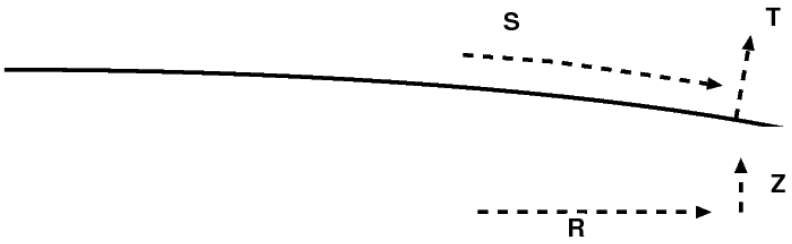
Notes on the QST coordinate system

Stephen Kent, September 27, 2019

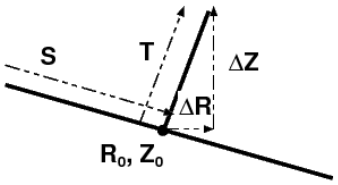
DESI docdb #530 defines the QS coordinate system and how it relates to the CS5 Cartesian system. The surface of best focus of the DESI optics is modeled as an axisymmetric asphere in the echo22 design. (This surface was retained unchanged during a respacing exercise after the lenses were fabricated.) The CS5 coordinate system is defined so that its origin is at the origin of this surface. In practice, the location of $X5 = 0$ and $Y5 = 0$ is defined to be the average of the actual locations of petals in the Focal Plane Array (FPA) (as determined via metrology of the fiducials combined with viewing with them with the Fiber View Camera [FVC]); this will be known with enough precision that deviations from the optical axis are not expected to be significant. The location $Z5 = 0$ is determined by focusing the telescope, and in practice it is defined by the mean Z location of all the GFA CCDs.

One can define cylindrical coordinates R, ϕ in the usual fashion. In the QS, the Q coordinate is the same as ϕ. The S coordinate measures linear distance along a curved path within the focal surface. The QS system does not define a third coordinate analogous to the $Z5$ coordinate in CS5, but it is needed when incorporating the fiducial metrology into analysis of FVC images. The reason is that the fiducials are not positioned precisely on the focal surface, and one needs to account for ray propagation from their actual positions in 3-D space.

The telescope is approximately telecentric, meaning that the telescope beam (here, defined by the chief ray, which is what the FVC sees) comes in approximately perpendicular to the focal surface. At the edge of the field of view, the beam has a tilt of close to 6 deg to the $Z5$ direction. If a fiducial is at a Z distance of, say, 100μ from the focal surface, the location in R will change by 10μ between the fiducial and the focal surface. This change is large enough that we should account for it. To do so, I define a coordinate T that is the distance from the focal surface along a line that is perpendicular to the surface at a given S:



Relation between "petal coordinates" S and T and cylindrical coordinates R and Z.
(Angular coordinate Q is the same in either system.)



Given S, T compute R, Z

$R_0 = F_1(S)$
$Z_0 = F_2(S)$
$m_1 = dF_1/dS$
$m_2 = dF_2/dS$
$\Delta Z = m_1 T$
$\Delta R = -m_2 T$

F_1 and F_2 are polynomial functions

In converting R, Z to S, T,
one round of iteration is needed

The conversion from S, T to R, Z coordinates is given in the figure. The inverse conversion requires an iterative process to compute R_0, Z_0.

The fiducial metrology is provided in the form of X, Y, Z coordinates in a system that matches the CS5 system (aside from clocking and small offsets and rotations arising from imperfect petal insertion into the FPA). In order to use this information, all petal orientation and offset transformations should be applied first, then the coordinates are converted to Q, S, T. Since rays travel in the T direction, the FVC image of a fiducial depends only on the Q, S coordinates. These coordinates (or their X, Y equivalents) are what PlateMaker takes as input.

The telescope is not precisely telecentric. At 0.47μ (the wavelength used to backlight the fiducials), the maximum deviation is about 0.65 degrees at a radius of 250 mm. The error induced by ignoring this angle is roughly $T/100$ and can be ignored unless T is of order several hundred microns or more.