Defining Tilts and Decenters

Many modern optical systems lack rotational symmetry, and, in fact, lack a common centerline; the ability to model them accurately in computer programs such as CODE V has contributed to their growing value and use. Examples are:

- Fold mirrors
- Periscopes
- Prism systems
- Scanning systems (laser scanners, FLIRs, etc.)
- Head up displays (HUD)
- Simulators
- Holographic displays and HOE construction optics
- Spectrometers, monochromators

Decentered systems require a more conscious knowledge of system coordinates. Surfaces are always defined relative to their own local coordinate system. But in decentered and/or tilted systems, the position of these local coordinate systems must also be defined with respect to the coordinate system of the previous surface.

Other topics relating to tilted and decentered systems are covered in Chapter 2A, *Entering/Changing Data - Special Topics*:

- “Defining Array Elements” on page 2A-383
- “Defining Non-sequential Surfaces and Elements” on page 2A-397

Decentered System Philosophy

In CODE V, all surfaces are always centered with respect to their local coordinate systems. When we refer to a “tilted” or “decentered” surface, we actually refer to a tilted or decentered coordinate system, in which the surface is centered and not tilted. This eliminates the need for a special surface type to define a tilted or decentered surface - tilts and decenters can be applied to any surface. For simplicity, in CODE V, when we refer to a decentered surface, we refer to a surface that can have both tilts and decenters.

In general, after the decenters and tilts are applied to a surface’s coordinate system, the following surfaces are defined in this decentered coordinate system until explicitly changed again.

Centered Systems

A centered optical system has only one Z axis - the local coordinate systems for each surface are spaced along this axis according to the specified THI values representing thickness or separation. In such a system users are not aware that they are really defining a mechanical axis only; the fact that a light beam also travels down this axis has led to it being called the optical axis. Thus the optical axis and mechanical axes coincide - light traveling down the optical axis will always follow the mechanical Z axis, too. The +Y axis has been chosen as “up” and +X chosen to form a right handed coordinate system with +Z; letting the Y-Z plane represent the plane of the paper, +Z is to the right, +Y is up, and +X extends behind the paper. See Figure 1.

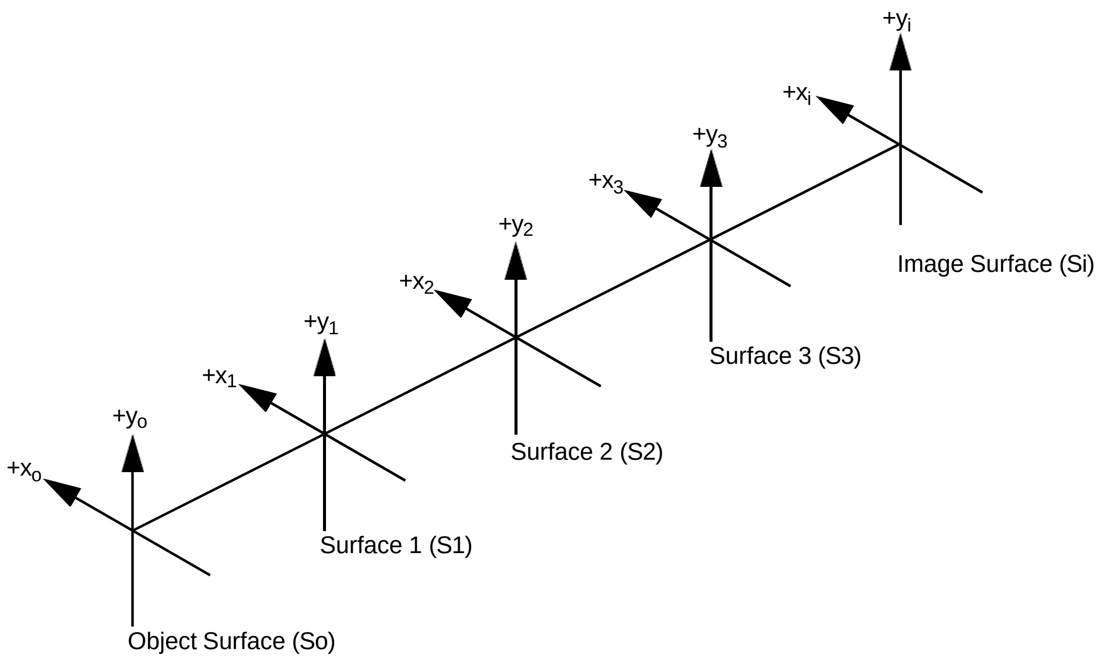

Figure 1. Centered system (3 surfaces)

Thus, the hidden assumptions in centered surfaces are:

- That the X, Y decenters and α, β, γ tilts at each surface are zero. Only the Z coordinate is expressed, in the thickness (THI).
- That the optical and mechanical axes coincide; you do not need to move the optics in space to follow the light.

Decentered Systems

In decentered systems, the user is only defining the mechanical arrangement by specifying a series of mechanical axes, each one defined relative to a point in the preceding coordinate system. There may be no optical axis; often one of the object points will be considered the center point of the object and its chief ray will be considered the "optical axis." It may be physically impossible for this light beam to follow the mechanical axis through the optical system; indeed, the user may choose to define the system with convenient geometry, rather than attempting to closely follow the light beam through the system. It is up to the user to position the image surface to properly intercept the images because first order solves usually are no longer meaningful; Automatic Design and Wavefront Analysis can help to choose the best focus.

Coordinate Break

Thus, the essence of defining a decentered system is to define segments of centered systems (one or more surfaces). Define a new segment relative to the prior segment by constructing a reference coordinate system where the next surface of the prior segment would have been (using the thickness of the last surface of that segment); then construct the new mechanical axis starting at a point (X, Y, Z) in this coordinate system and tilted through an angle (with Euler angles α, β, γ) with respect to the mechanical axis of the prior segment. This is done with the **X-**, **Y-**, and **Z-Decenter** fields and the **Alpha-**, **Beta-**, and **Gamma-Tilt** fields in the **Surface Properties** window (**Lens** menu), on the **Decenters** page. From the command line, use the XDE, YDE, ZDE, ADE, BDE, CDE commands as part of the surface data for the first surface of the new segment; thickness (THI) is part of the data for the last surface in the prior segment. **Technical Note:** This thickness and Z-decenter (ZDE) of the next surface affect the new mechanical axis the same way. Use them, when convenient, to relate your system to any desired mechanical reference point; often, though, Z-decenter is zero.

In Figure 2, surface 1 is not decentered, surface 2 has a Y-decenter (YDE) only, and surface 3 has only a positive α tilt (ADE). The image surface is not decentered relative to the previous surface (3), but it obviously is both tilted and decentered relative to the object surface. Thus decentered surfaces have a cumulative effect in the total system.

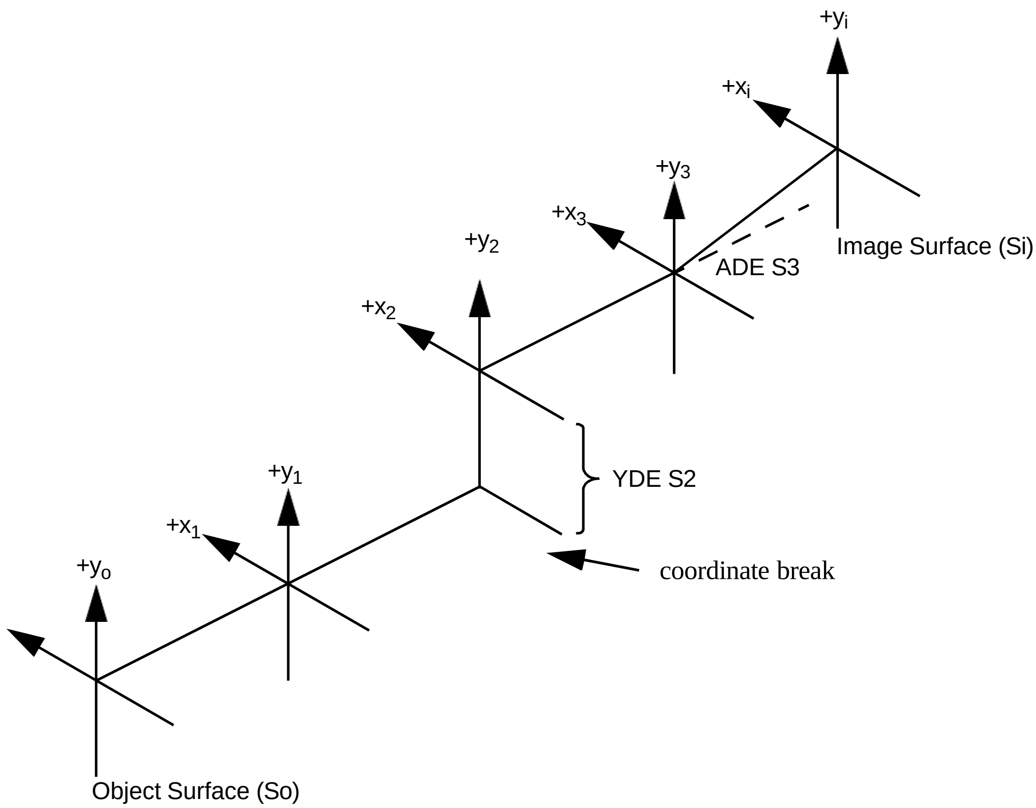

Figure 2. Decentered system (surface 2 decentered, surface 3 tilted)

Command Mnemonics
(alphabetical)

ADE	BDE	BEN	CDE	DAR	DEL BEN
DEL DAR	DEL DDA	DEL GLB	DEL REV	GLB	GLO
RET	REV	XDE	YDE	ZDE	

Tilt and Decenter Definitions

The coordinate system for a surface can be shifted in X,Y, Z and tilted in the Y-Z, X-Z, X-Y planes relative to the coordinate system of the previous surface. The order of applying the decenter and tilt data is important, and may differ, depending on the type of decenter used.

Screen Navigation

To shift the local coordinate system for a surface, choose the **Lens** > **Surface Properties** menu, and click **Decenters** in the **Surface Properties** window's navigation tree.

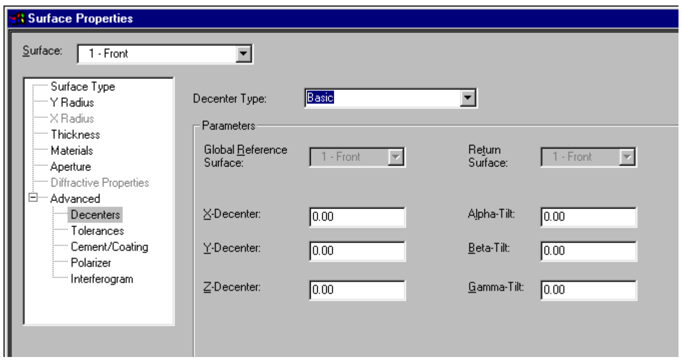

Figure 3. Entering decenter and tilt data in the Surface Properties window

Command Summary

Command Syntax		Control Code
Screen Control	**Explanation**	
XDE Sk x_displacement [... z] **YDE** Sk y_displacement [... z **ZDE** Sk z_displacement [.... z]		See **XDC** **YDC** **ZDC**
X-Decenter **Y-Decenter** **Z-Decenter**	Defines starting point of new axis relative to the X-Y plane (perpendicular to the old Z axis) defined by the previous surface and its thickness (THI Sk-1). From the command line, XDE, YDE, ZDE can be entered in any order, and are executed prior to ADE, BDE, CDE. The meaning of the displacement value is changed in: Decenter and Return (DAR) surface - Old coordinate system restored immediately after representing the selected surface (Sk) in new coordinate system Reverse Decenter (REV) surface - Signs of values are reversed and XDE, YDE, ZDE are done after CDE, BDE, ADE.	
ADE Sk alpha_tilt_degr [. .. z] **BDE** Sk beta_tilt_degr [. .. z] **CDE** Sk gamma_tilt_degr [. .. z]		See **ADC** **BDC** **CDC**
Alpha-Tilt **Beta-Tilt** **Gamma-Tilt**	Defines angle of new axis relative to the old Z axis defined by the previous surface: Alpha-Tilt (ADE) α tilt (degrees) about the new X axis defined by XDE, YDE, ZDE - meridional plane decenter BDE β tilt (degrees) about the new Y axis defined by XDE, YDE, ZDE, ADE - skew decenter CDE γ tilt (degrees) about the new Z axis defined by XDE, YDE, ZDE, ADE, BDE - rotation about new mechanical axis **Range:** -180° to +180° Note order dependence. The meaning of the tilt values is changed in: DAR surface - Old coordinate system restored immediately after represent- ing Sk in new coordinate system BEN surface - ADE and BDE are applied again after reflection, and a sec- ond CDE is determined and applied to generate the reflected axis REV surface - Signs of values and order of operation are reversed.	

Decenter Definitions

The basic coordinate system for each surface is a right-handed coordinate system with the surface oriented relative to the Z axis. When a surface is decentered, its local coordinate system can be shifted in three directions. In the GUI, these shifts are specified in the **Surface Properties** window (**Lens** menu), on the **Decenters** page, in the **X-**, **Y-**, and **Z-Decenter** fields. From the command line, use XDE, YDE, ZDE. Figure 4 shows the geometry of these shifts.

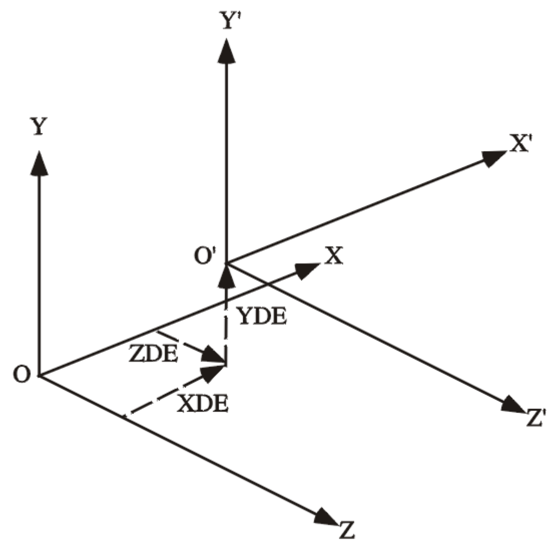

Figure 4. Geometry for decenters

In Figure 4, the coordinate origin O is shifted to a new coordinate origin O'. The X, Y, Z coordinate axes are shifted, but are still parallel to the original axis directions. Note that ZDE acts as a sort of additional thickness (THI) from the previous surface. In Figure 4, the XDE, YDE, ZDE shifts are all shown as positive.

Tilt Definitions

The coordinate system can also be tilted in each of the Y-Z, X-Z, X-Y planes. In the GUI, the tilts in each of the planes are defined in the **Surface Properties** window (**Lens** menu), on the **Decenters** page, in the **Alpha-Tilt**, **Beta-Tilt**, and **Gamma-Tilt** fields. From the command line, use ADE, BDE, and CDE. The definitions of these tilts are as follows, and are shown in Figure 5.

- Y-Z plane. The tilt is referred to as an alpha tilt (α) and is specified in the **Alpha-Tilt** field (ADE, or alpha decenter). The rotation is left-handed about the +X axis.
- X-Z plane. The tilt is referred to as a beta tilt (β) and is specified in the **Beta-Tilt** field (BDE, or beta decenter). The rotation is left-handed about the +Y axis.
- X-Y plane. The tilt is referred to as a gamma tilt (γ) and is specified in the Gamma-Tilt field (CDE, or gamma decenter; c is the third letter in the English alphabet and gamma is the third letter of the Greek alphabet). The rotation is right-handed about the +Z axis.

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