Using The Ross Null Test

By Peter Ceravolo

Introduction

Measuring zones with the aid of a zonal mask, while requiring little in the way of special equipment, is decidedly not the ideal way to test a parabolic mirror at the center of curvature. Early on in my mirror making days I longed for a more accurate and easily applied testing technique which was also faster to perform. Null tests, where the spherical aberration of the mirror at the center of curvature is canceled out by auxiliary optics, are the ideal. With null tests, deviations from the desired figure stand out clearly when used in conjunction with the simple Foucault test. Other, more quantitative testing techniques such as interferometry can be performed on the mirror with the aid of a null test.

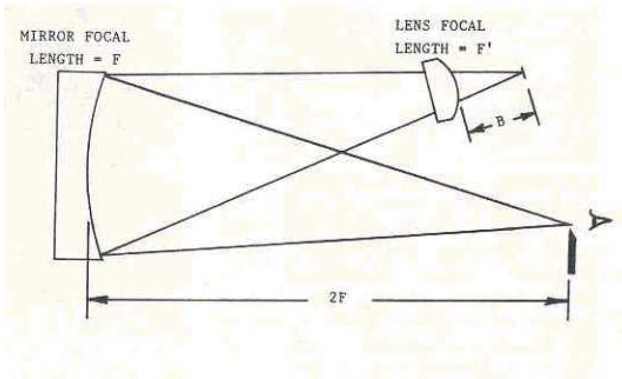
The Autocollimation Test

Experienced telescope makers know the best method to test parabolic mirrors is the autocollimation test. The tester, Ronchi or Foucault, is placed at the focus of the mirror under test. This test usually requires a diagonal mirror, as in a typical Newtonian configuration, to keep the tester out of the light path. The parabolic mirror under test collimates the beam, which is then retro-reflected back to the primary and refocused at the knife-edge. The autocollimation test is very sensitive in the detection of figure errors because the light rays bounce off the primary twice. Two reflections from bare glass also reduces the light level significantly, calling for either a darkened room or a very bright light source.

The autocollimation test simulates the condition of imaging an infinitely distant source, such as a star, therefore it is suitable only for parabolic primaries, which are capable of forming a perfect image for an object at infinity. The hyperbolic primary of a Ritchey-Chretien Cassegrain, or the elliptical primary of the Dall-Kirkham Cassegrain, do not form perfect images at their (the primary's) focus. These mirrors require a variable null system because the shape of the Cassegrain primary changes from system to system. However, for most hobbyists it is the expense of a large optical flat that prohibits the use of the autocollimation test. A large mirror by today's standard is 20" in diameter or greater. An optical flat for such large mirrors is out of the question for the average hobbyist.

The Dall Null Test

The first null test I used, over 20 years ago while making a 12.5" f/5 parabolic mirror, was the Dall null. The Dall Null test (www.atm-workshop.com/dall-null.html) places a small, high quality plano-convex lens in front of the pinhole in a Foucault test. The light emanating from the pinhole passes through the null lens, bounces of the mirror under test to return to the knife-edge or Ronchi screen. The pinhole/null lens spacing is set to cancel out the spherical aberration of the light cone returning from the primary to the focus. A perfect mirror will gray over, or null, uniformly when a knife-edge cuts into the beam at the focus.



Dall Null Test Layout

The Dall null is a variable null test. The spacing of the pinhole and lens can be altered to accommodate a range of parabolic, hyperbolic or elliptical mirrors. As the amount of aberration goes up (i.e. bigger, faster mirrors) so does the size of the lens required to produce an acceptable null. However, because the Dall null lens is off-axis, the size of the lens must be kept small, since a large source/return beam separation would induce a problematic amount of astigmatism.

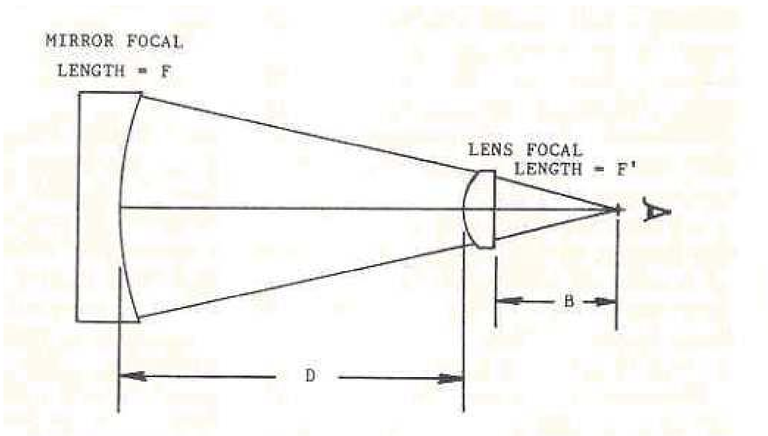
When using a white light source the simple null lens will disperse the beam. The resultant chromatic aberration can be eliminated with a filter placed at a convenient point in the beam. The choice of filter must coincide with the design spacing since the spacing is wavelength dependant.

A precision cell must be made to hold the pinhole and null lens at the appropriate spacing. This cell requires careful machining. Moreover, if the tester is to be used for a variety of mirrors of varying diameters and focal ratios, the cell will have to be adjustable, thus complicating its design.

I found the Dall null easy to use in practice, but it does have its problems when larger, fast mirrors are tested. The large separation between the pinhole and knife-edge, required in order for the return beam to clear the null lens, introduces residual astigmatism. The situation worsens as the mirror—and the required null lens—grows in diameter to the point where the Dall null test is inappropriate. An experienced mirror maker can learn to ignore the effects of astigmatism, concentrating solely on zonal figure errors. However, as the figure improves, and the residual astigmatism dominates the test result, the added "noise" does compromise the null, making subtle zones hard to see. The increasing magnitude of the residual astigmatism eventually renders the Dall null test unusable for large optics. While the Dall null test has its place for small, slow mirrors, there is a better refractive null test for larger mirrors.

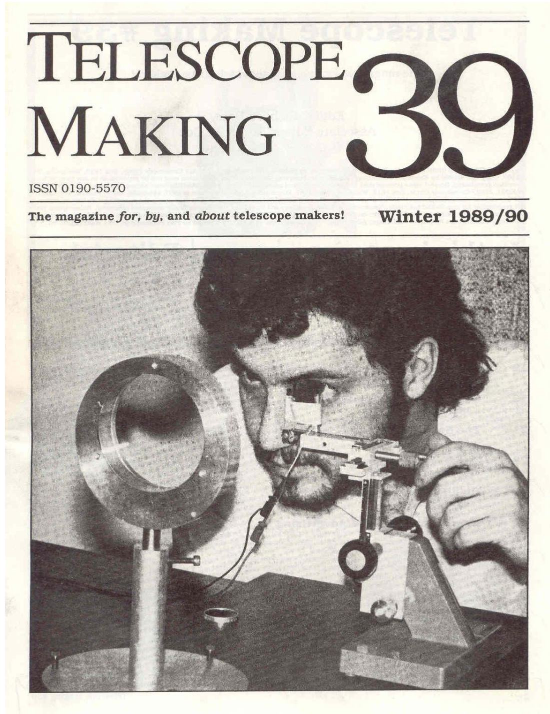
The Ross Null Test

In the Ross null test a large plano convex lens, placed ahead of a conventional tester, is used to null the spherical aberration of a telescope mirror under test. Unlike the Dall null, the source and return beams both pass through the Ross null lens. This in-line characteristic of the Ross test eliminates the problems caused by induced astigmatism which plagues the Dall null test. Consequently the Ross null lens can be made quite large so as to yield a high quality null for large mirrors. In fact, the only potential limitation in applying the Ross null test is that the size of the lens can get too large to be practical.



Ross Null Test Layout

The Ross null can also be applied to non-typical test situations. See Scott Milligan's Stellafane Schupmann (www.stellafane.com/schupmann/schupmann5.html) telescope web site for details.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The Ross null test was first described in detail in
Telescope Making magazine #39 by Ceravolo and Stolzmann

Ross Null Set Up

The Ross lens is placed at a predetermined distance from both the source and the mirror under test. A simple Ross null software (www.ceravolo.com/testing/rossnull.zip), package courtesy of Douglas B. George of Diffraction Ltd., is used to calculate the required mirror-to-lens, and lens-to-focus separations.


This set-up of the author’s Ross null test was used for many years to produce a variety of mirrors

Choosing a Lens

Bigger is better! The larger the lens, the better the null. But in practice, a lens size that produces a residual wavefront error of 1/10th wave or better will work very well. This set up will produce a 1/20th wave surface if the mirror is figured perfectly. Imagine the largest, fastest mirror you are likely to test, and pick a lens focal length and size that will produce a good null. The size of the lens should be at least 10% larger than the minimum required. This avoids requiring that a lens have a perfect figure at the edge, and the resulting buffer makes the test easier to set up.

The light passes through the Ross null lens twice, doubling its effect on the wavefront. It is crucial that the lens have an excellent, smooth figure if the theoretical quality of the null is to be realized. Also, the quality of the substrate is important for the same reason. A variation in refractive index will affect the wavefront. Optical glass such as BK7, when procured from reliable suppliers, will almost always be of excellent quality. Any off-the-shelf lens must be eyed with suspicion until proven otherwise. It is necessary to verify claims of accuracy, via interferometry, if the lens is to serve as a true standard by which high quality mirrors are to be judged.

For a given mirror, the size of the required null lens is governed by the lens focal length. The longer the focal length of the lens, the larger it must be since it will need to be closer to the mirror to produce a good null. A short focal length lens can be relatively small, but the residual aberration will be greater.

The precision Ceravolo Ross null lens is 80mm in diameter, with a focal length of 390mm. When the test set up is calculated for a 16" f/5 mirror, only 54mm of the diameter is used, thus producing a null with only 1/60th wave residual—perfect, for all intents and purposes.

When used with a 30" f/4.5 mirror, the COS null lens will have 70mm of its aperture utilized, and the residual wavefront aberration is 1/13th wave peak to valley. With a perfect set up and perfect figuring on stable substrate one can produce a figure better than 1/20th wave peak to valley.

A 6" f/4 mirror will use only 40mm of the lens diameter and produce a wavefront error of only 1/132nd wave, essentially a ridiculously perfect null. The COS lens will be ideal for most mirrors in between these two extremes.

Mounting the Lens

Since the lens in the Ross null test is large, the lens/mirror spacings are also larger and less sensitive to positional errors. A carefully machined lens cell is no longer required; an adjustable stand fabricated from wood is quite sufficient. A simple 3-point adjustment, similar to a standard mirror cell but with the lens mounted in a hole in the center, will work well to adjust tip and tilt. The lens should also be adjustable in height, although this adjustment does not need fine controls.

The author's 3.5" Ross null lens in a simple holder. Note the 1" square Ronchi grating dangling from a piece of tape.

Use the slitless Foucault tester

The slitless version of the Foucault tester, or a variation on the theme, is necessary to keep the source and knife-edge in close proximity to avoid astigmatism. The k/e source combination must be adjustable in height, and the whole assembly easily moved about. A quick method of switching from k/e to Ronchi screen is very desirable. The switching does not have to be very refined however. I tape a 1" square glass Ronchi grating over the k/e source. I have found a 100 line grating ideal for most testing applications.

It is desirable to have the k/e removable from the light source in order to provide a bright source for alignment. My tester is not the pure slitless type. I have found it desirable to place a second k/e opposite the active k/e to get rid of the extraneous light, essentially forming a slit. I have found that this modification increases contrast and the visibility of subtle zones.

The unit pictured in this article, adapted from a microscope stage, has proven ideal. An easy way to accomplish the height adjustment is to mount the Foucault apparatus on a telescope focuser. The focuser should be bolted to a heavy base plate for stability, and there should be a way to lock the drawtube in place.

As in the Dall null, the light source must be filtered in order to eliminate the effects of chromatic aberration. Because the light is passing through the lens twice, the problem is doubly worse in the Ross null test, particularly when testing fast mirrors. I place a red gelatin filter over the k/e source combination to "double filter" the light. The light is filtered on its way to the mirror and filtered again before it reaches the eye.

Interferometry

Of course one can use an interferometer in conjunction with the Ross null test. Interferometers typically require a spherical wavefront and an in-line test; both requirements are met by the Ross null test. The mechanics of holding the interferometer in place needs careful consideration, as the set up will be very sensitive to flexure and vibration.

In practice it is more efficient to use the conventional Ronchi/Foucault test while actually figuring. Interferometry can then be used to quantify the quality of the figure.

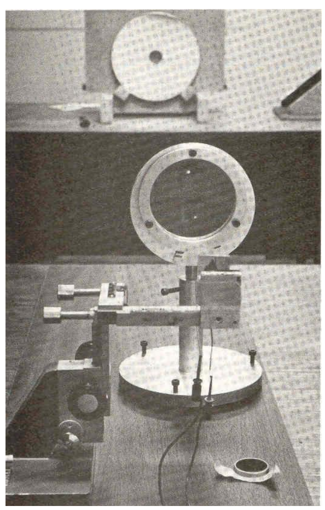
Setting up the Ross null test

1) Set the lens cell, tester and the mirror's center at the same height.

2) Adjust the tilt of the mirror in its holder so that the center of curvature is at the same height.

3) Roughly set the lens-to-mirror spacing. A carpenter's tape works well.

4) Set the tester behind the null lens at its approximate distance. In a bright room, look past the k/e and adjust the lens holder and tester height as required to center the view of the mirror in the lens.



Looking past the k/e, the height of the lens and tester is adjusted until the view of the mirror is centered in the lens.

5) Refine step 4 in a darkened room. Look around the k/e for the return image of the light source. The mirror aperture will be illuminated if you are close to focus, otherwise you will see an image of the source. Adjust the height and lateral position of the tester and lens until everything is centered. Be careful not to confuse the spurious internal reflections of the light source within the lens with the image returning from the mirror. It

is easier to accomplish this stage of adjustment if the k/e is removed from the tester so as to provide a bright light source.

6) Use a Ronchi grating to perform the final alignment. The bands will look asymmetrically bowed, top to bottom, if the lens/tester is not at the right height or if the lens is tilted. If the bands are curved off to the side in one direction the lens needs to be swiveled left to right. Often a combination of tip, tilt and height adjustments are required.

8) Refine the primary-to-lens spacing and adjust alignment if necessary

Once the initial set has been accomplished, the effort required to realign for subsequent testing will depend on how repeatable the primary mirror placement is. A well made primary stand will make alignment very repeatable and the testing iterations very short.

Early on in testing, when the ideal figure is hours or days away, I do not get too excited about achieving perfect alignment. As the figure approaches a good null, a little extra effort in alignment makes subtle zones easier to see.

Check and recheck your set up!

When calculating the required spacings and setting the separation of the lens and mirror, it pays to be **paranoid**! A healthy does of **paranoia** has served me well in my optics career. This **paranoia** developed after having screwed up a few times.

I messed up a couple of times early on when using the Ross null test. In one instance I used only approximate numbers for the radius, 100" instead the actual 99.84". I also used the lens's refractive index for yellow light (most commonly used) instead of the index applicable for deep red light. I spent a lot of time figuring that 12.5" f/4 mirror to a very smooth null. The theoretical residual aberration intrinsic to the test was only 1/40th wave peak to valley. When the setup was recalculated with the proper parameters, the null was found to be actually 1/14th wave, and the resultant under-correction could easily be seen in the figured mirror when the test set up was re-jigged.

In another, more serious instance, I set the lens up backwards—the flat surface faced the mirror. The result, after a few weeks of figuring a 12.5" f/6 mirror past the point of what was necessary, was a hyperbola six times deeper than the hoped-for parabola! My own little Hubble primary! But at least I did do a sanity check on the mirror before it was aluminized or put in a telescope.

Check and re-check your calculations, the mirror's radius, and the calculated distances. After the figure has been roughed in, and you are at the point of smoothing zones, remove the null lens and do a sanity check. Use the standard Foucault test and measure the total amount of aberration, between the center and edge zones, and compare that value to what it should be. This does not have to be a precision measurement; no zonal masks are required. You are looking for signs of a drastic mistake causing a huge, 3 or 4 times, difference in the expected spherical aberration.

A few tips

The sensitivity of the test to positioning error of the lens increases with the speed and diameter of the mirror under test. A 6” f/6 mirror tested with the COS Ross null lens has quite loose tolerances. A 20” f/4 is much touchier. When parabolizing by hogging out the center of the mirror, its vertex radius of curvature changes measurably. For large mirrors (16” and up) or smaller, very fast Cassegrain primaries (f/3), I double-check the radius of the mirror after the figure has been roughed in. The radius change can make a significant difference in the quality of the null.

When measuring the radius of curvature of an aspheric mirror, the k/e is positioned so the central zone grays over uniformly. The k/e is then at the mirror’s “vertex” radius of curvature. When you see a hint of a donut pattern in the center, you’ve gone a bit too far. I use a carpenter’s tape to measure the radius of the zone. Be careful to support the tape in the middle to prevent sagging, and keep the tape taught. A piece of thin tape over the hook will prevent scratches on the mirror’s surface. The play in the hook, designed to account for its thickness, should be checked for accuracy.

To set the lens-to-mirror spacing accurately, I cut a piece 1”x1” wood strip to the required length plus an additional ¼”. I then file it (no sandpaper) to the final length, taking care the file is perpendicular to the edge, then measure the strip length carefully with a carpenter’s tape. I clamp the tape to one end to make the task easier if I am working alone. Chamfer the ends of the stick to reduce the face width so as not to cause a spacing problem with concave surfaces. The wood strip should be placed at the mirror’s center, then the center of the lens’s convex surface brought to bear on the other end. There should be no problems with scratching the glass surfaces.

If the mirror has a central hole, as for a Cassegrain primary, you’ll have to position the stick at the edge of the hole. Be sure to account for the difference in sag in the length of the stick.

The double pass nature of the Ross null test doubles the dispersion of light by the lens. The red filter should be placed over the slit and the k/e simultaneously. This double filtering will mostly eliminate the residual chromatic aberration. But when the null is very good a small residual amount of chromatic aberration can confuse the view, making it difficult to see subtle zones. The effect is at its worst when a large or fast mirror is under test, since a larger percentage of the lens diameter is used.

One can deal with the residual chromatic aberration by filtering the light further, but the light level goes down. Something other than an incandescent light can be used, such as a laser (with the proper precautions), but the speckle pattern associated with laser light will introduce a lot of noise in the view. I have found that the easiest way to deal with the small chromatic residual is to assess the correction away from the exact null focus position. Advance the k/e a few thousands of an inch forward of the null position. The shadow will move in from the mirror’s edge when the k/e cuts into the beam. Look for an even movement; if the central part of the mirror darkens first, the figure is slightly undercorrected. If the edge darkens first it is slightly over-corrected. If the shadow moves in quickly, smoothly and uniformly, the mirror is finished. Again, the k/e is only moved slightly forward of the null position. If you are too far forward of the null, the sensitivity of the test will suffer.

To align the Ross null set up I use a Ronchi screen, taped in place over the k/e. Interpreting the Ronchi bands in a misaligned set up is easier than figuring out what the shadows are doing. Similarly, in the early stages of figuring I use the Ronchi screen to quickly assess the mirror's shape. When I am close, smoothing out zones or polishing off the last bit of glass in the center of a mirror, I always switch to the k/e test. It is cleaner; there is none of the light scatter caused by imperfections in the Ronchi grating or its glass base, or the presence of skin oils or dirt on the grating.

Before you start parabolizing, or using the Ross null or any other null test, it is a good idea to check for astigmatism in the mirror. Twelve years ago I started figuring a 10" f/5.5 mirror with the Ross null test immediately after a good polish was achieved. I finished the figuring and decided to test the mirror on a big Zygo interferometer (a professional unit worth about $100,000) at work. I was pleased the parabolic figure turned out to be an excellent 1/20th wave peak to valley, and very smooth. However that fabulous parabolic figure also had about 1/2 wave of astigmatism! During the polishing process I was careless in the way I supported the mirror on the polishing table. With the Ross and Dall null tests, one can actually cancel out astigmatism that is actually present on the primary by adjusting the set up accordingly. The moral: check the mirror for astigmatism when the mirror is close to a sphere.

Know When to Quit

A good null test will reveal more figure errors on your mirror than you need to see. Most likely the elimination of subtle zones will have no impact on the star or planetary images in the finished telescope. In fact, thermal conditions in the telescope's tube and the turbulent atmosphere are typically orders of magnitude greater in effect than a slight zone which is faintly visible in the workshop under ideal conditions.

It is important to know that some zones are more detrimental than others. Zones at or beyond 70% of the mirror's semi-diameter should be minimized as much as possible. Zones in this area of the aperture have a significant effect on images because they occupy a large percentage of the mirror's surface. For example, a 1" wide zone near the edge of a 12" mirror affects more surface area than a 1" radius bump in the center of the mirror (we are ignoring the fact the central obstruction will negate this bump anyway).

I spend a great deal of time bringing the area outside the 70% zone in line. A null test is ideal for detecting a rolled edge. Just inside the null focus, cut in to the beam slightly with the k/e. A wide rolled edge is betrayed when a shadow forms around the rim of the mirror before it starts to move across the face. If that rim shadow is sharp, the fall off is great. If the rim shadow has a diffuse inner edge, the roll off is subtle. I spend a lot of figuring time getting rid of the roll-offs and zones just inside the edge.

Null tests, when mated to the Foucault k/e or the Ronchi grating, are qualitative, not quantitative. In essence, you know you have a zone but it is not easy to tell how bad it is. But there is a quick and easy way to see what the classic ¼ wave error looks like. The output from Doug George's Ross null software tells you the magnitude of a ¼ wave k/e shift at the null focus. If you are using a slitless type tester, this should be halved, as the k/e and source are moving together. If the magnitude of the change in the shadow pattern caused by the ¼ wave shift is huge in comparison to the zone in question, then this is probably a good time to quit.

The only reason to continue is for ego gratification. Unfortunately, I have a healthy ego. I typically keep figuring until I cannot see a thing. One then does not have to worry about quantifying anything because there isn't much there! Then, the only way to put a number on the figure (for marketing reasons typically) is to replace the k/e tester with an interferometer and computerized fringe analysis.

Conclusion

I have tried to be thorough and practical in describing the implementation of the Ross null test. At first reading, with all my caveats and warnings, the whole process may sound intimidating. But with persistence and practice—qualities in abundance in the average telescope maker—the Ross null test can be mastered.

The Ross null test was introduced to the telescope making community over ten years ago. Since then computers have changed the hobby. Doug George's software has made it easier to implement the test. Affordable interferometry [link to the booklet page] and computerized fringe analysis [link to COS Quick-Fringe page], places professional capabilities in the hands of the hobbyist. Telescope makers are no longer limited to the tools and techniques of the last century.

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