen lamp, but do not get too close to the lamp! The heat from the lamp will stretch or melt the film, ruining the filter.

The filter is now complete. Place the filter over the end of your telescope and enjoy.

Using the Filter

Here are some tips for using the filter:

- Inspect the filter every time you use it, to ensure there are no holes or scratches in the film.
- Make sure the aperture isn't obstructed by a spider vane.
- To aim the telescope, *do not use your finderscope or Telrad!* Instead, point the telescope until it casts the smallest shadow possible behind it.
- If your scope has an open tailgate, you will need to cover it with some type of shroud to prevent daylight from leaking in the scope and overpowering the view.
- You may need to counterbalance your scope against the added weight of the filter.

Moon Filter

You can use these plans to build an off-axis aperture filter for Moon viewing. A Moon filter lowers the brightness of the Moon through medium and large aperture scopes. Just omit the inner circle, and the solar safety film.

The Dobsonian Sun Telescope

friend David North looks through the author's Sun Scope

At left is an example of another contribution to amateur astronomy by John Dobson: an extremely safe Sun telescope.

One immediately notices the mirror tilted at 45-degrees at the front of the tube... This is actually a piece of one-way mirror, which serves two purposes: One, to deflect up to 95% of the incoming sunlight, thereby acting as a filter, and, two, to act like a normal diagonal mirror: to bounce the light gathered by the *unaluminized* primary out the side of the tube to be magnified by a suitable eyepiece--but not before this light passes through a welders' glass to filter out any harmful infrared or ultraviolet radiation.

Designed into this failsafe method to view the Sun, is this: If the front mirror is broken, or becomes accidentally dislodged, the viewer will be protected since no direct sunlight will reach the eyepiece; the eyepiece will, in fact, be pointed safely at the ground!

Key Materials

- An **unaluminized** primary. Keep it small, 4.5" or 6" works just fine. Keep it "slow" F/8 or F/10.

- Partially aluminized parallel-plate glass (5% transmission). A "one way" mirror also works fine; the stuff, in other words, commonly used in casinos and department stores. Be sure to mount the aluminized surface **inside** (toward the primary).

- **Sonotube**. With a Sun Scope, we do not have to worry about "tube currents" and have our tube 2" larger in diameter than our primary--if you can fit your primary inside the tube, it will work fine.

- ***Sky and Telescope***, August '89 p.207ff. *Sidewalk Astronomer* Tom Mathews' article which inspired me.

Construction Tips

Note that I have cut the telescope tube in half about 12" from the focuser--this is necessary since I glued (with 100% Silicone glue) the one-way mirror directly on the cardboard sonotube; it is necessary, that is, so I can mount, or de-mount, the focuser or welders' glass which is glued to the bottom of it. (Line--glue-- the inside of one half of the tube with "sleeve material,"--cardboard tube in which you have cut a section out, or other appropriately thin material).The focuser I use here is a "***2-inch to 1-1/4-inch adapter***"--a $20 item available from telescope outfits like *Lumicon* or *Orion*. It is low and sturdy; and provides a flat bottom in which to glue the welders' glass. You will need to experiment with the grade of welders' glass you will need, by the way. My 6-incher requires a "grade seven," I believe. I would also recommend the "gold anodized" version of welders' glass over the traditional green glass--to yield a more natural, yellowish, transmission of light.

You must cut the front of the tube at *exactly* 45-degrees, if you glue the front mirror directly on the cardboard as I did. Tape enough 8-1/2" X 11" paper together end to end to go around your tube. Cut both ends at 45-degrees, making a trapezoidal shape. Bring the two ends together so that one edge of the paper is snug against the tube (some trimming will be required). Trace a line; cut to it.

With all that weight up front, you will have to make a tall rocker box, or use weight at the rear of your tube (I did both).

What will you see? Sunspots, faculae, granulation!

ATM – amaterska izrada teleskopa

ATM - amaterska izrada teleskopa

Željko Andreić
Korado Korlević

http://www.astro.hr/atm/index.html

PAŽNJA !!!!

Autori upozoravaju da učestalo bavljenje ovim sportom stvara **TRAJNU OVISNOST** i cijeli niz psihičkih poremečaja poznatih pod zajedničkim imenom **"Sindrom gurača stakla"!!!**

Ovom aktivnošću bavite se na vlastitu odgovornost!

Zbog vrlo ozbiljnih simptoma, navodimo najvažnije simptome ove bolesti

- Bolest karakterizira potrebu oboljelog da u beskonačnim krugovima obilazi oko bačve na kojoj gura jedan stakleni disk preko drugog.

- Oboljeli od te bolesti pričaju kako im je krajnji cilj izrada zakrivljene plohe koja ćce im omogućiti pogled u nebrojene tajne Svemira. Ovakve grandiozne izjave treba primiti s tolerancijom i simpatijom koja se iskazuje prema mentalno poremećenim osobama.

- U najgorim slučajevima **"Sindrom gurača stakla"** je kronična bolest. Prijatelji i rodbina oboljelih se upozoravaju da još nije poznata metoda liječenja, a zabrana bavljenja simptome samo pojačava. Rodbini se zatopreporuča iskazivanje strpljenja i trpeljivosti prema njihovim dragima koji pate od te bolesti.

Odlučio sam, na vlastitu odgovornost čitam dalje!

AMATERSKA IZRADA TELESKOPA

Privlače vas slike velikih teleskopa? Srce vam zaigra kad ugledate stakleni disk poput ovog na slici? Noću sanjate kako padate sa ljestava na kojima ste opažali i pri tome razbijate zrcalo svojeg teleskopa? Ako je tako, i ako vas zanima kako se uz puno truda a malo alata i novaca može u kućnoj radinosti izraditi vlastiti teleskop ove stranice pisane su baš za vas!

Dobro dosli u **ATM -** svijet!

ATM je engleska skracenica za kovanicu **A**mateur **T**elescope **M**aking, u prijevodu amaterska izrada teleskopa. U nasim uvjetima samo veterani ovog sporta znaju koliko odvaznih pokusaja, volje, truda, razocaranja i bijesa, dobrih teleskopa i ushicenja stoji iza ta tri slova! Pred vama je serija stranica od koje se nekad kanilo napraviti knjigu. Vrijeme koje je iza nas nije omogucilo nastanak tog prirucnika za izradu teleskopa, a vremena koja su pred nama ne obecavaju vise. Uz to se svijet amatera astronoma mijenja takvom brzinom da mozda danas niti ne postoji potreba za prirucnikom na Hrvatskom jeziku, koji nam omogucava da iz **NULE** napravimo teleskop vrhunskih optickih svojstava?

Glavni je razlog svakako neinformiranost. Vecina amatera ne zna kako bi pocela i na koji ncin izradila svoj teleskop. Drugi Veliki razlog sigurno je i ludi tempo zivota koji nam danasnje vrijeme namece. Jer, izrada teleskopa je hobi koji uz snalazlivost, celicnu volju i kreativnost zahtjeva i puno slobodna vremena, necega sto danas i nema bas u izobilju.

Da ne duljimo, evo prirucnika u *.html obliku, dostupnog na WEBu.

Autori: Zeljko Andreic_____ prvi s lijeva , Korado Korlevic____treci s desna

Linkovi

San Francisko Sidewalk Astronomers ... J. Dobson je jedan od osnivaca, tu je i njegova cuvena konstrukcija za solarni teleskop .... teleskopi za dvadesetak dolara i puno rada.

Europljanima i "cistunciuma" pada mrak na oci kad te stvari vide, a na starparty-jima u Americi nema boljih optika! Treba li reci vise? Fenomenalno...

http://members.aol.com/sfsidewalk/cdobplans.htm

Sredjeni podatci s ATM news grupe, tone stiva za ovisnike!

http://www.system.missouri.edu/atm/

Resursi za graditelje teleskopa, svega pomalo .. i lijepih slikica:

http://www.atmpage.com/

Ostali linkovi ... nije ni potrebno, ovi gore sami imaju mnostvo linkova, sljediti te ....

UVOD

Brušenje zrcala odvija se u nekoliko faza. Prvo je naravno potrebno nabaviti ili iz debelog ravnog stakla izraditi stakleni disk kojeg ćemo brušenjem i poliranjem pretvoriti u zrcalo našeg teleskopa. U prvoj fazi brušenja dubi se u staklu udubina da bi se dobila potrebna zakrivljenost zrcalne plohe. Ovaj postupak se naziva grubo brušenje. Kad je postignuta željena zakrivljenost na cijeloj površini zrcala, pristupa se finom brušenju.

Fino brušenje smanjuje neravnine nastale kod grubog brušenja i plohu zrcala sve više približava sfernoj plohi. Završni dio finog brušenja priprema plohu za poliranje.

Poliranje konačno dotjeruje oblik zrcala gotovo do savršenstva i daje njegovoj plohi sposobnost refleksije svjetla. Pri kraju poliranja, kad su uklonjeni svi, pa i najfiniji tragovi brušenja, pristupa se optičkoj kontroli i korekciji plohe zrcala kako bi joj se dao potreban oblik.

Prije nego što se prihvatimo brušenja, moramo ipak naučiti nekoliko osnovnih stvari o zrcalima i teleskopima. Ovo znanje bit će nam potrebno kasnije, kod planiranja našeg prvog teleskopa. određivanja polumjera zakrivljenosti zrcala i kod kontrole procesa brušenja i poliranja. Prvi dio ovog teksta posvečen je zato optici.

ČEMU SLUŽE TELESKOPI?

Teleskop je osnovni astronomski instrument. On nam omogućava da opažamo nebeske objekte slabijeg sjaja nego što to možemo golim okom. Svaki teleskop uz to povećava sliku nebeskih objekata pa tako na njima vidimo sitnije detalje. Najbitniji dio teleskopa je objektiv. On sakuplja svjetlo zvijezda i stvara njihovu sliku u svojem žaristu. Koristi li se teleskop za fotografiranje ili neku drugu vrstu instrumentalnog opažanja, žariste je mjesto gje dolazi film ili ulazni otvor dodatnog instrumenta. Amateri su još jedina preostala vrsta astronoma koji zaista gledaju kroz teleskop. Da bi to mogli, iza žarista objektiva mora se staviti okular. Okular igra ulogu povečala: on povečava sliku i istovremeno nam omogućava da je vidimo u punoj oštrini.

O objektivu teleskopa ovisi kvaliteta i svjetlina slike, pa nije čudo da se teleskopi opisuju upravo karakteristikama svojih objektiva. Tu se prvenstveno navodi promjer objektiva a tek onda i njegova žarisna daljina. Vrlo često se umjesto žarisne daljine navodi f broj objektiva. On se u astronomiji definira na isti način kao i u fotografiji: kao omjer žarišne daljine i promjera objektiva.

$$F/ = f/D$$

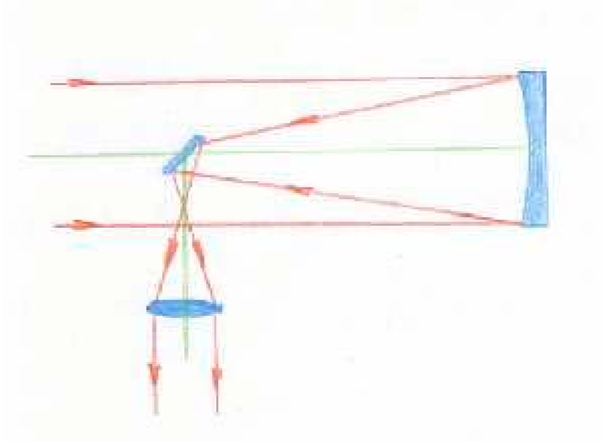
Tu smo koristili uobičajene oznake: F/ za f-broj, f za žarišnu daljinu objektiva i D za promjer objektiva. Kod računa treba paziti da f i D budu izraženi u istim jedinicama. Amateri obično koriste milimetre, a profesionalni astronomi naravno metre. U Americi i Engleskoj gotovo isključivo se još uvijek koriste inči (koje označavaju sa “ iza samog broja). Zato je dobro zapamtiti da je

$$1'' = 25{,}4\ \mathrm{mm}$$

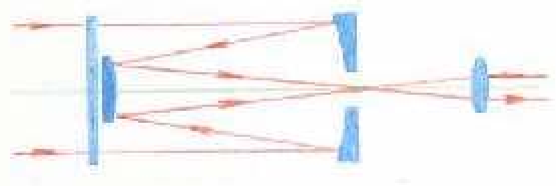
Spomenimo ovdje da fotografi koriste gotovo isti način označavanja svojih objektiva. Oni prvo navode žarisnu daljinu objektiva (jer ona određuje veličinu slike na filmu) a tek onda njegov F/broj, pišući pri tome umjesto “F/” “1:” . Uz to fotografi F/broj nazivaju blenda. Tako će npr. za teleskop promjera objektiva od 100 mm i žarišne daljine od 500 mm astronom reći 100 mm teleskop F/5, a fotograf za isti teleskop 500 mm objektiv 1:5.

Prema tipu objektiva teleskopi se dijele u tri skupine: refraktore, reflektore i mješovite (neki puta naići ćete na jezikolomni naziv katadioptrički teleskopi). Refraktor je teleskop kod kojeg je objektiv napravljen od jedne ili više leća. Kod reflektora je objektiv jedno ili više zrcala a složeni ili katadioptrički teleskopi imaju objektive koji su sastavljeni od kombinacije leća i zrcala.

Objektiv teleskopa refraktora sastoji se od jedne ili više leća. Objektiv paraleni snop svjetla koji dolazi iz smjera nebeskih objekata lomi prema svojem žarištu, u kojem nastaje umanjena slika nebeskih objekata. Iza žarišta snop svjetla ponovno se širi. Kako naše oko može tvoriti oštru sliku samo ako je snop svjetla koji u njega ulazi paralelan, moramo na neki način šireći snop svjetla ponovno pretvoriti u paralelni. To je uloga povečala koje se ovdje (kao i kod drugih optičkih instrumenata!) naziva okular. Primijetite da se središte objetiva, žarište i središte okulara nalaze na istom pravcu (osi) koji se u optici naziva optička os. Teleskop refraktor obično je dugačak instrument, čiji objektiv je sastavljen iz dvije ili tri leće točno proračunatih svojstava. Zato su objektivi refraktora, a time i kompletni teleskopi ovog tipa prilično skupi. Kod najednostavnijih objektiva F/broj se kreće između 10 i 5, a samo vrlo skupi objektivi mogu raditi sa manjim F/ brojem. Ovaj tip teleskopa nije pogodan z amatersko brušenje leća, jer čak i nanjednostavnija leća ima 4 plohe koje moraju biti vrlo precizno izrađene i prilagođene jedna drugoj. Uz to, neke od tih ploha su ispupčene, što je dodatni problem jer su metode testiranja ispupčenih ploha znatno složenije od metoda testiranja udubljenih ploha. Dodatni problem je taj da leće moraju biti izrađene od točno određenih tipova optičkog stakla, kojeg je vrlo teško i skupo nabaviti u potrebnom obliku. Za ilustraciju težine tog posla, jedan od autora (ŽA) izbrusio je mnoštvo kvalitetnih zrcala promjera između 10 i 40 cm, ali ni nakon mnogo truda i pokušaja još nije dovršio najjednostavniji objektiv za refraktor promjera sam 7 cm!). Što naravno ne znaći, da se u ovo ne treba upustiti ako baš imate želju; no prije toga dobro ispecite zanat na zrcalim!



Što je promjer objektiva veči, to je teže i skuplje izraditi kvalitetan objektiv. Zato se kod većih promjera objektiva (u amaterskim uvjetima to obično znaći kod objektiva većih od oko 10 cm u promjeru) umjesto leće kao objektiv koristi zrcalo. Nanjednostavnija konstrukcija teleskopa sa zrcalom na mjestu objektiva koja se danas koristi naziva se Newton-ov teleskop. Kod njega se svjetlo odbija na površini udubljenog zrcala koje mora biti paraboličnog oblika (ako je F/ broj veći od 10, a promjer objektiva manji od oko 15 cm, zadovoljavajuću sliku daje i sferno zrcalo koje je znatno jeftinije) da bi zrcalo tvorilo oštru sliku. Kako kod zrcala slika nastaje ispred zrcala, ne možemo tu staviti okular jer bismo kod opažanja glavom zaklonili svjetlo koje ide prema zrcalu. Zato je malo ispred žarišta zrcala umetnuto malo ravno zrcalo, koje stoji pod 45 stupnjeva prema optičkoj os i prebacuje sliku na stranu od glavnog zrcala. Okular sad može biti sa strane teleskopa i opažač više ne smeta svjetlu. Pored toga što je samo zrcalo kod većih promjera znatno jeftinije od leće, Newton-ov teleskop obično ima F/ broj između 4,5 i 8 pa je takav teleskop znatno kraći od odgovarajućeg refraktora. Ovo je tip teleskopa koji se obično izrađuje u kućnoj radinosti, bilo da kupujemo gotovo zrcalo, ili se upuštamo u brušenje vlastitog zrcala. Za razliku od leća, zrcalo se može izraditi gotovo od svake vrste stakla, što nam omogućava da se koristimo staklom koje najlakše možemo nabaviti.



Treči, danas vrlo popularni, složeni (katadioptrički) tip objektiva sastvaljen je od kombinacije leća i zrcala. Njegova velika prednost je da je dužina teleskopa oko 2-2,5 promjera objektiva, bez obzira na to što mu se F/ broj obično kreće oko 10. Za modernog amatera, koji mora putovati do dalekih opažačkih mjesta d abi pobjegao od svjetlosnog zagađenja, ovo je velika prednost. Uz to, kompaktost teleskopa pojeftinjuje i njegovu montažu, pa je ovo jedan od najzastupljenijih tipova teleskopa na tržištu, i obično ima promjer od 20 cm. No, za početničku amatersku izradu nije pogodan, barem ne dok se dobro ne uvježbamo izrađujući jednostavniju zrcalnu optiku Newton-ovog teleskopa. Teškoće sa kojima se susreće amater-brusač ovakve optike su slične onima kod teleskopa refraktora. Dodatno je potrebno i nešto specijalnog alata i pribora izrada kojeg zahtijeva nešto znanja fine mehanike i pristup tokarskom stroju.

SVJETLOSNA SNAGA TELESKOPA

Osnovna i **NAJVAŽNIJA** funkcija teleskopa je da sakuplja svjetlo. Više sakupljenog svjetla znaći da ćemo moći opažati objekte slabijeg sjaja, pa je jasno da je veći objektiv bolji od manjeg jer ima veću površinu. Uzmemo li da je promjer zjenice ljudskog oka priviknutog na tamu oko 7 mm (u stvarnosti je on različit od čovjeka do čovjeka, i se kreće u granicama od 6 do 8 mm) onda objektiv promjera D milimetara sakuplja onoliko puta više svjetla koliko mu je puta površina veća od površine zjenice ili:

$$\mathbf{S = (D/7)^2}$$

pri čemu promjer objektiva (D) moramo uvrstiti u milimetrima. Veličina S naziva se svjetlosna snaga teleskopa.

PRIMJER:izračunati svjetlosnu snagu objektiva dvogleda promjera 30mm, malog refraktora promjera objektiva 80 mm i velikog teleskopa promjera objektiva 200 mm.
dvogled sa objektivom promjera 30 mm

$$S = (30/7)^2 = 18$$

mali refraktor sa objektivom promjera 80 mm

$$S = (80/7)^2 = 131$$

teleskop promjera 200 mm

$$S = (200/7)^2 = 816$$

Uz pomoć svjetlosne snage možemo odrediti koliko slabe zvijezde ćemo moći promatrati teleskopom. Ako objektiv sakuplja S puta više svjetla od golog oka, onda ćemo sa njime moći vidjeti zvijezde S puta tamnije. Kako prostim okom možemo vidjeti zvijezde oko 6 zvijezdane veličine, uz primjenu fotometrijske formule (fotometrijska formula matematički opisuje skalu zvjezdanih veličina) dolazimo do slijedeće formule:

$$\mathbf{mg = 6 + 2{,}5\log(S)}$$

gdje je mg tzv. granična zvjezdana veličina, odnosno veličina zvijezda najslabijeg sjaja koje još tim teleskopom možemo vidjeti.

***NAPOMENA**: Svatko tko se ozbiljno želi baviti izradom teleskopa mora dobro poznavati osnovne veze između promjera objektiva, količine svjetla te povečanja teleskopa. Zarto je ovaj podugačak i prilično suhoparan uvod neophodan. No sam matematicki postupak i finese računa koji vode do ovdje iznesenih formula za amatere nisu toliko bitne pa ih slobodno možete preskoćiti ako vas ne zanimaju. To posebno vrijedi za mlađe čitaoce, i one ostale koji su srednješkolsku matematiku odavno zaboravili. Dakle, ako vam je teoretski dio dosadan, ili nerazuljiv, slobodno ga preskočite i proučite samo tabelu na kraju svake stranice koja sažima najvažnije rezultate teoretskih računa.*

PRIMJER: naći graničnu zvijezdanu veličinu za prije spomenute instrumente promjera objektiva od 30, 80 i 200 mm.
dvogled sa objektivom promjera 30 mm

$$mg = 6 + 2{,}5\log(18) = 9{,}2$$

b. mali refraktor sa objektivom promjera 80 mm

$$mg = 6 + 2{,}5\log(131) = 11{,}3$$

c. teleskop sa objektivom promjera 200 mm

$$mg = 6 + 2{,}5\log(816) = 13{,}3$$

Opažanja različitim teleskopima pokazuju da se u stvarnosti granična zvijezdana veličina dostiže samo u tamnim, vedrim noćima bez mjesečine i to pri velikim povečanjima. U najboljim uvjetima moguće je opaziti zvijezde i za oko 2 zvjezdane velićine tamnije od vrijednosti koju predvida ova formula. Tu svakako veliku ulogu uz čistu atmosferu bez svjetlosnog zagađenja igraju i optička kvaliteta objektiva i nadasve opažačko iskustvo.

Uvrstimo li u formulu za graničnu zvjezdanu veličinu umjesto svjetlosne jačine (S) izraz koji je povezuje sa promjerom objektiva, dobit ćemo drugi oblik formule za graničnu zvjezdanu veličinu koji se vrlo često koristi:

$$mg = 6 + 5\log(D/7) = 1{,}8 + 5\log(D)$$

promjer objektiva (mm)	mg
50	10,3
60	10,7
80	11,3
100	11,8
150	12,7
200	13,3
300	14,2

POVEČANJE TELESKOPA

Slijedeća važna funkcija teleskopa je povečanje. Povečavajući sliku nebeskih objekata, teleskop nam omogučava da na nebeskim objektima uočimo sitnije detalje nego što bismo to mogli golim okom. Povečanje teleskopa (P) izračunavamo tako da žarišnu daljinu objektiva (F) podijelimo sa žarišnom daljinom okulara (f):

P = F/f

Povečanje se ne može mijenjati u proizvoljnim granicama. Ako je povečanje premalo, dolazi do gubitka svjetla pa teleskop nije do kraja iskoristen. Ako pak pretjeramo sa povečanjem dobit ćemo tamne, razvodnjene slike bez detalja, a istaknut ćemo sve nesavršenosti optike i titranje zraka. Granice u kojima se moze kretati povečanje ovise o promjeru objektiva, njegovom tipu i kvaliteti. U največem broju slučajeva objektiv je zadovoljavajuće kvalitete tako da kvalitetu slike ograničavaju samo zakoni optike (difrakcija) i titranje zraka.

Povečanja se dijele na mala, srednja i velika. Kod malih povečanja slika je svijetla a vidno polje veliko. Ona se zato koriste za traženje objekata na nebu i promatranje objekata slabog sjaja (kometi, maglice i sl). Kod malih povečanja titranje zraka ne utječe na kvalitetu slike.

Srednja povečanja koriste se za promatranje Mjeseca i planeta, dvojnih zvijezda, sjajnijih maglica ili maglica malih dimenzija itd. Slika je kod ovih povečanja tamnija, a vidno polje manje. Titranje zraka primjetno je samo kad je izrazito veliko. Ovo su povečanja koja se najčešće koriste.

Velika povečanja koriste se uglavnom za promatranje Mjeseca, planeta i bliskih dvojnih zvijezda, ako je atmosfera dovoljno mirna. Vidno polje je kod njih vrlo malo, slika je tamna i jako osjetljiva na titranje zraka. Zato se ova povečanja ne koriste često. Granice izmedu pojedinih vrsta povečanja nisu strogo postavljene a dane su slijedećim formulama:

premala povečanja su manja od

Pmin = D(mm)/7

mala povečanja su između Pmin i Ps

Ps = D(mm)/3

U mala povečanja spada i tzv. normalno povečanje Pn koje se često koristi kod dvogleda:

Pn = D(mm)/5

srednja povečanja nalaze se između Ps i Pv:

Pv = D(mm)

a iznad Pv počinju velika povečanja koja se kreću sve do Pmax:

Pmax = 3D(mm)

Povečanja veća od Pmax su prevelika, slika postaje pretamna i mutna.

U svim ovim formulama D je promjer objektiva teleskopa u mm. Primijetite da ova povečanja ovise samo o promjeru objektiva.

PRIMJER: odrediti korisna povečanja za objektive promjera 30, 80 i 200 mm:
a. dvogled sa objektivom promjera 30 mm

Pmin = 30/7 = 4 x
Pn = 30/5 = 6 x
Ps = 30/3 = 10 x

Pv = 30 = 30 x Pmax = 3´ 30 = 90 x b. mali refraktor sa objektivom promjera 80 mm Pmin = 80/7 = 11 x Pn = 80/5 = 16 x Ps = 80/3 = 27 x Pv = 80 = 80 x Pmax = 3´ 80 = 240 x c. teleskop sa objektivom promjera 200 mm Pmin = 200/7 = 29 x Pn = 200/5 = 40 x Ps = 200/3 = 67 x Pv = 200 = 200 x Pmax = 3´ 200 = 500 x

---

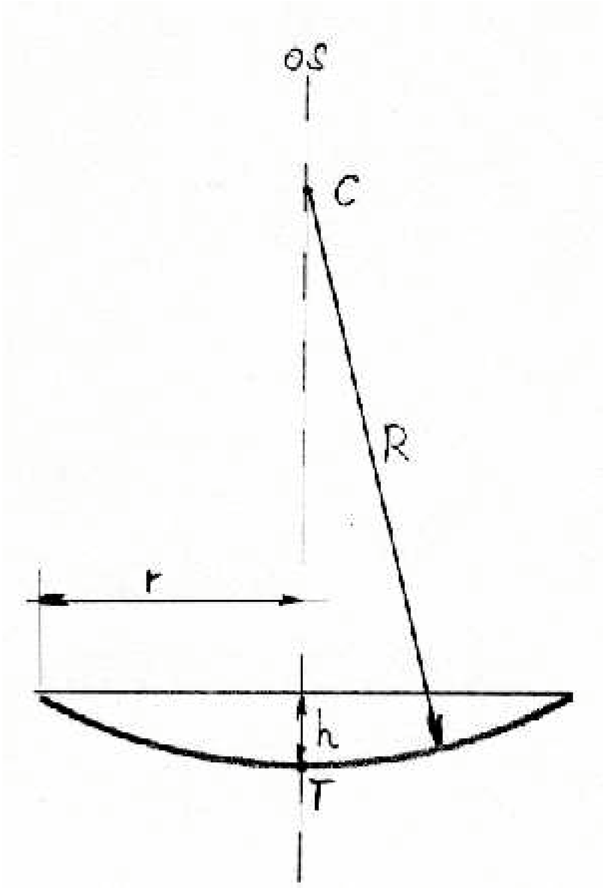
Recimo još na kraju nekoliko riječi o razlučnoj moći teleskopa. Zakoni optike ograničavaju oštrinu slike koja se može postići objektivom određenog promjera tako da za opažanje sitnijih detalja moramo upotrijebiti objektiv većeg promjera. Najsitniji kutni razmak (R) dvije zvijezde istog sjaja, koji se još može razdvojiti objektivom promjera D mm dan je tzv. Dawes-ovom formulom:

R (") = 120/D(mm)

gdje je R kutni razmak u lučnim sekundama ako je D promjer objektiva u mm. Ako dvije zvijezde nisu istog sjaja, razmak koji se još moze razlućiti raste sa razlikom u sjaju izmedju tih dviju zvijezda. Razlučivanje za objekte malog kontrasta npr. detalje planeta i sl. često puta mnogo je lošije nego što to ova formula pređvida.

PRIMJER: odrediti razlučnu moć za objektive promjera 30, 80 i 200 mm: a. dvogled sa objektivom promjera 30 mm R = 120/30 = 4" b. mali refraktor sa objektivom promjera 80 mm R = 120/80 = 1,5" c. teleskop sa objektivom promjera 200 mm R = 120/200 = 0,6"

GEOMETRIJA SFERNOG ZRCALA



Sferno zrcalo je dio kugline plohe. Polumjer zakrivljenosti, R, te kugline plohe naziva se polumjer zakrivljenosti zrcala, a središte kugline plohe središte zakrivljenosti zrcala, C. Promjer zrcala, D=2r obično se izražava u mm, a u engleskoj literaturi vrlo često i u inčima (1 inč (") = 25,4 mm). Udubina zrcala, h, je dubina kugline plohe u sredini zrcala. Ovakvo sferno zrcalo fokusira paralelni snop svjetla u svoje žarište. Udaljenost od tjemena zrcala, T, do žarišta naziva se žarišna daljina zrcala, f. Ona je jednaka polovici polumjera zakrivljenosti zrcala, dakle

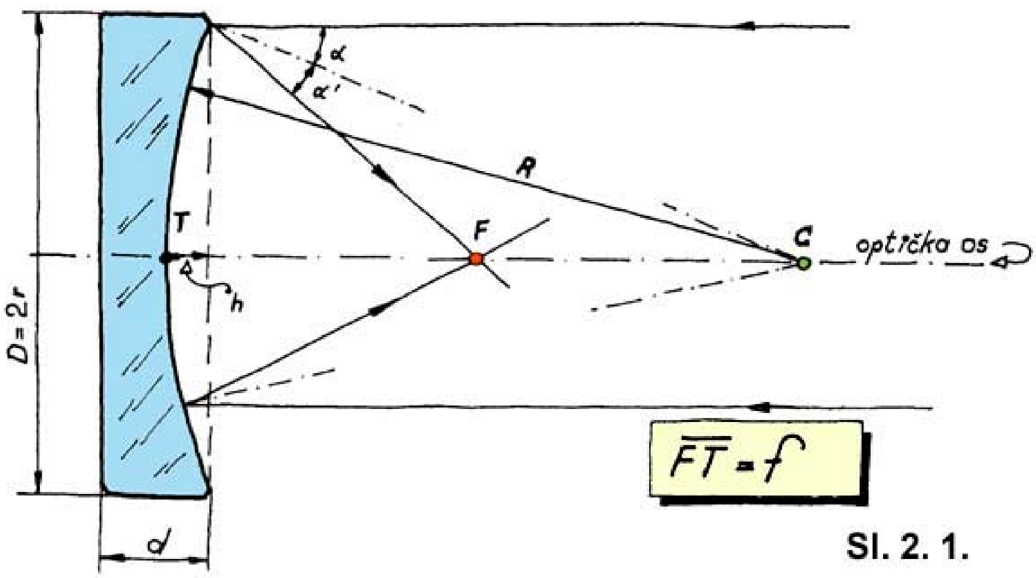
f=R/2

Navedimo još formule koje povezuju udubinu, polumjer zrcala i polumjer zakrivljenosti zrcala, jer će nam one biti potrebne kod mjerenja polumjera zakrivljenosti zrcala.:

$h=R-sqr(R^2-r^2)$

$r=sqr(2Rh-h^2)$

$R=(r^2+h^2)/(2h)$



Sl. 2. 1.

Materijal potreban za izradu zrcala promjera oko 15 cm

Prije samog brušenja potrebno je pripremiti prostor u kojem ćemo raditi i izraditi jednostavne uređaje za kontrolu procesa brušenja i poliranja. Za to nam je dovoljan mali radni stol ili stalak na kojem možemo nesmetano raditi i nešto malo ručnog alata (pila i turpija za drvo, ručna bušilica, čekić). Sve ovo je detaljnije opisano na idućim stranicama, a sada dajemo samo kratki popis najnužnijih stvari, potrebnih za samu izradu zrcala promjera oko 15 cm.

1. stakleni disk debljine 15 do 25 mm
2. alat za brušenje, najbolje još jedan stakleni disk istih dimenzija

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3. karborundum ili korund finoće 70 do 120 oko 500 g
4. karborundum ili korund finoće 220 oko 200 g
5. karborundum ili korund finoće 320 100 g
6. korund finoće 400 do 600 50 g
7. korund finoće 800 do 1000 50g
8. još finiji brusni prah, ako ga možemo nabaviti 20 g

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9. smola za izradu matrice 1 kg
10. kalofonij 1 kg
11. pčelinji vosak 100 g

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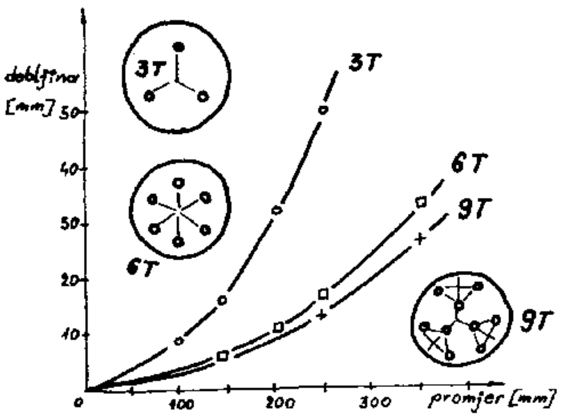
12. cerij oksid za poliranje 100 g

DISK ZA ZRCALO - TEORIJA

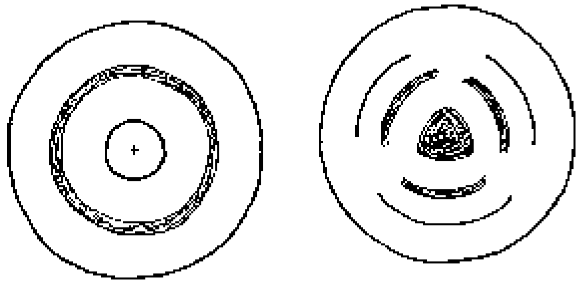
Postupak brušenja pretvara komad stakla u jednu od najpreciznijih tvorevina koju ljudska ruka može izraditi, u plohu sa točnošću od nekoliko milijuntinki milimetra! Nanošenjem tankog metalnog sloja na nju ova površina postaje zrcalo koje ćemo ugraditi u naš teleskop. Sva staklena masa ispod zrcalne površine ima samo jednu jedinu ulogu: da služi kao nosač tankom metalnom sloju zrcala i da čuva njegov oblik neovisno o opterečenjima kojima je zrcalo u toku upotrebe izloženo. Ako je kučište zrcala dobro izrađeno, ta opterečenja potiću samo od vlastite težine zrcala. Kako za vrijeme promatranja teleskop mijenja svoj položaj, mijenja se i položaj zrcala prema smjeru sile teže pa se mijenja i opterečenje zrcala nastalo zbog same težine materijala od kojeg je ono izrađeno. Zato debljina materijala od kojeg je zrcalo izrađeno mora biti dovoljno velika da zrcalo pod djelovanjem vlastite težine ne promijeni primjetno svoj oblik. Isto naravno vrijedi i za opterečenja kojima je zrcalo izloženo prilikom brušenja i poliranja. Staro pravilo je da se za podlogu zrcala uzima stakleni disk čija debljina je jednaka 1/6 njegovog promjera. Iskustvo i teoretski račun deformacije zrcala pokazuju međutim da je moguće izraditi sasvim dobra zrcala i na dvostruko tanjim staklenim diskovima. Razlog ovog odstupanja je taj što je pravilo 1/6 izvedeno iz iskustava profesionalnih optičara koji za obradu stakla koriste strojeve. Opterečenja zrcala kod strojne obrade znatno su veća nego kod ručnog brušenja, pa zato optičari vole da je staklo nešto deblje.

Drugi razlog za ovo pravilo je da su davno izvedeni proračuni (pod davno mislimo stvarno davno, još u 19. stoljeću!) pokazali da je kod podupiranja zrcala u tri točke potrebna ova debljina stakla. Ovi računi nisu uzimali u obzir ovisnost potrebne debljine stakla o promjeru zrcala i obično su rađeni za staklene diskove promjera 150 do 200 mm, jer je većina amaterskih reflektora početkom stoljeća (20tog) kad su se amateri masovnije poceli baviti vlastitom izradom zrcala, bila ovog promjera. Nešto modernije i detaljnije proračune izvršio je poznati ruski optičar D. Maksutov. Najvažniji rezultati do kojih je došao sakupljeni su u slijedećoj tabeli.

najmanja debljina staklenog diska za zrcalo u ovisnosti o broju točaka u kojima je zrcalo poduprto					
promjer (mm)	100	140	200	250	350
3 točke	8	16	32	50	100
6 točaka	3	5	11	17	33
9 točaka				14	27
cijelo zrcalo				12	20



Vidimo da prijelaz sa 3 na 6 točaka podupiranja značajno smanjuje potrebnu debljinu zrcala, dok prijelaz na još veći broj točaka više nema tako veliki uticaj. Na malim skicama sa strane prikazan je raspored točaka u kojima se zrcalo treba poduprijeti. Primijetimo za sada samo još da je moguće zrcalo staviti na elastičnu podlogu i tako ga poduprijeti po cijeloj njegovoj donjoj strani, što bi odgovaralo beskonačnom broju točaka podupiranja. Amateri vrlo često koriste ovu tehniku podupiranja svojih zrcala, dok profesionalni astronomi svoja (daleko veća) zrcala još uvijek podupiru na točno određenim mjestima, no to je već sasvim druga priča...



Difrakciona slika zvijezde koju daje pravilno montirano zrcalo (treba nam vrlo veliko povećanje i izrazito mirna atmosfera!) potpuno je okrugla i sastoji se od svijetlog diska okruženog sa jednim do dva slaba prstena. Ako je zrcalo pretanko ili loše montirano dolazi do deformacija slike koje se odražavaju u promjenu izgleda difrakcione slike. Na slici desno je primjer deformacije koja nastaje kod podupiranja u tri točke.

Ovaj proračun uzima u obzir samo deformacije zrcala nastale zbog njegove vlastite težine. To znači da kučište zrcala mora biti tako izradeno da dodatno ne opterečuje zrcalo. Također, kod same izrade zrcala može doći do različitih mehaničkih opterećenja koja mogu izobličiti stakleni disk i onemogućiti postizanje potrebne točnosti zrcalne plohe. Zbog toga su proračunate debljine podloge za promjere ispod 100 mm premalene, pa je za zrcala manja od 100 mm preporučljivo koristiti staklo debljine 8 do 10 mm, neovisno o promjeru zrcala.

Minimalna debljina staklenog diska od kojeg se još može izraditi dobro zrcalo, ovisi i o iskustvu brusača. Iskusni amateri u stanju su raditi sa znatno tanjim diskovima od neiskusnih. Naprimjer, Bob Kestner, čovjek koji je izradio mnoštvo zrcala promjera 300 do 600 mm, preporučuje slijedeće minimalne debljine staklenih diskova, u ovom slučaju od Pyrex stakla:

promjer (mm)	do 450	450-650
debljina (mm)	25	40

Ove minimalne debljine preporučuju se **ISKUSNIM** amaterima, dakle onima koji su izradili nekoliko dobrih zrcala promjera 150 do 300 mm. Neiskusnima se još uvijek preporučujemo da za svoje prvo zrcalo uzmu stakleni disk debljine 1/8 do 1/6 promjera.

Osim mehaničkih opterečenja zrcalo mijenja svoj oblik i zbog promjena temperature. Staklo se, kao i svaki drugi materijal, na toplini rasteže. Ovo rastezanje nije veliko, ali je dovoljno da izazove promjene oblika plohe zrcala kad ono nije svugdje iste temperature. Razlike u temperaturi pojedinih dijelova zrcala, naročito između površine i sredine, nastaju kad se temperatura okoline prebrzo mijenja, tako da se temperatura zrcala ne stigne izjednačiti sa temperaturom okoline. Tada unutar staklenog diska dolazi do razlika u temperaturi koje dovode do nejednakog toplinskog rastezanja pojedinih dijelova staklenog diska a time i do promjene oblika zrcalne plohe. Ova pojava može kod loše izrađenog teleskopa i kod naglih promjena temperature potpuno uništiti kvalitetu slike.

Toplinski koeficient rastezanja stakla (po stupnju C)	
prozorsko staklo	0,0000075
boral, pyrex, tempax	0,0000033
kvarcno staklo	0,00000056
zerodur, ULE, sital	0

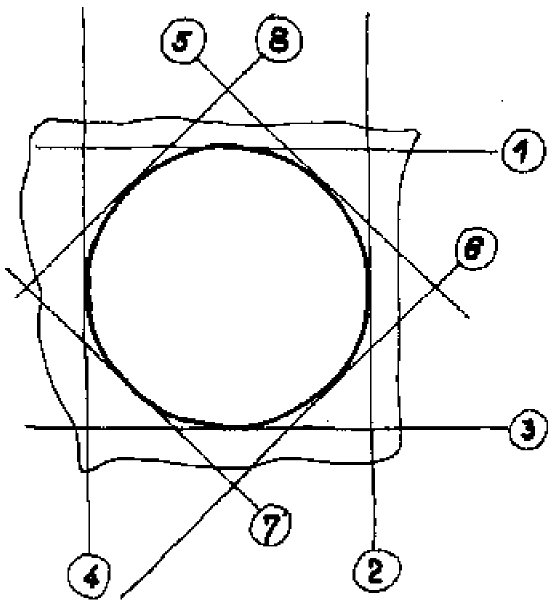
Promjene oblika zrcala koje nastaju zbog promjena temperature smanjuju se na dva načina: izradom zrcala iz stakla sa malim koeficientom toplotnog rastezanja i konstrukcijom cijevi teleskopa koja omogućava brzo izjednačavanje temperature instrumenta i okoline. Posebno je važno da se instrument ne iznosi iz tople prostorije u hladnu noć prije samog opažanja ili da preko dana ne bude izložen direktnom suncevom svjetlu. Najbolje je instrument sat dva prije početka opažanja (ne prije zalaska Sunca) postaviti na njegovo mjesto. Ako je on montiran u kućici ili kupoli, odmah nakon zalaska Sunca treba je otvoriti da bi se do početka opažanja dobro provjetrila. Dobra cirkulacija zraka prilično ubrzava izjednačavanje temperature.

Što se tiće vrste stakla od kojeg se izrađuju zrcala, ona je kod nas određena cijenom i mogučnošću nabavke. Amateri u razvijenim zemljama koriste gotovo isključivo vatrostalno staklo poznato pod imenom Pyrex (Duran 50 i Tempax u Europi, Boral kod nas). Mnoga odlična zrcala izrađena su medutim i od običnog prozorskog stakla (i Mt. Wilson 2,5 m teleskop!!), kod čega su naročito popularni stari brodski prozori jer su pristupačne cijene i imaju potreban oblik i debljinu. Kod nas se nažalost i prozorsko staklo, a kamoli brodski prozori, teško nabavlja. Najveća debljina prozorskog stakla koja se može naći u slobodnoj prodaji je 10 mm, a vrlo rijetko se naiđe na nešto deblje staklo (15 do 20 mm).

Staklo za izradu astronomskih zrcala obićno se lijeva ili preša u diskove ili sača potrebne debljine. Nakon lijevanja hladi se u posebnim pečima vrlo polagano kako bi se naprezanja u staklu nastala zbog hlađenja svela na najmanju moguću mjeru. Ovaj postupak traje nekoliko dana do nekoliko mjeseci, ovisno o debljini i vrsti stakla. Kod nas se nažalost ovako opušteno staklo ne moze lako nabaviti. I diskovi od Borala, ako uspijete doći do njih, i debelo prozorsko staklo hlade se znatno brže, pa nisu tako dobro opušteni kao stakla za astronomsku upotrebu. Srećom kako tehnologija napreduje i obično prozorsko staklo postaje sve kvalitetnije pa se može koristiti bez većih problema. isto vrijedi i za Boral staklo. Međutim može se dogoditi da su naprezanja u staklu tolika da od tako napregnutog komada stakla nije moguće izraditi dobro zrcalo. Ovo se obićno manifestira kod poliranja na taj način da se ploha nikako ne moze dobro korigirati i da se njen oblik mijenja i samim stajanjem. Imate li “sreću” da ste naišli na takav disk, nema vam druge nego zrcalo izraditi na drugom staklenom disku, a ovaj upotrijebiti za alat ili ga u nastupu bijesa opustiti bacanjem iz sve snage u najbliži stup.

DISK ZA ZRCALO - PRIPREMA

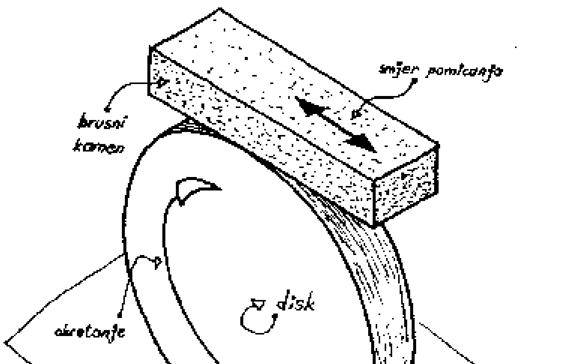
Prije nego što pristupimo brušenju zrcalne plohe moramo stakleni disk prirediti za brušenje. Ako smo uspjeli nabaviti lijevani ili obrušeni disk možemo odmah početi sa ravnanjem gornje i donje plohe diska. Ako pak nismo te sreće, pa smo nabavili pravokutni ili nepravilni komad debelog stakla, moramo ga prvo pretvoriti u okrugli disk. S obzirom na to da se radi o staklu debljine nekoliko centimetara, zarezivanje običnim rezačima za staklo i lomljenje po zarezanoj crti ne dolazi u obzir, barem ne u neiskusnim amaterskim rukama. Ovakvi pokušaji obicno završe lomom stakla pa ostajemo bez dragocijenog materijala. Da bi debelo staklo puklo po zarezanoj liniji, pogotovo kad je ona zakrivljena (kružnica!) potrebna je velika vještina kod zarezivanja pa se tog posla nerado prihvačaju i iskusni staklorezači. Pa što onda napraviti?



Postoji li u blizini staklorezač koji ima pilu za staklo, možemo ga zamoliti da nam staklo dovede u približno kružni oblik tako da pilom odreže kuteve kvadratičnog komada stakla. Potrebno je na ovaj način napraviti barem 15 do 30 rezova kako bi oblik izrezanog stakla bio dovoljno blizu kružnom.

Preostale neravnine moramo ukloniti ručnim ili strojnim brušenjem. Za ručno brušenje potreban nam je grubi brusni kamen (onaj za brušenje noževa ili kosa obično je prefin). Najbolja je stara brusna ploča od karborunduma (korund može poslužiti ali će rad sa njime trajati nešto duže) krupnoće 120 ili grublje. Ploča može biti i polomljena jer nam i tako treba komad koji možemo držati u ruci. Obrezani komad stakla postavimo okomito na prikladnu podlogu, nabolje negdje vani jer je posao dosta prljav. Kao podloga može posluziti svaka čvrsta ravna ploha visine običnog stola, na koju možemo staviti komad plastične folije da se ne zaprlja.

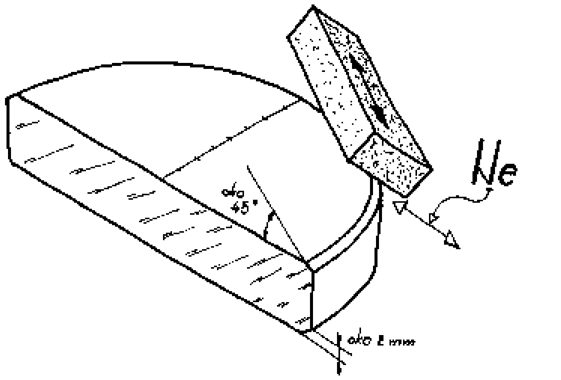
Pored brusnog kamena potrebna nam je posuda u kojoj ćemo ga vlažiti i dosta vode jer ćemo često morati prati i sebe i stakleni disk. Stakleni disk postavimo okomito na podlogu i pridržavamo ga jednom rukom.



U drugu ruku uzmemo brusni kamen, dobro ga navlažimo i uz pritisak brusimo obod staklenog diska. Kod toga stakleni disk polagano zakrećemo kako bi cijeli rub bio jednolično izbrušen.

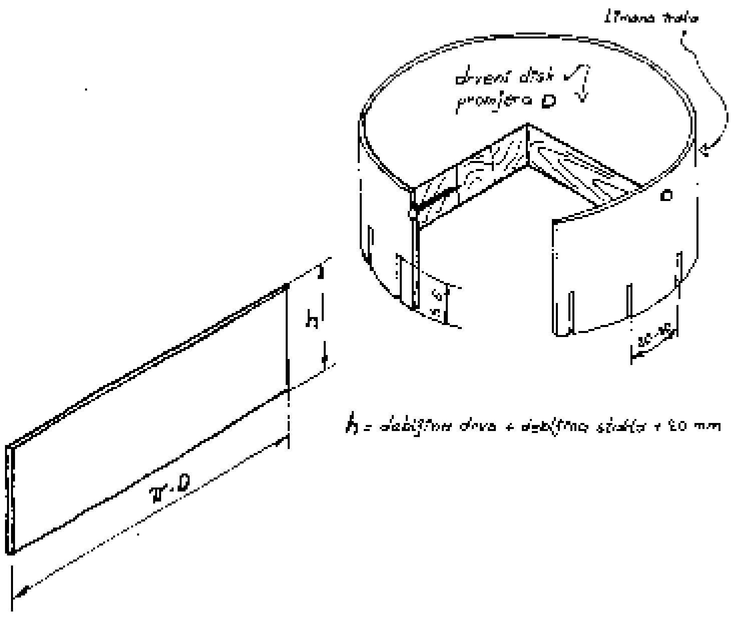
U toku brušenja pomićemo kamen približno u ravnini staklenog diska kako bi se smanjila mogućnost odlamanja komadića stakla sa rubova diska. Brusni kamen mora stalno biti vlažan. Kad se sve neravnine preostale od rezanja izbruse, provjerimo mjerenjem nekoliko promjera da li disk ima kružni oblik. Dovoljno je da odstupanja od kružnog oblika budu oko 1% promjera diska ili manja. Ako su veća, odredite koji dijelovi diska imaju najveći promjer i brusite samo njih, dok se oblik diska ne dovede dovoljno blizu kružnom. Kod ovog posla najvažnije je strpljenje jer on može potrajati danima. Kako je uz to i fizički dosta naporan, potrebno se često odmarati. U literaturi se pod vremenom brušenja uvijek misli na vrijeme trajanja samog brušenja. Pauze nisu uzete u obzir, što ne znaći da nisu rađene i to često. Tako npr. kad naiđete na podatak da za poliranje 500 mm zrcala treba 8 do 12 sati, to ne znaći da se taj posao može obaviti u jednom danu. Prije spomenuti Bob Kestner, polira tako velika zrcaka dnevno dva puta po 15 minuta jer je takav rad vrlo naporan. Izrada zrcala manjih od 200 mm ne zahtijeva velike fizičke napore, ali i tu treba prekinuti rad kad se osjeti zamor.

Na kraju možemo obod izradenog diska fino izbrusiti kamenom finoće 220 ili 400 kako bi se hrapavost od brušenja grubim kamenom smanjila, ali ovaj postupak uglavnom ima estetski karakter. Nakon toga prvo grubim, a onda i finim kamenom izradimo i fazete, tj. zakošenja rubova diska. Disk postavimo vodoravno na podlogu i po cijelom obodu odbrusimo rubove diska pod kutem od oko 45 stupnjeva tako da oni budu 2 do 3 mm široki. Ovaj postupak neophodan je kako bi se spriječilo odlamanje komadića stakla sa ruba diska kod brušenja zrcala. Kad god se fazeta zbog brušenja smanji ispod 1 mm, potrebno ju je ponovno izbrusiti!



Fazete izradite tako da brusnim kamenom odbrusite rubove diska pod kutem od oko 45 stupnjeva. Brus stalno vlažite vodom, i mičite samo U SMJERU oboda a nikako ne okomito na njega.

Ne postoji li u blizini staklorezač, ili je cijena njegove usluge previsoka, možemo stakleni disk izrezati sami, uz upotrebu tzv. krunskog svrdla. Krunsko svrdlo je tanka metalna cijev sa nareckanim rubom. Ovaj rub maže se smjesom vode i grubog karborunduma. Krunsko svrdlo pritišće se na stakleni komad koji se reže i istovremeno se lagano okreće, bilo stalno u istom smjeru, bilo amo-tamo. Na mjestu dodira svrdla i stakla brusni prah će ubrzo izgrebsti kanal koji se polagano produbljuje. Postupak bušenja vrlo je spor, ali je njegovo trajanje usporedivo sa vremenom potrebnim da se grubo izrezani stakleni komad ručno dotjera u okrugli oblik kao što je to opisano ranije.



h=debljina drva+debljina stakla+2 do 3 cm

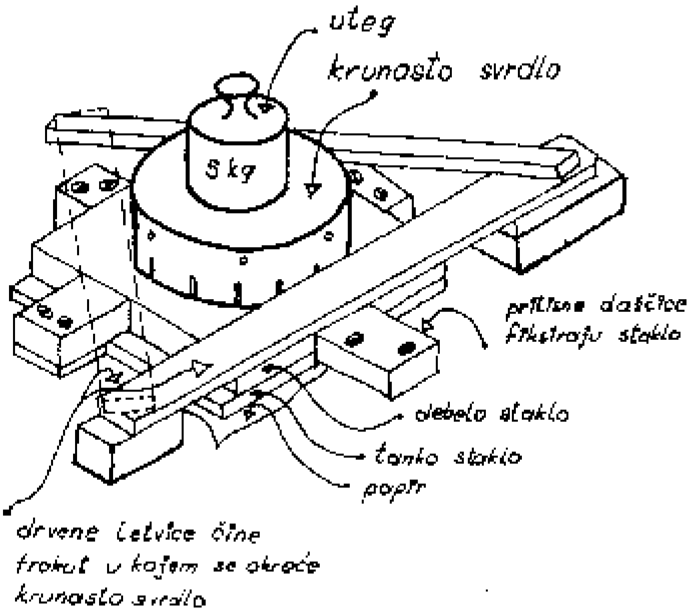
Jednostavno krunsko svrdlo može se vrlo jednostavno izraditi. Prvo od komada daske ili panel ploče debljine 2 do 3 cm izrežemo drveni disk čiji promjer je jednak promjeru budućeg zrcala. Neravnine zaostale od rezanja možemo obrusiti brusnim papirom, ako nam se ćini da su prevelike. Od željeznog ili bakrenog lima debljine 0,5 do 1 mm izrežemo traku čija dužina je jednaka opsegu drvenog diska, a širina 2 do 3 cm veća od zbrojene debljine stakla i drvenog diska. Naprimjer, ako je staklo debelo 20 mm a drveni disk 30 mm, sa promjerom od 151 mm, dimenzije limene trake će biti 474 x 60-70 mm. Limenu traku omotamo oko drvenog diska, tako da se rub trake poklopi sa rubom diska, i prikucano je čavlićima. Pilom ili turpijom zarežemo slobodni rub limene trake svaka 2 do 3 cm nekoliko mm duboko. Točnost razmaka između susjednih rezova je nevažna pa se ovaj posao može obaviti i od oka. Isto tako je nevažna dubina ureza i njihova okomitost na rub trake. Kad se kod bušenja traka toliko istroši da se dubina ureza smanji na oko 1 mm, možemo ih lako opet produbiti.

Prije bušenja dobro je na donju stranu stakla koje bušimo smolom zalijepiti komad običnog prozorskog stakla. Ovo staklo spriječit će odlamanje većih komada stakla kad krunsko svrdlo prореže svoj put kroz staklo koje bušimo. Prije ljepljenja moramo oba komada stakla lagano zagrijati na 50 do 60 stupnjeva. Najbolje je da uzmemo posudu dovoljno veliku da oba komada stakla stanu u nju. Na dno posade postavimo nekoliko drvenih letvica debljine 2 do 3 cm, a na njih oba komada stakla.

Posudu napunimo vodom na sobnoj temperaturi tako da za 2 do 3 cm prekriva stakla. Sve zajedno postavimo na peć i lagano zagrijavamo. Nemamo li termometar, možemo se posluziti činjenicom da u vodu temperature oko 50 stupnjeva možemo na kratko umočiti prst a da se ne opečemo. Istovremeno u nekoj maloj posudici rastopimo malo smole (bitumena) tako da bude tekuća, ali ne prevruća. Za tu svrhu je najbolje uzeti neku staru konzervu, jer se posuda jednom zamrljana smolom vrlo teško čisti, a staru konzervu možemo nakon upotrebe baciti. Kad su stakla zagrijana, izvadimo ih iz vode i brzo osušimo brisanjem. Ne hvatajte stakla golim rukama jer ćete se opeći, a staklo će vjerojatno završiti u više komada na podu. Za držanje stakla upotrijebite kožne rukavice ili suhe krpe.

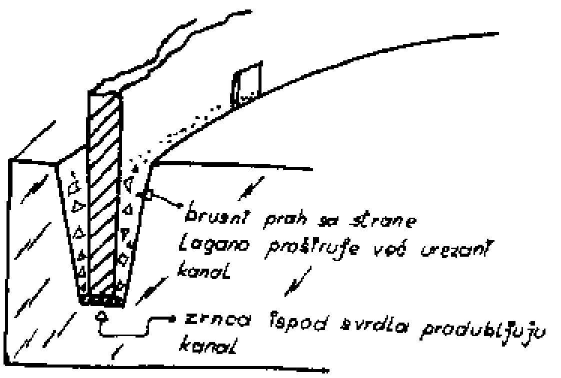
Jedno staklo postavimo na vodoravnu podlogu, najbolje na nekoliko slojeva novinskog papira koji će zadržati višak smole. Podloga ne smije biti metalna da se staklo ne bi prenaglo hladilo. Sad rastopljenu smolu prelijemo kružnim pokretima preko stakla tako da pokrije cijelu njegovu površinu. Drugo staklo spustimo na smolu i mićemo ga amo-tamo uz pritisak da bi se višak smole istisnuo izmedu stakala. Kad zbog hladenja micanje postane preteško, opteretimo gornje staklo sa nekoliko kg utega koje postavimo na drvenu daščicu i sve zajedno ostavimo da se ohladi, najbolje do sutradan. Ako između stakala zaostane nekoliko mjehurića zraka, ne smeta. Zbog isparavanja rastopljene smole i njenog krajnje nezgodnog svojstva da se lako lijepi na sve što dotakne, najbolje je da cijeli ovaj postupak obavimo vani i u staroj odječi. Odjeću zamrljanu smolom praktički je nemoguće očistiti.

Kad je sve ovo završeno, na ravnu i čvrstu podlogu postavite nekoliko slojeva papira ili najlon foliju. Najbolje je koristiti prije opisani radni stol ili dasku. Na tako pripremljenu podlogu postavite sljepljena stakla tako da je ono koje se buši (debelo staklo) gore. Staklo osigurajte od micanja, najbolje sa tri komadića drveta prikucana za podlogu. U nekoj posudici, npr. čašici od jogurta, priredite smjesu karborunduma i vode tako da izgleda kao žitko blato. Višak vode ne smeta jer će karborundum ubrzo sjesti na dno posude. Za bušenje je potrebno uzeti grubi karborundum, najbolje finoće 120, makar se moze koristiti i 220. Grublji karborundum buši brže, ali ostavlja i znatno grublju površinu. Bušenje finoćom većom od 220 vrlo je sporo. Ako ne vjerujete, pokušajte! Žlicicom zagrabite ovlaženi prah i nanesite ga po obodu krunskog svrdla. Svrdlo prislonite na staklo i uz pritisak okrećite lijevo-desno. Bušiti se može i okretanjem u istom smjeru, ali se pokreti lijevo-desno lakše izvode. Dobro je svrdlo opteretiti sa nekoliko kg tereta, kod većih promjera i sa više od 10, kako bi se uklonila potreba za stalnim pritiskanjem svrdla koje zamara mnogo više od samog okretanja svrdla. Zvuk brušenja, ispočetka vrlo glasan, ubrzo će se stišati što je znak da se brusni prah usitnio. Kad se to dogodi, nadignite krunsko svrdlo i nanesite svježi brusni prah. Možete ga nanijeti i na staklo po tragu koji je ostavilo krunsko svrdlo. S vremena na vrijeme, kad se na staklu nakupi mnogo brusnog praha, operite svrdlo i staklo čistom vodom pa onda nastavite brušenje. U početku treba paziti da se svrdlo uvijek okreće po istom tragu, dok si ne ureže kanal koji će ga voditi kod daljnjeg bušenja. Ovo neki puta baš ne polazi od ruke. U tom slučaju možete si pomoći tako da svrdlo fiksirate sa tri letvice. Vodite računa o tome da se svrdlo dade lagano okretati.



Ako je svrdlo na ovaj nacin fiksirano, možete na njega pričvrstiti i drvenu ručku uz ćiju pomoć ćete ga lakše okretati. Ne zaboravite opteretiti svrdlo!

Već nakon nekoliko minuta bušenja svrdlo će u staklu urezati plitki kanal, no dok prođe kroz cijelu debljinu stakla potrebno je nekoliko sati rada, neki puta i mnogo duže ako je staklo debelo a svrdlo velikog promjera. Staklo debelo 10 mm može se svrdlom promjera 100 mm uz karborudum finoće #120 probušiti za sat do dva rada ali za deblje staklo i veće diskove, pogotovo ako radite sa finijim brusnim prahom trebat će mnogo više vremena. Naoružajte se dakle strpljenjem!



Stakleni disk izrezan na ovaj način bit će gotovo savršeno okrugao, ali blago stožastog oblika. Stožast oblik potječe od toga što se za vrijeme bušenja lagano bruse i stijenke izbušenog kanala a ne samo njegovo dno pa kao krajnji rezultat dobivamo blago stožasti disk, ćiji je gornji promjer oko 1 mm manji od donjeg. Ovakav blagi stožasti oblik uopće nije bitan za buduće zrcalo pa ga ne moramo posebno ispravljati.

Kad svrdlo prođe kroz cijelu debljinu gornjeg stakla i to na svim točkama oboda diska (svrdlo može otići malo koso ili staklo moze biti nejednako debelo) nastavite bušenje dok se svrdlo malo ne zareže u donje staklo. Želite li biti oprezni, probušite i donje staklo skroz (zato je dobro da ono bude što tanje), ali udarite li ga drvenim čekičem, neće se dogoditi ništa loše i ono će najvjerojatnije puknuti po zabrušenom tragu svrdla. U svakom slučaju, gornji disk neće biti oštećen (pazite da vam kod izbijanja drvenim čekičem ne padne na pod!). Da biste odvojili tanko staklo od debelog, diskove opet polagano zagrijte, ovaj puta na nešto višu temperaturu, pa pritiskom na stranu skliznite tanko staklo sa debelog (rukavice!). Odvojene diskove ostavite da se polagano ohlade na zraku. Ostatak smole mozete oprati benzinom, alkoholom ili acetonom, vec prema želji i otapalu koje vam je na raspolaganju. Zbog isparavanja i ovo pranje najbolje je napraviti vani.Ne zaboravite na disku izraditi zaštitne fazete!

ALAT ZA BRUŠENJE

Da bismo mogli izbrusiti zrcalo, osim staklenog diska za buduće zrcalo, potreban nam je i alat na kojem ćemo brusiti. Kao alat obično se koristi drugi stakleni disk istog promjera kao i onaj za zrcalo, no on može biti nešto tanji. Dobro je da oba diska budu od iste vrste stakla, ali ni to nije nužno. Najčešće se zbog cijene za alat koristi disk od prozorskog stakla.

Kako je kod nas svaka vrsta stakla vrlo skupa a do debljeg stakla se vrlo teško dolazi (najdeblje staklo koje se obično može nabaviti je staklo za prozore izloga debljine 10 mm), može se dogoditi da nam nabavka dva jednaka diska bude prevelik problem. U tom slučaju možemo bez ikakvih problema sami izraditi nešto drugačiji alat. Ovaj alat u principu se sastoji od krutog diska na koji se smolom ili nekim lijepilom (najbolje je dvokomponentno epoksidno ljepilo, npr. Donipox ili UHU) zalijepi prozorsko staklo debljine 6 do 10 mm. Kod malih udubljenja zrcala podloga može biti ravna, no ako izrcalo ima mali polumjer zakrivljenosti, pa mu je udubljenje gotovo jednako debljini nalijepljenog stakla, ili je čak i veće, podloga također mora biti zakrivljena, da kod brušenja nebismo potpuno potrošili gornju staklenu ploču.

Ako je podloga zakrivljena, staklena ploča koja se na nju lijepi ne može biti od jednog komada, jer je ne možemo prilagoditi zakrivljenosti podloge. Umjesto toga, na podlogu se lijepe kvadratići stakla veličine oko 20x20 mm, sa razmakom od 3 do 5 mm između pojedinih kvadratića. Kod ljepljenja kvadratića kreće se iz sredine podloge i to tako da se sredina podloge nalazi ispod jednog kuta staklenog kvadratića, a nikako ne ispod njegove sredine. Na ovaj način izbjegava se pojava koncentričnih zona na zrcalu, koje je kasnije vrlo teško ukloniti.

Kao podloga na koju se lijepi staklo može se upotrijebiti metalni disk ili disk izliven od gipsa ili cementa. Debljina metalnog diska treba biti 1-2 cm (za zrcala do 30 cm promjera), dok je kod gipsanog ili cementnog diska bolje da su nešto deblji (2-4 cm ovisno o promjeru zrcala). Disk od gipsa ili cementa vrlo je jednostavno izraditi. Od drveta izrežite disk potrebnog promjera i po njegovom obodu namotajte nekoliko slojeva debljeg papira tako da dobijete zdjelu potrebne dubine. Papir učvrstite čavlićima, ljepljenjem ili gumicom. Tako izrađen kalup iznutra dobro namažite tankim slojem vazelina ili masti da se gips (cement) ne primi. Potrebnu količinu gipsa izmiješajte sa vodom i ulijte u kalup. Ako radite sa cementom, pomiješajte ga sa pijeskom ili sitnim šljunkom u omjeru 1:1. Idući dan kalup možete ukloniti, a izliveni disk zamojtate u nekoliko slojeva vlažne krpe. Sve zajedno stavite u najlon vrećicu da se vlaga ne izgubi, i ostavite da odleži nekoliko dana, nakon čega disk ostavite na zraku da se dobro osuši. Da ne bi upijao vodu (posebno gips) morate ga prelakirati nekom bojom. Najbolja je boja za beton, ali se mogu koristiti i bezbojni nitrolakovi za drvo ili boje za metal. Možemo upotrijebiti i poliestesku smolu koja ujedno dobro lijepi staklo na disk a najlakše je nabavimo u vidu kompleta za popravljanje auto karoserija. Za naše potrebe dovoljan je najmanji komplet.

Ako disk mora imati zakrivljenu površinu, izrada je nešto složenija. Ova površina ne mora biti previše točna, bitno je samo da otprilike slijedi potrebnu zakrivljenost. Kod metalnog diska u tom slučaju se najčešće tokare stepenice visine 0,5-1 mm, a kod gipsanog diska ove stepenice možemo izliti tako da na dno kalupa složimo nekoliko slojeva masnog kartona s rupama potrebnog promjera. Potrebne promjere rupa (ili istokarenih stepenica) lako izračunamo uz pomoć formule za udubljenje sferne plohe. Promjer plohe sad postaje promjer rupe a udubljenje ukupna debljina slojeva kartona ili visina stepenice (mjereno prema sredini diska!). Kod lijevanja vodite računa o tome da za ispupčeni alat treba udubljeni kalup za lijevanje. Kalup za lijevanje će dakle u sredini imati udubinu, kako bi izliveni alat na tom mjestu imao ispupčenje.

RAVNANJE GORNJE I DONJE PLOHE ZRCALA

Idući korak u izradi zrcala je ravnanje gornje i donje plohe staklenog diska. Kod gornje plohe, a to je ona na kojoj ćemo izraditi samo zrcalo, dovoljno je da se uklone sve neravnine veće od nekoliko desetinki milimetra. Donja ploha može na sebi imati udubine ili oštečenja, ali se mora izbrusiti tako da bude potpuno ravna, jer će na njoj ležati zrcalo i kod izrade i kod rada u teleskopu.

Prije nego što započnemo samo ravnanje ploha, moramo obavezno rubove diskova zakositi pod kutem od oko 45 stupnjeva, kao što smo već opisali na prethodnoj stranici. U toku brušenja treba povremeno kontrolirati rub, i kad se zakošenje smanji ispod 1mm, treba ga ponovno pojačati.

Da bismo poravnali plohe zrcala poslužit ćemo se jednostavnom ali efikasnom metodom. Znamo da kod brušenja gornji disk (zrcalo) postaje udubljen, a donji (alat) ispupčen. Ako kod brušenja u pravilnim vremenskim razmacima zamjenjujemo gornji i donji disk, oba diska postat će približno ravna. Da bi se osigurala apsolutna ravnoća ovako brušenih ploha, koristi se i dodatna, treća, ploha. Naime, ako ove tri plohe u potpunosti odgovaraju jedna drugoj u svim mogućim kombinacijama, one mogu biti samo ravne plohe. Kad plohe ne bi bile ravne, neke njihove kombinacije ne bi odgovarale jedna drugoj, i razlike bi se ubrzo međusobno izbrusile. Postupak brušenja ravnih ploha ovom metodom vrlo je jednostavan. Prvo odaberemo vrijeme brušenja jedne plohe na drugoj, naprimjer 5 ili 10 minuta. Po isteku tog vremena zamijenimo plohe i opet brusimo isto vrijeme. Nakon toga jednu od ploha uklonimo, i umjesto nje uzmemo treću plohu, pa ponovimo cijeli postupak. Bitno je kod ovakvog rada da se naprave sve kombinacije, kojih ima 6. Označimo li plohe slovima A, B i C, možemo ove kombinacije ovako napisati:

brusi A na B
brusi B na C
brusi C na A
brusi A na C
brusi C na B
brusi B na A
brusi A na B

Ove kombinacije mogu se izvesti bilo kojim redom, ali je važno da se sve izvedu isti broj puta. Najbolje je da ih napišemo na komad papira, i da nakon završenog brušenja jedne kombinacije tu kombinaciju prekrižimo. Kad smo tako izveli svih 6 kombinacija, ukupno vrijeme brušenja jednako je šesterostrukom vremenu brušenja jedne kombinacije, a svaki disk brušen je u 4 od 6 kombinacija.

Znam, pitat ćete sad, odkuda nam treći disk? Radimo li zaista ravno zrcalo, ima smisla koristiti tri jednaka diska, jer tako odmah dobivamo tri ravna zrcala. No, koristimo li ovu metodu samo za ravnanje zadnje strane zrcala, treći disk nam nije potreban. Alat i disk zrcala su dovoljni. Naravno, tu zaista moramo imati alat sa ravnom plohom, te ako smo izradili alat unaprijed zakrivljene plohe, moramo izraditi još jedan sa ravnom plohom, ili jednostavno na donju stranu alata zalijepiti dodatni komad ravnog stakla. Kako će ono služiti samo za ravnanje diska zrcala, možemo upotrijebiti i obično prozorsko staklo debljine 3 ili 4 mm. Kod brušenja jednostavno koristimo obje strane diska budućeg zrcala i jednu stranu alata.

Ako su naši diskovi od prozorskog stakla, koje je samo po sebi vrlo ravno, ravnanje ploha mozemo izvesti sa praškom finoće 320 ili čak 600, pri čemu će vrijeme brušenja jedne kombinacije od 5 minuta biti sasvim dovoljno. Ako je pak disk za zrcalo od Boral stakla koje je prešano u kalup, njegove površine najčešće imaju po sebi neravnine zaostale od prešanja koje mogu biti veće od milimetra. U tom slučaju upotrijebit ćemo najgrublji prašak koji imamo i njime brusiti sve dok se bar na jednoj plohi diska zrcala ne uklone sve neravnine. Ovo može potrajati znatno duže, pa se za vrijeme brušenja jedne kombinacije može uzeti 10 min. I pored toga će najvjerojatnije trebati nekoliko puta ponoviti sve kombinacije. Kad su neravnine uklonjene, potrebno je donju plohu dotjerati sa finijim brusnim prahom, barem finoće 220. Ako smo počeli brusiti sa vrlo grubim prahom (#40 ili #70), bit će prvo potrebno izvršiti brušenje sa finijim prahom (#100 ili #120), pa tek onda sa #220. Ne zaboravite prekontrolirati fazete!

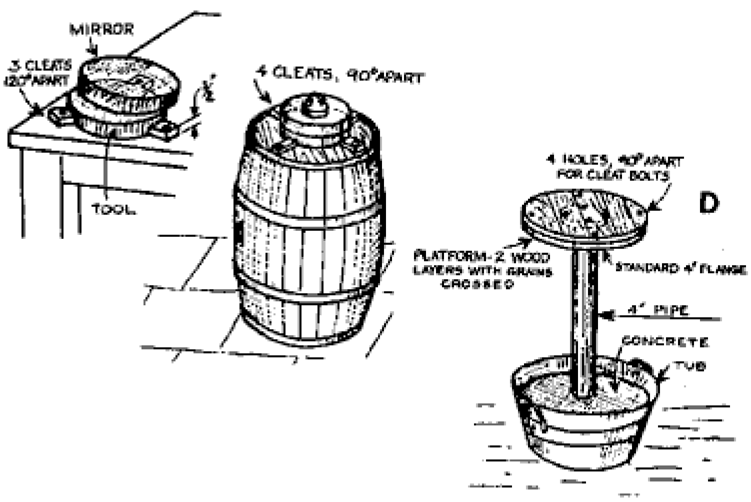
STOL ZA BRUŠENJE

Za brušenje i poliranje moramo imati odgovarajuću radnu površinu. Ova površina mora biti ravna i stabilna kako se kod brušenja i poliranja zrcalo ne bi micalo. Visina joj treba biti takva da, kad se na njoj nalazi zrcalo pripremljeno za brušenje, ruke položene na zrcalo budu negdje u visini pupka. Ploha može biti malo niža ali nikako ne mnogo viša. Ako je ploha niža, morat ćemo se više ili manje nagnuti nad zrcalo čime postižemo veći pritisak na njega, ali ubrzo dolazi do zamora u ledima. Ako je ploha znatno viša, potreban pritisak bit će teško održavati i vrlo brzo će nas početi boljeti ruke. Tu si možemo malo pomoći tako da na zrcalo stavimo uteg koji zamjenjuje pritisak ruku. Kod manjih zrcala (promjera do oko 150 mm) možemo raditi i u sjedećem položaju. U tom slučaju radna podloga moze biti i običan stol na koji ćemo postaviti prikladnu radnu plohu. Primjer takve radne plohe prikazam je na lijevoj slici. Na komad furnirane iver ploće zaostale od posljednje promjene kuhinjskih elemenata mposlavljen je metalni disk (i lakirani drveni disk sasvim je dobar) koji se može okretati. Da se ne bi prelagano okretao, disk leži na gumi, a na mjestu ga drži obična drvena tipla uglavljena u sredinu daske koja lagano ulazi u rupu u sredini metalne ploče. Sve je postavljeno na običan kuhinjski stol. Zrcalo je upravo skinuto sa alata, oprano i osušeno da bi mu se mogao izmjeriti polumjer zakrivljenosti. Radna ploha mora se moći lako čistiti. U prostoriji u kojoj radimo ne smije biti pretoplo, a nikako ne treba polirati na direktnom Suncu. Brušenje nije toliko osjetljivo na vanjsku temeperaturu i može se raditi i vani, što je za grubo brušenje zbog lakšeg čišćenja i prepručljivo.

Poliranje zahtijeva temperaturu izmedu 18 i 25 stupnjeva Celziusa. Postupak brušenja nije tako osjetljiv na temperaturu okoline pa se brusiti može i na ljetnom suncu, naravno dok vama ne postane pretoplo. Ako je prehladno, koćit će vam se prsti pa se zimi ipak ne moze raditi na otvorenom. Za ovakav rad najbolje su podrumske prostorije jer je u njima kroz cijelu godinu stalna temperatura, što je važno kod testiranja i poliranja. Medutim, sasvim se dobro moze raditi i u garažama, šupama, kuhinjama ili kupaonicama. Kod rada u stanu treba paziti na čistoću da vas ukučani ne bi izbacili iz stana ili vam zabranili daljnji rad.

Postupak rada zahtijeva da se gornji disk lagano okreće u jednom, a donji u drugom smjeru. Obično se donji disk pričvrsti na podlogu, pa brusač hoda oko njega. Gornji disk je slobodan i s njime se vrše pokreti brušenja i potrebno okretanje u drugom smjeru. Radna ploha koja omogučava hodanje oko nje obicno je montirana na malom stoliću ili tronošcu koji mozemo i sami izraditi. Američki amateri vrlo rado u ovu svrhu koriste bačve za naftu. Njihova prednost je da su odgovarajuce visine, da se mogu donijeti na željeno mjesto i onda napuniti vodom da bi bile stabilne. I mi smo se često koristili bavama, no njih nažalost zaista ne možete staviti u stambeni prostor.

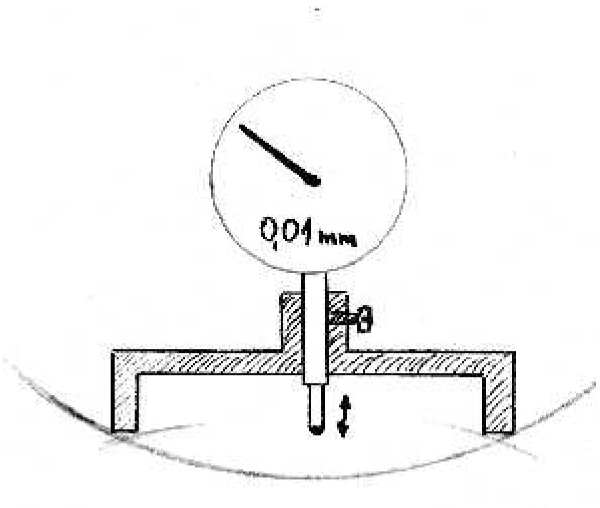
Alat se na radnu plohu, bez obzira da li se radi o radnoj dasci ili cijelom stoliću, pričvrsti na isti način: sa tri drvene dašćice prikucane na gornju dasku. Da bi alat mogli lako ukloniti, jedna od tih dašćica je malo odmaknuta od alata a alat se uglavljuje malim drvenim klinom. Klin se treba utisnuti samo toliko da se alat kod rada ne miće. Ako je prejako utisnut, može doći do deformacija alata, a kao posljedica toga i do nepravilne plohe zrcala. U većini slučajeva dovoljno je da se klin utisne rukom, a ako to nije dovoljno upotrijebite maleni čekić i vrlo lagane udarce.



JEDNOSTAVNI SFEROMETRI

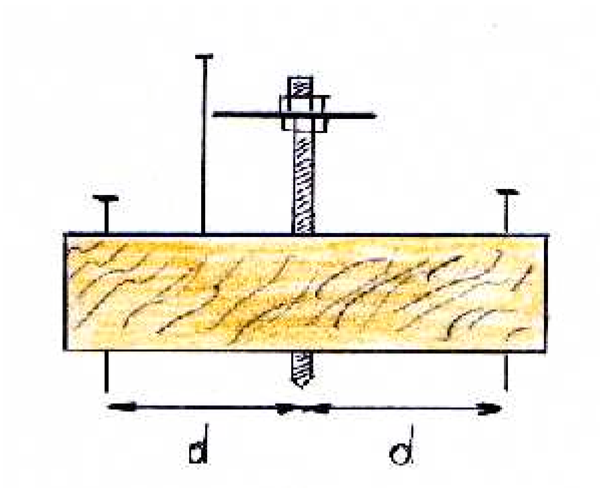
Sferometar je sprava za mjerenje polumjera zakrivljenosti sferne plohe. Ovo je precizni instrument kojim se najčešće mjeri udubljenje plohe, pa se onda iz udubljenja računa polumjer zakrivljenosti.

Da bi se točnost mjerenja poboljšala, udubljenje plohe se obično određuje kao razlika očitanja mikrometarskog vijka ili mjerne ure kod mjerenja sferne plohe i mjerenja referentne ravne plohe. Za ovakvo mjerenje moramo naravno imati preciznu ravnu plohu. I dok profesionalni optičari za tu svrhu koriste točno polirane kvarcne standarde, mi kao referentnu plohu možemo upotrijebiti zadnju stranu zrcala, naravno ako smo je pažljivo izbrusili tako da bude ravna, o čemu će još bit riječi.



Na ovoj skici prikazan je sferometar sa čašicom. On se vrlo često koristi jer ga relativno lako izraditi. U profesionalnoj izvedbi čašica je napravljena od kaljenog čelika sa precizno brušenim rubovima. Za amaterski rad dovoljna je točno istokarena čašica, pri čemu treba paziti da rubovi budu oštri (s vremena na vrijeme prebrusimo čašicu na komadu ravnog stakla brusnim praškom veličine zrna oko 100, pomiješanim sa uljem). Pbratite pažnju na to da se za mjerenje udubljenih ploha koristi vanjski, a za mjerenje ispupčenih ploha unutarnji rub čašice.

Najčešće ipak nemamo pristup tokarskom stroju. U tom slučaju možemo izraditi jednostavni sferometar od obične dašćice, dva čavlica i običnog vijka. Skica ovakvog sferometra prikazana je na slijedećoj slici.

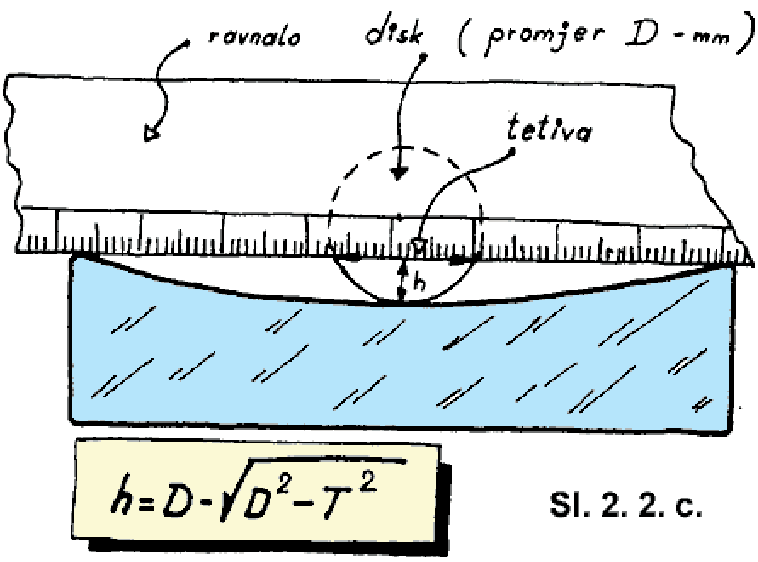


Ako ga pažljivo izradimo, ovakav jednostavni sferometar može biti će dovoljno točan za naše potrebe. Ako možemo, rupu za vijak i rupice za čavliće probušimo na stupnoj bušilici kako bi bile potpuno okomite na dašćicu. Za čavlice bušimo rupice nekoliko desetinki mm manjeg promjera od promjera čavlića, a za vijak 1 mm manju od promjera vijka. Najbolje je upotrijebiti vijak M6 jer on ima hod od 1 mm, pa nam je lako izraditi podjelu na kotačiću koji na njega montiramo i sa kojeg ćemo očitavati pomak vijka.

Kao kotačić upotrijebimo kartonski ili plastični disk promjera 5-10 cm na koji nacrtamo podjelu kruga na 20 dijelova (crtica svakih 18 stupnjeva). Zaokret vijka za 1 podjelu odgovara pomaku vrha vijka od 0,05 mm (ako je vijak M6!) što je za naše potrebe dovoljna točnost. Vrh vijka turpijom zašiljimo, pri čemu je dovoljno da on bude smanjen na promjer od oko 1 mm. Pazimo pri tome da je šiljak u osi (sredini) vijka. Isto vrijedi i za vrhove čavlića. Dobro je vrhove čavlića i vijka zaobliti brušenjem sa finim brusnim papirom kako kod mjerenja ne bismo slučajno zaparali staklo. Vijak namažemo sapunom ili uljem i na silu ga uvrtimo u srednju rupu u drvenoj letvici. Pazimo pri tome da vijak ide okomito u nju. Na ovaj način smo u drvetu napravili maticu koja nema zazora pa će mjerenje biti točnije. Kao pokazivač mozemo uz disk u letvicu zabiti mali čavlić.

Razmak vrhova čavlića odaberemo tako da je za 1 do 2 cm manji od promjera zrcala jer veći razmak čavlića omogučava točnije mjerenje. Ovim sferometrom mjeri se tako da se on bez pritiska prisloni uz ravnu plohu (zadnja strana zrcala ili sl.), pa se laganim zakretanjem vijka njegov vrh dovede u dodir sa plohom. Kod toga treba paziti da se mikrometar drži tako da vijak stoji okomito na plohu.Sad se očita i zapiše polozaj vijka prema skali na njemu. Na ovaj način smo odredili tzv. nulu mjerenja, odnosno pložaj vijka kad je udubina zrcala jednaka nuli. Postupak mjerenja sad ponovimo na sfernoj plohi zrcala, pri čemu ne smijemo zaboraviti brojiti i pune okrete vijka jer svaki od njih dodaje po 1 mm izmjerenom udubljenju. Udubljenje sferne plohe razlika je položaja vijka kod mjerenja na sfernoj i na ravnoj plohi. Ovu vrijednost uvrstimo u formulu za polumjer zakrivljenosti sfernog zrcala, gdje umjesto polumjera zrcala uvrstimo polovicu razmaka čavlića mikrometra. Razmak čavlića najlakše odredimo tako da sferometar lagano pritisnemo na papir. Vrhovi čavlića na njemu će ostaviti otiske čiji razmak pažljivo izmjerimo ravnalom. Kao polumjer mjerenja, d, uzmemo polovicu ove vrijednosti. Točnost od nekoliko desetinki milimetra je ovdje dovoljna.

Kad nije potrebna velika preciznost možemo umjesto sferometra upotrijebiti neki drugi predmet poznate debljine, npr. limove za podešavanje razmaka ventila kod automobilskih motora i ravnalo i tako vrlo jednostavno odrediti zakrivljenost našeg zrcala. Ravnalo stavimo na zrcalo tako da leži preko njegove sredine, pa limove umećemo ispod njega dok ne dobijemo potrebnu debljinu. Za račun zakrivljenosti koristimo istu formulu kao i kod sferometra, samo što za promjer sferometra uvrštavamo promjer zrcala jer se ravnalo proteže preko cijelog zrcala. Pazimo pri tome da oduzmemo fazetu koju smo izbrusili na rubu diska!



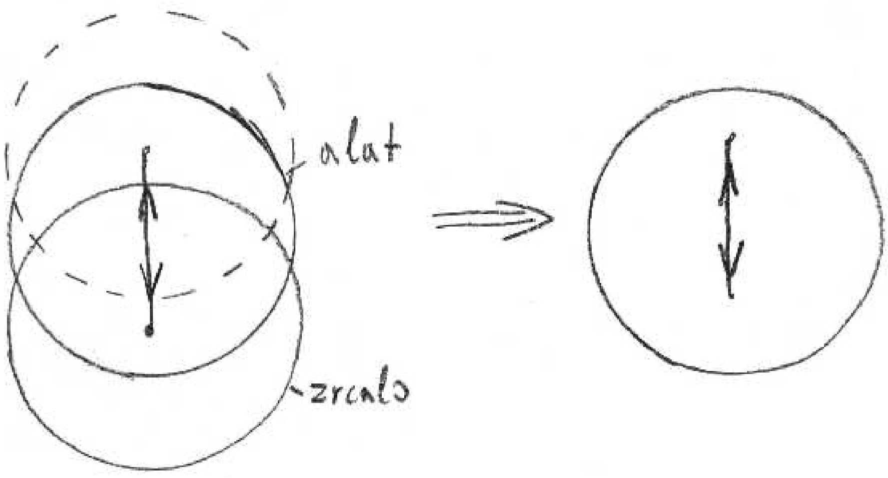
$$h = D - \sqrt{D^2 - T^2}$$

Sl. 2. 2. c.

Slika 2.2c - Kad nije potrebna velika preciznost mozemo upotrijebiti novcic i ravnalo i na taj jednostavan nacin odrediti zakrivljenost naseg zrcala.

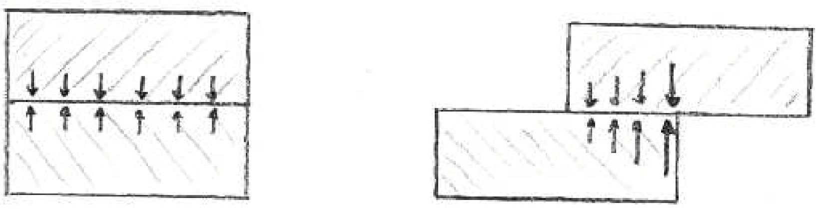
GRUBO BRUŠENJE

Kod brušenja gornji disk (buduće zrcalo) mičemo uz pritisak amo-tamo po donjem disku (alatu) koji je namazan tankim slojem ovlaženog brusnog praha. Ovisno o načinu izvođenja pokreta i finoći brusnog praha gornji disk se brže ili sporije dubi pri čemu oblik udubine ovisi o pokretima kod brušenja. Zbog toga se koristi nekoliko različitih vrsta pokreta sa različitim utjecajem na oblik i produbljivanje udubine na zrcalu. Da stvari što zornije prikažemo, poslužit ćemo se grafičkim prikazom izvođenja pokreta. Kod skica pokreta skicira se pogled na alat odozgo i na njemu se označi put koji kod izvođenja pokreta prelazi središte zrcala.



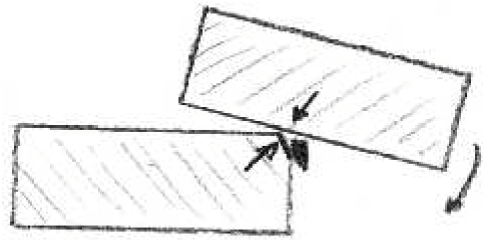
Kod osnovnog pokreta zrcalo se postavlja na alat centrično. Na zrcalo lagano stavimo obje ruke i uz umjereni pritisak mičemo zrcalo naprijed natrag tako da središte zrcala prelazi preko središta alata. Po tome je pokret dobio ime centralni ili poprečni, jer središte zrcala putuje preko središta alata. Dužina pokreta izražava se u dijelovima promjera zrcala, tako da npr. pokreti od 1/2 promjera znaće da kod micanja zrcala naprijed-natrag njegovo središte prevaljuje put otprilike jednak polovini promjera zrcala. Kad na ovaj način napravimo 6 do 10 pokreta naprijed-natrag, zaokrenemo zrcalo za neki kut (recimo 30 do 40 stupnjeva) udesno, a alat za nešto manji kut (10 do 15 stupnjeva) ulijevo pa opet napravimo 6 do 10 pokreta, itd. Ako je alat fiksiran, npr. na popularnoj bačvi, umjesto da alat zaokrećemo, pomaknemo se mi za taj kut oko njega. Ovdje je VAŽNO istaknuti da niti dužinu pokreta, niti kuteve okretanja ne smijeno izvoditi precizno. Naime, pokušaj da oni budu uvijek apsolutno jednaki dovodi do periodičkih odstupanja plohe zrcala od sfernog oblika što se kasnije teško ili nikako ne može ispraviti. Važno je samo da prosječna duzina pokreta i prosječni kutevi zakretanja budu slični navedenim vrijednostima.

Pogledajmo sad malo podrobnije što se kod ovakvog pokreta dešava sa zrcalom i alatom. U trenutku kad su zrcalo i alat točno jedan na drugome, podjednako su opterečene sve točke i alata i zrcala. Međutim, kad se zrcalo izmakne u krajnji položaj

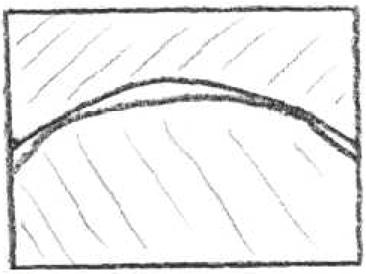


površina dodira izmedu zrcala i alata se smanjuje pa se opterečenje na preostaloj površini dodira povečava. Brzina brušenja ovisna je o opterečenju, pa će se kod sad više trošiti dijelovi alata i zrcala koji su u tom trenu u dodiru. A to su kod alata rubni, a kod zrcala središnji dijelovi diska. Na taj način zrcalo postaje udubljeno a alat ispupčen. Nastala ploha je približno sfernog oblika zato jer kod ploha čiji oblik nije sferan dolazi do kontakta samo u nekim točkama plohe, pa se ti dijelovi vrlo brzo izbruse i oblik plohe se automatski približava sfernom. Jedino dvije sferne plohe istog polumjera zakrivljenosti možemo micati jednu po drugoj, a da pri tome one uvijek budu u svim svojim točkama u dodiru. Ovaj jednostavan geometrijski princip i ovisnost brzine brušenja o pritisku omogučavaju nam da izradimo sferne plohe vrlo velike preciznosti!

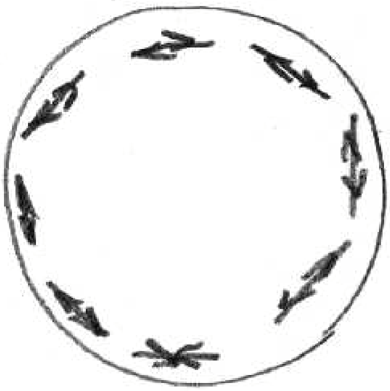
Stalno zakretanje alata i zrcala služi tome da se i alat i zrcalo jednako bruse po svim svojim promjerima. Kad bismo izostavili ovo zakretanje, dobili bismo umjesto sferne, cilindričnu plohu, koja je za nas neupotrebiva (cilindrične plohe se upravo tako i bruse!).



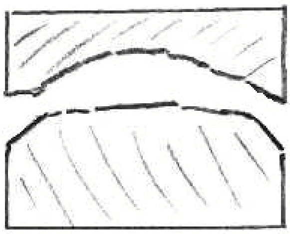
Što je centralni potez duži, brže se stvara udubina na zrcalu. Međutim, kod pokreta dužih od 2/3 promjera može doći do odvajanja (klackanja) zrcala od alata što se pod svaku cijenu mora izbjeći jer ovakvo klackanje zbog naglog opterečenja ruba alata obično dovodi do odlamanja komadića stakla s alata i paranja plohe zrcala. Zbog toga se centralni pokreti duži od oko 2/3 promjera ne koriste. Vrlo brzo se stekne osjecaj kod koje dužine pokreta zrcalo postaje nestabilno pa brusač automatski skrati pokrete da izbjegne klackanje zrcala. Pored toga, kod dugih centralnih pokreta (ovo su pokreti dužine 1/2 do 2/3 promjera) ploha zrcala i ploha alata ne dobijaju sferni vec hiperbolični oblik.



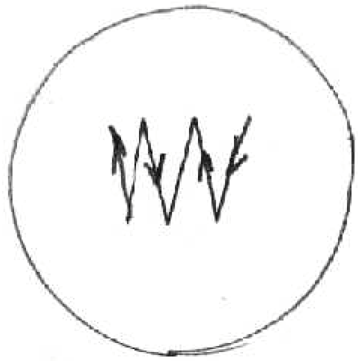
Hiperbolične plohe se vrlo brzo i lako dovode u sferni oblik kračim centralnim potezima (potezima dužine oko 1/4 promjera). Dugi centralni potezi koriste se zato na početku grubog brušenja da bi se što prije iskopala potrebna udubina zrcala. Kad je udubina iskopana, plohe se dovedu u sferni oblik kračim potezima koji se onda dalje koriste i kod finog brušenja.



Kod zrcala većih promjera "kopanje" udubine centralnim potezima vrlo je sporo, bez obzira na dužinu poteza. Zbog toga se često koristi tzv. forsirano brušenje koje se sastoji od toga da se sredina zrcala miče po tetivama alata, vrlo blizu njegovom rubu. Ovakvi potezi vrlo brzo bruse udubinu zrcala, ali je dobiveni oblik izrazito nepravilan, obično stepenast.



Ako se koriste forsirani potezi, prelazi se na duge centralne poteze kad udubina dosegne potrebnu vrijednost, ili je čak malo i premaši, jer će se kod prbližavanja obliha plohe sfernom udubina malo smanjiti. Na kraju se opet prijeđe na kratke centralne poteze da bi se ploha dovela što bliže sfernom obliku. Još jedan nedostatak centralnih poteza je taj da neki puta mogu dovesti do pojave zona na zrcalu koje su obično posljedica prepravilnog ponavljanja pokreta brušenja. Da se to izbjegne može se na kraju grubog brušenja umjesto kratkog centralnog poteza početi koristiti "W" potez.



Kod ovog poteza, koji se uglavnom koristi za fino brušenje i poliranje, možemo mijenjati dužinu poteza i njegovu širinu. Tipičan W potez ima dužinu izmedu 1/4 i 1/3 promjera zrcala i širinu oko 1/5 promjera zrcala. Variranjem dužine i širine "W" poteza, mjesta na kojem se on izvodi i mjesta pritiska na zrcalu postize se većina korekcija kod završnog poliranja, no o tome više kasnije. Kod brušenja se "W" potez izvodi kao centralni potez, tj. središte "W" figure koju opisuje središte zrcala uvijek se nalazi u blizini središta alata.

Recimo još samo to da, u slučaju da smo pretjerali s "kopanjem" i dobili preveliku udubinu na zrcalu, grešku vrlo jednostavno možemo ispraviti tako da na kratko zamijenimo mjesta alata i zrcala. Dakle zrcalo dolje, a alat gore. Sad će se više trošiti rub zrcala i sredina alata pa će se udubna smanjiti. **OPREZ:** ovo je vrlo efikasno, pa često kontrolirajmo udubinu, da je nebismo previše smanjili! Kod ovakvog "vračanja" udubine koristite kraće "W" ili centralne poteze.

Svrha grubog brušenja je da se što prije i sa što manje napora u staklenom disku izradi udubina približno sfernog oblika i potrebne dubine. Zbog toga se u ovoj fazi za rad koristi najgrublji karborundum. Može se bez ikakvog problema koristiti i korund, ako do karbunduma ne možemo doći. Jedina razlika je u tome da korund sporije "grize" staklo, pa ćemo na kopanje udubine morati utrošiti više vremena. Finoća karborunduma sa kojim ćemo raditi ovisi o veličini staklenog diska i udubini koju je potrebno napraviti. Ako je stakleni disk velik ili je udubina duboka (recimo više od nekoliko mm) grubo brušenje započinje se prahom finoće 70 ili čak 40. Kod diskova promjera oko 15 cm uz dubine plohe od 1 do 2 mm, ovaj prah je pregrub pa je bolje grubo brušenje započeti sa praškom finoće 120. Kod zrcala manjeg promjera i kad su udubine manje od 1 mm, može se poćeti brusiti i sa praškom finoće 220. Naime, moramo računati da nam za svaku frakciju (tj. finoću brusnog praha) treba oko 1 do 2 sata brušenja da bismo uklonili tragove brušenja prethodnom, grubljom frakcijom. Ako je udubina mala, isplati se potrošiti nešto više vremena na grubo brušenje finijom frakcijom jer tada otpada tih sat do dva brušenja koje bismo ionako tom frakcijom morali odraditi da uklonimo tragove grublje frakcije kojom smo tako brzo izradili želejnu udubinu.

Ovdje je iskustvo najbolji vodić. Zbog toga je uvijek dobro voditi dnevnik brušenja u koji se zapisuju najbitiniji podaci o postupku brušenja: frakcija, potezi, vrijeme brušenja i postignuti rezultati (npr. udubljenje zrcala po završetku rada).

Kod grubog brušenja koriste se ili dugi centralni potezi ili forsirani potezi. Forsirani potezi obično se koriste kod većih zrcala (promjera 15 cm i više) i kad su udubine veće od nekoliko mm. Brusni prah miješamo sa vodom tako da dobije oblik blata ili paste. Grubi prah gotovo odmah se slegne na dno posude, a ako iznad njega zaostane nešto vode, ne smeta. Žlićicom zagrabimo prah i nanesemo ga preko cijele plohe alata sa nekoliko poteza. Zrcalo postavimo odozgo, i sa dva-tri lagana kružna poteza rasporedimo brusni prah preko cijele plohe zrcala jednoliko. Tek tada započinjemo sa brušenjem. Grubi brusni prah brzo se usitnjava pa ga često treba dodavati. Kod dodavanja odvojimo staklene diskove i kao i prije nanesemo novi prah na alat. Prah se dodaje kad se zvuk brušenja utiša, što je siguran znak da se prah između zrcala i alata usitnio. S vremena na vrijeme treba zrcalo i alat oprati vodom da se ukloni stari prah i smrvljeno staklo. Otprilike svakih pola sata, a pred kraj grubog brušenja i češće, treba kontrolirati udubinu zrcala. Kod grubog brušenja možemo istrošeni prah sakupiti (mnogo ga jednostavno bude izgurano sa alata prilikom brušenja). Sakupljeni prah isperemo vodom tako da ga stavimo u neku posudu, zamutimo, pričekamo 5-6 sekundi i odlijemo vodu koja ostaje iznad staloženog praha. U vodi će ostati čestice stakla i smrvljenog praha koje ćemo tako dovojiti od još dobrog praha na dnu posude. Postupak pranja ponovimo 2-3 puta. Na taj način možemo dosta uštedjeti na utrošenom prahu. Kod finog brušenja ovo ne smijemo raditi jer dolazimo u opasnost da na zrcalo vratimo neko zaostalo zrno grublje frakcije i izgrebemo ga njime.

Pred kraj grubog brušenja moraju se forsirani potezi zamijeniti centralnim da bi se oblik plohe priblizio sferi. Koristimo nešto kraće centralne poteze (1/2 do 1/3 promjera) da bi se popravio oblik plohe koju brusimo. Grubo brušenje prekida se kad je udubina nešto manja od potrebne. Vrlo je teško reći koliko je to nešto manje jer će se udubina povečavati i kod finog brušenja, ali mnogo sporije. Kod zrcala uobičajenog F/ broja (izmedu F/5 i F/10) grubo brušenje treba prekinuti kad udubina bude 0,05-0,1 mm manja od potrebne. Po završetku grubog brušenja moramo dobro oprati zrcalo, alat i radni stol. Zaostane li kod toga ma i jedno zrno grubog brusnog praha, ono može kasnije doći između zrcala i alata i u hipu izgrebsti zrcalo. U tom slučaju preostaje nam samo da fino brušenje ponovimo od početka, a to može značiti desetak sati rada koji se mogao izbjeći pažljivijim pranjem i čišcenjem. Ako možemo, dobro je ispod alata podmetnuti plastičnu foliju koju na kraju brušenja određenom frakcijom jednostavno bacimo i stavimo novu foliju umjesto nje.

Kod brušenja grubim prahom brušena ploha (na slici gornja ploha diska) potpuno je mutna i neprozirna, pa se kroz nju ne mogu pročitati ni najveća slova novina na kojima disk leži (disk na slici promjera je 160 mm i debljine 20 mm). Kod ovog testa mutnoća donje plohe ne smeta jer ona leži direktno na novinama.

FINO BRUŠENJE

Postupkom finog brušenja uklanjaju se velike neravnine na staklu koje su posljedica brušenja grubim brusnim prahom kod izrade udubine. Uz to se istovremeno polumjer zakrivljenosti dovodi na željenu vrijednost. Dogodi li se da on postane premalen (udubina prevelika) ne treba očajavati. Dovoljno je zamijeniti mjesta alata i zrcala (dakle alat gore a zrcalo dolje) i uskoro će se udubina poceti smanjivati. Već kod finoće brusnog praha oko 600 udubina se praktički ne mijenja, barem ne toliko da bi nas to moralo zabrinjavati. Jedina posljedica polumjera zakrivljenosti koji za nekoliko cm odstupa od onog koji želimo izraditi je kod Newtonovog tipa teleskopa promjena zarišne daljine odnosno dužine cijevi. Zbog toga je rezanje cijevi na mjeru dobro ostaviti do trenutka kad zrcalo bude dovršeno jer ćemo tek tada znati njegovu točnu zarišnu daljinu. Kod finog brušenja koriste se kraći centralni potezi (1/4 do 1/3 promjera) ili W potezi iste dužine i širine oko 2 cm. Neke bitnije razlike među njima nema, osim što W potezi pomažu izbjegavanju zona kod brusača koji pretočno ponavljaju svoje pokrete.

No vratimo se finom brušenju. Po završetku grubog brušenja prelazimo na brušenje sa prvom finijom frakcijom brusnog praha. Naprimjer, ako smo grubo brusili sa prahom finoće 120, sad brušenje nastavljamo sa prahom finoće 220, pa 400 itd. Za svaku frakciju treba potrošiti najmanje 1 sat rada da bi se uklonili tragovi brušenja prethodnom frakcijom. Ako nismo sigurni da su svi tragovi uklonjeni, bolje je još malo produžiti brušenje. Kod prve dvije tri frakcije finoću površine lako ocijenimo promatranjem osušene i dobro osvijetljene plohe zrcala malim povečalom. Cijela površina mora izgledati jednako, bez većih uočljivih oštećenja i ogrebotina. Obratite pažnju na rub zrcala jer se on brusi najsporije. Udubine (točkice ili piknjice kako se često nazivaju) zaostale od grubog brušenja kod poliranja se pojavljuju iz ni čega i više se ne mogu ukloniti. Kad se zrcalo metalizira ističu se kao sivilo plohe a svjetlo raspršeno na njima kvari kontrast slike i ispire detalje. Zato budite vrlo pažljivi kod procjenjivanja da li su tragovi prethodne frakcije uklonjeni ili nisu. Mnogi amateri, posebno oni neiskusni, ne žele riskirati pa sa svakom finoćom brusnog praha bruse dva puta duže nego što je to ovdje preporučeno, dakle oko dva sata po frakciji. Na taj su način sigurni da su svi tragovi brušenja prethodnom frakcijom uklonjeni. Želiko li izbjeći ovaj dodatni rad, možemo si pomoći tako da dva komadića stakla međusobno brusimo nekoliko minuta samo onom frakcijom praha sa kojom trenutno radimo. Možemo si tako napraviti i cijelu seriju stakalaca medusobno brušenih samo sa jednom frakcijom brusnog praha, od one nagrublje, do one najfinije. Sad mozemo uspoređivati izgled plohe zrcala i ovako izbrušenog stakalca. Izgleda li ploha zrcala grublje, znaći da tragovi od brušenja grubljom frakcijom još nisu uklonjeni, pa brušenje još treba nastaviti. Ovdje je dosta važno da stakalca budu od iste vrste stakla kao i zrcalo. Boral brušen istim brusnim prahom kao i prozorsko staklo izgleda finije od njega jer je tvrđi pa nas to moze zavarati. No, imamo li alat od prozorskog stakla, možemo u tom slučaju maša stakalca uspoređivati sa plohom alata. Kasnije samo površinu zrcala projerimo povečalom, da ne bi slučajno imala većih ogrebotina.

Ponovimo još jednom: **ako nismo sigurni da su svi tragovi brušenja prethodnom frakcijom uklonjeni, nastavimo brušenje sve dok ne budemo potpuno sigurni da su svi tragovi brušenja grubljim prahom zaista uklonjeni. Pazite na rub zrcala!**

Na kraju finog brušenja već se kroz zrcalo (gornja ploha diska na slici je ploha zrcala) dadu čitati veća slova.

IZRADA MATRICE ZA POLIRANJE

Matrica na slici izrađena je ljepljenjem prethodno izrađenih kvadratića smole na alat za brušenje (promjer matrice je 160 mm).

Kad je fino brušenje završeno, možemo pristupiti poliranju zrcala. Dok smo kod brušenja izmedu dvije staklene plohe nanosili sve finiji i finiji brusni prah i tako smanjivali neravnine površine zrcala i alata, kod poliranja postupak je nešto drugačiji. Kod izrade preciznih optičkih ploha kao alat za poliranje gotovo isključivo se koristi smola. Smola je u stvari vrlo gusta tekučina koja u toku poliranja mijenja svoj oblik zajedno sa plohom zrcala i tako joj se stalno prilagođava. U inozemstvu se mogu nabaviti već gotove smole za poliranje, no u našoj zemlji to još nije moguće, barem ne u malim količinama, pa ćemo smolu morati prirediti sami. Gotovo svaka knjiga o izradi zrcala iznosi i pokoji "svoj" recept za smolu za poliranje, no glavni sastojci svih tih recepata uglavnom su isti. Za naše zrcalo potrebno je oko 1/2 do 1 kg smole za poliranje (bolje nešto više jer se lako može dogoditi da prvu matricu oštetimo pa ćemo morati izraditi novu). Nabavimo zato slijedeće sastojke:

bitumen oko 1 kg
kalafonij 1 kg
pčelinji vosak 50 do 100 g

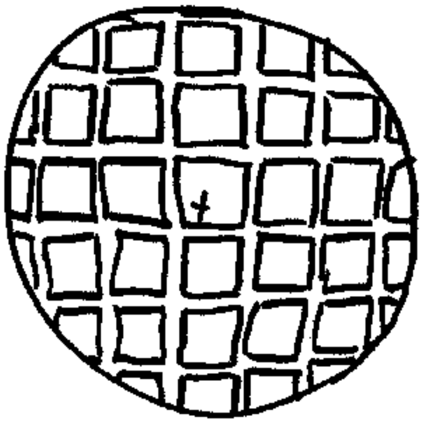
Bitumen mora biti tvrd. Nemojte kupovati tekući bitumen koji se koristi za premazivanje podova, automobila i sl. već kruti bitumen koji se mora topiti na vatri. Vrlo dobar je bitumen za ljepljenje krovnih ljepenki, ali ga je teško kupiti u količinama manjim od 25 kg. Postoji li u vašoj blizini neko gradilište, pokušajte zamoliti radnike da vam daju komadić te, za vas dragocjene, crne mase. Vrlo je dobra i crna postolarska smola koja se može dobiti i u malim količinama ali je ona znatno skuplja od bitumena.

Smolu za poliranje dobit ćemo tako da u nekoj staroj posudi rastopimo bitumen, pa mu zatim dodajemo kalafonij dok smola ne postane dovoljno tvrda, kako se to u optičkom žargonu kaže. Tvrdoću možemo otprilike odrediti tako da manju količinu rastopljene smole ohladimo tekućom vodom i onda u nju pokušamo utisnuti nokat. Smola je dobre tvrdoče kad nokat teško ulazi u nju. Ako ide lagano, premekana je i treba dodati još kalofonija, ili je otvrdnuti dugotrajnim kuhanjem. Ako nokat i kod jakog pritiska ostavlja samo plitak trag, smola je pretvrda i treba je omekšati dodavanjem bitumena. Ne pomaže li ni to (što je prilično nevjerojatno) možete dodati nekoliko kapi terpentina, no oprezno, jer i mala količina terpentina jako omekša smolu.

Tvrdoča smole jako ovisi o vanjskoj temperaturi. Sa porastom temperature smola naglo postaje mekša, tako da smola koja je dobra za rad na sobnoj temperaturi (oko 20 stupnjeva C), već kod 24 ili 25 stupnjeva postaje premekana, a ispod 18 pretvrda. U slijedećoj tabeli dani su recepti za smolu za poliranje. Postoci se odnose na težinu pojedinih sastojaka.

tip smole	kalafonij (%)	bitumen (%)	vosak (%)	radna temperatura (C)
P10	70	29	1	30 - 35
P9,5	60	39	1	25 - 30
P9	50	49	1	20 - 25
P8,5	38	61	1	18 - 22
P8	15	84	1	15 - 20

Kad smo "skuhali" smolu željene tvrdoće, možemo pristupiti izradi matrice za poliranje. Matricu za poliranje čini sloj smole debeo 3 do 8 mm, koji svojom zakrivljenošcu slijedi oblik plohe zrcala. Obično se ovaj sloj smole nanaša na alat za brušenje jer on već ima potrebnu zakrivljenost podloge, ali se kao podloga za smolu može koristiti i drugi komad stakla, metala ili sl. Bitno je da se debljina sloja smole ne mijenja od sredine do ruba podloge (barem ne više od oko 1mm). Da bi se matrica brže prilagođavala plohi zrcala, na njenoj površini izrezuju se kvadratići veličine 15 do 25 mm, ovisno o veličini zrcala, kod čega je važno da se sredina podloge nalazi u blizini ruba središnjeg kvadratića kako bi se izbjegla pojava zona na plohi zrcala. Zato se izrada ili lijepljenje kvadratiča matrice uvijek počinje od središnjeg kvadratića.



Najjednostavniji način izrade matrice je da se po rubu alata zalijepi traka masnog papira koja za oko 1,5 cm viri iznad ruba gornje (zakrivljene) plohe alata. Sad priredimo smjesu praha za poliranje i vode tako da lići na rijetko blato. Ne dodajte previše vode jer će ona, barem u početku poliranja, samo smetati i usporavati proces poliranja. Rastopljena smola za poliranje ulije se u priređeni kalup tako da tvori sloj debljine 8 do 10 mm. Smola ne smije biti prevruća da podloga ne bi pukla, a dobro je da se i podloga zagrije na 40 do 50 stupnjeva C (taman toliko da se još može držati u ruci). Smola se zagrije samo toliko da bude gusta kao med. Kad je smola ulivena u kalup, treba pričekati dok se toliko ne ohladi da više ne može teći, ali da još bude mekana. U međuvremenu plohu zrcala namažemo prije pripremljenom smjesom vode i praha za poliranje. Kad smola dovoljno otvrdne, uklonimo papir sa ruba podloge i na smolu spustimo zrcalo, pazeći pri tome da ispod njega ne zaostanu mjehuri zraka. Zato ga spuštamo koso tako da dodirne smolu na jednom rubu podloge pa ga onda polagano dovedemo u kontakt sa cijelom površinom smole. Kod toga zrcalo mićemo laganim kružnim potezima preko matrice i postepeno povećavamo pritisak na njega. Navlažimo li vodom zadnju stranu zrcala lijepo će se vidjeti koji dijelovi zrcala su u dodiru sa smolom, a koji još nisu. Dijelovi koji su u kontaktu sa smolom izgledaju sasvim crno. Kod ovog postupka dio smole bit će istisnut preko ruba podloge a debljina sloja smole će se smanjiti, ali na to se ne treba obazirati. Ohladi li se smola previše, tako da ni uz veliki pritisak više ne uspijevamo poboljšati kontakt zrcala i smole, smolu zagrijemo uranjanjem u vruću vodu (60 - 70 C). Tek kad je zrcalo sa svim svojim dijelovima u kontaktu sa smolom, ovaj dio posla je završen. Zaostane li pri tome nekoliko malih mjehurića zraka (ne većih od 2-3 mm), na njih se ne trebamo obazirati. Zrcalo sad odvojimo od smole, operemo i odložimo na stranu. Na smoli sad moramo izrezati kvadratiće. Najbolje je da prvo nekim oštrim predmetom zacrtamo linije po kojima ćemo rezati. Samo rezanje vrlo je prljav posao i najbolje je da se radi vani i u starom odijelu. Oštrimo nožem prvo uklonimo višak smole koji je kod formiranja matrice bio istisnut preko ruba podloge i to tako da je odrezani rub smole malo zakošen prema gore (promjer gornje plohe smole treba biti par milimetara manji od promjera zrcala. Kvadratiće izrezujemo oštrim nožem namazanim sapunicom ili sličnim alatom. Smola ne smije biti prehladna jer će inaće pucati kao staklo. Ne pokušavajte jednim rezom izdubsti cijeli kanal koji treba biti širok 3 do 4 mm i isto toliko dubok, već svakim rezom zarežite oko 1 mm u dubinu. Potrebno je dosta vježbe da bi se ovaj postupak naučio. Često puta se dogodi da se kod urezivanja uništi matrica pa je potrebno izliti novu. Kod urezivanja si možemo pomoći na nekoliko načina. Mozemo naprimjer kanale istopiti starim lemilom, pa rubove nakon toga popraviti nožem. Nešto više posla iziskuje izrada drvenog kalupa u koji se lijevaju pločice smole potrebnih dimenzija, koje se zatim s jedne strane naglo zagriju na plamenu (svijeća ili širitusni plamenik su dovoljni za to) i pritisnu na podlogu. Drvo kalupa mora biti glatko i prije lijevanja dobro navlaženo (namočite ga na pola sata u vodu) da se smola ne bi zalijepila. Texereau u svojoj knjizi o izradi zrcala preporuća isključivo ovaj način izrade matrica za poliranje, a iz svojeg iskustva mogu reći da se na taj način zaista najlakše izrađuje matrica koja od prve ispadne odlično. Isplati se dakle nešto vremena uložiti u pripremu da bi posalo kasnije bio jednostavniji!

Kad su kanali gotovi, zagrijemo matricu u toploj vodi (30 do 40 C) i na nju postavimo zrcalo premazano smjesom za poliranje. Zrcalo opteretimo sa nekoliko kg tereta i tako ostavimo dok se smola ne ohladi, dakle oko četvrt do pola sata.

Ovaj postupak naziva se toplo prešanje i on osigurava podudarnost ploha smole i zrcala (tzv. kontakt) prije početka rada. Nije li kontakt dobar, zrcalo će se nejednoliko polirati a dobivena ploha bit će nepravilna i trebat će uložiti mnogo truda da se njen oblik popravi na sferu. Dobar kontakt najvažniji je za uspjeh poliranja i kasnijeg korigiranja zrcalne plohe. Osim toplog prešanja postoji i hladno prešanje koje se primenjuje u pauzama kod poliranja, kad je kontakt vec postignut, pa ga samo treba održavati. Kod hladnog prešanja se zrcalo premazano smjesom za poliranje postavi na matricu i optereti kao i kod toplog prešanja, ali se sada tako ostavi nekoliko sati ili čak i preko noći (u tom slučaju ne opterečujte zrcalo; njegova težina sasvi je dovoljna!). Pri tome treba paziti da se smjesa za poliranje ne osuši pa je dobro rub zrcala i matrice omotati vlažnom krpom. Osuši li se smjesa za poliranje, smola će se zalijepiti na staklo a kod pokušaja odvajanja zrcala najčešće dolazi do lomljenja matrice.

POLIRANJE

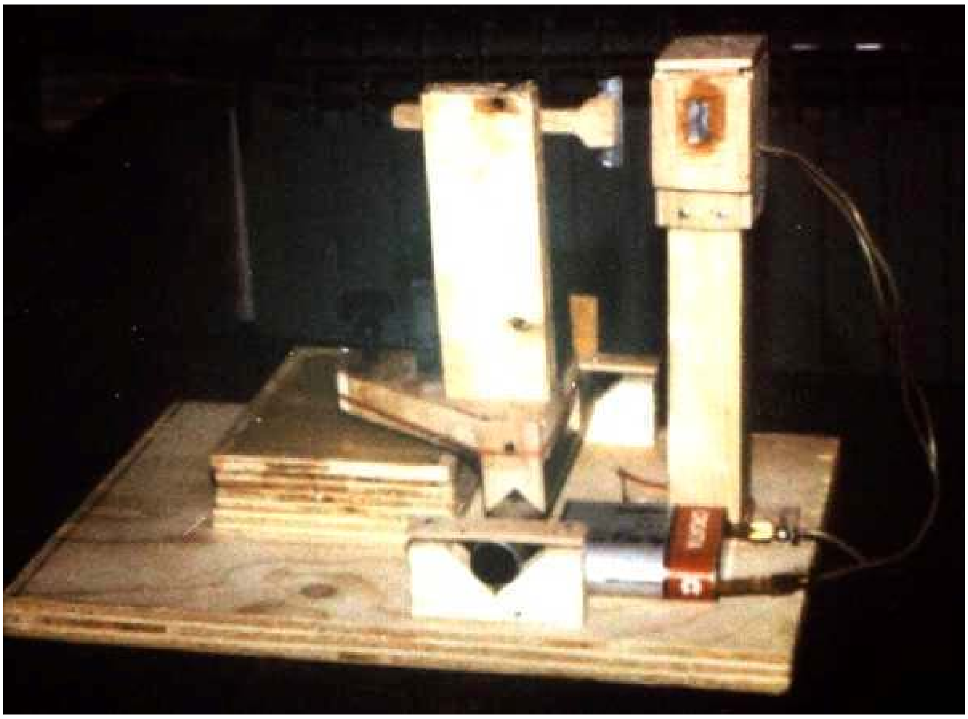
Slika: zrcalo (dolje) potpuno je prekriveno smjesom za poliranje. Kroz stakleni alat lijepo se vide pojedini kvadratići smole koji tvore matricu za poliranje.

Kad je matrica spremna za poliranje, pripremimo smjesu vode i praha za poliranje (ako nam je ostalo smjese od formiranja matrice, možemo je odmah upotrijebiti). U malo vode razmutimo nekoliko žlićica praha za poliranje tako da dobijemo rijetku pastu koju na zrcalo nanosimo žlićicom. Najbolje su plastične žličice za kavu jer su mekane pa nam se ne može dogoditi da slučajnim pritiskom ogrebemo zrcalo. Poliranje započinjemo sa matricom dolje, dakle u istom položaju kao i kod brušenja zrcala. Koristimo "W" poteze srednje dužine, i kao i kod brušenja, međusobno zakrečemo zrcalo i alat (matricu). Kod poliranja je otpor kretanju zrcala često mnogo veći nego kod brušenja, a zrcalo mora jednoliko kliziti preko matrice. Zapinje li zrcalo ili poskakuje, to je siguran znak da kontakt između plohe zrcala i matrice nije dobar pa treba ponoviti toplo prešanje. Ako je otpor kod poliranja prevelik, možemo kod toplog prešanja između zrcala i smole umetnuti komad mrežice za komarce i pritiskom je utisnuti u smolu. Mrežicu naravno namažemo smjesom za poliranje, da se ne zalijepi. Mrežicu nakon toga uklonimo i hladnim prešanjem popravimo kontakt. Površina kvadrata smole sad je dodatno podijeljena na mnoštvo malih kvadratića koji smanjuju otpor kod poliranja i omogučavaju lakše održavanje kontakta. Kod loše tehnike poliranja oni medutim mogu biti uzrokom tzv. mikrohrapavosti plohe koja može pokvariti kvalitetu slike budućeg zrcala. Ona se najčešće javlja kod forsiranog poliranja većim pritiskom i brzinom pa zato kod poliranja ne treba žuriti.

Već nakon desetak minuta rada površina zrcala poćet će se sjajiti. Kad je alat dolje, poliranje obično počinje od sredine. Da se zrcalo potpuno ispolira, potrebno je u prosjeku 6 do 10 sati. U početku poliranja lako ćemo pratiti kako napreduje poliranje ako zrcalo okrenemo prema suncu ili žarulji pa povečalom promatramo površinu zrcala u samom refleksu žarulje (pazite da vas refleks ne zaslijepi!). Još neispolirane hrapavosti zaostale od finog brušenja vide se kao sitne tamne točkice. Pred kraj poliranja ovih točkica je malo i teško se opažaju, ali se zato kod metaliziranja mogu pojaviti kao mutnoća površine zrcala. Ne žurite zato sa završetkom poliranja. Mnogo sigurniji test ispoliranosti plohe je fokusiranje slike žarne niti žarulje ili Sunca na ispoliranu plohu povečalom. Na dobro ispoliranoj plohi slika niti jedva će se vidjeti. Pojavljuju li se unutar slike sjajne točkice, to su preostale rupice od brušenja i one su siguran znak da poliranje još nije završeno.

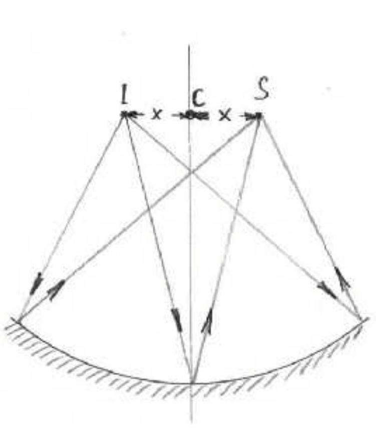
Ako nakon nekoliko sati poliranja na rubu ostaje mnogo točkica koje teško izlaze, možemo zamijeniti položaj zrcala i matrice. Kad je zrcalo dolje, matrica jače polira rub zrcala pa će on uskoro biti ispravno ispoliran. Tek kad je zrcalo sasvim ispolirano, pristupa se optičkim kontrolama i korekcijama oblika plohe zrcala. To se radi zbog toga što prerana kontrola dovodi do pokušaja korekcije, a kad je zrcalo dobro korigirano teško se odlučuje za nastavak poliranja da bi se uklonile preostale točkice. Rezultat je zrcalo sa dobro korigiranom plohom, ali i mnoštvom točkica koje raspršuju svjetlo i kvare kontrast slike, posebno kod planeta ili Mjeseca. A kako se točkice obično naglo pojave nakon aluminizacije zrcala, koja nije jeftina, teško da će zrcalo ikad biti do kraja ispolirano. Takvo zrcalo izvor je mnogih razočaranja i bolje je da ga nemate. Zato pričekajte sa optičkim kontrolama dok zrcalo ne bude potpuno ispolirano. Tada se mirno možete posvetiti korekcijama, ne razmišljajući o tome hoće li se točkice izgubiti ili ne.

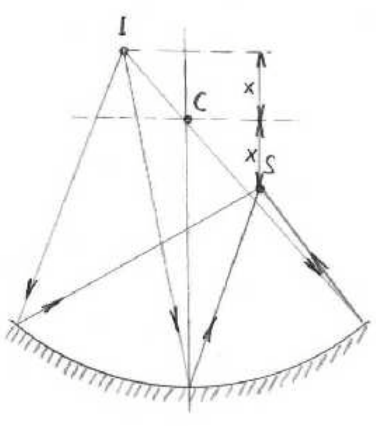
FOUCALT-OV UREĐAJ ZA TESTIRANJE



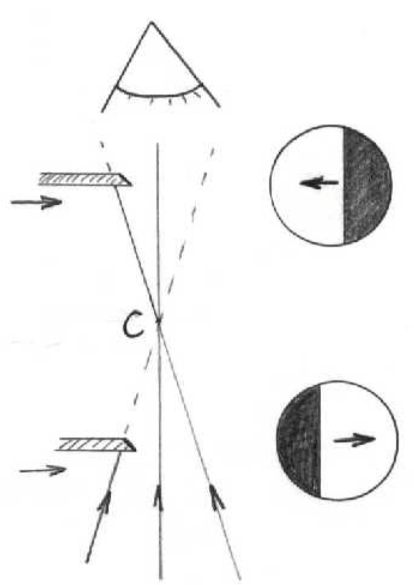
Ova naizgled primitivna sprava nezamjenjivi je dio opreme svakog ozbiljnog brusača zrcala. Ona se po svojem izumitelju, francuskom znanstveniku Leon Foucalt-u (provjerio sam kod francuskih kolega, ime se izgovara otprilike kao Fuko) i danas, preko 150 godina od kada je nastala,naziva Foucalt-ov uređaj za ispitivanje zrcala. Sprava na slici izrađena je po uputama J. Texereau-a (čita se otprilike Teksero), koji je 20tih godina prošlog stoljeća napisao jednu od najboljih knjiga o amaterskoj izradi astronomskih zrcala uopće. Originalna knjiga napisana je na francuskom, no njen modernizirani engleski prijevod može se nabaviti kod američkog izdavača "Willman-Bell" (http://www.wilbell.com/, trenutna cijena knjige oko 25$) i svakako je preporučljivo štivo svima koji žele proširiti svoje znanje u ovom području. Primitivni izgled Foucalt-ovog uređaja na gornjoj slici zavarava ali i pokazuje kako je pravilnom upotrebom fizikanih principa vrlo jednostavno moguće izraditi vrlo precizne naprave.

Foucaltov uređaj radi na vrlo jednostavnom principu: Znamo da sferno zrcalo zrake svjetla koje izlaze iz njegovog središta zakrivljenosti vraća natrag točno u njega. Stavimo li dakle u središte zakrivljenosti zrcala točkasti izvor svjetla, njegova slika poklopit će se sa samim izvorom i bit će iste veličine, dakle isto tako točka. Tu se naravno u račun miješa ogib svjetla pa od točkastog izvora nastaje njegova ogibna slika, no u ovom času utjecaj ogiba možemo zanemariti. Foucalt je znao za ovo svojstvo sfernog zrcala i dosjetio se kako da ga iskoristi. Svako odstupanje oblika zrcala od sfernog oblika dovodi do toga da slika točkastog izvora bude promijenjena. Analizom promjena slike možemo ustanoviti da li je naše zrcalo zaista sferno ili ne. Dakako, da bismo sliku mogli analizirati, moramo prvo doći do nje, tj.moramo je odmaknuti sa točkastog izvora. Foucalt je jednostavno točkasti izvor malo odmaknuo od osi zrcala, što je dovodi do toga da se slika izvora za istu udaljenost odmiće od osi u suprotnu stranu. Tako mu je slika sad postala dostupna.





Foucatov "trik" zorno je prikazan na skici. Ako točkasti izvor svjetla (I) koji se nalazio u središtu zakrivljenosti zrcala, odmaknemo za neku udaljenost (x) od optičke osi, njegova slika (S) odmakne se za istu udaljenost u suprotnu stranu. Na taj način smo sliku odvojili od izvora i omogućili njeno proučavanje. Isto (desna slika) se dogodi ako izvor primičemo zrcalu, ili ga odmičemo od njega. Naravno,ovo vrijedi kad je udaljenost x mala u usporedbi sa polumjerom zakrivljenosti zrcala, a gornja slika je radi preglednosti crtana sa ekstremno velikim x.



Idući "trik još je genijalniji. Foucalt je brzo ustanovio da proučavanje same slike povečalom ne pomaže mnogo u određivanju odstupanja oblika plohe od sfrenog. Naime, kao i kod direktnog testiranja teleskopa na zvijezdama, odstupanje oblika zrcala od idealnog dovodi do promjena u difrakcionoj slici, ali se one ne mogu na jednostavan način povezati sa mjestom i veličinom samog odstupanja plohe zrcala. Foucalt je zanemario djelovanje ogiba i poslužio se jednostavnim principima geometrijske optike.

Uzeo je predmet ravnog, oštrog ruba (tzv. optički nož) i njime lagano sjekao stožac svetla koji od zrcala dolazi prema slici rupice. Pri tome je svoje oko postavio malo iza samog središta zakrivljenosti, toliko da cijelo zrcalo vidi osvijetljeno. Kad sad nož "zasječe" u snop svjetla, neke od zraka svjetla ne mogu više doći do opažača pa on dio zrcala sa kojeg zrake dolaze više ne vidi, tj.taj dio zrcala naglo potamni. Pri tome (pogledajmo skicu!) sjena putuje u istom smjeru kao i nož ako je nož ispred slike, a u suprotnom ako je nož iza nje. Pogodimo li točno mjesto gdje se slika nalazi, zrcalo će renutno potamnjeti i mi nećemo moći reći sa koje straneje sjena dšla. Na taj je način moguće sa velikom točnošću (do par stotinki mm) odrediti položaj slike. Pobrinemo li sa zu to da je ona na istoj udaljenosti od zrcala kao i sama rupica, jednostavnim mjerenjem udaljenosti noža od tjemena zrcala dobivamo njegov polumjer zakrivljenosti.

Uzmemo li ubzir da slika rupice, kao i sama rupica, u promjeru ima samo nekoliko stotinki milimetra, jasno je da se nož mora moći vrlo precizno pomicati. Testiranje dakle ne možemo izvesti držeći nož u ruci, već nam je za to potrebana preciznija sprava. Ona se naziva Foucaltov-ov uređaj za testiranje I ponos je svakog ozbiljnog brusača zrcala. I bez obzira na potrebnu preciznost, ovakva sprava dade se lako izraditi u svakoj kučnoj radionici, kao što to slika na početku ove stranice zorno prikazuje. Pogledajmo je zato još jednom malo detaljnije:

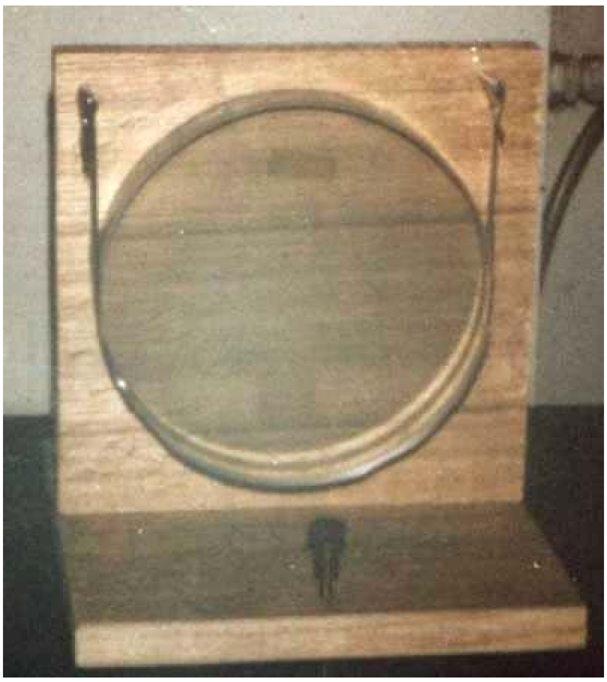
Cijela sprava montirana je na komadu daščice velikom oko 20x25 cm. Na desnoj strani montiran je stupić (A) izrađen u ovom slučaju od šper-ploče (upotrijebite bilo koji prikladni materijal koji imate pri ruci!), visok oko 20 cm. Njegova uloga je da izvor svjetla drži na oko 20 cm iznad donje ploče, kako bismo kod mjerenja bez problema mogli približiti glavu optičkom nožu. Na vrhu stupića (B) nalazi se držač rupice,a u stupiću iza njega smještena je žaruljica koja osvjetljava rupicu. U ovom slučaju umjesto rupice upotrijebljena je tanka pukotina izrađena od dvije polovice žileta zalijepljene dvokomponentnim ljepilom na podlogu. Kod lomljenja žileta na pola (žilet se vrlo lako prelomi ako ga pažljivo presavinemo po dužini na pola) pazite da se ne porežete!. Razmak žileta je namješten od oka tako da je držač okrenut prema nekom jačem izvoru svjetla, a žileti namještani tako dugo dok između njih nije ostala samo vrlo tanka linija svjetla jednolike svjetline. Nećete vjerovati koliko je oko osjetljivo na male razlike u svjetlini, pa je ovako "od oka" izrađena pukotina zaista jednake širine po cijeloj dužini. Pukotina pred rupicom ima tu prednost da propušta mnogo više svjetla, pa je testiranje olakšano. S druge strane, optički nož mora biti strogo paralelan sa njom, što malo komplicira konstrukciju uređaja i zahtijeva početno namještanje noža, no to se lako savlada. Da bi žaruljica jednoliko osvjetljavala pukotinu, jednostavno je omotana jednim slojem paus papira. Upotrebljena je žaruljica od baterijske svjetiljke, tako da je uređaj neovisan o električnoj mreži. Ova mala žaruljica daje dovoljno svjetla, a ne zagrijava se prejako (kod testiranja glavu držimo na par cm od njenog kučišta!).

Ako je nekome izrada pukotine presložena, može umjesto nje staviti malenu rupicu. Rupicu je najlakše izraditi u tankoj metalnoj foliji (poklopac od čašice jogurta idealan je materijal za to!). Komadić folje stavimo na tvdu podlogu (komadić stakla ili metala), uzmemo običnu iglu za šivanje i pritisnemo je na foliju. Zavrtimo je prstima nekoliko puta lijevo desno, pazeći da ne sklizne i održavajući pritisak na podlogu. Nakon malo vježbe ovako ćemo bez problema izraditi rupicu koja nam treba. Imamo li pri tome problema, pokušajmo pod foliju staviti list ili dva papira, sve dok ne dobijemo rupicu željene veličine. Oblik i veličinu rupice možemo provjeriti jačim povečalom (okular teleskopa žarišne daljine oko 20 mm odlično će poslužiti!). Rupicu jednostavno montiramo na mjesto pukotine i uređaj koristimo kao i sa pukotinom,s time da namještanje paralelnosti pukotine i noža naravno otpada.

Na lijevoj strani nalazi se mehanizam za testiranje. Optički nož također je izrađen od polovice žileta i montiran je na maloj ručici na vrhu drvenog nosača. Ručica je u sredini vijkom učvrščena na nosač tako da se dade okretati oko vijka. Ovim pomicanjem dovodimo optički nož u paralelu sa slikom pukotine koju daje zrcalo koje testiramo. Cijev F uglavljena je u dva "v" nosača ispiljena od dva komadića drveta. Ona na sebi nosi mehanizam za testiranje i omogučava njegovo pomicanje prema zrcalu i od njega. Fino pomicanje u ovom smjeru vrši vijak M6 koji gura zadnju stranu nosača (na ovoj slici skriven je iza samog nosača). Gumica E služi kao opruga i stano vuće nosač prema vijku, tako da kod pomicanja mehanizma nema zazora. Vijak je uvijen direktno kroz rupu u drvenoj daščici učvršćenoj na zadnji nosač cijevi F. Rupa u dašćici pri tome treba biti 0,5 do 1 mm manjeg promjera od promjera vijka, pa kad vijak na silu uvijemo u nju, dobijemo maticu bez zazora. Na kraj vijka pričvrstimo nešto veći kotačić (2-4 cm u promjeru) čiji obod podijelimo (npr. zamatanjem mm papira ili označavanjem flomasterom) na 20 jednakih dijelova. Koristimo li vijak M6, svaka podjela kotačića odgovara 0,05 mm pomaka stola, što je za dovoljno za testiranje svih zrcala, osim onih vrlo velikog otvora (manjeg od F/4, ako ikad uopće poželite izraditi tako ekstremno zrcalo). Uz jednu stranu kotačića možemo postaviti komad lima ili žice koji će nam olakšati očitavanje položaja vijka. Ne zaboravimo kod pomicanja brojiti pune okrete vijka!

Siječenje slike (pomicanje noža prema pukotini ili od nje) obavljamo vijkom D koji je uvijen u nosač noža i čiji vrh klizi po staklenoj ploči ispod njega, kod uređaja na slici, podignutoj na potrebnu visinu podlaganjem dva komadića debele šper-ploče. Umjesto stakla možete slobodno upotrijebiti i keramičku pločicu ili komad ultrapasa, važno je samo da ova podloga bude tvrda, ravna i što je moguće glađa. Kako se vijak uvija prema dolje, podiže tu stranu nosača, cijeli nosač se naginje prema izvoru svjetla inož ide prema pukotini. Nož se doduše pri tome pomiće po kružnici, ali kako se radi o malim pomacima, to nije primjetno.

Zrcalo je kod testiranja obično montirano u vertikalnom položaju. S jedne strane to olakšava testiranje velikih zrcala jer je udaljenost od tjemena zrcala do optičkog noža približno jednaka polumjeru zakrivljenosti zrcala (zamislite si da kod testiranja zrcalo jednostavno stavite na pod, a vi sa cijelim uređajem za testiranje balansirate na ljestvama nekoliko metara iznad njega pokušavajući uloviti sliku pukotine), a s druge strane ujedno smanjuje opasnost od promjene oblika zrcala uslijed vlastite težine. Dobro je za tu svrhu izraditi poseban stalak koji će sigurno držati zrcalo na njegovom mjestu i ujedno omogućiti fino podešavanje njegovog položaja. Jedan takav jednostavni stalak prikazan je na slijedećoj slici:



Stalak je izrađen od dvije daščice, okomito pričvršćene jedna na drugu. Na prednjoj strani donje dašćice nalazi se vijak za podešavanje nagiba stalka, a na njenoj zadnjoj strani su odozdo pričvršćene dvije gumene nogice. Zrcalo visi obješeno na elastičnoj traci, u ovom slučaju komadu plastične trake za vezanje ambalaže. Elastična traka znatno smanjuje mogućnost nejednakog pritiska na obod zrcala. Bilo kakva plastična ili platnena traka širine otprilike jednake debljini zrcala i dovoljne čvrstoće dobra je za ovu svrhu. Kod ovakve montaže postoji opasnost da zrcalo padne prema naprijed. Ovdje je to spriječeno komadićem obostrano ljepljive trake koje zadnju stranu zrcala drži zalijepljenu na dašćicu iza njega, no bolje je iznad zrcala zabiti još jedan čavlić (naravno prije nego što stavite zrcalo na nosač, bez obzira na to što ste zadnjih 1300 čavala zabili bez najmanje pogreške) na kojem je mali komadić lima ili šperploće koji okretanjem možete staviti preko ruba zrcala tako da ga osigura od pada. Ovaj drugi način osiguranja svakako je preporučljiv za veća i teža zrcala (ovo na slici je 15 cm u promjeru).

Za testiranje nam je potrebna prostorija koju možemo zamračiti (ili možemo testiranje raditi noću) čija dužina je barem 1 m veća od polumjera zakrivljenosti zrcala. Dobro je ako u noj vlada što je moguće više stalna temperatura jer miješanje toplog i hladnog zraka može potpuno onemogućiti testiranje. Podrumske prostorije su zato za ovu svrhu posebno podesne. Stalak za zrcalo stavimo na stol, policu ili neki drugi prikladni nosač uz jedan zid prostorije. Na suprotnoj strani, na otprilike istoj visini treba biti uređaj za testiranje. Kako se testiranje znade odužiti, najbolje je da sve namjestimo tako da kod testiranja možemo udobno sjediti.

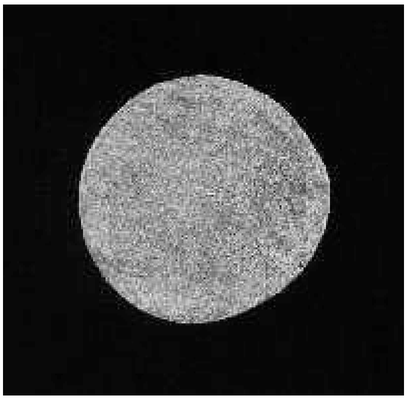
Sad dolazi najteži dio posla: uređaj za testiranje i zrcalo treba međusobno tako namjestiti da slika pukotine padne u procijep između noža i nosača pukotine. Za to postoji nekoliko načina, a ja obično koristim slijedeči: uređaj za testiranje postavi se tako da je udaljenost noža od tjemena zrcala otprilike jednaka polumjeru zakrivljenosti zrcala. Sad je potrebno zrcalo usmjeriti tako da sliku pukotine vrača u pravom smjeru. Ja za tu svrhu koristim baterijsku svjetiljku. Svetiljku treba držati ispred zrcala otprilike na spojnici tjemena zrcala i optičkog noža, ali znatno bliže od samog noža. Sad pokušamo okom uhvatiti sliku svjetiljke u zcalu, i zakretanjem nosača zrcala te njegovim naginjanjem dovesti sliku svjetlije što je moguće bliže svjetiljci. Ne gubeći iz vida odraz svjetiljke sad se polagano udaljavamo od zrcala, popravljajući pri tome položaj zcala, ako je to potrebno. Kad dođemo u blizinu uređaja za testiranje, zrcalo je već grubo podešeno. Kod ovog je još jedan pomagač koji lagano podešava položaj zrcala prema vašim uputama je dobrodošao, posebno ako se radi o zrcalu većeg polumjera zakrivljenosti.

Kad smo tako grubo usmjerili zrcalo, upalimo žaruljicu uređaja za testiranje i, sa glavom iza njega, gledajući kroz procijep između nosača pukotine i noža, pokušamo uloviti odraz pukotine u zrcalu. Ne uspijemo li, uređaj približitmo 10-20 cm prema zrcalu, pa pokušamo ponovo. Kad uhvatimo odraz, lagano pomičemo uređaj prema natrag, pazeći da pri tome ne izgubimo odraz. Kad odraz prvi puta uhvatimo, bit će vjerojatno manji od samog zrcala. Sad malo odmaknemo glavu prema natrag. Smanjuje li se veličina odraza u zrcalu, oko nam se nalazi iza slike pukotine i obratno. Sad još podesimo udaljenost uređaja od zrcala tako da cijelo zrcalo bude jednoliko osvijetljeno, pa onda pokušamo nožem sječi sliku pukotine. Putuje li pri tome sjena noža u istom smjeru kao i nož, nalazi se nož ispred slike pukotine i obratno. Kad nađemo mjesto u kojem cijelo zrcalo trenutno potamni, nalazi se nož u ravnini slike pukotine. Pri tome je polumjer zakrivljenosti zrcala jednak polovici zbroja udaljenosti pukotine od tjemena zrcala i noža od tjemena zrcala. Na ovaj našin ujedno smo točno izmjerili polumjer zakrivljenosti zrcala, a time i njegovu žarišnu daljinu. Za samo testiranje dobro je da je nož otprilike u ravnini zadnje strane nosača pukotine kako bismo kod testiranja okom mogli doći dovoljno blizu slike pukotine da bismo cijelo zrcalo vidjeli osvijetljenim. To je posebno važno kod zrcala sa velikim relativnin otvorom (F/5 ili manje).

TESTIRANJE PLOHE

Stigli smo, eto, do velikog finala izrade zrcala: nakon mnogo sati brušenja, pranja, čišćenja i poliranja naše remek-djelo udobno se smjestilo na stalku za testiranje a slika pukotine Foucalt-ovog testera namještena je na njegov nož. U idućih par sekundi konačno ćemo saznati da li se trud isplatio... Ili tako barem mislimo. Testiranje je posao koji upravo u trenutku kad smo nestrpljivi traži strpljenje, mnogo strpljenja. Naime, rijetko ćemo biti takvi sretnici da od prve ugledamo brzo, jednoliko zatamnjivanje cijele plohe zrcala kad nožem zasječemo snop svjetla koje od njega dolazi. Ne zaboravite da je Foucaltov test izuzetno osjetljiv, posebno kod velikih F-brojeva. Krenimo dakle polako, redom. Prvo lagano zasijecimo snop svjetla, i nađimo mjesto gdje zrcalo potamnjuje najjednoličnije i najbrže. Sad prvo odredimo točan polumjer zakrivljenosti zrcala: da bi to postigli, izmjerimo udaljenost od zrcala do pukotine te udaljenost od zrcala do noža. Rekli smo prije da se nalazimo u središtu zakrivljenosti zrcala kad su ove dvije udaljenosti jednake, no u praksi razlika od 2-3 cm između njih ne igra nikakvu ulogu. Polumjer zakrivljenosti zrcala dobijemo tako da uzmemo srednju vrijednost ove dvije udaljenosti (tj. zbrojimo ih pa rezultat podijelimo sa 2). I uz pomoć običnog metalnog metra možemo tako odrediti polumjer zakrivljenosti sa točnošću od 1-2 mm, što je i više nego dovoljno za naše potrebe, pogotovo zato što je žarišna daljina jednaka polovici polumjera zakrivljenosti, pa se netočnost mjerenja polumjera zakrivljenosti dijeli na pola!

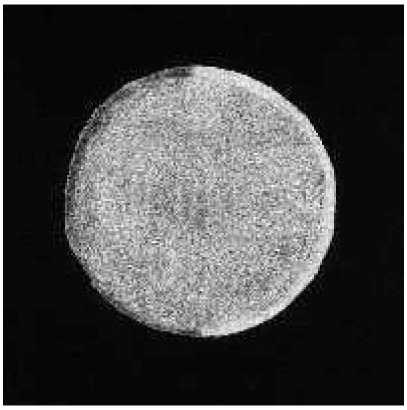
Analizirajmo sad na tom mjestu način na koji zrcalo potamni kad nožem siječemo snop svjetla. Potamni li zrcalo vrlo brzo, ili gotovo trenutno, bez obzira na to koliko polagano pomićemo nož, imamo posla sa izuzetno dobrom sfernom plohom. Ako pri tome ne možemo reći iz kojeg smjera je sjena došla na zrcalo, možemo odahnuti, otvoriti šampanjac, vikati eureka ili veseliti se kako već znamo. Odstupanja plohe od idealne sfere zasigurno se mjere samo desetinkama valne duljine svjetla!



Izgled idealnog sfernog zrcala u trenu kad nož zasiječe snop svjeta u središtu zakrivljenosti. Cijela ploha jednoliko je zatamnjena i ne može se odrediti smjer iz kojeg je sjena došla. Kod ove i svih slijedećih slika nož dolazi sa lijeve strane (zamišljeni izvor svjetla nalazi se s desne strane!). Rub zrcala okružen je kao kosa tankim svijetlim ogibnim rubom koji je tako nježan da se na crtežu ne može prikazati.

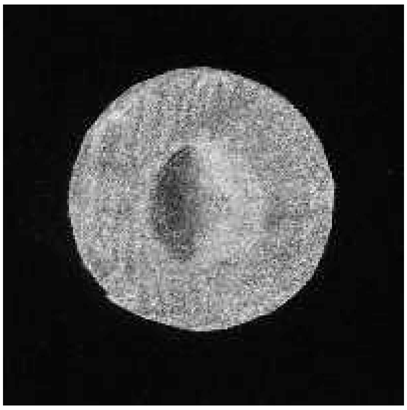
Kad smo se malo opustili od prvog veselja, provjerimo sve još jednom. Pri tome sad pogledajmo koliko moramo nož pomaknuti prema ili od zrcala da bismo mogli opaziti smjer iz kojeg sjena dolazi na plohu zrcala. Da li se kod istog pomaka prema i od točke najbržeg tamnjenja sjena jednako ponaša, naravno sa promijenjenim smjerom dolaženja? Primiječujemo li na zrcalu svjetlija i tamnija područja ili prstenove (tzv. zone). Ako ih nema, ili su slabo izražena, zrcalo je zaista odlične kvalitete. U slučaju da zaista vidimo svijetlija i tamnija mjesta, odredimo da li se radi o "uzvišenjima" ili "udubljenjima" na plohi zrcala. Pod "uzvišenjem" se ovdje misli na dio plohe zrcala koji je iznad idealne sferne plohe, a pod "udubljenjem" na dio plohe koji je ispod nje. Pri tome je jednoliko sivi dio zrcala onaj, koji odgovara sferi čije središte zakrivljenosti se nalazi točno na nožu uređaja za testiranje. Ta sfera naziva se "referentnom sferom" jer kod testiranja se sva odstupanja plohe zrcala od sfernog oblika prikazuju relativno prema referentnoj sferi. Primijetite da pomicanjem noža prema ili od zrcala mijenjamo referentnu sferu. Ovo je izuzetno važno zapamtiti jer pravilnim odabirom referentne sfere možemo puno lakše i brže popraviti nedostatke oblika plohe, o čemu će biti puno više riječi na idućim stranicama. Zapamtite isto tako da je odabir referentne sfere proizvoljan, tj. ne postoji jedna, bogom dana, sfera koju bi morali poštovati više od ostalih. Vratimo se sad udubinama i uzvišenjima, odnosno svijetlijim i tamnijim područjima plohe zrcala. Da bismo odredili radi li se o udubinama ili izbočinama, poslužit ćemo se slijedećim jednostavnim trikom: ako si zamislimo da svjetlo pada na plohu zrcala pod vrlo malim kutem i to tako da dolazi prema nožu, bit će kao i kod reljefa zemljine površine dio plohe nagnut prema izvoru svjetla svijetliji a onaj koji se od njega otklanja tamniji. Sad u glavi treba zamisliti taj reljef i iz rasporeda svijetlih i tamnih zona zaključiti imamo li posla sa udubinom ili izbočino.

Komplicirano, zar ne? U stvari nije, ali treba biti pažljiv i temeljit. Ako idući od strane zamišljenog izvora svjetla idemo prema nožu, pa prvo naiđemo na svijetliji dio koji kasnije prelazi u tamniji, radi se o izbočini (padina prema "suncu" je svijetlija, a ona s druge strane je u "sjeni"). Ako je raspored svjetla i sjene obratan, radi se o udubini. Oprez, naš mozak lako se može "nagovoriti" da ovaj "reljef" doživi obrnuto. Dakle, polako, i tri puta provjeriti zaključke ovakve analize! Greška ovdje učinjena može kasnije u postupku popravljanja plohe lako dovesti do prave katastrofe. Dakle, još jednom, strpljenja, i uvijek trostruko provjerite svoje zaključke. I ne zaboravite pri tome da se kod rada sa Foucalt-ovim uređajem najčešće radi o blagim nijansama svijetlijeg i tamnijeg, osim kod izrazito asferičnih ploha o kojima će biti riječi kasnije.

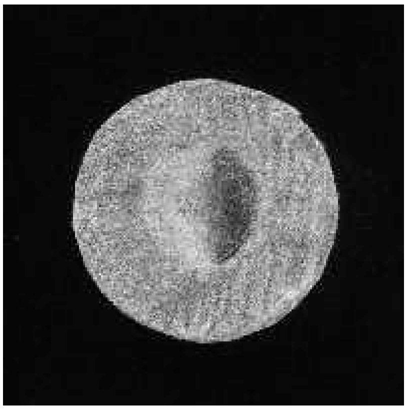


Izgled sfernog zrcala sa spuštenim rubom. Nož siječe snop svjetla u središtu zakrivljenosti zrcala. Rub zrcala pokazuje naglo povećanje polumjera zakrivljenosti, a širina spuštene zone obično je 2-10 mm. Uzdignuti rub pokazao bi istu sliku sa zamijenjenom svijetlom i tamnom stranom prstena, no njega je vrlo lako ispraviti nastavkom poliranja. Nož dolazi sa lijeve strane (zamišljeni izvor svjetla nalazi se s desne strane!)

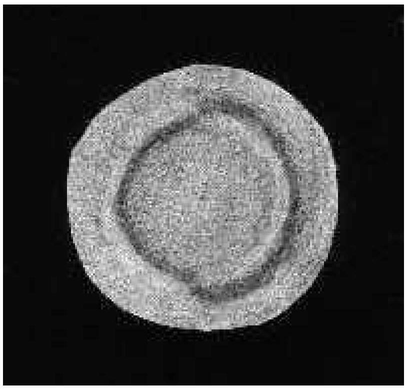
Sad posvetimo pažnju rubu zrcala. U idealnom slučaju rub zrcala istaknut je vrlo tankim svijetlim ogibnim prstenom po cijelom svom obodu. Mnogo češće ovaj je prsten svjejtliji na strani sa koje svjetlo prividno dolazi što ukazuje na tzv. spušteni rub. Spušteni rub je uža ili šira zona uz sam rub zrcala u kojoj zbog gotovo neizbježnih procesa kod poliranja dolazi do većeg odnašanja materijala pa se u toj zoni polumjer zakrivljenosti prema rubu zrcala sve više povećava. Spušteni rub je obično širok nekoliko milimetara, iako nisu rijetki ni slučajevi kad mu je širina veća od centimetra. U ovoj fazi izrade zrcala on i nije tako bitan jer kod parabolizacije i tako vanjske zone zrcala moramo "spustiti", tj. povećati im polumjer zakrivljenosti u usporedbi sa sredinom zrcala. Jedino u slučaju da želimo izraditi sferno zrcalo, moramo spuštenom rubu u ovoj fazi posvetiti malo više pažnje. Kao prvo, treba odrediti njegovu širinu, a onda da li je njegov utjecaj na kvalitetu slike toliki da se isplati pokušati ga popraviti. Naime, poliranjem možemo samo uklanjati materijal sa površine zrcala, a ne ga nanositi. Želimo li popraviti uski spušteni rub, moramo zapravo poliranjem skinuti cijelu plohu zrcala uz nadu da problem na rubu zrcala nećemo pogoršati ili napraviti druge pogreške koje mogu biti mnogo štetnije od uskog spuštenog ruba. Čak i ako sve ide kako treba to zapravo znači još jednom ispolirati zrcalo. I zaista, često se više isplati cijelo zrcalo još jednom prebrusiti najfinijim brusnim prahom i ponovno ga polirati nego ići ispravljati spušteni rub. No, prije toga treba postojeće stanje dobro proanalizirati. Da bismo odredili širinu spuštenog ruba, izrežimo iz papira zaslon čiji vanjski promjer je jednak promjeru zrcala a promjer rupe u njemu je za 2 cm manji. Zaslon stavimo ispred zrcala, pazeći da je ispravno centriran i učvrstimo ga ljepljivom trakom ili na sličan način da se ne pomakne. Sad ponovimo Foucalt-ov test. Vidimo li sad nježni ogibni prsten po rubu zasklona ili se spušteni rub još može opaziti? Ako se spušteni rub još vidi, izradimo zaslon sa još manjim otvorom. No, najčešće to nije potrebno, već možemo postupak ponoviti sa zaslonom koji ima nešto veći otvor. Na ovaj jednostavan način možemo do u milimetar točno odrediti širinu spuštenog ruba, ili ako to ljepše zvući, promjer kod kojeg se zrcalo još ponaša kao idealna sfera.



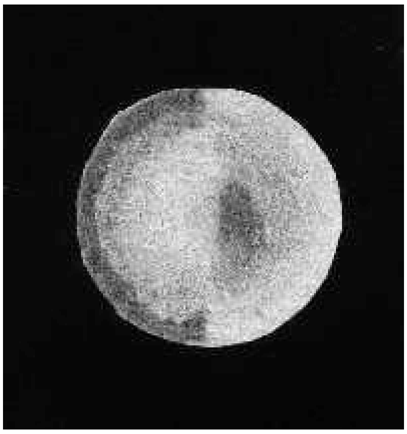
Sferno zrcalo sa uzvišenjem u sredini u trenu kad nož zasiječe snop svjetla u središtu zakrivljenosti vanjskog sfernog dijela. Ako se centralno uzvišenje i pojavi, obično je toliko maleno da ga možemo zanemariti, pogotovo što je središnji dio zrcala i tako zasjenjen pomoćnim zrcalom. U svakom slučaju, ova pogreška plohe mnogo je poželjnija od spuštenog ruba jer se relativno brzo i lako može ukloniti. Nož dolazi sa lijeve strane (zamišljeni izvor svjetla nalazi se s desne strane!)



Sferno zrcalo sa udubljenjem u sredini u trenu kad nož zasijeće snop svjetla u središtu zakrivljenosti vanjskog sfernog dijela. Ako se centralno udubljenje pojavi, moramo daljnjim testiranjem provjeriti da li ga se može zanemariti ili se mora ispraviti. Primijetite da sjene izgledaju jedinako kao i kod centralnog uzvišenja, ali sa zamijenjenim tamnijim i svijetlijim mjestima. Kod testiranja dakle oprez!



Sferno zrcalo sa udubljenom zonom u trenu kad nož zasijeće snop svjeta u središtu zakrivljenosti vanjskog sfernog dijela. Zone se obično pojavljuju ako je raspored kvadratiča smole na matrici za poliranje simetričan prema sredini zrcala. Udubljena zona veliki je problem i mora se ukloniti dugotrajnim poliranjem zrcala, sve dok se ne dobije sferni oblik. Prije toga treba naravno provjeriti matricu za poliranje i poraviti je a ako to nije uzrok zone, treba svakako promijeniti pokrete kod poliranja i paziti da ne budu tako periodični. Ispupčena zona ima isti uzrok ali se puno lakše ispravlja jer treba ukloniti samo materijal zone a ne cijelu plohu zrcala spustiti do dna udubljene zone.

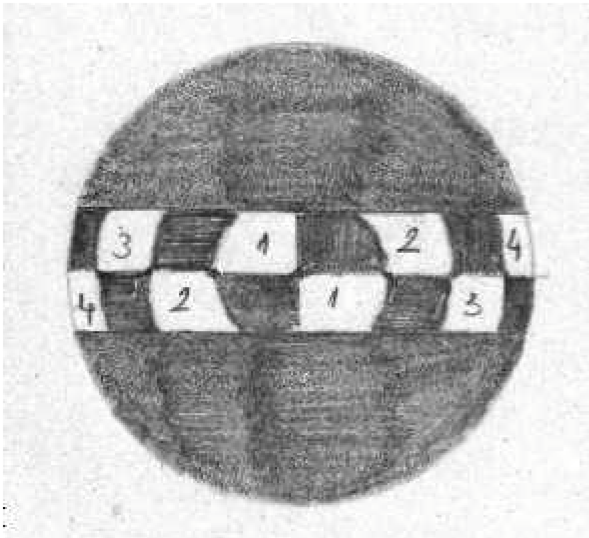


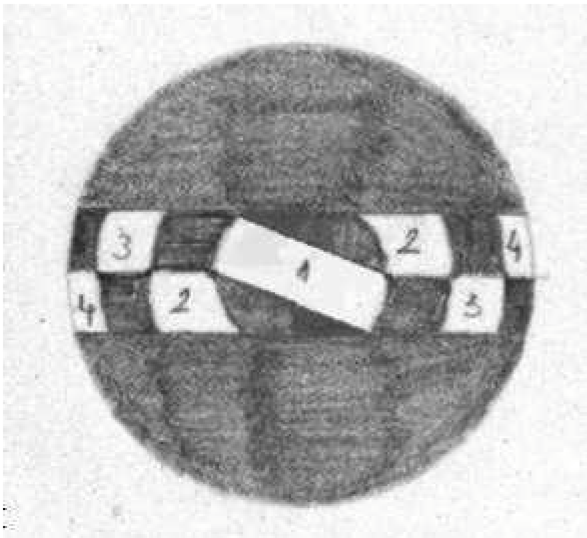
Asferno zrcalo bez većih pogrešaka plohe kad je nož na mjestu središta zakrivljenosti 70% zone (to je zona sa polumjerom jednakim 70% polumjera zrcala). Različite asfere razlikuju se samo po kontrastu svijetlijih i tamnijih zona pa se bez detaljnog testiranje ne može reći radi li se o elipsoidu, paraboli ili hiperboli.

U slučaju da već od samog početka ploha izgleda loše, ili mi barem tako mislimo, provjerimo prvo našu postavu za testiranje. Stoji li Foucaltov uređaj stabilno? Da li je temperatura u prostoriji ujednačena? Miješanje zraka može totalno pokvariti sliku koju vidimo kod testiranja, a prepoznat ćemo ga po tome što svijetlija i tamnija mjesta stalno putuju po površini zrcala. Test je toliko osjetljiv da možemo vidjeti strujanje toplog zraka oko dlana ruke koju stavimo neposredno ispod snopa svjetla koji ide prema nožu! Nadalje, da li je zrcalo iste temperature kao i okolni zrak? Zrcalo koje se hladi prepoznajemo po tome što mu se oblik s vremenom polagano mijenja (znatno sporije nego kod miješanja zraka!). Ako smo ga donijeli iz hladnije ili toplije prostorije, ostavimo ga pola sata do sat vremena da mu se temperatura izjednači sa okolinom. Ako je uz to zrcalo debelo pa još i od prozorskog stakla, trebat će mu možda i nekoliko sati da se potpuno prilagodi temperaturi okoline. Ostavimo ga dakle na stalku, pa nakon pola sata do sat vremena provjerimo da li se slika popravila ili promijenila. Čak i kod zrcala od vatrostalnog stakla (pyrex, boral, tempex, ovisno o proizvođaću) dovoljno je na njegovoj plohi oko pola minute držati palac da bi se izbočina nastala lokalnim širenjem zagrijanog stakla opazila kod testiranja, naravno ako je uređaj za testiranje dobro izrađen i zrak u prostoriji zaista miran. Ozbiljno testiranje možemo započeti tek kad je slika koju vidimo zaista mirna i stabilna, inače nam se može dogoditi da u pokušaju popravke plohe u stvari stalno jurimo toplinske efekte i na kraju nakon mnogo uzaludnog truda i utrošenog vremena razočarani odustanemo od svega. Vrlo rijetko ćemo se susresti sa staklom koje u sebi ima toliko zaostalih naprezanja (naprezanja koja su ostala od izrade stakla i zbog prenaglog hlađenja nisu uklonjena već su ostala "zamrznuta" u krutom staklu), a tada zaista nema drugog lijeka nego uzeti drugi stakleni disk, a ovaj ili upotrijebiti za alat, ili ga sa užitkom tresnuti u prvi (što jači to bolji!) željezni stup uz cestu. "Osveta" je slatka zar ne! Poslije uklonite krhotine, astronomi su poznati po ekološkoj svijesti!

Foucalt-ov test idealan je za testiranje udubljenih sfernih ploha. Kod njih naime cijela ploha istovremeno potamni, a preostala odstupanja lako se vide. Test je toliko osjetljiv da iskusni optičar može opaziti odstupanja od sferne plohe koja se mjere stotinkama valne duljine. U literaturi ćete neki puta naići na tvrdnju da je ovaj test tzv. nula test za sfernu plohu. Pri tome se misli na efekt istovremenog naglog zatamnjenja cijele plohe zrcala kad se nož uređaja za testiranje nalazi u središtu zakrivljenosti zrcala. Kod takvog jednolikog zatamnjenja je oko izuzetno osjetljivo na preostale male razlike u svjetlini plohe. Nažalost, za sve ostale oblike plohe ovo se ne događa već se potamnjuje samo ona zona zrcala čiji polumjer zakrivljenosti odgovara udaljenosti noža od tjemena zrcala (uz pretpostavku da se izvor svjetla nalazi na istoj udaljenosti!), a ostali dijelovi zrcala su znatno svijetliji ili tamniji, što smeta opažača u procjeni oblika plohe. Za testiranje asfernih ploha moramo dakle primijeniti dodatne "trikove". Zanemarimo sada razne optičke modifikacije samog uređaja za testiranje koje mogu od njega napraviti nula test za bilo koju asfernu plohu, i to zato jer su dosta složene za izvedbu (potrebne leće moraju biti vrlo precizno izrađene i vrlo točno postavljene, sjetimo se samo svemirskog teleskopa i njegove zaostale sferne aberacije!). Uz to, optički modificirani test je nula test samo za unaprijed određen oblik plohe pa za svako novo zrcalo moramo uređaj ponovno modificirati. Preostaje nam dakle da probamo upotrijebiti uređaj u njegovom izvornom obliku. Toje zaista i moguće s time da točnost mjerenja opada sa povećanjem odstupanja plohe od sfernog oblika (tzv. asferičnost). U svakom slučaju, točnost mjerenja za amaterska zrcala još uvijek je više nego dovoljna pod uvjetom da F-broj zrcala nije manji od oko 4.

Kod testiranja asfernih ploha Foucalt-ovim uređajem u stvari mjerimo polumjere zakrivljenosti pojedinih zona zrcala, bolje rečeno mjerimo razliku među njima jer je to jednostavnije i točnije. Pri tome si pomažemo maskama raznih oblika koje nam fizički odvajaju pojedine zone jedne od drugih. U principu bismo mogli koristiti nekoliko zaslona od kojih svaki otkriva samo jednu određenu zonu (prsten) zrcala, no kod zamjene tih maski lako može doći do pomicanja zrcala pa mjerenja padaju u vodu. Zato se koristi jedna maska na kojoj su raznim otvorima izdvojene pojedine zone pa se jednom namještena maska ne mora više dirati.





Maska za testiranje asfernog zrcala sa 4 zone. Maska se nacrta na karton (crno) pa se onda izrežu odgovarajući otvori (bijelo). Svakoj zoni pripadaju dva otvora na suprotnim stranama zone. Širina zona obično se prema rubu zrcala smanjuje jer se tamo polumjer zakrivljenosti brže mijenja nego u sredini zrcala. No, otvori ipak ne smiju biti preuski (širine manje od oko 1 cm nisu poželjne) jer ogib na rubu otvora otežava točnost mjerenja kod vrlo malih otvora. Kod većih zrcala mogu se izraditi maske sa više (5-8) otvora, no do otvora od oko 20 cm 4 zone sasvim su dovoljne. Kod nekih izvedbi maske oba otvora središnje zone (1) spojena su zajedno u dugoljasti otvor koji stoji koso pod 45 stupnjeva.

O tome kako se najbolje mogu odrediti širine pojedinih zona postoje različita mišljenja i prijedlozi. No, praksa je pokazala da jako točno određivanje tih polumjera i nije tako važno, tako dugo dok se njihova širina polagano smanjuje prema rubu zrcala. Texereau koristi neku vrstu razlike kvadrata vanskog i unutarnjeg promjera zona kja se prema rubu postepeno smanjuje, no i sam priznaje da velika točnost nije potrebna. Slično je i sa polumjerom za koji zapravo mjerimo položaj žarišta zone. Teoretski je to geometrijska sredina vanjskog i unutarnjeg polumjera zone, no Texereau navodi da po njegovom iskustvu je bolje uzeti srednji polumjer zone jer oko teži tome da uspoređuje svjetline u sredini odgovarajučih otvora. Uz to, kod dovoljnog broja zona, razlika između aritmetičke i geometrijske sredine polumjera je premala da bi imala veći utjecaj na rezultate. Ja sam do sada uvijek koristio aritmetičku sredinu, a širine zona određivao otprilike (naravno uz smanjenje širine prema rubu) i nikad nisam primijetio da bi to uticalo na točnost mjerenja, odn. kvalitetu gotovog zrcala. Za one koji ipak žele neki "recept" za polumjere zona evo jedne priručne tablice koja je u skladu sa gore izloženim razmatranjima. Ovi polumjeri određeni su tako da je promjena polumjera zakrivljenosti plohe od zone do zone otprilike jednaka, što osigurava najlakša i najoptimalnija mjerenja.

ukupno zona→ / ↓ zona br.	4	5	6	7	8	9	10
1	0,50	0,45	0,41	0,38	0,35	0,33	0,32
2	0,71	0,63	0,58	0,53	0,50	0,47	0,45
3	0,87	0,77	0,71	0,65	0,61	0,58	0,55
4	1,00	0,89	0,82	0,76	0,71	0,67	0,63
5		1,00	0,91	0,85	0,79	0,75	0,71
6			1,00	0,93	0,87	0,82	0,77
7				1,00	0,94	0,88	0,84
8					1,00	0,94	0,89
9						1,00	0,95
10							1,00
za zrcala do	10 cm	15cm	20 cm	25 cm	30 cm		40 cm

U tablici su uneseni vanjski polumjeri zona izraženi u dijelovima polumjera zrcala. Unutarnji polumjer neke zone jednak je naravno vanjskom polumjeru prethodne zone! Da dobijete prave polumjere, pomnožite broj iz tablice sa stvarnim polumjerom zrcala (ne zaboravite odbiti rubno zakošenje!). U doljnjem redu dana je i preporuka o najvećem broju zona za određenu veličinu zrcala. Testirati zrcalo od 10 cm promjera sa maskom od 10 zona zaista nema smisla!

Stavimo dakle masku na zrcalo i odredimo prvo mjesto na kojem središnja zona jednoliko potamni. Zapišimo položaj noža kod kojeg se to dogodi, prema mjernoj skali našeg uređaja. Postupak ponovim za sve preostale zone, posebno pazeći kod rubne zone da nas spušteni rub ili ogibni prsten ne bi zavarali. Mjerenja za svaku zonu ponovimo nekoliko puta i kao rezultat uzmimo srednju vrijednost pojedinih mjerenja. U idućem koraku odredimo razlike u polumjeru zakrivljenosti pojedinih zona, tako da od izmjerenih vrijednosti za svaku zonu odbijemo vrijednost koju smo izmjerili za središnju zonu. Dobivene razlike koristit ćemo za analizu oblika plohe zrcala. Optička teorija govori da je ta razlika kod paraboličnog zrcala dana jednostavnom formulom:

$$\Delta R = r^2/R$$

ovdje je ΔR razlika u polumjeru zakrivljenosti zone zrcala prema polumjeru zakrivljenosti središta zrcala a r je polumjer zone zrcala. Pazite da ne pobrkate r i R! Ova formula vrijedi za uređaj za testiranje sa nepomičnim izvorom svjetla (pukotinom). Pomiće li se izvor svjetla prema ili od zrcala zajedno sa nožem uređaja, moramo vrijednosti izračunate gornjom formulom podijeliti sa 2. Kod mjerenja za polumjere zona uzimamo, kao što smo to već spomenuli, srednju vrijednost vanjskog i unutarnjeg polumjera otvora na maski koji određuje zonu mjerenja.

Primjer: recimo da smo koristili masku sa 4 zone na zrcalu polumjera 60 mm i polumjera zakrivljenosti od 1976 mm. Pri tome je zakošenje ruba zrcala 2 mm, pa je polumjer optičke plohe zrcala 58 mm. Sve rezultate zapisujemo i radi preglednosti konačne vrijednosti unosimo u tablicu:

zona	r_V	r	Δ R izračunat mm	Δ R izmjeren mm	Δ R izmjeren + 0,1 mm
1	30	15	0,1	0,0	0,1
2	42	36	0,7	0,5	0,6
3	51	47	1,1	0,8	0,9
4	58	54	1,5	1,3	1,4

U prvom stupcu je redni broj zone, a u drugom njen vanjski polumjer. Podsjetimo se pri tome da je vanjski polujer jedne zone ujedno unutarnji polumjer slijedeće! U slijedećoj koloni nalazi se srednji polumjer zone. Slijedi izračunata razlika polumjera zakrivljenosti za svaku zonu a nakon toga i srednje vrijednosti izmjerenih razlika. Da bismo ih lakše mogli usporediti, dodamo izmjerenim vrijednostima razlika izračunatu razliku prve zone. Razlika za prvu zonu nije nula jer je ova zona prilično velika. Ovo dodavanje malog broja (konstante) svim izmjerenim vrijednostima smijemo napraviti jer ono u stvari pretstavlja povećanje polumjera svih zona osim središnje istu malu vrijednost (0,1 mm u našem slučaju) koja je potpuno nebitna. Ova konstanta ispravlja zapravo pogrešku koju činimo kad uzimamo da je razlika polumjera za cijelu zonu jednaka. U stvari je ona za unutarnji rub zone manja nego za vanjski i kod velikih zona i kod zrcala malog F-broja ona može porasti na nekoliko desetinki milimetra. Usporedimo sad izmjerene vrijednosti iz zadnje kolone sa teoretski izračunatima: vidimo da su one nešto manje od potrebnih. Za takvo zrcalo kažemo de je podkorigirano. Kako takva ploha ima oblik elipsoida, neki puta govori se i o elipsoidnom zrcalu. Ako su izmjerene vrijednosti prevelike, zrcalo je prekorigirano ili hiperbolično.

Jedno upozorenje: u mnogo knjiga, posebno starijih, tvrdi se da je zrcalo dovoljno dobro ako izmjerene vrijednosti odstupaju za određeni postotak od izračunatih. Po tome bi tolerancija za razliku polumjera zakrivljenosti prema rubu rasla, dakle na rubu bi se tolerirala veća odstupanja od onih u sredini zrcala. U stvarnosti je upravo obrnuto: što smo bliže rubu, dozvoljeno odstupanje razlike polumjera zakrivljenosti zone od teoretski izračunate vrijednosti je sve manje. Razlog je zapravo vrlo jednostavan: zrake bliže rubu odbijaju se prema optičkoj osi ppod većim kutem nego one u blizini središta zrcala, pa je i mala pogreška u nagibu plohe dovoljna da ih izbaci iz ogibnog kružića i tako pokvari sliku koju zrcalo daje. Dodajmo tome da je sredina zrcala i tako zasjena pomoćnim zrcalom, pa taj dio plohe uopće ne sudjeluje u stvaranju slike i njegov točan oblik je potpuno nebitan. To objašnjava i činjenicu da su tolerancije kod malih F-brojeva (=veći kutevi zraka prema optičkoj osi!) puno strože od onih za zrcala većih F-brojeva. No, o svemu tome više riječi na slijedećoj stranici.

KOREKCIJE OBLIKA PLOHE

Kad smo odredili oblik plohe zrcala počinje najteži dio posla: popravljanje nedostataka i dobivanje parabolične plohe. Ovaj dio posla zahtijeva veliku pažnju jer je sa samo nekoliko minuta krivih poteza moguće uništiti cijeli prethodni rad i trud. Koncentrirajmo se dakle i krenimo pažljivo na posao. Prvo treba dobro proučiti grafikon tolerancija. Kako izgleda ploha našeg zrcala? Izlazi li i gdje izvan krivulja tolerancije? Naš slijedeći potez ovisi o rezultatima ove analize. Ona će nam pokazati neku od donjih pogrešaka, ili čak i njihovu kombinaciju:

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1. ploha je sferna, ili vrlo blizu njoj. Znak da smo dosad sve ispravno napravili i nažalost relativno rijetka sreća! Rad nastavljamo parabolizacijom zrcala. I ovdje razni autori imaju različita rješenja, a po mojem iskustvu pokazalo se da je najjednostavnije alat staviti dolje, zrcalo na njega i koristiti duge "W" poteze sa nešto većim šetanjem lijevo-desno nego kod poliranja. Tu treba paziti da se na krajevima poteza zrcalo ne "klacka" na rubu alata jer će to iskopati veliku središnju rupu koju je teško popraviti. Niste li sigurni, krenite radije sa malo kraćim potezima. Isto tako ne pretjerujte sa radom. Prvo napravite samo jedan krug oko alata (par minuta poliranja maksimalno!) pa ponovno izmjerite oblik plohe. Moderni polirni prašci znatno su brži od onih klasičnih, pa ne vjerujte previše starim knjigama, kad vam tvrde da parabolizacija traje nekoliko sati. 20 cm F/8 zrcalo dade se parabolizirati za nekoliko minuta (računajući samo rad na poliranju naravno!), jednom smo zrcalo od 40 cm F/4,5 u 15 min rada iz sfere preveli u hiperbolu, pa ga u idućih pola sata srećom uspjeli vratiti na parabolu. Oprez je dakle ovdje zakon!

Ide li oblik plohe prema paraboli nastavite dalje, i pazite da ne pretjerate. Hiperbolu je mnogo teže vratiti na parabolu, nego od sfere doći do parabole! Pojavljuje li se neka od dolje navedenih grešaka, promijenite pokrete da bi izbjegli njihovo pojačavanje. O svemu treba voditi detaljan dnevnik, iz kojeg ćete kasnije u miru moći zaključiti što u vašem slučaju pojedini potezi rade.

OK, OK, nismo te sreće. Ploha ima ozbiljnije pogreške. Tu je princip rada da se uvijek prvo "napada" najozbiljnija pogreška, pa kad se ona ukloni, pažnju posvećujemo slijedećoj. Idemo dakle redom, prvo od najtežih pogrešaka:

2. krumpir (nepravilna ploha) znak je da sa matricom nešto ozbiljno nije u redu. Provjerite zato kvadratiće i temperaturu sobe u kojoj radite. Smola ne smije biti pretvrda, premekana smola nosi sa sobom moguće probleme spuštenog ruba ali nikad nepravilan oblik plohe. Zagrijte matricu u toploj vodi, namažite je dobro smjesom za poliranje pa na toplo otprešajte na zrcalu da postignete dobar kontakt. Nakon 10-15 min počnite sa poliranjem, uz uobičajene W poteze, pa nakon oko pola sata rada provjerite plohu. Ako se njen oblik popravlja, nastavite dok nepravilnosti sasvim ne nestanu, pa onda krenite u korekcije.

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3. zone. Ako su blage povećajte pokrete sa kojima radite. Provjerite prije nastavka da li je matrica u redu, posebno da li su svi kvadratići smole u kontaktu sa plohom, jer je loš kontakt uz kratke poteze najčešći uzrok zona. Svakako provjerite da li je centar matrice u uglu središnjeg kvadratića a ne u njegovoj sredini. Ovakva zabuna lako vodi do zona! Zone je najbolje ukloniti širokim W potezima (bočno šetanje jednako dužini poteza) koji nisu previše dugi, da ne pokvarimo rub. Pokušajte za početak sa dužinom poteza od oko pola promjera zrcala.

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4. spušteni rub, sam ili uz druge pogreške. Spušteni rub može biti vrlo veliki problem, pogotovo ako je širi od nekoliko mm. Uski spušteni rub često puta nije moguće izbjeći, pa ako je ostatak plohe u redu, najbolje ga je ignorirati i kasnije rub zrcala pokriti kružnom maskom. No, ako je širi, mora ga se ukloniti, jer nitko ne želi polovicu promjera zrcala maskirati zbog spuštenog ruba! Doduše, jednom davno u danas nepostojećoj zemlji sagradjen je najveci teleskop na svijetu s azrcalom od 6 m promjera. Upravo zbog lošeg ruba nekoliko je godina radio sa zaslonom otvora 4 m! Vi dakle sami odlučujete koju širinu spuštenog ruba ćete trpjeti a koju ne...

Imate li problem sa spuštenim rubom, prvo uredite rub alata i uklonite svu smolu koja je istisnuta preko njega. Popravite i oblik kvadratića smole ako treba. Zrcalo stavite dolje i napravite jedan ili dva kruga kratkim centralnim potezima. Mijenjajte pri tome malo dužinu poteza i povremeno napravite par uskih W poteza da izbjegnete nastanak zona. Pokaže li ispitivanje oblika plohe da se rub ispravlja, nastavite u tom smjeru, no ako nema promjene, pokušajte smanjiti promjer alata za 5-6 mm tako da podrežete rubne kvadratiće smole. Tvrdokorni spušteni rub može se pokušati ukloniti bočnim potezima uz pritisak na rub zrcala, no taj je postupak dosta riskantan i može napraviti veliku štetu, pa ga ostavite kao zadnju mogućnost. Parabolizaciju nastavite tek kad je spušteni rub potpuno uklonjen. Kod ponovne parabolizacije smanjite malo bočno pomicanje kod poteza za parabolizaciju i često kontrolirajte. Poćne li se rub opet spuštati, smanjite i dužinu poteza za parabolizaciju a možete malo i smanjiti promjer matrice za poliranje.

5. centralna rupa. Provjerite da li je veća od male poluosi pomoćnog zrcala. Ako nije, ostavite je jer će i tako biti u sjeni pomoćnog zrcala. Ako je, nastavite rad srednjim W potezima i zrcalom dolje, dok se rupa ne ukloni. Pazite pri tome na rub! Kad uklonite rupu, nastavite sa normalnom parabolizacijom.

6. ploha je hiperbolična. Odmah zamijenite mjesto zrcala i alata, te stavite zrcalo dolje. Nastavite rad srednjim centralnim potezima, sa povremenim W potezima, da spriječite pojavu zona. Svakih 15tak minuta kontrolirajte vraća li se oblik plohe prema kugli, ili ne. Često će nakon ovog "vraćanja" zaostati spušteni rub, kojeg onda treba na kraju ukloniti. Ako je hiperbola jako izražena (zonska odstupanja od sfere su dva i više puta veća od onih za parabolu) najbolje je zrcalo prebrusiti najfinijom frakcijom sve dok se ne uklone svi znakovi poliranja (pazite na rub!) pa onda krenuti sa poliranjem izpočetka. Radite li novu matricu, upotrijebite nešto tvrđu smolu.

7. što god da radim, ništa ne pomaže! Ovo je znak da nešto ozbiljno i sitematski ide krivo. Proučite dnevnik poliranja, razmislite o smoli, potezima, položaju zrcala, vašim namjernim i još više nenamjernim pritiscima na alat ili zrcalo. Prebrusite zrcalo najfinijom frakcijom, dok tragovi poliranja potpuno ne nestanu, izradite novu matricu i krenite iz početka sa poliranjem. Oho, ovo je već peti put? Tu pravog savjeta nema. Moguće je, iako rijetko, da disk zrcala nije ispravan i da u njegovom staklu ima previše zaostalih naprezanja. Nema druge nego pokušati sa novim diskom, po mogućnosti iz drugog izvora i provjerene kvalitete, a ako ni onda ne bude bolje, možete poćeti sumljati u sebe... Tu više pravog savjeta više nema, sami morate odlučiti želite li i dalje uporno tražiti (i vjerojatno na kraju naći) uzrok problema, ili vam je jednostavnije napustiti ovaj dio izrade teleskopa....

ALUMINIZIRANJE ZRCALA

Da bi izradjeno ogledalo vršilo svoju funkciju, potrebno je prethodno njegovu površinu presvući tankim slojem metala koji reflektuje svetlost. U današnje vreme, aluminizacija ogledala je u potpunosti zamenila tradicionalno posrebravanje ogledala (koje se inače može uspešno uraditi i u amaterskim uslovima, što sa aluminizacijom nije slučaj) .

Dobro uradjen sloj aluminijuma je otporan na atmosferske uticaje i traje nekoliko godina, dok srebrni sloj traje najviše 6 meseci kada se mora obnoviti.

Poklopac vakumske komore s prstenom od pet volframovih isparivaca (u koje se umetne aluminijska zicica) i centralnom casicom za silicij dioksid.

Umetanje zrcala u komoru

Vakumska komora za naparivanje, zatvorena i u pogonu

IZRADA OKULARA

Iako izrada leća nije teža od izrade zrcala, ona ima svoje specifičnosti. Kao prvo, leće okulara znatno su manje od zrcala i obično su promjera izmedu 5 i 30 mm. Ovako male optičke elemente ne možemo izrađivati tehnikom koja se koristi za zrcala. Leće se obično izraduju tako da se alat montira na osovinu koja se okreće prikladnim motorom. Brzina okretanja raste sa smanjenjem promjera leće i za leće navedenih promjera kreće se izmedu nekoliko desetaka i nekoliko stotina okreta u minuti. Pored toga, kako se leća sastoji od dvije plohe, potrebno je paziti na njihovu koncentričnost, ili po završetku izrade leće izvršiti njeno centriranje. Za oba postupka potreban je skup dodatni pribor. No najveća poteškoča leži u činjenici da su leće u većini okulara izradene od nekoliko različitih vrsta optičkih stakala kako bi se korigirale kromatska i druge optičke pogreške. Kako je optičko staklo u našoj zemlji praktično nemoguće nabaviti u malim količinama, što uostalom ni u inozemstvu nije jednostavno, jer se optičko staklo uglavnom prodaje u blokovima tezine desetak kg, sasvim je jasno da amatersko brušenje okulara nije jeftin hobi. Kilogram običnog optičkog stakla stoji oko 50 EUR, a specijalna stakla mogu koštati i dvadesetak puta više. Što onda učiniti?

Kao prvo možemo iskoristiti okular nekog starog dalekozora ili dvogleda. Ovi okulari u pravilu su dovoljno kvalitetni za dalekozor opisan u ovom priručniku. Većina ovih okulara je tzv. Kelerovog tipa, koji se ponekad naziva i akromatski Ramsden okular, ali se mogu naći i egzotične izvedbe, posebno na dvogledima ruske proizvodnje. Okulari dvogleda obično zadovoljavaju na dalekozorima kod kojih F broj nije manji od 8 ili 7, ali ima i lošijih. Čak i kupnja i rastavljanje novog dvogleda isplati se usporedimo li cijenu jeftinijeg dvogleda i okulara kojeg moramo kupovati iz inozemstva. U svakom slučaju, ako kupujete dvogled za ovu namjenu, udružite se sa prijateljem, ili drugu polovicu dvogleda iskoristite kao tražilo.

Pored toga, mozemo pokušati u prodavaonicama rabljenih stvari kupiti dvogled, povečalo, objektive starih fotoaparata i sl., naravno ako su po cijeni pristupačni. Objektiv fotoaparata može se u nuždi upotrijebiti kao okular za malo povečanje, ali se ne može unaprijed reći hoće li odredeni objektiv dati dobru sliku ili neće. To se jednostavno mora isprobati.

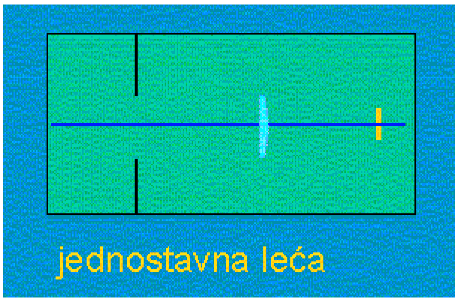
Nadalje, od sakupljenih optičkih dijelova možemo pokušati složiti neki okular. I tu je nemoguće predvidjeti ishod. Samo proba na našem dalekozoru može pokazati da li tako složeni okular daje zadovoljavajuću sliku ili ne. Od sakupljenih leća i lećica mozemo probati sastaviti jedan od slijedeća četiri tipa okulara:

1. Jednostavna leća
2. Huygensov okular
3. Ramsdenov okular
4. Simetrični okular

Svi ostali tipovi okulara zahtijevaju međusobno usklađene leće točno propisanih optičkih svojstava i tu se slaganjem iz nasunce sakupljenih dijelova ništa ne može napraviti.

Ako imate starih leća, svakako pokušajte nešto složiti jer uvijek postoji šansa da se dobije upotrebiv okular. Prošvrljate po dučanima sa rabljenom robom, foto dučanima i sl. pitajte rodbinu, možda netko ima razbijeni dvogled ili sličnu spravu. I pustite mašti na volju. Zašto napr. ne bi od ruske "trube" 10x30 uzeli okular za svoj astronomski dalekozor (odličan okular), od leća iz okretača slike te iste trube sastavili simetrični okular i montirali ga na ostatak trube koju ćete onda upotrijebiti kao tražilo? Za tu svrhu možete izraditi i Ramsdenov okular. Truba je doduše uništena, ali dobili ste okular i tražilo uz umjerenu cijenu.

Jednostavna leća

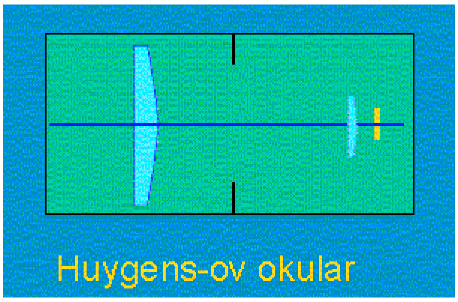


Jednostavna leća, najbolje ako je plankonveksna, može se koristiti za velika povećanja. Nije korigirana na boju, pa najbolje radi kod dalekozora velikog F broja, naprimjer kod refraktora. Nekad se koristila za velika povecanja. Nedostatak joj je maleno vidno polje dobre slike koje se kreće između 15 i 25 stupnjeva.

Prednost joj je velika udaljenost izlaznog otvora od zadnje plohe leće, koja je otprilike jednaka žarišnoj daljini leće. Kod okulara malih žarišnih daljina ovo nije zanemariva prednost, pa ako imate refraktor, svakako razmotrite i ovaj tip okulara. Kod ovog tipa okulara ravna strana (ili strana manje zakrivljenosti, ako leća nije plankonveksna) okrece se prema objektivu dalekozora.

Imate li u svojoj zbirci akromatsku leću male žarišne daljine, bit će i ona odličan okular ovog tipa, uz bolje ispravljanje optičkih pogrešaka, ali nažalost sa isto tako malenim vidnim poljem.

Huygensov okular

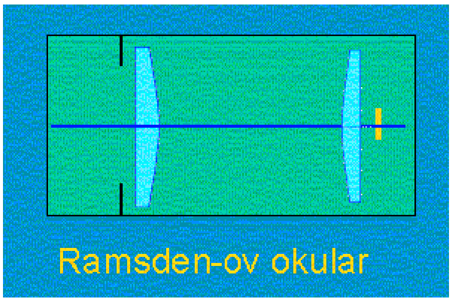


Huygensov okular sastoji se od dvije pozitivne leće, obićno plankonveksnog oblika. On je zasnovan na principu da je kombinacija dvije leće, izrađene od iste vrste stakla, akromatična ukoliko su te dvije leće razmaknute za polovicu zbroja svojih žarišnih daljina. Drugim riječima, ako je žarišna daljina prve leće F1, a druge leće F2, onda ćemo akromatski okular dobiti ako ih postavimo na razmak od D = (F1+F2)/2.

Najčešće se za ovaj okular koriste dvije leće cije žarišne daljine su u omjeru 1:3, pri ćemu je leća manje zarišne daljine bliža oku. Ovo je tip tzv. negativnog okulara, što znaći da mu se zarišna ravnina (ravnina slike) nalazi između leća okulara. Kod pozitivnih okulara (preostala tri tipa okulara opisana u ovom dijelu su pozitivna) žarišna ravnina nalazi se ispred prve leće okulara, pa se pozitivan okular moze koristiti i kao povečalo.

Udaljenost izlaznog otvora od zadnje plohe leće okulara je znatno manja od one kod jednostavne leće i iznosi oko 0,3 zarišne daljine okulara. Huygensov okular ima veliko vidno polje, neki puta i do 50 stupnjeva. Na žalost, kvaliteta slike ograničena je aberacijama pa ovaj okular nije moguće koristiti kod F brojeva manjih od 10, a najbolje radi na refraktorima. Iz istih razloga okulari ovog tipa ne rade se sa zarišnim daljinama manjim od oko 15 mm. Većina jednostavnih mikroskopskih okulara ovog je tipa.

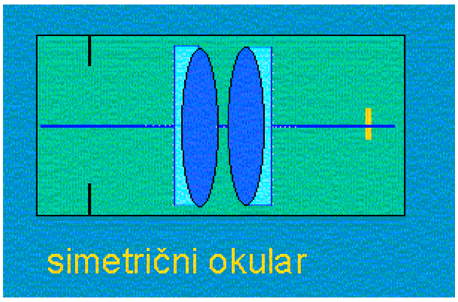
Ramsdenov okular



I ovaj okular zasnovan je na istom principu akromatičnosti kao i Huygensov okular, ali je za razliku od njega pozitivan. Ramsdenov okular sastoji se od dvije identične plankonveksne leće s trbusima okrenutim jedan prema drugome i razmaknutim za 2/3 do 3/4 žarišne daljine jedne leće. Vidno polje nešto je vece, do 30 stupnjeva, a moze se koristiti i na reflektorima do F broja 7 ili 6. Ovaj okular zasniva se na principu da dvije iste leće, razmaknute za svoju žarišnu daljinu, tvore akromatski okular. No, kako je u tom položaju izlazni otvor na zadnjoj plohi izlazne leće, smanjuje se malo razmak izmedu leća da bi se izlazni otvor odmaknuo od nje, što rezultira gore spomenutim razmakom izmedu leća. U tom slučaju izlazni otvor blizu je zadnjoj plohi okulara, obično 0,1 do 0,2 žarišne daljine okulara iza nje.

Žarišnu daljinu kombinacije dviju leća možemo izračunati uz pomoć formule za žarišnu daljinu dvije tanke leće, ali je bolje izmjeriti žarišnu daljinu izrađenog okulara, napr. mjerenjem promjera izlaznog otvora okulara. Dobri okulari mogu se dobiti ako leće i nisu sasvim plankoveksne, pa čak i ako im se žarišne daljine malo razlikuju. Kao i prije, samo proba na dalekozoru pokazuje da li je izrađeni okular uspio ili nije. Ovo je inaće odličan okular za tražilo!

Simetricni okular



Imamo li sreću da smo nabavili dvije iste ili slične akromatske leće, možemo od njih napraviti simetrični okular. Leće jednostavno montiramo tako da su im trbusi okrenuti jedan prema drugom tako da se skoro dotiću (0,1 do 1 mm razmaka sasvim zadovoljava). Pazite da se ne dotaknu, jer će se leće oštetiti. Ovakav okular ima veliko vidno polje, neki puta i do 50 stupnjeva, veliku udaljenost izlaznog otvora (oko 0,8 žarišne daljine) i uglavnom dobro radi na većini dalekozora do F broja 5 ili cak 4. Neki puta se ovaj okular pogrešno naziva Plossl.

MEHANIKA

Zadatak montaze teleskopa je odrzavane u idealnom odnosu elemenata optickog sustava, te da omogucava gledanje raznih tocaka nebeske sfere. Osnovni uvjeti koje mora zadovoljavati dobra montaza teleskopa su:

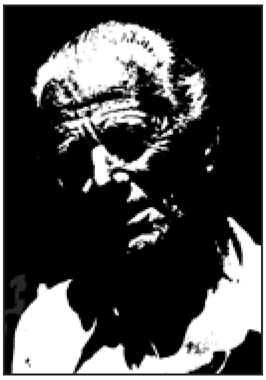
Velika stabilnost i krutost konstrukcije.
Lakoca i preciznost pomicanja u obije osi.
Balansiranost, tezišta se moraju nalaziti u osima pomicanja.
Mogucnost vršenja promatranja od horizonta do zenita u svim pravcima.
Kompaktnost konstrukcije, koja omogucava bolje korišcenje prostora, lakši transport i vecu krutost.
Mogucnost udobnog promatranja u svim polozajima teleskopa.
Jednostavnost konstrukcije te primjena jeftinih materijala.

Od nastanka teleskopa do danas nastao je citav niz montaza koje zadovoljavaju ove opce, a i mnoge specificne zahtjeve. Bez obzira na to povijesno bogatstvo, u posljednje se vrijeme stvaraju i radikalno nove koncepcije mehanickih djelova teleskopa.

Mnoge montaze koje su zbog nekih svojih nedostataka gotovo pale u zaborav danas se, zahvaljujuci primjeni novih materijala ili racunala, vracaju ponovno u uporabu.

Kako su montaze beskonacna tema, za sad dosta o njima da ne ispadne knjiga o njima, iako prije ili poslje ce trebati u digitalni zapis staviti neke neobjavljene tekstove koji se tuda vuku .....

DOBSON montaza nastala je iz potrebe da se " ni iz cega " izradi teleskop. Takva je konstrukcija bila izazov veoma sofisticiranim montazama koje su u americi izradivali amateri okupljeni oko casopisa" Scientific American " i " Sky and Telescope-a ". Autor te montaze John Dobson dokazao je da se sa veoma skromnim sredstvima moze izraditi dobar i upotrebljiv prijenosni instrument. Danas, kad se zbog sve veceg svjetlosnog zagadenja iz mnogih mjesta više ne mogu vršiti astronomska promatranja, sve se više traze takvi prijenosni instrumenti. Newtonov teleskop na Dobson montazi tu naprosto nema konkurencije.



JOHN DOBSON

Vedantinski redovnik,
ziveci 23 godine u manastiru, veoma je teško dolazio do materiala i novca za izradu teleskopa. Poseban mu je problem bila i zabrana takvog rada u manastiru. Kako biod drugih sakrio svoju aktivnost, nocu bi brusio zrcala u lavoru punom vode, gušeci na taj na cin zvuk brušenja. Stakleni je disk bio dno boce ili brodsko prozorsko staklo, a abraziv kvarcni pijesak. Dovršene bi teleskope poklanjao djeci u susjedstvu, pod uvjetom da mu omoguce promatranje sa njima. Da bi aluminizirao zrcalo od 18 inch a skupljao je sa dna bazena upale novcice dvije godine (45$). Napuštanjem manastira 1967. godine za njega zapocinje veoma plodan period popularizacie astronomije i izrade teleskopa. U to vrijeme se teleskopi takve konstrukcije izraduju samo u astronomskom klubu " San Francisko Sidewalks astronomers ".

Tek se 1980. godine javljaju prvi takvi komercijalni teleskopi (firma Coulter) koji nose Dobsonovo ime. Danas mnoge tvornice koriste taj oblik montaze. Amateri u SAD gotovo isklju civo izraduju takve teleskope, ali John Dobson od toga nema ništa. Sa 74 godine prestar je da nešto drugo pocinje raditi, zivi od milostinje, a obroke dijeli sa svojim psom. Ipak, nema niti jednog skupa ATM na kojem se pojavi a da se oko njege ne okupi guzva "obozavatelja".

Svaka se Dobson montaza sastoji od podloge, sanduka i tubusa. Materijal za njenu izradu je naj cešce uko ceno drvo ili panel plo ca, pa je to i najjeftinija od svih montaza. Na cin spajanja tubusa sa sandukom i sanduka sa podlogom povecava joj krutost. Njoj bi od drugih montaza najviše sli cila azimutalno postavljena viljuškasta montaza. Izuzetno je prakti cna za neke oblike rada. Od svih postojecih montaza ona je najlakša, pa se lako prenosi do mjesta promatranja.

Naravno da, kao i svaka druga azimutalna montaza, ima i citav niz veoma ozbiljnih nedostataka, ali oni ni najmanje ne smetaju koristimo li tu montazu u traganju za kometama, promatranju maglica ili trazenju supernovih zvijezda u susjednim galaksijama.

Do danas je objavljeno mnogo clanaka o poboljšanju te montaze, ali se poboljšavanjem gube glavne osobine te montaze a to su : niska cijena i prakti cnost.

Tubus:

Funkcija je tubusa da opti cke elemente drzi u opti ckoj osi na fiksnoj udaljenosti, te da onemogucava ulazak svjetla sa strane u teleskop (parazitsko svjetlo). Takoder tubus mora omogu cavati slobodnu cirkulaciju zraka u teleskopu radi postizanja ujedna cene temperature. Iako na prvi pogled to izgleda lak zadatak, pri pokušajima izrade, moze nam se desiti da naš tubus " ne zadovolji". Sam naziv " tubus " ili cijev moze nas navesti na pomisao da je neophodno da taj element tako i izgleda. Cijev, bez obzira na neka veoma dobra svojstva, se gotovo ni ne koristi, jer nam razne kombinirane konstrukcije daju bolje rezultate. Kako bi se parazitsko svjetlo svelo na najmanju mjeru u tubus se stavljaju posebni elementi " dijafragme " ciji je zadatak da hvataju svjetlo koje se reflektiralo sa stijenki tubusa. Radi upijanja svjetla sva se unutrašnjost tubusa boja crnom mat bojom.

Originalne su Dobson montaze koristile kartonski tubus. Danas se cešce koristi tubus od fiberglasa za manje instrumente,a rešetkasti tubus za vece.

Izuzetno je vazno da se rešetka izradi u obliku spojenih trokuta kako bi deformacije tubusa pod raznim opterecenjima bile što manje. Radi lakšeg spajanja tubusa sa osi visine koja se oslanja na sanduk, centralni se dio Dobson teleskopa izraduje u obliku cetverokuta, a cesto i cijeli tubus.

U našem slu caju tubus je cetvrtasta konstrukcija drvenih letvica, na nekim mjestima zatvorena šperplo com. Takav je odabir materijala i konstrukcije bio uvjetovan prvenstveno cijenom i lakocom izrade..

Nosac objektiva

Ovaj izuzetno vazan dio teleskopa ima funkciju da u bilo kojem polozaju teleskopa zrcalu pruza takav oslonac da se deformacije koje nastaju zbog vlastite tezine zrcala svedu u podnošljive okvire, te omogucava namještanje zrcala u opti cku os. Tendencija, da se objektivi izraduju od sve tanjih diskova stakla, potaknula je razvoj nosa ca objektiva, kako u profesionalnoj tako i u amaterskoj primjeni. Kako je i veoma komplicirani nosa c lakši i jeftiniji od debelog zrcala, ta ce se ta tendencija " stanjivanja " sigurno i nastaviti.

U našem je slu caju nosa c od panel plo ce, a moze se zamijeniti tezim materijalom, trebamo li sa zadnje strane balansirati tubus. Kako su naša zrcala veoma debela, odlu cili smo se za najjednostavniji na cin hvatanja, ljepljenjem.

Nosa c sekundarnog zrcala " pauk "

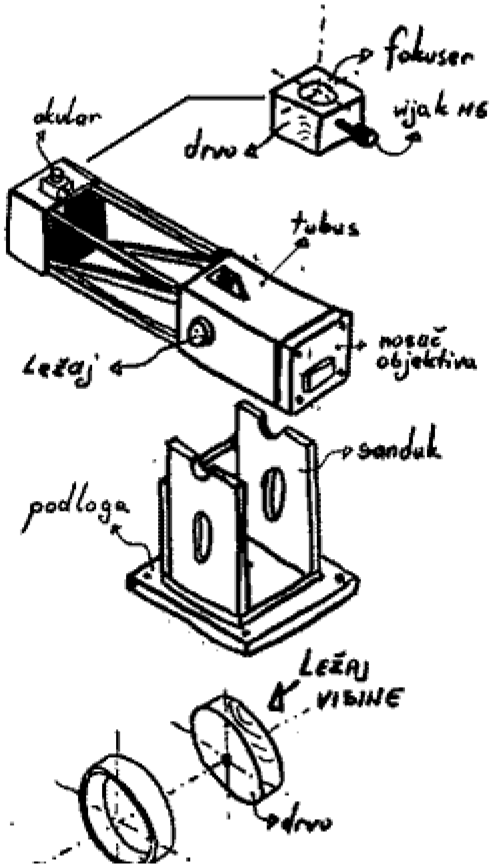
Nalazi se u opti ckoj osi teleskopa i nosi sekundarno zrcalo. Nosa ci zrcala i samo zrcalo smanjuju koli cinu svjetla koje stize do objektiva, a ujedno kvare kvalitet slike. Radi toga je potrebno da su što manjih dimenzija.

Difrakcija svjetla na nosa cima stvara grešku koja se vidi u obliku krakova na sjajnim zvijezdama. Greška je nešto manja koristimo li cetiri umjesto tri nosa ca. Posebnim oblikom nosa ca ona se gotovo moze izbjeci. Za teleskope sa Dobson montazom izraduje se najjednostavniji takav nosa c, jer za vrstu rada za koju se koriste ti instrumenti, ta se greška ne uocava.

Nosac okulara i fokuser

Njegov je zadatak da vrši finu promjenu udaljenosti izmedu objektiva i okulara, a da se pritom oni ne pomi cu van opti cke osi. Ovaj se dio teleskopa uglavnom kupuje gotov, ali se, ako smo skromnijih zahtijeva, moze i izraditi. Sa cijenom od 50 150 US$,takav bi nas element koštao u samogradnji koliko i sam teleskop.

Kod izrade ili nabave moramo odlu citi za koji promjer okulara ce taj fokuser biti korišten. Standardni su promjeri okulara 25 mm,1.25" (32 mm), 2" (51 mm), a okulari koji se naj cešce koriste su od 32 mm.



Lezajevi

Kod Dobson montaze koristimo klizne lezajeve koje sami izradujemo od komada plasti cne cjevi ili plasti cne plo ce. U tu se svrhu naj cešce koristi plastika "Teflon", ali mogu posluziti i druge plasti cne mase. Obi cno se o lezajevima razmišlja kao o elementima kod kojih je veoma vazno da je trenje što manje. To nije slu caj sa lezajima kod te montaze. Lezajevi tu imaju višestruku funkciju, osim kao lezajevi sluze i kao klizne spojke.

Sanduk

Dio teleskopa na koji se oslanjaju osovine tubusa, a on se naslanja na podlogu, zovemo sanduk. Taj element montaze mora imati veoma veliku krutost i dobro gušiti vibracije. Drvo je veoma zahvalan material za njegovu izradu. Sanduk se moze prilikom transporta koristiti kao kutija za prijenos elemenata teleskopa.

Podloga

To je plo ca na koju se oslanja sanduk. U zavisnosti od zahtjeva koje si postavimo za teleskop, ona moze biti više ili manje komplicirana. Dobro je ako postoji mogucnost njezina fiksiranja za tlo. Na njoj su zaljepljeni plasti cna plo ca ili tri komada Teflona koji sluze kao aksialni lezaj azimutne osi.

Balansiranje

Kod svake je montaze balansiranje vazno radi što manjeg opterecenja na pogonske mehanizme. Kod Dobsona to je osnovni uvjet rada. Teleskop svoj polozaj odrzava samo zahvaljujuci trenju u lezajevima. Svaka i malo veca sila naš ce teleskop pomaknuti, pa itekako trebamo paziti da nam se zbog lošeg balansiranja, teleskop ne po cinje sam micati.

Bojanje

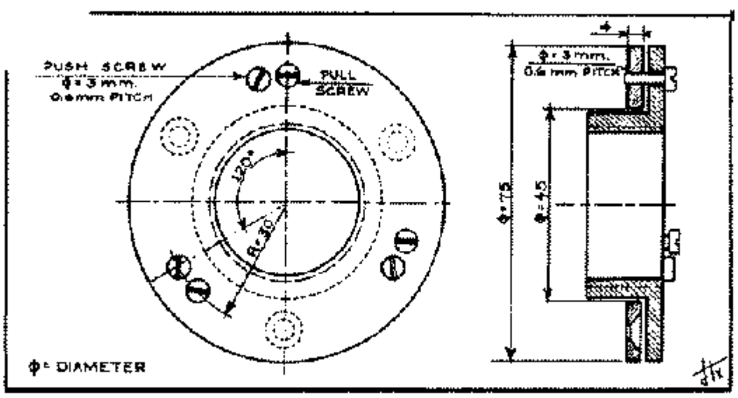
Bojanje teleskopa ima naravno ulogu da drvo štiti od vlage prilikom promatranja, ali od njega ovisi i završni izgled teleskopa.Tradicionalna boja teleskopa (bijela) gotovo se i ne koristi za Dobson montaze. Jedino boje i slike na motociklima (coperima) mogu prevazici boje Dobson teleskopa na kojima njihovi vlasnici ispoljavaju svoju kreativnost. I onako nitko taj teleskop nece dozivjeti kao nesto posebno lijepo, zato ako imate smisla za crtanje ili prijatelja kojemu se to da ......

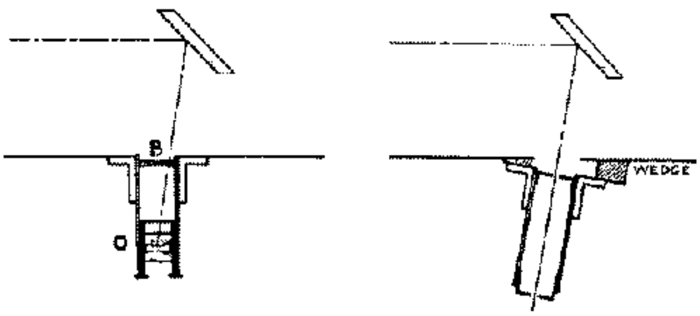
Centriranje Newton reflektora

Da bi naš reflektor davao kvalitetnu sliku, moramo sve njegove elemente dovesti na zajedni cku opti cku i mehani cku os. Ovaj postupak naziva se centriranje (ili justiranje) i kad se jednom nau ci, ne predstavlja poseban problem i ne oduzima mnogo vremena. Centriranje se moze grubo podijeliti na mehani cko i opti cko centriranje. Kod mehani ckog centriranja osiguravamo okomitost okularnog tubusa na tubus dalekozora i podešavamo nosa c sekundarnog zrcala tako da se centar sekundarnog zrcala nalazi na mehani ckoj osi tubusa. Ovo centriranje obi cno se provodi kod prvog sastavljanja instrumenta. Ako je instrument dobro izraden, mehani cko centriranje više nije potrebno ponavljati, osim u slu caju da je instrument jako udaren ili sl. S druge strane, opti cko centriranje potrebno je cešce kontrolirati jer se, ovisno o konstrukciji dalekozora, moze dogoditi da i manji udarci, premiještanje instrumenta ili promjene okolne temperature, pokvare opti cko centriranje. Prednost reflektora sa velikim F brojem je ta da je kvaliteta slike znatno manje osjetljiva na male neto cnosti u centriranju. Tako naprimjer, reflektori sa malim F brojem (4 do 5) moraju biti vrlo tocno centrirani, pri cemu je neki puta potrebno koristiti i posebna pomagala za tu svrhu. Reflektori srednjih i velikih F brojeva (8 i više) mogu se vrlo jednostavno centrirati bez posebnih pomagala.

Mehanicko centriranje

Okomitost okularnog tubusa na os glavnog tubusa obi cno je dovoljno dobro osigurana samom mehani ckom konstrukcijom okularnog tubusa. Sumnjamo li medutim, da ona nije dobra, mozemo je provjeriti (napr. kao na slici) i po potrebi dotjerati podlaganjem listica tamo gdje je to potrebno.





Polozaj centra sekundarnog zrcala moramo podesiti kod montaze nosa ca sekundarnog zrcala u tubus instrumenta.

Opticko centriranje

Opticko centriranje pocinjemo provjerom polozaja sekundarnog zrcala. Okularnu cijev zatvorimo zaslonom koji u sredini ima rupicu promjera 2 do 3 mm. Najbolje je da od komadica plastike ili drveta istokarimo ovakvo pomagalo za centriranje, ali ce isto tako dobro posluziti i obican okrugli komadic kartona, pod uvjetom da je to cno izraden. Promjer rupice nije jako vazan, ali je potrebno da ona bude to cno u sredini (osi) okularnog tubusa. Kad kroz ovu rupicu pogledano prema sekundarnom zrcalu, ono mora biti u sredini okularne cijevi. Ako nije, podešavanjem nosa ca sekundarnog zrcala moramo ga dovesti u taj polozaj. Nakon toga podešavamo samo sekundarno zrcalo okretanjem ili naginjanjem njegovog nosa ca uz pomoc vijaka koji se na njemu nalaze (obi cno tri vijka rasporedena pod 120 stupnjeva) tako dugo dok slika primarnog zrcala koju vidimo u sekundarnom zrcalu ne bude u sredini sekundarnog zrcala. Kod toga se prvo sekundarno zrcalo rotira oko osi glavnog tubusa dok slika primarnog zrcala ne dode u sredinu sekundarnog zrcala, gledano u smjeru osi tubusa. Sad se uz pomoc tri vijka podesi nagib zrcala tako da slika primarnog zrcala bude to cno u sredini sekundarnog. To se obicno radi tako da se malo pomakne jedan od tri vijka sekundarnog zrcala uz istovremeno gledanje slike primarnog zrcala u njemu. Prema pomaku te slike odredujemo da li vijak treba okretati ulijevo ili udesno, ili je potrebno prijeci na drugi ili treci vijak. Ovdje je vjezba najbolji u citelj. Kad smo to postigli, obratimo paznju na sjenu sakundarnog zrcala i njegovog nosa ca na primarnom zrcalu. Uz pomoc tri vijka na nosa cu primarnog zrcala, naginjemo primarno zrcalo tako dugo dok sjena sekundarnog zrcala ne padne u sredinu primarnog zrcala. Kad smo to postigli, instrument je namjesten i spreman za promatranje.

Nakon malo vjezbanja, postupak centriranja postaje vrlo jednostavan i brz. Uglavnom je potrebno samo malo popraviti polozaj sekundarnog i primarnog zrcala, za što je dovoljno nekoliko minuta rada. Dobro je prije svakog promatranja provjeriti da li je instrument najustiran, kako ne bismo promatrali sa nepodešenim instrumentom.

ODRŽAVANJE OPTIKE

Vijek trajanja našeg instrumenta, okulara i drugog pribora, uveliko ovisi o pažnji koja mu se posvećuje. Sve optičke elemente, dakle leće i zrcala, treba čuvati na suhom mjestu zaštićenom od prašine. Dobro je stoga izraditi poklopce sa kojima će se naš instrument zatvarati kad ga ne koristimo. Na taj će se naćin prašina znatno sporije skupljati na optičkim elementima, pa će čišcenje biti rjeđe potrebno.

Zapamtite pored toga da su sve optičke površine osjetljive i da se lako mogu zagrebsti. Zato ih nikad ne dodirujte prstima, i ne brišite ih uz primjenu pritiska. Za brisanje koristite samo jelenju kožicu ili meku, mnogo puta prokuhanu lanenu ili pamučnu tkaninu (napr. stare maramice) ili pak specijalni papir koji se može kupiti u prodavaonicama foto opreme. Ovo se posebno odnosi na aluminizirane površine jer su zrcalni slojevi mnogo osjetljiviji od antirefleksnih slojeva na lećama. U slučaju da optički dijelovi budu poprskani vodom, odmah ih obrišite. Ako se na njima kod unošenja iz hladnije okoline uhvati rosa, ostavite ih na toplom mjestu da se osuše, pa ih tek onda spremite. I zapamtite: čistite ih što rjeđe i to onda kad se na njima zaista nakupilo prašine i druge prljavštine. Nekoliko zrnaca prašine na zrcalu zaista ne smeta, a učestalo brisanje uskoro će izgrebsti osjetljivi aluminijski sloj sa vrlo primjetnim efektom gubitka kontrasta u slici jer ogrebotine raspršuju mnogo svjetla preko cijelog vidnog polja.

Čišćenje zrcala

Prašinu prvo pokušajte otpuhnuti gumenom pumpicom (može se nabaviti u prodavaonicama foto opreme). Ne pušite ustima, jer u dahu često puta ima sitnih kapljica sline koju ćete vrlo teško ukloniti sa zrcala bez posljedica. Ako nakon otpuhivanja zaostane nekoliko zrnaca prašine koja su se zalijepila, zanemarite ih. No, ako ih ima mnogo, zrcalo stavite u posudu sa mlakom vodom sa zrcalnim slojem prema gore. U vodu dodajte samo nekoliko kapi deterđenta za pranje stakla ili posuđa, i ostavite desetak minuta da se prašina odmoći. Voda treba pokrivati zrcalo u sloju debelom jedan do dva cm. Nakon desetak minuta lagano, bez pritiska, kružnim pokretima prebrišite cijelo zrcalo grumenom vate, ali tako da kod svakog poteza okrenete vatu na još neuporebljeni dio kako se ne bi greblo s česticama koje su se već uhvatile na vatu. Zrcalo dobro isperite pod tekućom vodom bez dodirivanja zrcalne površine i isplahnite ga sa malo destilirane vode. Nakon toga ga ostavite da stoji uspravno na nekom mjestu bez prašine dok se ne osuši. Još bolje je da ga osušite sušilom za kosu, ali pazite da struja zraka bude mlaka a ne vrela. Ono što ni nakon ovog postupka nije uklonjeno sa zrcala, ostavite tamo gdje je, ili pokušajte lagano ukloniti čistim izopropilnim alkoholom uz upotrebu gumenih rukavica da se masnoća s ruku ne prenese na zrcalo. Svaki pokušaj uklanjanja tvrdokorno zalijepljenih zrnaca prašine obično izgrebe zrcalni sloj, ili još gore i samo staklo ispod njega. Zato ne budite preveliki čistunci!

Nakon posla na suho zrcalo mogu se priljepiti naelektrizirane dlačice i prašina koju veoma jednostavno micemo naelektriziranom krpom od poliestera kakve se baš za skidanje prašine u domačinstvima prodaju u trgovinama kučnih potrepština.

Čišćenje leća

Leće se čiste na sličan način kao i zrcala, sa tom razlikom da se ne potapaju u vodu, već se obrišu sa malo vate namoćene u vodu kojo je dodano malo deterđenta za pranje stakla ili posuđa, a mozemo koristiti i specijalnu tekućinu za čišćenje foto optike (koja najčešće i nije ništ adrugo nego gore opisana "čarobna" tekućina) ili izopropilni alkohol. Okulare se ne demontira i ne potapa u tekućinu već se s lagano namoćenom vaticom prođe preko površine leće da se ona navlaži, a nakon nekoliko sekundi se ta tekućina s prljavstinom odmah skida brisanjem sa drugom suhom vatom da tekućina ne bi ušla u okular. Dogodi li se to, morat ćete rastavljati cijeli okular, što ponekad nije ni jednostavno ni lako, a greške u poretku i oštećenja leća kod ponovnog sastavljanja nisu rijetkost. Ako su leće veoma male, jako su pogodni stapići za čisćenje ušiju.

Nakon brisanja okulare osušite mekanom krpicom ili s malo suhe vate, stalno uzimajući čisti dio na koji se još nisu zaljepila zrnca prasine koja bi mogla izgrepsti plohu. Pazite na dlačice koje vata rado ispušta posvuda, a ukloniti ih možete naelektriziranom krpom od poliestera. Antirefleksni slojevi na lećama tvrđi su od aluminijskih slojeva na zrcalima, pa kod njihovog čišćenja ne moramo biti tako nježni, ali moramo svakako biti pažljivi. I leće, kao i zrcala ne treba glancati svaki čas jer su neke vrste optičkog stakla koje se koriste u slozenim okularima i objektivima znatno mekanije od stakla za zrcala, pa se i znatno lakše ogrebu. Pazite kod ruske optike jer su njihovi antirefleksni slojevi često puta vrlo osjetljivi!