

Collimation Testers

Testing Collimation Using Shearing Interferometry Manfred W. Grindel

Abstract

The collimation tester is one of the simplest devices available for examining optical wavefronts. Based on a shearing interferometer, its sensitivity can be adjusted as required. Methods of use in collimating laser beams will be described, in addition to other applications involving planarity. Versatility in wavelength coverage will be discussed.

The collimation tester is basically designed as a null device to establish the collimation of laser light. This is done by adjusting whatever collimating optics are being used until the fringes produced by the tester are observed to be aligned to a preset cursor wire. This avoids the problems of estimating or measuring beam diameter over some range of distances, calculating divergence and comparing the results to expectations. With perfectly plane or spherical wavefronts, straight fringes are obtained. Any departure from straightness or wiggles are indicative of aberrations in the system.

The collimation tester consists of a piece of high quality BK-7 with very flat surfaces having a slight wedge angle between them. When a plane wave is incident at an angle of 45° , two reflected wavefronts result. These are separated laterally because of the plate thickness and angularity due to the wedge. The lateral separation is referred to as shear which is why the device is referred to as a shearing interferometer. With plane wavefronts incident, the area of overlap between the two reflected beams will show fringes when projected on a screen. The fringes will appear solely from the wedge angle and their spacing will be $f = \lambda / 2N\theta$ where f is the fringe spacing, λ is the wavelength, N is the refractive index and θ is the wedge angle. These fringes will be perpendicular to the wedge orientation and parallel to the wire cursor stretched across the collimation tester.

Should the incident wavefront be spherical instead of plane, another factor is introduced; the incident wavefront on a plane parallel is without any wedge, as in Figure 2. The two reflected wavefronts are separated by the shear. If the wavefront radius is very large compared to the plate thickness, the condition is just like that of the Young two-pinhole experiment. You have radiation coming from two virtual point sources, separated by the shear, S , at a distance of R , the wavefront radius. When projected on a screen, straight fringes are seen, perpendicular to the shear direction, with a spacing of $\lambda R / S$. If we now substitute the collimation tester for the plane parallel, with the shear direction at right angles to the wedge, the two angles combine. The two point sources are separated vertically by the wedge angle and horizontally by the shear. The resulting fringes are perpendicular to the direction of the separation with a spacing inversely proportional to the combined angle. As the wavefront radius is increased and made more parallel, the horizontal angle decreases. The fringes become more horizontal until the wavefront is plane and the fringes are parallel to the preset cursor. As the wavefront radius becomes steeper, the fringe direction deviates more from horizontal, and since the combined angle increases, the fringe spacing decreases. The collimation tester therefore has a variable sensitivity. the further from collimation, the lower the sensitivity, and vice versa. As you go through collimation, from converging to diverging, the slope of the fringes will change from positive to negative.

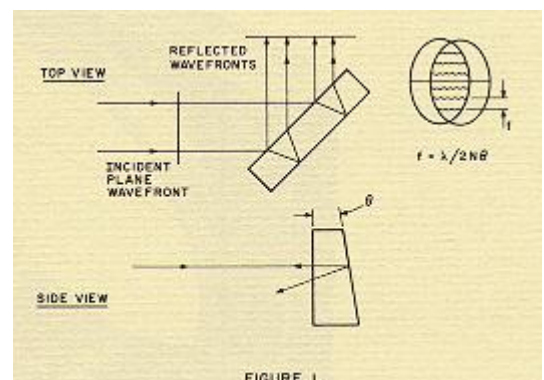


FIGURE 1.

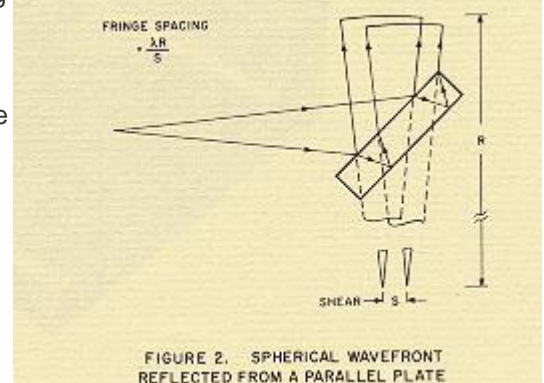


FIGURE 2. SPHERICAL WAVEFRONT REFLECTED FROM A PARALLEL PLATE

As long as the wavefront radius is large compared to the plate thickness, and small angle approximations can be used, the wavefront radius or beam divergence can be calculated from the measurements with the collimation tester. Simply shown, the radius at the screen is $R = \frac{Sd}{\lambda \sin A}$ where S is the shear, d is the fringe

spacing perpendicular to the fringe orientation, A is the orientation of the fringes with respect to the cursor and λ is the wavelength. All the measurements can be made from the observation screen. If, because of edge illumination, the shear is not apparent, a vertical wire or point in the center of the beam will produce two images whose separation can be measured. The angular divergence of the wavefront is simply the width of the beam divided by the radius of curvature.

To be useful in testing collimation, the sensitivity must be examined. As seen in Figure 4, using a shear equal to half the projected beam width, and a fringe spacing (near collimation) of one-fifth the diameter, we can estimate the fringe angle to one-fifth fringe over the shear distance, which calculated to an angle of 0.08 radians. Putting these values in the equation for divergence, we arrive at a value of $0.8 \lambda/D$. This is approximately the divergence expected from a diffraction limited plane wave. Under ideal conditions, the collimation tester is accurate to the theoretical limit in determining collimation. When measuring actual wavefront curvature, the null setting technique is not used and the values of fringe spacing, orientation and shear have to be measured, yielding somewhat higher errors. While the error is a function of a number of factors, in practice it is found that a wavefront curvature can be measured to about 0.2%.

The collimation tester was designed to be a versatile laboratory device useable for a range of apertures, from the full diameter down to about one-fifth of the diameter.

This is the basis for designing the wedge to have 5-6 fringes. sensitivity and would diameters. The the diameter for the variable as a shows a plot of the 1.517. The shear 0.752 times the however, and at 45° recommended for

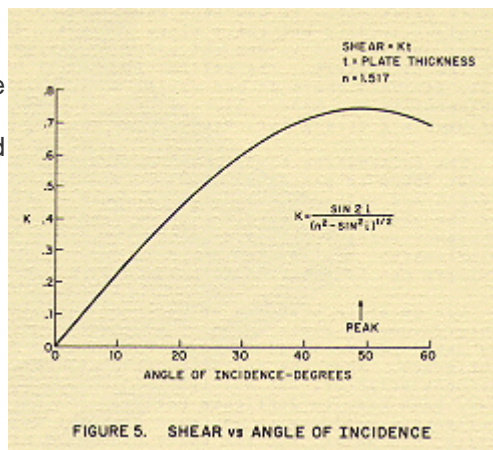


FIGURE 5. SHEAR vs ANGLE OF INCIDENCE

When aligning a laser collimator, the initial setting may be so far from collimation that the fringes are too close to be distinguished. In that case, reducing the angle of incidence will reduce the shear, and consequently the sensitivity.

Since wavefront curvature can be measured, the collimation tester can be used to measure surfaces with large radii. Figure 6 shows how this can be done. The first screen checks for an incident plane wavefront while the second screen measures the wavefront after reflection from the surface under test. The wavefront is measured at the screen and the surface-to-screen distance must be added or subtracted, depending on whether the surface is concave or convex. The mirror radius is twice the wavefront radius. Murty has demonstrated that this is the most accurate method of measuring large radii, other than the multi-conical method recommended by Zygo, which can only be used with concave surfaces.

The homogeneity of optical components can also be tested with the use of a well collimated laser source and a collimation tester.

The part is placed in the laser beam and the exiting beam analyzed as mentioned previously. If the beam is deviated, as in the case of a wedge or prism, the collimation tester must be oriented appropriately to the exiting beam. This technique of checking homogeneity or overall wavefront deformation has the advantage of obtaining single pass information without the complications of a Mach-Zehnder

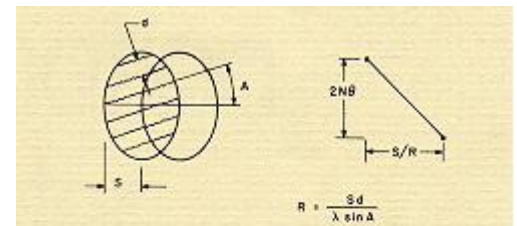


FIGURE 3. WAVEFRONT ANGLES IN COLLIMATION TESTER

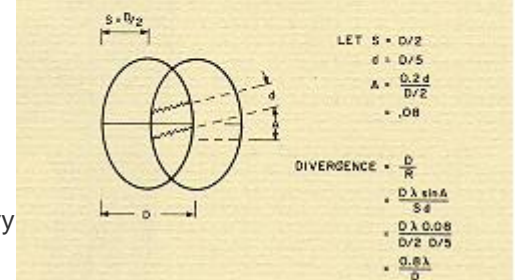


FIGURE 4. COLLIMATION TEST SENSITIVITY

Fewer fringes would yield a higher make the device less useful for smaller shear is also designed to be less than half same reason. The shear is actually function of angle of incidence. Figure 5 shear vs the incident angle for an index of peaks at an angle of 49° with a value of thickness. The function varies slowly, is only 1% smaller, so 45° is convenience.

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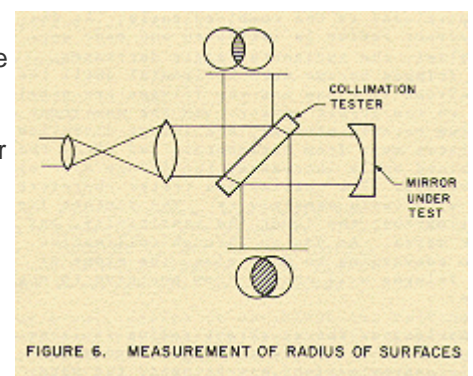


FIGURE 6. MEASUREMENT OF RADIUS OF SURFACES

interferometer. The overall simplicity and cost compare favorably with other methods, single or double pass.

In a shearing interferometer, the wavefront is compared to itself, rather than to a flat reference wavefront, as in other interferometers. As a result fringe interpretation is quite different. It has been shown that a change in wavefront curvature will produce straight fringes, but their slope changes. The analysis of fringe patterns to derive wavefront aberrations is not the purpose of this paper. This information is already available in the literature. The collimation tester has proven useful in the alignment of an off axis parabola where it can easily be seen whether the wavefront aberration is improving as adjustments are made. Aberrations can be isolated from defocus by noting whether the fringes are straighter, even if they are at an angle to the cursor.

The collimation tester can be used over the wavelength region of transparency, from about 350nm to past 2000nm. Account must be taken of the effects on sensitivity of wavelength and refractive index. The main problem becomes one of "seeing" the fringes outside of the visible spectrum. Fluorescent screens can be used in the UV. In the near IR, Kodak phosphor screens, IR image converters and CCD cameras have been used. For use at longer wavelengths, collimation testers have been made from calcium fluoride and germanium. Fringes can be observed by using a pyroelectric vidicon or other IR imager.

One question that has arisen pertains to the intensity of the fringe pattern. Since the interferometer plate is uncoated, most of the light is transmitted. Maximum reflection can be obtained by illumination with the plane of polarization perpendicular to the plane of incidence. When the surfaces are coated with partial reflectors, the observed pattern becomes brighter, but multiple images arise, which becomes confusing to interpret. Attempts have been made to fabricate collimation testers from partially absorbing materials with reflective surfaces to both increase the brightness and suppress multiple images. In principle this works, but the thick pieces of material required do not have the necessary homogeneity for testing wavefronts to their theoretical limit.