

OPTICAL TESTS USING FIBERS, BALLS, AND RONCHI GRATINGS

Robert E. Parks

Optical Sciences Center, University of Arizona
Tucson, Arizona 85721

ABSTRACT

Optical fibers and ball bearings can be used as test tools. An optical fiber may be easily fashioned into a bright source that causes a minimum of obscuration. Ball bearings may be repolished to nearly perfect spheres and used as autoreflecting optics at nearly inaccessible foci in certain tests. Finally we look at the Ronchi test and discuss its suitability as a test device in many differing situations.

OPTICAL FIBERS

The situation often arises where it is necessary to place a point source in the middle of a test setup. The test of a concave ellipse is an example of this case (see Fig. 1). Most ordinary light sources create a large obstruction in the test. Possible alternatives would be to use beamsplitters or folding mirrors, but even these methods are often not satisfactory.

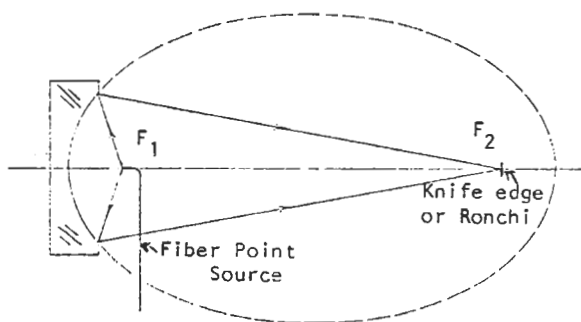


Fig. 1. Test of a fast ellipsoidal section using a fiber source.

This problem can be circumvented by the use of optical fibers. The method was introduced to me by W. Raymond Boyd at Frank Cooke, Inc. Ray obtained optical fiber preforms from Walter Siegmund at American Optical. The preforms were about 3 mm in diameter and 30 cm long. The preforms were clad core material from which optical fibers are drawn.

Ray would heat the preform with a propane torch and draw the glass out to 0.05 mm to 0.12 mm in diameter. After breaking the fiber at its thinnest point, the fiber was heated 6 mm from the end by the underside of the flame so that the fiber would droop forming a right angle bend. The smallest diameter that could be drawn was about 0.05 mm. Thinner diameters caused the cladding to break down,

producing scattered light and a nonround source. Even though the preform was clad, these fiber optic sources were painted black to reduce stray light. Each source was examined after completion to check its brightness and roundness. (A microscope is handy for checking the source geometry.) The yield was about one satisfactory source for every three attempts. Of course, too, the sources are very fragile and some are lost before getting them into a test setup or are damaged by unknowing persons examining a test.

To use the fiber source, the tip end is placed where the point source is desired and the larger end is illuminated with a focusable microscope illuminator (such as the AO# 653). The fiber end is placed several centimeters from the condensing lens and focus is adjusted for the smallest spot size. A brilliant white point source of $\sim 50 \mu\text{m}$ is produced at the other end of the fiber. Although we have never measured the uniformity of these fiber sources, results from our test setups indicate less than a 2:1 variation in illumination over a full hemisphere solid angle.

For all the apparent advantages of these sources, there are two drawbacks; a fair amount of skill is required to draw the fibers from the preform, and the preforms are not commercially available. In an attempt to avoid these problems, Dick Sumner in our shop tried to make sources using readily available fibers from Edmund Scientific (No. 2516). The individual fibers are 50 μm in diameter. To efficiently couple the light into the fiber, Dick would start with a 25 cm to 30 cm length of a single fiber and slowly lower one end into the flame of a propane torch. A ball forms on the fiber and grows to about 1 mm. By holding the fiber at the correct angle, the ball stays centered on the fiber and acts as a condenser when illuminated. A right angle bend was added as previously described. The completed fiber is shown in Fig. 2.



Fig. 2. Optical fiber test source with integral condenser.

Another of our opticians found that he could get as bright or brighter source without the condenser ball or the right angle bend. Furthermore, the single unbent fibers require no blackening. The fiber was simply attached to an x-y-z stage by means of a fine wire support. Masking tape or a drop of wax or glue is all that is required to secure the fiber. Figure 3 illustrates the use of a single fiber to test a 2.5 cm diameter $f/2$ parabola. The fiber is placed at the parabolic focus and the collimated light is reimaged by the collimator to the right of the figure.

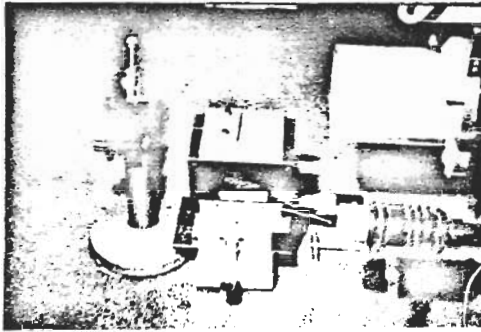


Fig. 3. Test of a parabola using a single fiber source.

Should the 50 μm diameter of the source not be small enough, the fiber may be used in conjunction with a microscope. A 10X objective will make the source appear to be 5 μm , etc. Errors of $\lambda/10$ are easily detected on fast spherical surfaces when using a 20 to 40X objective. If you do not want to modify an eyepiece to hold the fiber, a catalog item eyepiece (# 700-10-36A) is available from Gamma Scientific complete with 50 μm source and fiber optics connector cable. The device was designed for use in a radiometer, but works beautifully as a source. Figure 4 illustrates the use of the Gamma Scientific eyepiece in a microscope to test the roundness of a ball bearing.

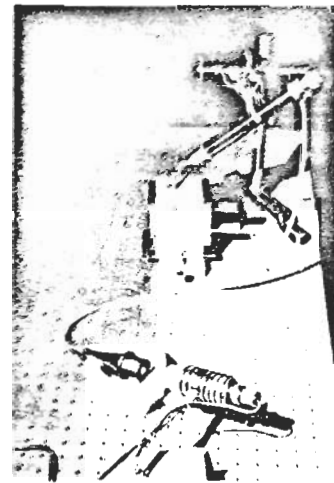


Fig. 4. Test of a ball using a microscope with a fiber optic eyepiece.

POLISHED BALL BEARINGS

Highly polished ball bearings make excellent test devices. They are perfect for autocollimating a test from nearly inaccessible foci or for testing very fast optics such as high power microscope objectives. The beauty of the balls is twofold; they are readily available and easy to polish, plus they can be made more spherical than your ability to measure. This last property occurs because a sphere has no edges and thus with sufficient polishing can be made "perfectly" spherical to the very limits of detectability.

The first interesting thing about ball bearings is the quality of the balls right out of the box. Figure 5 shows an interferogram of a 5 mm ball viewed with an $f/0.7$ Zygo transmission sphere. Although a little rough, the figure is certainly better than $\lambda/4$ over a full 90° solid angle cone.

The larger balls are not as uniform but may be improved with a little polishing. A pair of cup-shaped laps is needed that measure about 70% of the diameter of the ball. The lip of the cup should be lined with sheet lead and the ball should be squeezed between the cups to "press" the lead to fit the ball. After lightly serrating or scratching up the lead, the laps are charged with a very small quantity of 1 μm diamond paste. The ball is worked by hand in each lap to smooth out the serrations. The ball is then placed between the laps setup so that they are counter rotating. An angle of about 150° is maintained between the axes of the two laps. We do this by mounting one lap to the spindle of a small polishing machine and the other in the chuck of a reversible, variable speed electric drill. Both spindles rotate at about the same speed at several hundred rpm. Figure 6 illustrates the progress on an 11 mm ball in 10 minute increments.



Fig. 5. Interferogram of an unpolished 5 mm ball over an $f/0.7$ aperture.

and align (the image has to fall within the 1 cm diameter ruling). Third, the test is relatively insensitive to vibration, and a flashlight bulb can be used for a source as in the Ann Arbor Tester version (Fig. 7). Plain Ronchi gratings in many line spacings are available from Edmund Scientific for several dollars each.

RONCHI TESTER

The Ronchi test has several advantages. First, it is inexpensive. Second, it is easy to set up

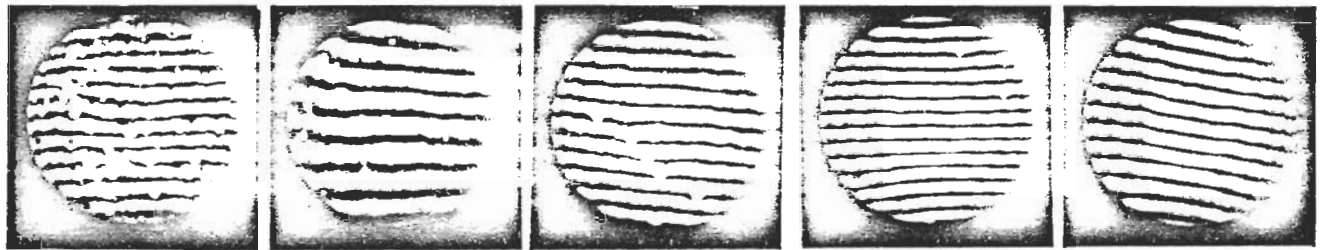


Fig. 6. Interferograms of an 11 mm ball before and after every 10 minutes of polishing with lead laps and $1 \mu\text{m}$ diamond.

In addition to the ease of use, there is a great flexibility built into a Ronchi test. It may be used in single or double pass, and its sensitivity may be varied by changing the ruling spacing. In the single pass mode, the ruling may be placed in the focal plane of a telescope and a star may be used as the source. The variable sensitivity can be useful when testing visual or infrared optics where the quality level may be 5 to 10 visible fringes of irregularity, too gross an irregularity to measure easily using interferometry.

Finally, the test may be used in the null or non-null configuration. For example, the null or perfect imaging situation would be to test a sphere at its center of curvature. In the non-null situation, the Ronchi ruling may be used at the center of curvature of a parabola. The only requirement is that the ruling and camera lens have a sufficiently large aperture to capture all the light returning in the caustic. In this case the Ronchi ruling is used in a fashion analogous to a Hartmann screen but with much less investment.

To understand how the Ronchi works in all these ways, it is easiest to think of the ruling as a multiplicity of thin knife edges or one knife edge moved through a light beam in equal steps. Each new position of the knife edge corresponds to a new Ronchi shadow band as illustrated in Fig. 8. Thus a single Ronchi photograph



Fig. 7. An Ann Arbor Ronchi Grating Optical Tester.

After 40 minutes polishing time the irregularity is less than $\lambda/20$ (the limit of the transmission sphere) independent of the test location on the ball.

The polishing results in a test optic worth several hundreds of dollars in terms of its optical quality and angular usefulness. Since the polishing setup is special, you should make several balls at the same time. To handle the finished test optics we suggest gluing the balls to short lengths of stiff wire and storing the assemblies in a safe place. Keep the balls free of finger prints as they will etch into the surface.

contains all the information as would many separate knife edge pictures.

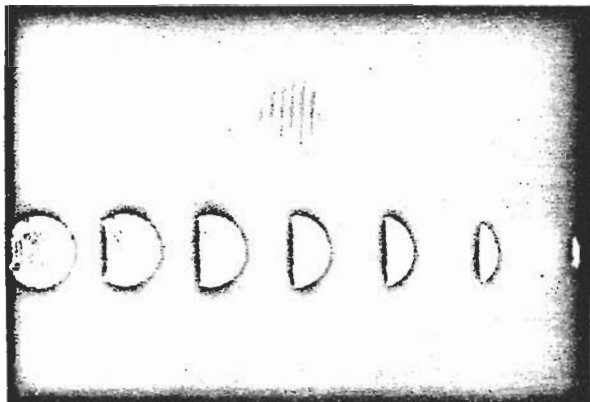


Fig. 8. Seven positions of a knife edge test compared with the equivalent single Ronchi exposure of the same optic.

distance from the optic to the Ronchi grating. This gives the wavefront error in terms of the same dimensions as the test parameters.

For the non-null case, you must calculate what the Ronchi band spacing should be.¹ Subtract the actual results from these data and fit the result with a least squares fit straight line and proceed as for the null situation.

Table 1. Sample data analysis of Ronchi test of a parabola showing the conversion of slope data to wavefront error.

Ronchi Shadow Number	Measured Shadow Edge (mm)	Best Fit Straight Line (mm)	X over Error (mm)	Sum X over Error (mm)	Height Error (X.01) (um)
1	0.26	0.44	0.18	0	0
2	1.55	1.55	0	0.18	1.8
3	2.76	2.66	-0.10	0.18	1.8
4	3.90	3.77	-0.13	0.08	0.8
5	5.00	4.88	-0.12	-0.05	-0.5
6	6.06	5.99	-0.07	-0.17	-1.7
7	7.10	7.10	0	-0.24	-2.4
8	8.14	8.21	0.07	-0.24	-2.4
9	9.21	9.32	0.11	-0.17	-1.7
10	10.31	10.43	0.13	-0.06	-0.6
11	11.44	11.54	0.10	0.07	0.7
12	12.65	12.65	0	0.17	1.7
13	13.94	13.76	-0.18	0.17	1.7
				-0.01	-0.1

$$\text{Scale Factor} = \frac{\text{average shadow width}}{\text{exit pupil distance}} = \frac{1.11 \text{ mm}}{111 \text{ mm}} = 0.01$$

For all these apparent advantages, why isn't the Ronchi test used more widely? Principally because it does not indicate wavefront errors directly, but rather wavefront slope errors. These must be integrated (or summed up) to yield wavefront error.

However, anyone with a \$100 pocket calculator can do the required integration to determine the shape of the wavefront. (Anyone with access to a polynomial fringe fitting program can do the three-dimensional case as well.) For the null situation, simply find the least squares best fit straight line through the Ronchi shadow data (Table 1). Then take the resulting differences between the data and the straight line and sum them up. The running sum represents the wavefront profile as shown in Fig. 9. These results are multiplied by a scaling factor equal to the apparent average Ronchi shadow band width on the optic under test divided by the

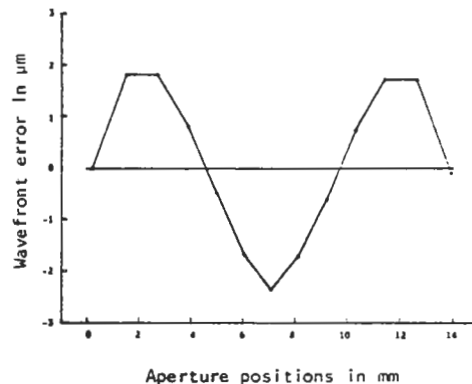


Fig. 9. Graph of the wavefront error calculated in Table 1.

REFERENCES

1. Malacara, D., ed., Optical Shop Testing, Wiley & Sons, New York, 1978, p. 302.