Setting the Wedge Factor

Mike Zecchino

Wedge Factor is a vertical scaling parameter that converts measured wavefront difference to the desired measurement quantity.

Introduction

The Wedge Factor is a vertical scaling parameter that is applied to measurement data to account for the geometry of the optical test setup. This technical note explains the purpose of the Wedge Factor and its correct values for measuring wavefront error and surface height in common testing configurations.

In an interferometer the source beam is divided into two wavefronts. One wavefront is directed to a high quality reference and the other to the test optic. The two beams are then reflected back to the interferometer and combined, creating an interference fringe pattern from which the wavefront difference can be determined.

This measured wavefront difference, however, may or may not equal the desired measurement quantity (i.e., the measurand) because the geometry of the test setup will act to scale the measurand. The Wedge Factor (also called "Scaling Factor," or "Interferometric Scaling Factor") converts the measured wavefront error to the desired quantity.

Wedge Factor can be calculated as A * B * C, where:

A equals **1** when measuring transmitted or reflected wavefront, or **1/2** when measuring surface height.

B compares the number of passes through, or reflections from, the optic in use versus the number of passes/reflections in the test setup. When the measurand is surface height or reflected wavefront:

$$B = \frac{\text{No. of Reflections}_{\text{in use}}}{\text{No. of Reflections}_{\text{in test}}}$$

When the measurand is transmitted wavefront:

$$B = \frac{\text{No. of Passes}_{\text{in use}}}{\text{No. of Passes}_{\text{in test}}}$$

C compares the angle of incidence θ for the incoming beam, in use and in the test setup:

$$C = \frac{\cos(\theta)_{\text{in use}}}{\cos(\theta)_{\text{in test}}}$$

Table 1 summarizes these values.

Table 1. Summary of Wedge Factor Values

Measurand	A	B (Passes or Reflections)	C (Incident Angle)	Wedge Factor
Transmitted or Reflected Wavefront	1	$B = \frac{\text{No. of Passes}_{\text{in use}}}{\text{No. of Passes}_{\text{in test}}}$ or $B = \frac{\text{No. of Reflections}_{\text{in use}}}{\text{No. of Reflections}_{\text{in test}}}$	$C = \frac{\cos(\theta)_{\text{in use}}}{\cos(\theta)_{\text{in test}}}$	Wedge = A*B*C
Surface Height	1/2			

where θ = the angle of incidence.

4D Technology

An Onto Innovation Subsidiary

Measuring Reflected Wavefront Error and Surface Height for a Mirror

In Figure 1, a transmission flat (t-flat) and test mirror are both positioned at normal incidence to a Fizeau interferometer. The test beam passes through the t-flat's reference surface, reflects from the test mirror and then returns to the interferometer.

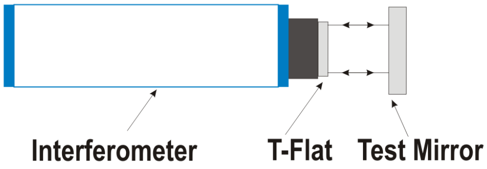


Figure 1. Measuring the reflected wavefront and surface height of a mirror.

If the measurand is reflected wavefront, then this optical setup exactly matches the in-use configuration for the mirror. A = 1, B = 1/1, C = 1/1, and **Wedge Factor = 1**.

Now, consider that the measurand is surface height. Figure 2 shows an exaggerated pit on the mirror surface. The test beam must travel an additional length X to reach the bottom of the pit and then must travel that distance again to exit the pit. The measured wavefront error is therefore twice the actual depth of the pit; the Wedge Factor will need to correct for this 2X scaling. Per our equation, A = 1/2, B = 1, C = 1, and thus **Wedge Factor = 1/2**. The 2X scaling is therefore corrected by the Wedge Factor.

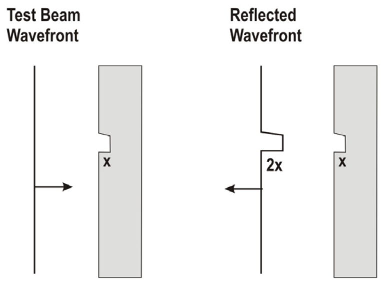


Figure 2. Error in the reflected wavefront is twice the height of surface errors; the Wedge Factor of 1/2 corrects for this scaling.

These values for Wedge Factor are also true when measuring a concave or convex surface (see Table 2).

Transmitted Wavefront Measurement

In Figure 3a, a t-flat is mounted on a Fizeau interferometer. A test window and high-quality return mirror are placed in the test path at normal incidence. The test beam passes through the window then reflects from the mirror back through the window to the interferometer.

Each time the test beam passes through the window it takes on any error due to the window. In actual use, light may pass through this window just once, say, from a source to a detector (Figure 3b); or, it may pass through the window twice (Figure 3c).

The B term in the Wedge Factor equation converts the measured wavefront error for either case:

$$B = \frac{\text{No. of Passes}_{\text{in use}}}{\text{No. of Passes}_{\text{in test}}}$$

If the window will be used in a single-pass configuration, then A = 1, B = 1/2, C = 1, and **Wedge Factor = 1/2**.

If the window will be used in double-pass, then A = 1, B = 2/2, C =1, and **Wedge Factor = 1**.

4D Technology
An Onto Innovation Subsidiary

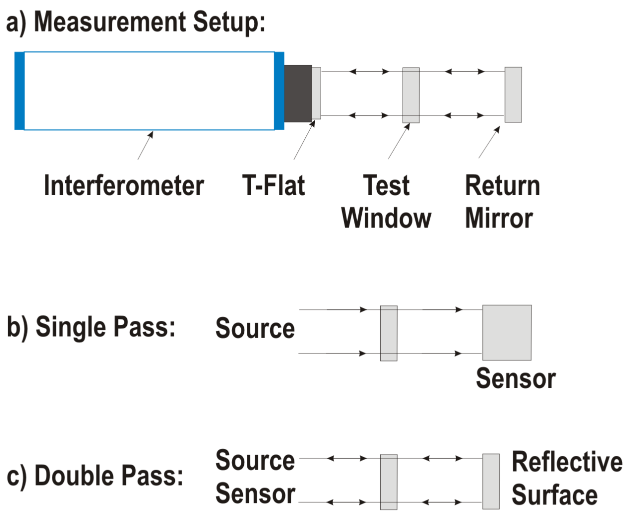


Figure 3. Measuring transmitted wavefront error of a window (a), and the in-use single pass (b) and double-pass (c) configurations.

This discussion is also relevant when measuring the transmitted wavefront error of a telescope or a lens (Table 2).

Correcting for Non-Normal Incidence

In the examples above the test optic was at normal incidence (i.e., perpendicular to the incoming beam) in both the test and in-use setups. In other cases the optic may be placed at an angle relative to the incoming beam. The "C" term of the equation accounts for both the in-use and in-test incidence angles:

$$C = \frac{1}{\cos(\theta)_{in\ test}}$$ for surface height, and $$C = \frac{\cos(\theta)_{in\ use}}{\cos(\theta)_{in\ test}}$$ for wavefront error.

In Figure 4 the surface height of a large optic is being measured at angle θ so that the interferometer can image a larger area of the surface.

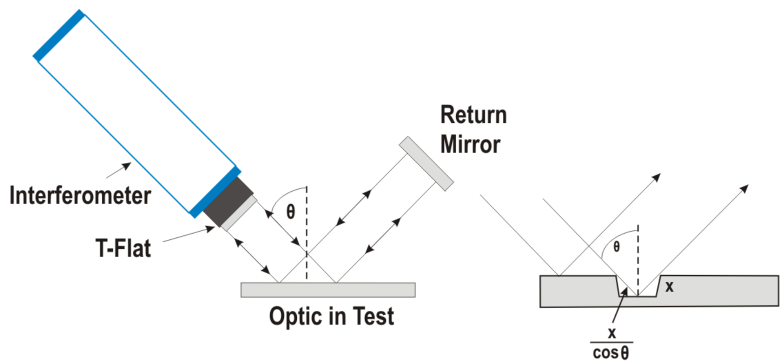


Figure 4. The surface height is measured at an angle θ for an optic that will be used at 0 degrees.

When the measurand is surface height, then A = 1/2. If the number of in-use reflections is 1 and the number of reflections in test is 2, then B = 1/2, C = 1/cos $\theta_{in\ test}$, and **Wedge Factor =** $\frac{1}{4cos\theta}$.

In Figure 5 an optic that will be used at incidence (0 degrees) is measured at a small angle to avoid back reflections. When the measurand is transmitted or reflected wavefront error, A = 1, B = 1/2, C = $\frac{\cos(\theta)_{in\ use}}{\cos(\theta)_{in\ test}}$, and therefore **Wedge Factor =** $\frac{\cos(\theta)_{in\ use}}{2\cos(\theta)_{in\ test}}$.

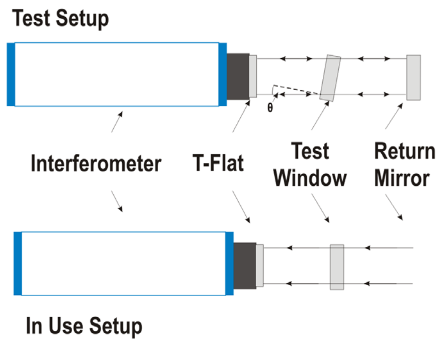


Figure 5. The transmitted wavefront error of an optic that will be used at normal incidence is measured at an angle θ to avoid back reflections.

Ritchey-Common Test

The Ritchey Common Test is (Figure 6) a non-normal angle of incidence test, where the angle is a function of the field point rather than a constant. Set **Wedge Factor = 0.5** for wavefront measurements or **Wedge Factor = 0.25** surface height. 4Sight's built-in algorithm will calculates the wedge factor according to:

$$Wedge = \frac{\cos(\theta(x,y))}{4}$$ for surface, and

$$Wedge = \frac{\cos(\theta(x,y))}{2}$$ for wavefront,

where Θ(x,y) is computed using your supplied f-number and nominal angle.

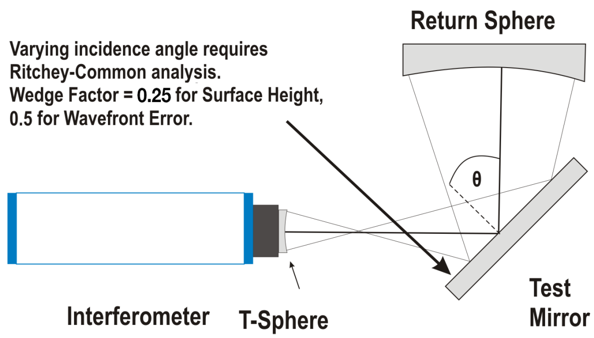


Figure 6. The Ritchey-Common analysis calculates the varying incidence angle; Wedge Factor converts to wavefront error or surface height.

Parabola in Auto-Collimation

In some setups there are potentially several measurands. Figure 7 shows a parabola in an autocollimation configuration. A perforated mirror is used as the return optic.

If the measurand is single-pass reflected wavefront error of the parabola, then: A = 1, B = 1/2, C = 1, and the **Wedge Factor = 1/2**.

If the measurand is the single-pass reflected wavefront error of the return mirror, then the setup essentially reduces to that shown in Figure 1: A = 1, B = 1/1, C = 1/1, and **Wedge Factor = 1**.

If the measurand is the surface height of the return mirror, then the setup essentially reduces to that shown in Figure 2. A = 1/2, B = 1/1, C = 1/1, and **Wedge Factor = 1/2**.

Measuring surface height for the parabola, however, is more difficult in this arrangement. The angle of incidence varies across the parabolic surface, and this difference cannot be accounted for with a single Wedge Factor value. Instead, the system would need to be modelled and the resulting function applied to determine surface height. 4Sight will correcly complete the field-dependent calculation if set up properly and if the Wedge Factor is specified as above.

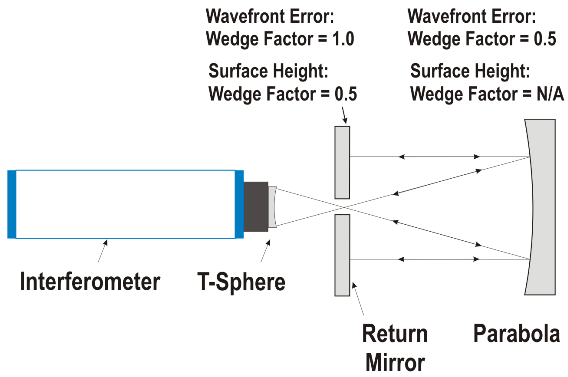


Figure 7. Parabola and return mirror in autocollimation configuration.

Prisms and Corner Cubes

Right angle prisms and corner cubes can be measured in a single pass configuration, in which the test beam passes once through the optic and then returns to the interferometer, or in double pass, in which a return mirror reflects the test beam back through the optic. Figure 8 shows these two configurations for a right angle prism.

Various software packages use different conventions to account for the Wedge Factor for these measurements. In 4Sight, the Right Angle Prism and Corner Cube analyses automatically set the Wedge Factor and manage masks when you select Single Pass or Double Pass as the test configuration. The measureand is typically transmitted (reflected) wavefront; therefore, setting the **Wedge Factor = 1.0** (A = 1, B = 1, C = 1) for Single Pass or **Wedge Factor = 0.5** (A = 1, B = 1/2, C = 1) for Double Pass measurements will ensure that the wavefront data appears correctly when viewed elsewhere in the software (for example, when viewing corner cube data in a 3D plot).

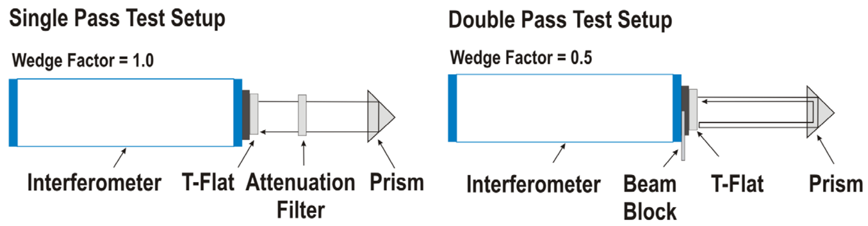


Figure 8. Single and double pass measurement of a right angle prism.

How to Set the Wedge Factor in 4Sight

In 4Sight software the Wedge Factor is set by choosing **Edit > Optical Parameters**, enter a Wedge Factor value of **1.0** or **0.5**, or enter any value in the **Other** box. These values will not affect prism or corner cube measurements in 4Sight. In 4Sight Focus set the wedge under **Scale > Optical Parameters > Wedge.**

Subtracting a Reference Measurement

A reference measurement can be subtracted from measurement data to remove any error in the cavity that is not directly attributed to the test optic. The reference measurement should typically be acquired using the same test configuration, and thus the same Wedge Factor, that will be used when the optic is measured. If the reference is acquired using a different Wedge Factor then the reference measurement should be scaled appropriately.

A=**1** for transmitted or reflected wavefront, or **1/2** for surface height.

$$B = \frac{\text{No. of Reflections}_{\text{in use}}}{\text{No. of Reflections}_{\text{in test}}}$$

for surface height or reflected wavefront, or

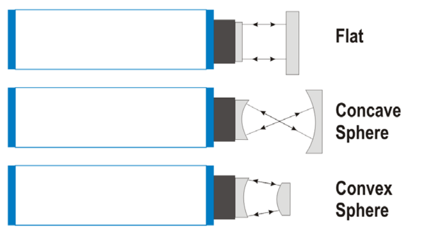
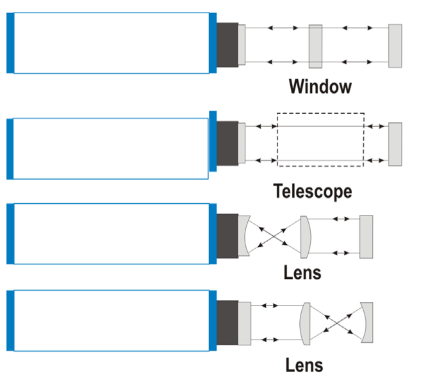
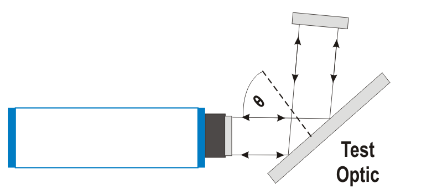
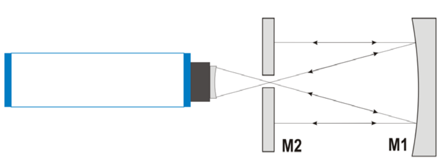
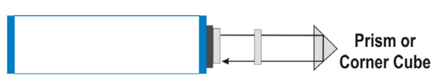
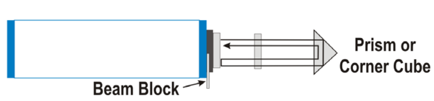
$$B = \frac{\text{No. of Passes}_{\text{in use}}}{\text{No. of Passes}_{\text{in test}}}$$

for transmitted wavefront.

$$C = \frac{\cos(\theta)_{\text{in use}}}{\cos(\theta)_{\text{in test}}}$$

Reference Guide for Wedge Factor Values

Table 2. Wedge Factor for Common Measurement Configurations.

Configuration	Measurand	A	B	C	Wedge Factor
	Surface		1	1	1/2
	Reflected Wavefront	1	1	1	1
	Transmitted Wavefront, Single Pass	1	1/2	1	1/2
	Transmitted Wavefront, Double Pass	1	1	1	1
	Surface Height		1/2	1	$\frac{\cos(\theta(x,y))}{4}$
	Reflected Wavefront, Single Pass	1	1/2	1	$\frac{\cos(\theta(x,y))}{2}$
	Reflected Wavefront, M1	1	1/2	1/1	1/2
	Reflected Wavefront, M2	1	1/1	1/1	1
	Surface Height, M1	-	-	-	N/A
	Surface Height, M2		1	1	1/2
	Reflected Wavefront, Single Pass	1	1	1	1
	Reflected Wavefront, Double Pass	1	1/2	1	1/2

4Sight and 4Sight Focus are trademarks of 4D Technology Corporation.