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This method will help you determine the best transmission sphere to use for testing a given concave or convex optic

Selecting a Transmission Sphere

Introduction

Interferometric testing requires two matched optics: the optic under test and a reference. When measuring spherical optics, the reference is a spherical surface with roughly the same curvature as the surface under test. The housing that contains the focusing lenses and reference surface is called a transmission sphere (t-sphere, or TS).

This application note discusses the calculations required to determine the correct transmission sphere to use in order to test a given optic, as well as the percentage of clear aperture that will be measured, and whether the focus can be physically achieved with the choice of optics.

Note: This note is intended as a reference for on-axis, temporal phase shifting Fizeau interferometers.

Two primary considerations must be met when selecting the appropriate t-sphere:

1. The interferometer must be able to image the sample clear aperture (CA) of interest.

2. The interferometer must be able to focus on the test part.

Both of these are discussed next.

Matching the Transmission Sphere to the Test Optic

To take full advantage of the interferometer's resolution, use as much of the test beam as possible to fill the clear aperture of the test optic. This is accomplished by selecting a t-sphere with the most appropriate radius of curvature (ROC) for the test optic.

Transmission spheres are typically specified by f-number (F/#), which is the focal length of the t-sphere divided by its diameter. The F/# describes the cone of light produced by the transmission sphere. A "faster" t-sphere will have a smaller F/#, i.e., a shorter focal length.

However, to describe the speed of a surface, it is more typical to refer to its R-number (R/#), which is given by ROC/CA, the radius of curvature (ROC) divided by the diameter of the test optic's clear aperture (CA).

To measure the test optic, the cone of light from the transmission sphere must illuminate (fill) the entire clear aperture of the test surface. In other words, the F/# of the TS must be equal to or smaller than the R/# of the test surface.

When the F/# of the t-sphere precisely matches the R/# of the test surface, the test beam will just fill the clear aperture of the test part. However, t-spheres are expensive optical assemblies and thus it is most common to choose a standard t-sphere that matches the test requirements as closely as possible.

For measuring concave optics, the underfill/overfill is determined solely by the F/#

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of the transmission optic. With convex samples however, the aperture size of the transmission optic is also important, since it is often less than the full aperture.

4D Technology offers transmission spheres with a range of F/#s. Figure 1 shows how the t-spheres will fill convex samples of various radii of curvature.

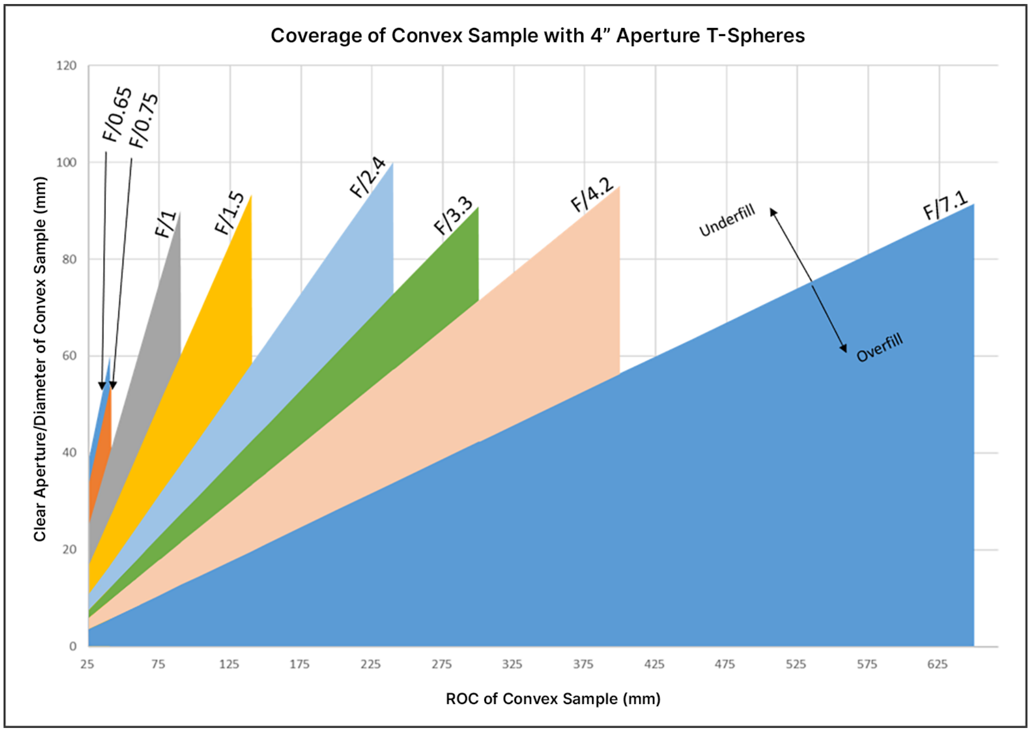

Figure 1. This chart shows how standard t-sphere options available from 4D will fill, underfill or overfill a convex sample, depending on the ROC of the sample.

If the t-sphere has a slower (larger) F/# than required, the sample will be underfilled, and only a subarea of the CA will be measured. This is typically undesirable. A slightly faster t-sphere (smaller F/#), on the other hand, will overfill the sample, which will still fill the entire CA. This is the preferred situation. However, if the t-sphere is too fast compared to the sample, the size of the test beam may become so small that the image at the camera has too little resolution.

A good rule of thumb is that the ratio (test optic R/#) : (t-sphere F/#) should be between 1 and 2 (< 1.5 is preferable).

To test a spherical surface, it must be placed in the test beam at the confocal position, i.e., the point at which its center of curvature is co-aligned with the t-sphere's focus.

The curvature of the test part and the size of the t-sphere housing must allow for the setup to be physically possible. The working distance of a transmission sphere is illustrated in Figure 2, where R is the radius of curvature of the reference surface and AD is the mechanical aperture of the t-sphere housing. The working distance of the t-sphere must be equal to or longer than the ROC of the sample. In addition, the diameter of the test part must be less than the aperture diameter, AD.

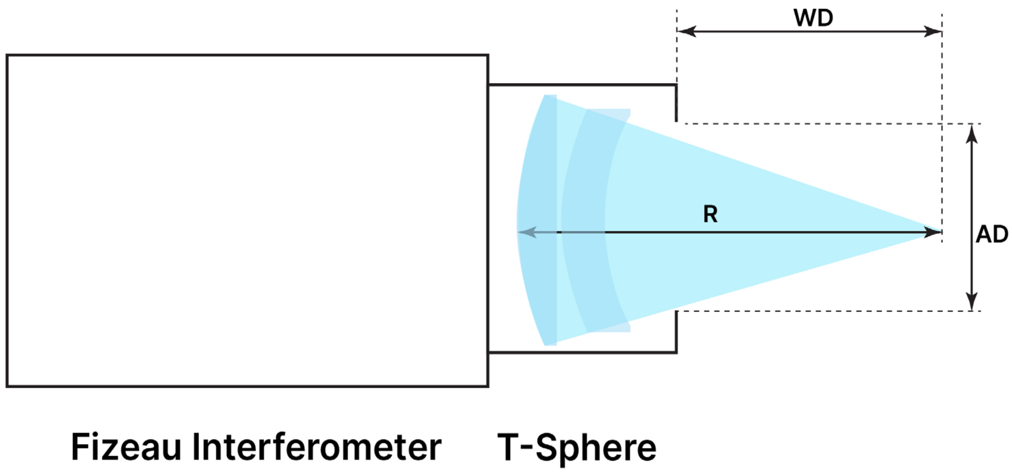

Figure 2. In order for a measurement to be physically possible, the working distance (WD) of a transmission sphere must be equal to or longer than the radius of the sample. Note that WD is measured from the front of the t-sphere housing and is therefore offset from the reference surface.

Table 1 shows the minimum working distances for the standard 4” t-spheres shown in Figure 1, for part diameters with a clear aperture greater than AD. Table 2 shows the same information for standard 6” t-spheres. This information ensures that there is not a mechanical limitation for the measurement.

F/#	R (mm)	AD (mm)	WD (mm)	EFL (mm)
F/0.65	39	60	22	61.1
F/0.75	48	64	29.4	70.5
F/1	90	90	72.2	105.5
F/1.5	142.7	96.4	130	150.4
F/2.4	264.5	110.2	255	243.7
F/3.3	344.7	104.2	336	339
F/4.2	465.6	110.7	458	428
F/7.1	800.1	112.7	794	723.5

Table 1. Operational parameters of 4D’s 4” transmission spheres. Parameters are shown in Figure 2, except EFL (Effective Focal Length), which is used to calculate distances in the following examples.

F/#	R (mm)	AD (mm)	WD (mm)	EFL (mm)
F/0.75	72.1	96	47	107.5
F/1.1	130.7	120.9	109	160.8
F/1.6	220.3	136.5	199	243
F/2.4	346.7	146.9	333	361.5
F/3.5	518.3	148.1	507	532.6
F/5.0	739.8	150.4	730	749.8
F/7.4	1128	152.4	1120	1127.4

Table 2. 4D Technology 6” transmission sphere options.

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Verifying that Focus is Possible

To determine whether the system can focus you need to know the ROC of your sample, the focal length of the t-sphere, and the focus limits of the Fizeau interferometer. The thin lens equation shown below provides a means to determine the approximate focus position:

$$\frac{1}{S_0} + \frac{1}{S_i} = \frac{1}{f}$$

where

S_o = object distance (always negative*)

S_i = image distance (always negative*)

f = focal length ≈ EFL (always positive*)

* For convergent transmission spheres

For reference, the focus range of 4D Technology's 4" aperture AccuFiz Fizeau interferometer is ± 2000 mm (± 4500 mm for 6" aperture AccuFiz).

Example 1: Concave Sample

In this example, the test optic ROC = 400 mm, outer diameter (OD) = 500 mm.

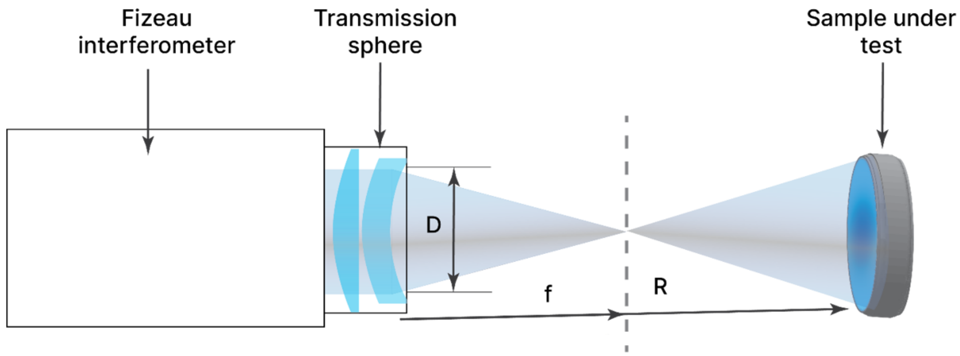

Figure 3. Example one has a concave sample of interest. Required distances are shown to approximate the focus position with use of the thin lens equation.

To select the correct t-sphere for this part, first determine the R/# of the sample. The R/# is determined by ROC/OD, where OD is the outer diameter. For this example, the R/# is 0.80 for this example. This means that to fill the sample to 100% (i.e., measure the entire aperture), a t-sphere with an F/# of 0.8 or faster is needed. In this case, the F/0.75 t-sphere is the best match of the 4D Technology t-spheres.

As noted earlier, a slower t-sphere would only partially fill the sample CA, leaving an unmeasured annulus at the edge, which is not optimal.

To determine whether the system will be able to focus using the F/0.75 t-sphere, we apply the thin lens equation, with the "positive" direction to the right, and using:

F - Focal length (EFL): 70.5 mm

S_o - Object distance: - (70.5 + 400) mm

The thin lens equation becomes:

$$\frac{1}{S_0} + \frac{1}{S_i} = \frac{1}{f} \rightarrow \frac{1}{70.5} + \frac{1}{(70.5 + 400)} = \frac{1}{S_i}$$

Solving for Si gives an image location of ~61 mm, which is within the focus range of the system.

Note: this approximation is better for slower t-spheres.

Example 2: Convex Sample

In this example, the test optic ROC = 200 mm, outer diameter (OD) = 50 mm.

As in Example 1, the R/# is given by ROC/OD and equals 4.0. Therefore, a t-sphere with F/# of 4.0 or faster is required to measure the entire CA of the sample. The standard F/3.3 t-sphere is likely the best choice. Note that the F/2.4 t-sphere would overfill the sample and fill 60% of the of the interferometer detector array.

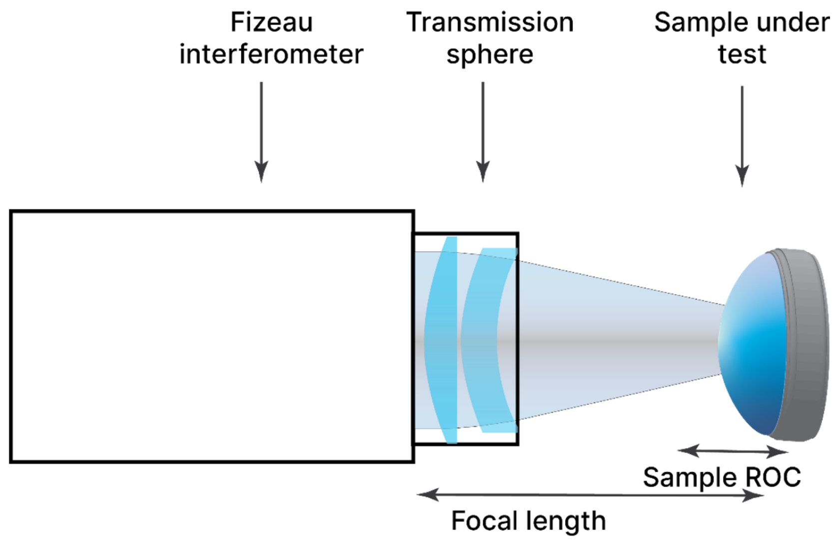

Figure 4: Example 2 shows the setup for a convex sample under test.

Applying the thin lens equation using:

T-sphere choice: F/3.3

F - Focal length (EFL): 339 mm

S_o - Object distance: - (339 - 200) mm:

$$\frac{1}{S_0} + \frac{1}{S_1} = \frac{1}{f} \rightarrow \frac{1}{339} - \frac{1}{(339 - 200)} = \frac{1}{S_1}$$

$$0.003 - 0.007 = -0.004$$

$$S_1 = -235\text{mm}$$

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Solving for S_1 gives a focal length of -235 mm, which is behind the transmission sphere and inside the interferometer, but still well within the range of the system's focus mechanism.

Alignment Procedure

Follow these basic steps to ensure quality measurement when using a t-sphere:

1. Mount the transmission sphere on the instrument using the bayonet mount. Make sure to tighten the bayonet mount so that the t-sphere is lined up with the instrument's optical axis and does not sag.
2. Coarsely align the transmission sphere tip and tilt using the on-screen interferometer alignment target
3. Mount the test optic in a 5-axis mount
4. Move the sample to the focus of the t-sphere
5. Center the t-sphere focus spot at the center of test part (cat's eye)
6. Finely adjust the t-sphere tip/tilt by minimizing cat's eye fringes in live video
7. Translate the 5-axis mount to the confocal position as calculated above
8. Finely align fringes using the adjustments on the 5-axis mount
9. Measure the surface error.

Conclusion

This note presented the method used to select the correct transmission sphere to use for testing a convex or concave spherical surface, using a Fizeau interferometer. Two examples illustrate a method for verifying that the interferometer will be able to focus on the surface under test, using the selected t-sphere. If you have questions about this procedure or need to purchase standard or custom transmission spheres, please contact the 4D Applications Team at 4Dinfo@ontoinnovation.com.

High-quality reference and return optics to complete your setup

4D offers a range of bayonet mount, 4- and 6-inch optics to complete your test setup. Choose from λ/10 or λ/20 quality transmission flats and return flats, or λ/10, λ/15 or λ/20 transmission spheres and reference spheres, from F/0.65 through F/12.5. Various reflectivities and attenuation coatings are offered. Larger optics up to 18 inches are also available.

Click here for the
Fizeau Mounts and Reference Optics
Data Sheet

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