The OMEGA Target-Positioning System

System Overview

Historically, several different styles of target positioners have been developed and deployed at LLE. The initial target positioner on the OMEGA 24-beam system used a 16-target carousel, which was located inside the experimental target chamber. This approach required that the entire target chamber be vented to load the target carousel; it further constrained the experimental operations by limiting target selection to one of the 16 on the carousel. This last constraint often limited the flexibility of the experimental program to change the target parameters during the shot sequence based on the results from the initial shots in the sequence. In addition, this carousel positioner did not allow rotational alignment of the target, which is required for flat-target experiments.

In the mid-1980s, a new style of target positioner was developed to support initial x-ray laser shots. It featured six axes of adjustment as well as a gas-feed capability; however, it also required that the entire experimental chamber be vented to load a single target. In addition, the six axes were configured in a manner that required complex compound motions for target alignment.

A third positioner developed for the OMEGA 24-beam system used a shuttle approach to load individual targets without requiring the experimental chamber to be vented. This positioner featured four axes of alignment motion without the complex compound motions of earlier positioners (see Fig. 71.46). Although this positioner was developed as an auxiliary positioner for backlighter targets, it soon became OMEGA's primary target positioner because it was reliable and provided quick turnaround between shots, while it maintained the maximum flexibility for the experimental program by allowing any available target to be used during a shot sequence. This positioner became the basis for the design of the target positioner for the OMEGA 60-beam system.

The OMEGA target-positioning system (TPS) has been developed to provide an accurate method for positioning a wide variety of targets at the required location at or near the center of the experimental target chamber within the 1-h shot cycle of the OMEGA system. This target positioner provides four alignment motions, which include three translation motions (X, Y, Z) and one rotation motion about the axis of the

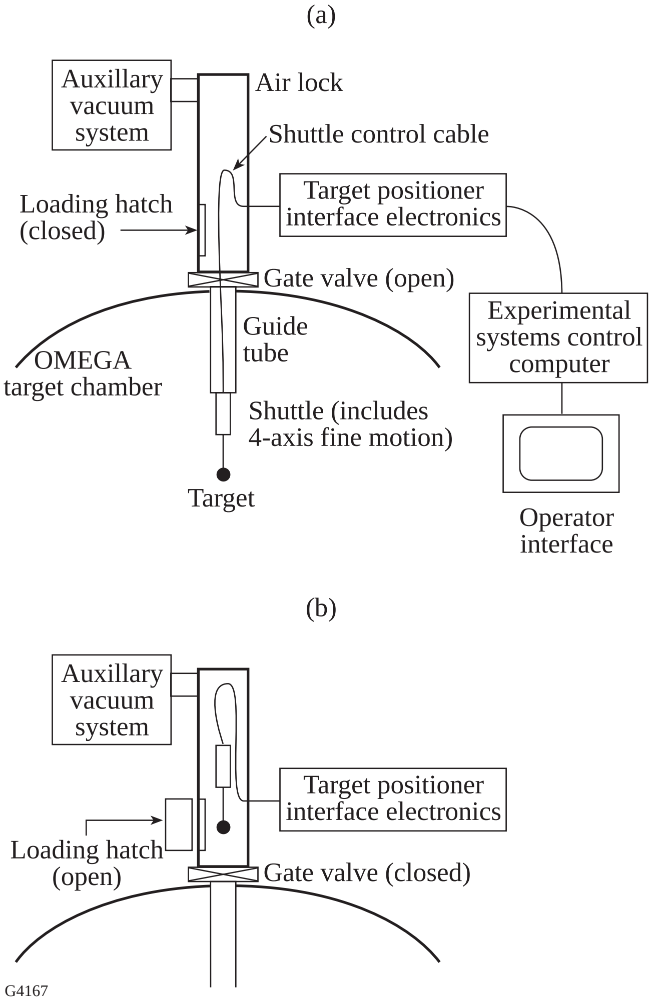


Figure 71.46
Shuttle-type target-positioning system: (a) target extended, (b) target retracted.

positioner (ω), with an option to add the remaining two rotation motions (θ, ϕ). (See Fig. 71.47 for the definitions of these motions.) The motion (T) used to transport the shuttle to the target chamber center (TCC) is independent of the fine alignment motions.

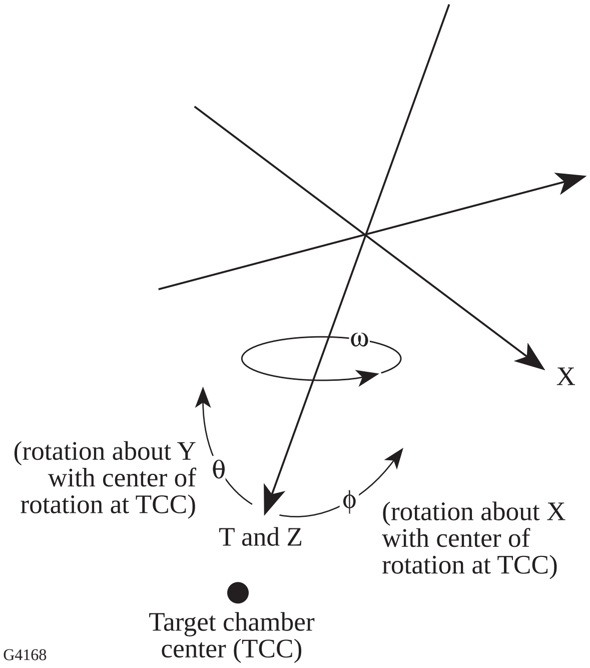


Figure 71.47
Definition of the OMEGA target-positioner axes.

The definition of TCC is provided by two nearly orthogonal target-viewing systems (TVS), which are rigidly attached to the chamber. The angle between the viewing systems is 101.5°, and the target positioner is 33.2° from being normal to the plane defined by the two viewing systems (see Fig. 71.48). This geometry does introduce coupling between the target-positioner motions and the two viewing systems; however, system operators learn to compensate and readily achieve target alignment.

A typical shot sequence begins with the target chamber evacuated to mid-10^{-6} Torr; the target positioner is retracted and the air lock vented. A target is manually loaded onto the end of the target positioner, and the air lock is closed and evacuated below 1×10^{-4} Torr. The gate valve is opened, and the target positioner is inserted into the TCC. Once the target is located in the viewing systems, final alignment is done to ±5 μm of the designated location using the fine positioning stages in the target positioner. Following the laser shot, the target positioner is retracted, the gate valve is closed, and the air lock is vented so that the process can be repeated.

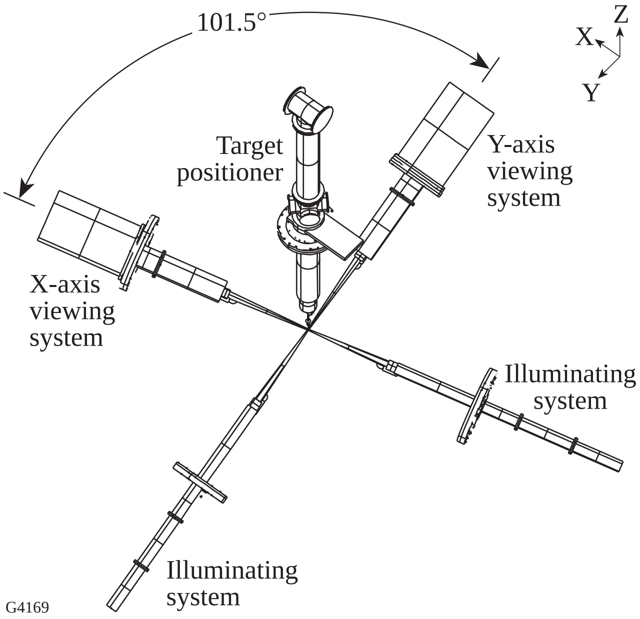


Figure 71.48
OMEGA target chamber viewing system geometry. (View: normal to plane of viewing system.)

Requirements and Concept

A draft specification written in mid-1993 served as the basis for the mechanical design of the OMEGA target positioner. This specification was based on a shuttle-style device (Fig. 71.46), which was thought to provide the best combination of short cycle time and flexibility in target selection during an experimental shot sequence. The seven axes of motion are defined in Fig. 71.47, where the T and Z axes are along the axis of the target positioner. Experience has shown that the configuration of these axes (shown in Fig. 71.49) is important to minimize coupling of the motion of each axis. In addition, the θ and ϕ motions should have pivot axes as close as possible to the TCC to minimize the translation of the target when these rotations are adjusted. (The basic requirements of the target positioner specification are summarized in Table 71.VIII.) In addition, the bulk of the target positioner is to be located at least 12 in. from the TCC to minimize the amount of ablation due to the reaction products and energetic debris from the implosion.

The OMEGA target positioner is shown in Fig. 71.50. The target is attached to the fine-motion stages, which are supported on the transfer assembly (see Fig. 71.51); this unit moves within the guide tube assembly to the TCC. The guide tube assembly is the main structural member of the positioner and provides the vacuum housing for the air lock. This assembly is attached to the chamber using a gate valve that allows the air lock to be independently vented. The target positioner currently deployed on OMEGA does not include the θ and ϕ motions, although these motions are shown in Fig. 71.51. The sections of the target positioner are discussed in detail in the following sections.

Table 71.VIII: Required performance of the OMEGA target positioner.

Parameter	Specification	Comments
Required alignment motions	X, Y, Z, ω	θ and ϕ may be added
X, Y, and Z motion range	1 in.	Target within a 1-in. radius
X, Y, and Z motion resolution	5 μm (0.0002 in.)	Maximum step size
ω range	360°	Continuous
ω resolution	0.25°	Maximum step size
θ and ϕ ranges	±5°	Minimum
θ and ϕ resolutions	0.25°	Maximum step size
T resolution	1 mm (0.040 in.)	Maximum step size
Stability over 60 min	Within resolution	For all axes
Maximum target acceleration	0.2 g	For all axes
Transport time	Within 5 min	From airlock to TCC
Orientation	Any port on chamber	

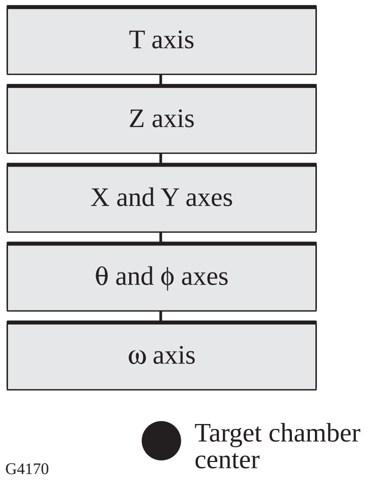


Figure 71.49
Configuration of OMEGA target-positioner axes.

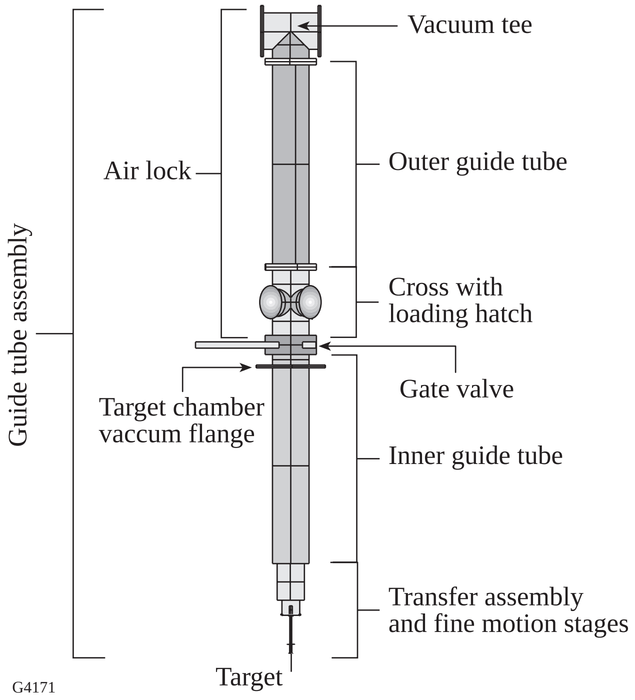


Figure 71.50
OMEGA target-positioner components.

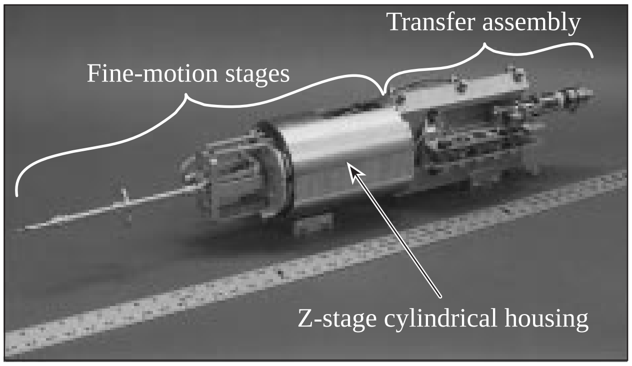


Figure 71.51
Transfer assembly and fine-motion stages.

Transport Motion

The transport motion transports the target from the target positioner's air lock to the TCC—a distance of 80 in. This motion is provided by the following subsystems: a guide tube assembly, a transfer assembly, and a cable assembly.

1. Guide Tube Assembly

The guide tube assembly consists of five sections: inner guide tube, gate valve, cross, outer guide tube, and vacuum tee (see Fig. 71.50). The guide tube sections are 8-in.-outer-diam stainless steel tube. The inner guide tube is inside the target chamber and includes a standard 12-in. OMEGA flange, which seals to the target chamber. The cross and outer guide tube make up the air lock for the target positioner when the transfer assembly is withdrawn to load a new target. The gate valve separates the inner and outer guide tubes. Attached to the cross are standard ISO-style electrical-feedthrough vacuum flanges for powering the insertion and fine positioning stages (see Fig. 71.52); a quick access door for manually loading targets; and a viewport. The fourth flange on the cross will be used for an auto target loader, which will be added to the positioner in the future. The vacuum tee terminates the outer end of the guide tube assembly and provides the interfaces to the roughing and vent valves, the turbo molecular high-vacuum pump, and the high-vacuum valve, which isolates this pump (see Fig. 71.53).

The guide tube assembly provides the structural support for the target positioner. This structure is approximately 94 in. long and is designed to provide the required stability of ±5 μm (±0.0002 in.) at the center of the target chamber. Finite element analysis (FEA) was used to calculate the normal modes of this structure and determine how it would respond to vibration from other equipment attached to the target chamber. This modeling determined that an input of 100 μg at the target chamber flange would displace the target by 0.4 μm at the first mode of 22 Hz. Modeling determined that adding a support to the vacuum tee increased the first mode to 72 Hz and decreased the forced response to 0.2 μm. However, in practice, this additional support has not been required on the target positioner currently deployed on OMEGA.

The guide tube assembly supports the cylindrical rails and drive rack for the transport assembly. The double rail design shown in Fig. 71.54(a) was chosen because it is simple and provides adequate straightness of motion. The technique for mounting the rails was taken from the six-inch manipulator (SIM) developed at LLNL and involves cross tapping the rails and using screws from the outside of the guide tube to secure the rail to the inside of the tube. The heads of the screws were then welded to the outside of the guide tube to maintain the vacuum integrity of the guide tube. This technique provided a simple fabrication method and yielded a stiff mounting for the rails after the screws are welded. One of the rails is spaced away from the inside surface of the tube [see Fig. 71.54(b)] to provide the proper clearance for the transport mechanism. The drive rack support is mounted to the inside surface of the guide tube using the same technique. The drive racks in the outer guide tube and the cross can be adjusted axially to allow them to be meshed with the drive rack in the inner guide tube. The

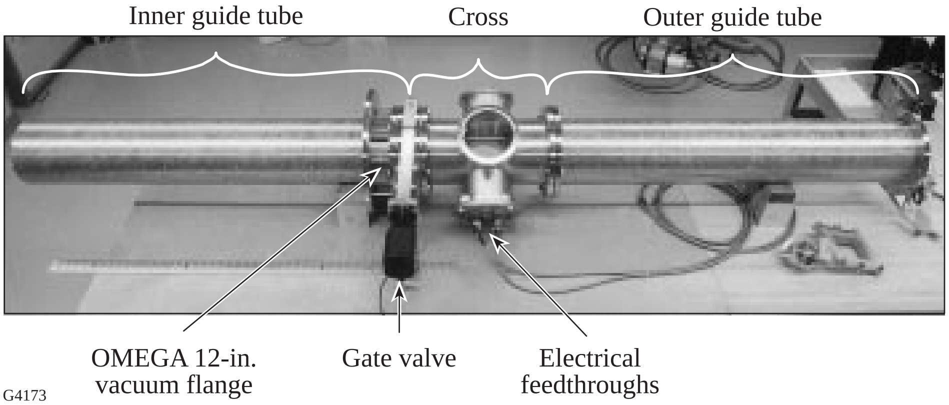


Figure 71.52
Guide tube assembly. (Note: The vacuum tee is not shown.)

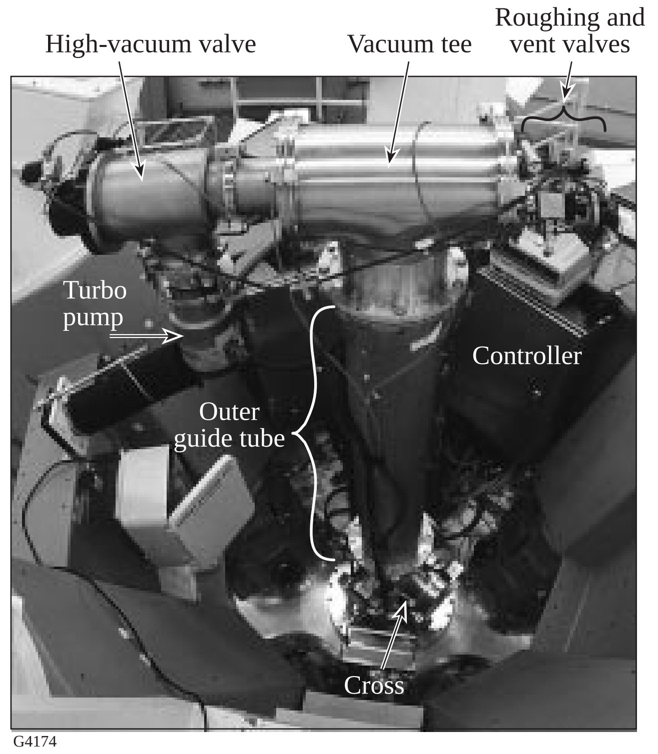


Figure 71.53
Target positioner on the top port of the OMEGA target chamber.

drive rack has a small gap at the joint between the outer guide tube and the cross and a 2-in. gap across the gate valve. The guide rails also have a 2-in. gap across the gate valve. The transfer assembly is designed to bridge these gaps.

2. Transfer Assembly

The transfer assembly is made up of the transfer body and the gear housing and provides 80 in. of motion inside the guide tube [see Fig. 71.55(a)]. It is constructed with ball-bearing rollers that run on the rails in the guide tube. On one side of the transfer body the rollers form three V's; the opposite side of the transfer body has fixed lower rollers to take the spring preload on the drive gears, and spring-loaded upper and side rollers to prevent binding during the translation in the guide tube [see Fig. 71.55(b)]. Three sets of rollers on each side allow the transfer body to bridge the gap in the rails at the gate valve. The drive motion is provided by a small gear motor driving three drive gears through a worm gear reducer [see Fig. 71.55(c)]. The gear housing deployed with the current target positioner uses two drive gears rather than the three gears shown in Fig. 71.55(c). The two drive gears are separated by a distance that allows the unit to bridge the gap at the gate valve. The three drive gears are used to improve the smoothness of the motion across the gap in the drive rack at the gate valve.

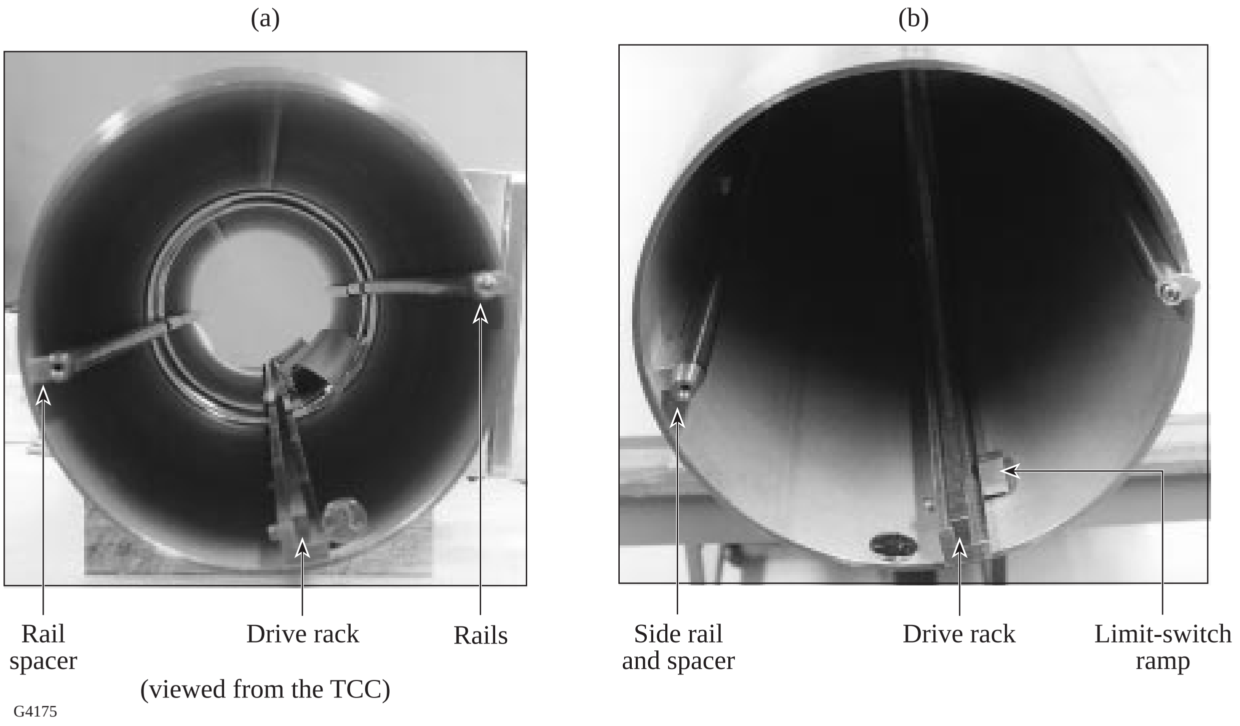


Figure 71.54
(a) End view of the guide tube rails and drive rack; (b) closeup of the guide tube rails and drive rack.

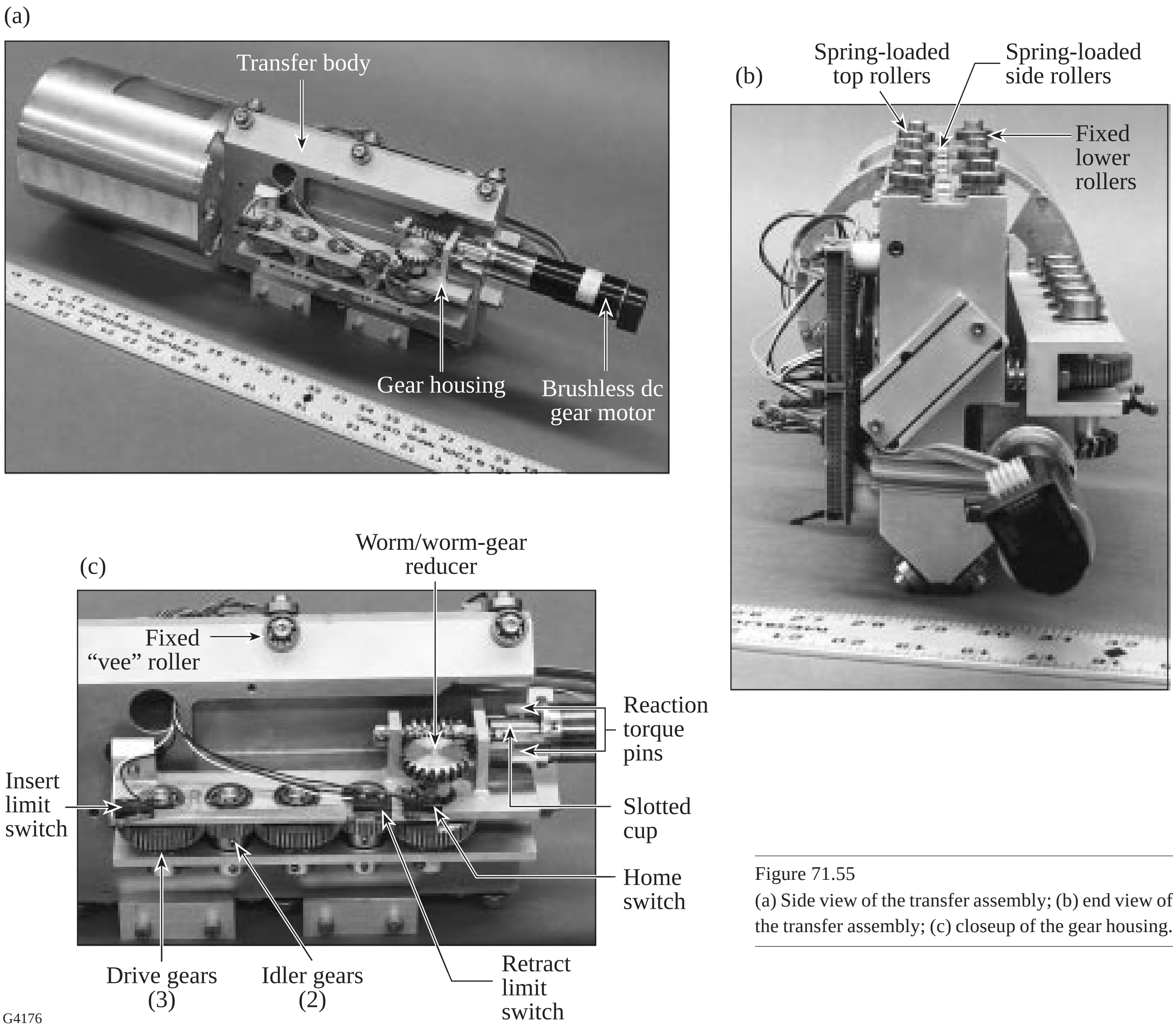


Figure 71.55
(a) Side view of the transfer assembly; (b) end view of the transfer assembly; (c) closeup of the gear housing.

The drive motor for the transfer motion was initially a brush-style dc motor with integral gear head and magnetic encoder manufactured by MicroMo Electronics. The brushes have had poor lifetime in the high-vacuum environment, so the motors were replaced every 6 to 8 weeks to minimize the possibility of a failure during an experimental shot sequence. The transfer motion motor has now been replaced with a brushless dc motor manufactured by MicroMo [see Fig. 71.55(a)]. The gear head chosen for this application is a planetary style that provides robust performance and withstands the full stall torque of the motor. The gear head is cleaned and lubricated for vacuum service at LLE.

The motor is sized to provide a transit time to the TCC of less than 5 min. The weight of the shuttle is 25 lbs (the estimated weight of the conceptual design was 27.3 lbs). The required torque at the motor/gear head was calculated from the estimated weight, and the motor's performance specifications (motor speed versus output torque) were used to calculate the shuttle's transit time for a range of torque settings. (These data are shown in Fig. 71.56.) The estimated torque for this application was ≈38 oz.-in. The transit time was estimated at 4.1 min and would increase to 4.3 min if twice the torque was required. Thus, the transit time is not a strong function of the torque required to move the shuttle.

The output shaft of the transfer motor is coupled to the drive gears with a 10:1 worm/worm-gear reducer, as shown in Fig. 71.55(c). This reducer provides the proper overall gear ratio for the drive motor and ensures that the transfer assembly

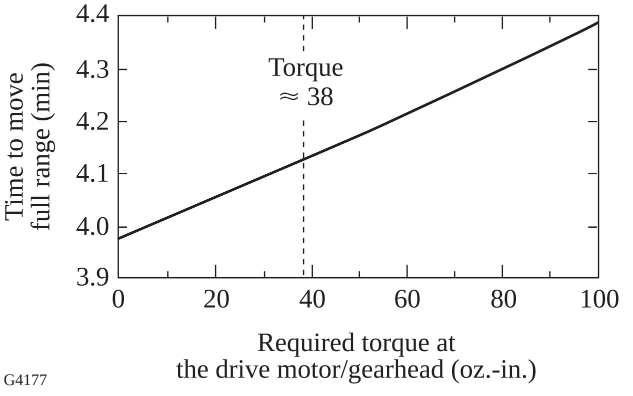


Figure 71.56
T-axis transit time versus torque required at the drive motor.

does not drive backward (due to gravity) when power is removed from the motor. The gear head on the motor is constructed with pressed-in shaft bearings, so the gear head cannot support the thrust loads generated by the worm/worm-gear reducer. These thrust loads required the worm to be mounted on a shaft, which is supported with adequate thrust-bearing capacity. The drive motor is coupled to the worm shaft by a slotted cup that engages the cross pin in the worm shaft. The reaction torque at the motor is taken by the two pins shown in Fig. 71.55(c). This arrangement allows the drive motor to be quickly removed from the gear housing and replaced in the event of a motor failure.

A belt drive was initially used to couple the two drive gears; however, this was abandoned because the belt could not be tensioned adequately for the load and the belt would slip as the transfer body moved across the gate-valve gap when the target positioner was mounted in a vertical orientation. A bevel-gear drive was also tried and dropped in favor of the compact and robust gear train shown in Fig. 71.55(c).

Motion along the *T* axis is restricted by limit switches that are activated at each end-of-travel [see Figs. 71.54(b) and 71.55(c)]. This motion uses an incremental encoder that must be zeroed at a repeatable location whenever power is lost to the controller. This switch is mounted with the end-of-travel limit switches and is tripped by the ramp for the retraction switch. In this manner, the *T* axis can be reset to home every time the transfer assembly is retracted from the TCC.

The brush-style drive motor initially used for the *T* axis incorporated a magnetic incremental encoder that produced 40 counts per revolution. This has been replaced with a brushless-style drive motor, which uses an optical encoder that produces 384 counts per revolution. (See Table 71.IX for a summary of the resolution of the target-positioner motions.)

Table 71.IX: Calculated performance of the OMEGA target positioner.

Parameter	Specification	Final Value
T-axis resolution	1 mm	0.0125 mm
T-axis transit time	5 min	≈ 4 min
Z resolution	5 μm	0.1 μm
X and Y resolution	5 μm	0.8 μm
θ and ϕ resolution	0.25°	0.6×10^{-6}°
ω resolution	0.25°	0.004°

3. Cable Assembly

The cable assembly consists of two ribbon cables, a tensioning pulley, an interface printed circuit board (PCB) mounted to the transfer body, and two electrical vacuum feedthroughs mounted in the tee section of the guide tube assembly. This assembly provides power to the gear motors used for each of the alignment motions in the target positioner. It also provides feedback from the encoders and limit switches to the controller, which is remote from the target positioner. The tensioning pulley rides on the same rails as the transfer body. Two constant-force springs provide the necessary tension on the pulley to prevent the cables from tangling without producing excessive load on the transfer motion motor. The electrical feedthroughs are shown in Fig. 71.52 and the PCB in Fig. 71.57.

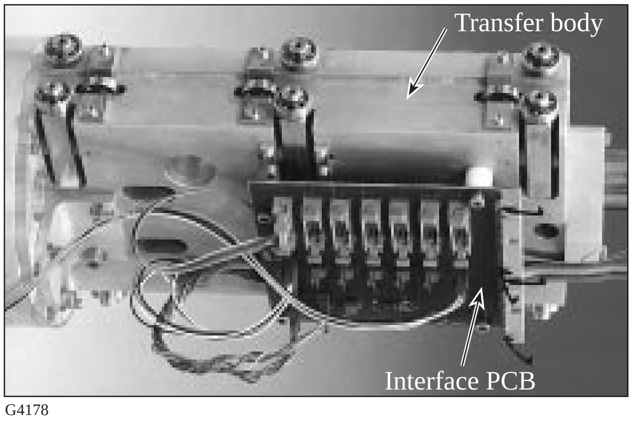


Figure 71.57
Printed circuit board on the transfer body.

Fine Positioning Motion

The final alignment of the target is accomplished with the fine-motion stages that provide four degrees of freedom: *X*, *Y*, *Z*, and ω (with the option of later adding θ and ϕ motions). These stages are cascaded from the transport assembly in the manner defined in the specification (see Fig. 71.49). All fine motions are powered with brush-style dc gear motors from MicroMo. The gear heads are a spur gear style with high ratios and fine resolution; however, these gear heads will not take the full stall torque of the motor: the output gear will break under a stall condition, and the gear head will need to be replaced.

1. *Z* Stage

The *Z* motion is supplied by a lead screw driving a yoke with three cylindrical pads [see Fig. 71.58(a)] that run on the inside of a 5.5-in.-inner-diam cylindrical housing (see Fig. 71.51). One of the pads is spring loaded against the cylindrical surface, and the other two pads are rigidly mounted to the yoke. This approach prevents binding during the full range of motion while maintaining accurate linear motion in any orientation. This design also allows the *X*- and *Y*-stage motors to be packaged within the volume of the *Z* motion, thus keeping the overall assembly compact and lightweight [see Fig. 71.58(b)]. A shoulder screw in the spring-loaded pad runs in a slit in the cylindrical housing to prevent rotation of the yoke [see Fig. 71.58(a)]. This screw also serves as the hard stop for the motion as well as the trip for limit switches [see Fig. 71.58(c)]. The lead screw provides 0.05 in. of translation per revolution, the motor gear head is a 272:1 ratio, and the transit time for the full range of travel (±1 in.) is approximately 48 s. The final resolution of the *Z* stage is listed in Table 71.IX.

2. *X* and *Y* Stages

The *X* and *Y* linear motions of the target are approximated by rotating about two orthogonal axes located 18 in. from the target. This approach was used successfully on the earlier shuttle-style target positioner developed and used on the OMEGA 24-beam system. A two-axis gimbal is used to generate these motions. Each rotation axis is produced by using two 1/8-in.-diam silicon nitride balls in brass conical seats. The two balls are preloaded by using cone point set screws with locking jam nuts [see Fig. 71.59(a)]. The drive motion for each gimbal is provided by a lead screw, which is mounted directly on the output shaft of the motor/encoder/gear head, as shown in Fig. 71.59(b) for the *X* stage and Fig. 71.58(b) for the *Y* stage. The lead screw provides 0.05 in. of motion per revolution; this yields a rotation of 2.35° because the lead screw is offset 1.218 in. from the pivot axis of the gimbal. The gear head is a spur gear style with a 1670:1 ratio to provide the required

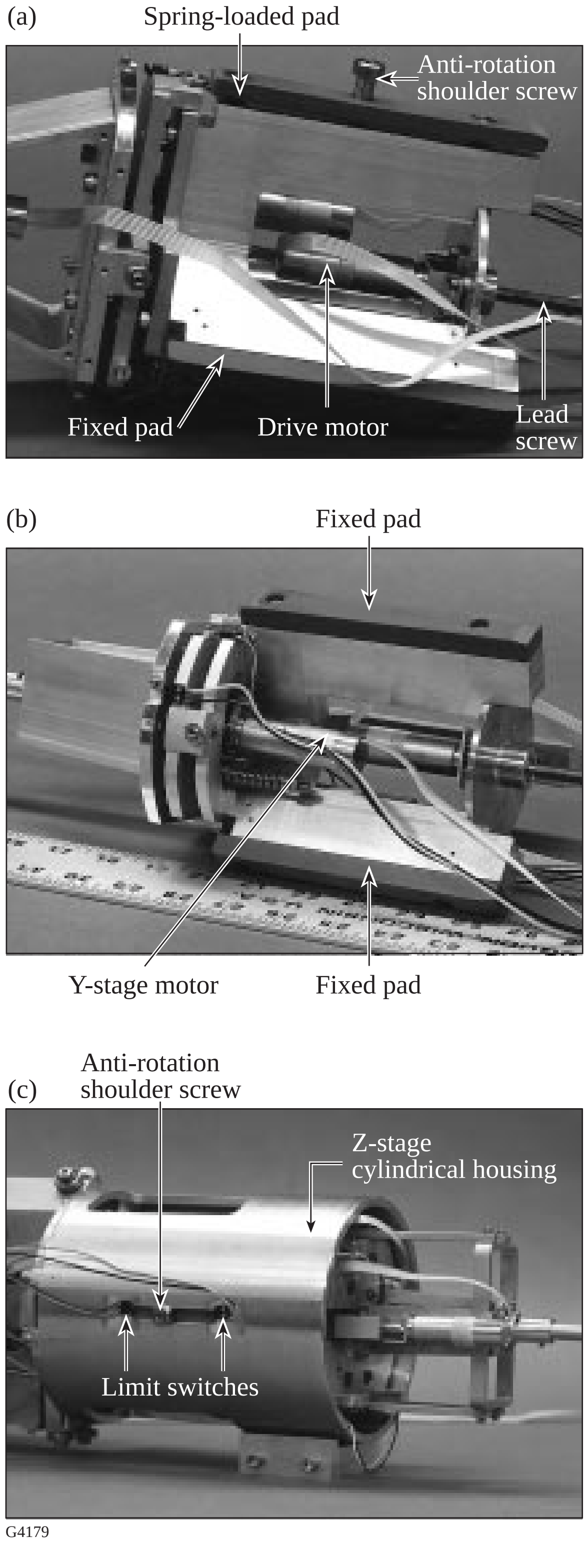


Figure 71.58
(a) *Z*-stage yolk assembly; (b) *Y*-stage motor packaged within the *Z*-stage yolk assembly; (c) *Z*-stage limit switches.

resolution for the *X* and *Y* motions. The motor-mounting plate is slotted to allow the motor/lead screw to translate as the screw is turned; the reaction torque on the motor is taken by two pins in the base plate, which ride in slots in the motor-mounting plate. The lead screw nut is mounted in the base plate. The gimbal plate is spring loaded against the lead screw to eliminate backlash. The tip of the lead screw is an 1/8-in.-diam silicon nitride ball, which seats against a flat hardened-steel pad in the gimbal plate. The base plate for the *X* stage is rigidly attached to the yoke of the *Z* stage. The gimbal plate of the *X* stage is also the base plate for the *Y* stage. This concept allows a compact, simple package for the two translation motions at the TCC. Although this style of motion leads to coupling of the *X* and *Y* motions to the *Z* motion, system operators quickly learn to compensate for this coupling, which does not exceed 0.03 in. of *Z* motion over the full range of *X* or *Y* travel. The final resolutions of the *X* and *Y* stages are listed in Table 71.IX.

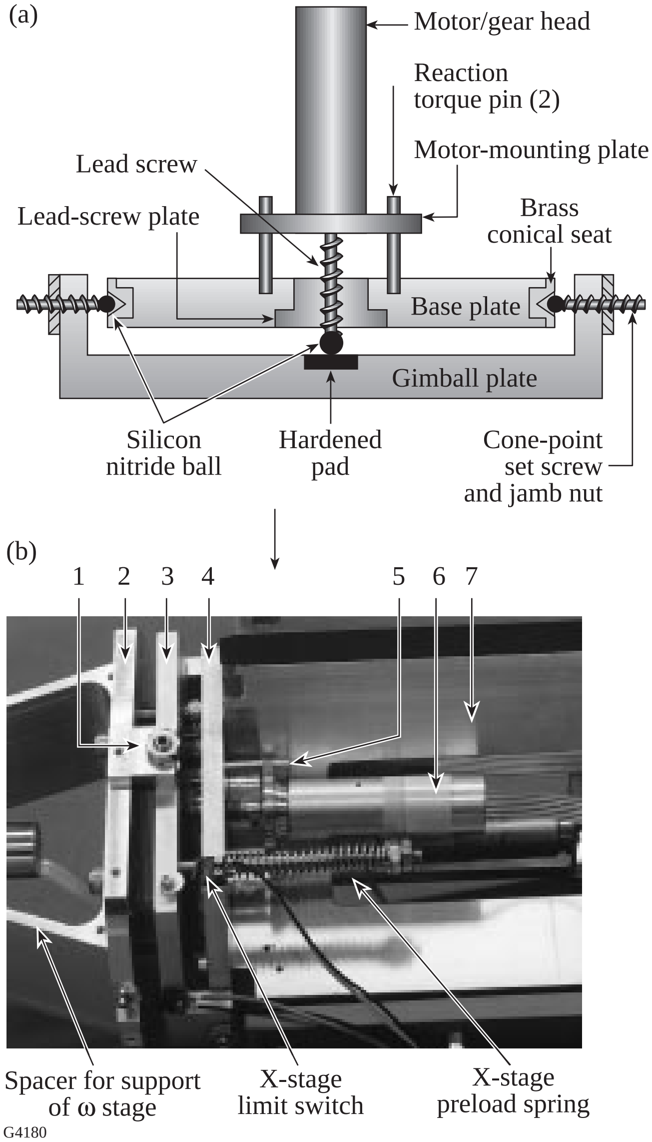


Figure 71.59
(a) *X*-, *Y*-stage concept; (b) *X*-, *Y*-stage closeup. (1) *Y*-stage cone-point set screw and jamb nut; (2) *Y*-stage Gimbal plate; (3) *X*-stage Gimbal plate; *Y*-stage base plate; (4) *X*-stage base plate; (5) reaction torque pin; (6) *X*-stage drive motor; (7) *Z*-stage yolk.

3. OMEGA Stage

The ω motion is rotation about the axis of the target positioner. The motor/encoder/gear head is the same as used on the *X* and *Y* stages. A 1/4-in.-diam drive shaft is rigidly coupled to the gear head output shaft, and the end of the drive shaft closest to the target is supported with a polymer sleeve bearing. A target holder threaded to the end of the drive shaft (Fig. 71.60) holds the target mount with a beryllium copper spring finger. The first plasma shield shown in Fig. 71.60 prevents ablation of the sleeve bearing, which supports the drive shaft. The second plasma shield provides line-of-sight protection for the remainder of the target positioner. The ω axis is supported from the *Y*-axis gimbal plate with a spacer as shown in Fig. 71.59(b). This spacer can be replaced with the θ and ϕ stages, which are described in the next section (see Fig. 71.51). The final resolution of the ω axis is listed in Table 71.IX.

4. θ and ϕ Stages

The OMEGA target-positioner specification requested the additional rotational motions θ and ϕ to allow precise alignment of nonspherical targets. These motions need to provide

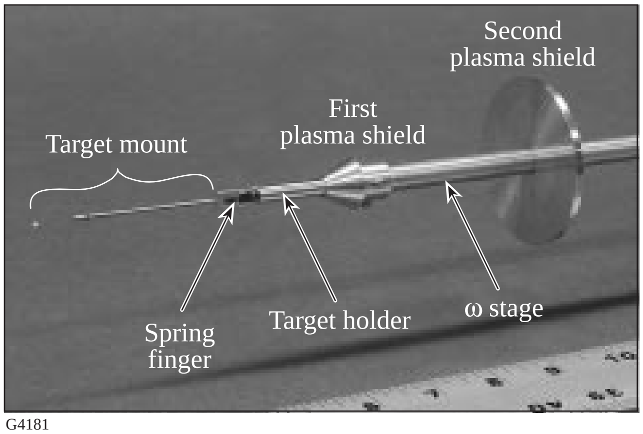


Figure 71.60
Closeup of the target holder and plasma shields.

±5° of rotation about the TCC; historically, this was accomplished with goniometric stages. Goniometric stages are difficult to package in the space envelope of the target positioner, so an alternative approach was developed using four-bar linkages. The geometry of these linkages is shown in Fig. 71.61(a).[1] This concept supports the ω axis on the bar labeled c in Fig. 71.61(a), so the rotation angle of the target located at the end of the ω axis is defined as θ. The law of cosines yields the following relationships for the four-bar linkages:

$$\psi = \cos^{-1}\left(\frac{h^2 + a^2 - b^2}{2ha}\right) + \cos^{-1}\left(\frac{h^2 + d^2 - c^2}{2hd}\right), \quad (1)$$

$$\tau = \cos^{-1}\left(\frac{c^2 + d^2 - a^2 - b^2 - 2ab\cos\phi}{2cd}\right), \quad (2)$$

$$h^2 = a^2 + b^2 + 2ab\cos\phi, \quad (3)$$

where ϕ is referred to as the crank angle.

The target's angle of rotation is

$$\theta = \pi - (\tau + \psi). \quad (4)$$

The location of a point P relative to the origin shown in Fig. 71.61(a) is

$$P_x = b\cos(\phi) + r\cos(\theta + \alpha), \quad (5)$$

$$P_y = b\sin(\phi) + r\sin(\theta + \alpha). \quad (6)$$

In the design of the θ and ϕ mechanisms the links shown as b and d in Fig. 71.61(a) are equal in length, and the geometry of the mechanism for the OMEGA target positioner, as shown in Fig. 71.61(b), yields the following relationships:

$$c = u\left(\frac{a}{u+w}\right), \quad (7)$$

$$b = \frac{w}{\cos\left[\tan^{-1}\left(\frac{a/2}{u+w}\right)\right]}, \quad (8)$$

$$\alpha = \tan^{-1}\left[\frac{u}{c/2}\right], \quad (9)$$

$$r = \frac{u}{\sin\alpha}, \quad (10)$$

where the linkage is designed to provide rotation about the remote point P, shown in Fig. 71.61(a). By defining the variables a (width between the fixed pivots), w (height of the mechanism), and u (distance from the mechanism to the

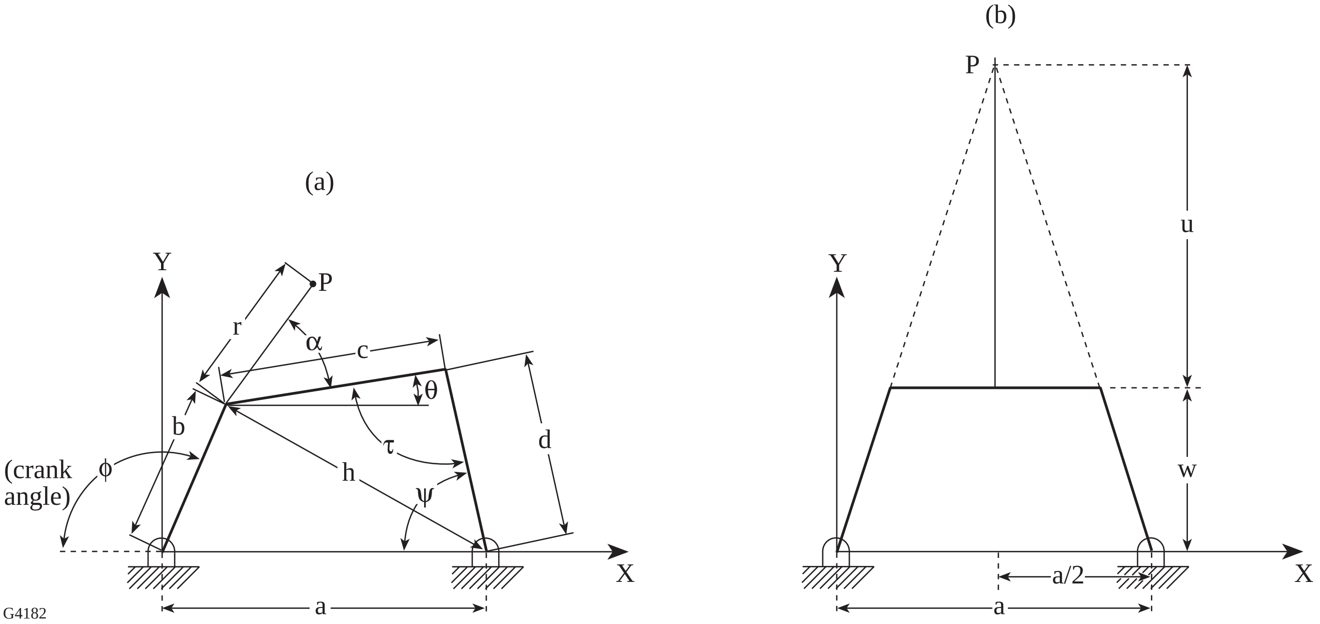


Figure 71.61
(a) Four-bar linkage geometry; (b) θ-and ϕ-stage geometry.

target), one may numerically solve for the angle of the target, θ, as a function of the crank angle ϕ by using Eqs. (7)–(10) and Eqs. (1)–(4). This has been done to understand the motion for various design dimensions, and the final design parameters are given in Table 71.X for both the θ and ϕ stages. The relationship of the rotation angle of the target to the rotation of the crank is nearly linear, as shown in Fig. 71.62. Equations (5) and (6) are used to calculate the movement of the target in the axial and lateral directions over the rotation range of 5°. These results are given in Figs. 71.63(a) and 71.63(b).

The θ and ϕ stages have been built in a nested fashion to minimize the size of the assembly and allow it to fit in the allotted space between the X/Y stages and the ω stage [see Figs. 71.64(a) and 71.64(b)]. Both the θ and ϕ stages are driven by the same dc gear motors as the X and Y stages. These motors are coupled to the stage crank shafts using a worm/worm-gear reducer. The θ motor is packaged within the Z-stage yolk (see Fig. 71.64); the ϕ-motor location is shown in Fig. 71.64(b). The final resolution of the θ and ϕ stages is listed in Table 71.IX.

Controls

1. Operator Interface

The experimental system operator (ESO) controls the TPS/TVS through a graphical user interface (GUI) residing on a computer terminal located in the control room (see Fig. 71.65). This GUI displays push buttons for control of TPS motions including selection of jog modes, direction, and jog-step size. Values representing the actual (implied) absolute position of each axis are useful. In addition, feedback of actual position within range (and/or limit-switch status) is displayed for each axis. The window provides for actuation of shutters, selection of illumination intensity, magnification option, and enhanced video options, etc., for TVS control.

2. Target-Positioner Control Elements

The OMEGA target positioner is comprised of two discrete and operationally independent functional areas (see Fig. 71.66): (1) the auxiliary vacuum controls that control entry into the target chamber while remaining under a high vacuum condition, and (2) the multiple-axis motion controller necessary for precision motion control of up to six individual axes.

Table 71.X: Final design parameters for the θ and ϕ axes.

Parameter	θ Stage	ϕ Stage
u (in.)	12.00	11.97
w (in.)	3.50	3.00
a (in.)	1.25	1.25

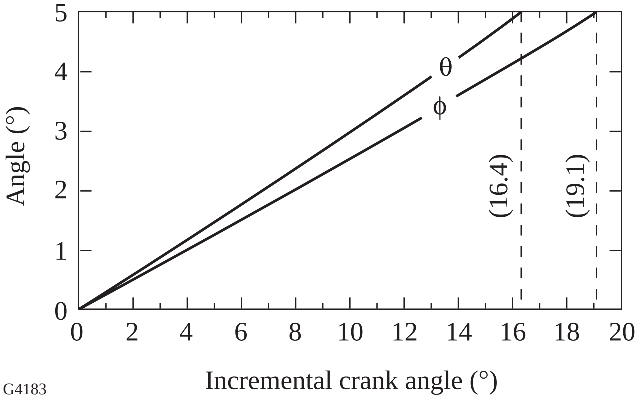


Figure 71.62
θ and ϕ rotation versus crank angle.

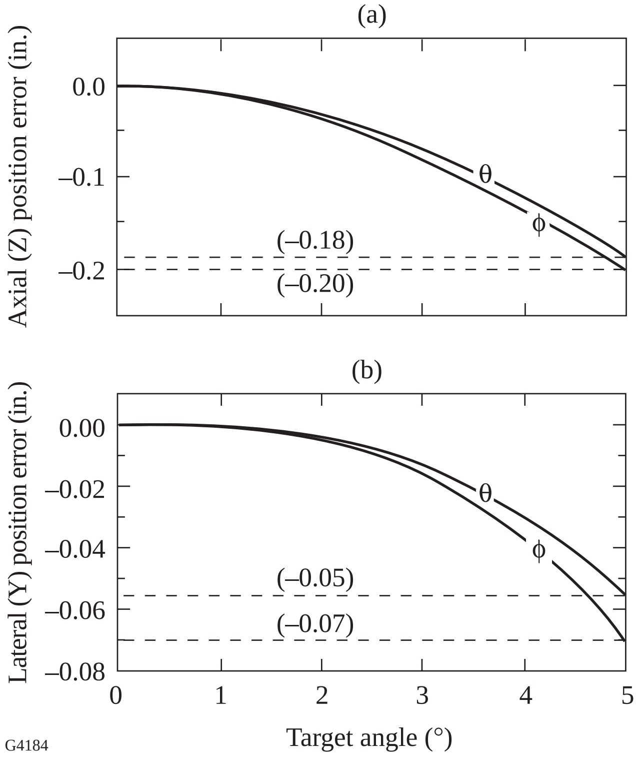
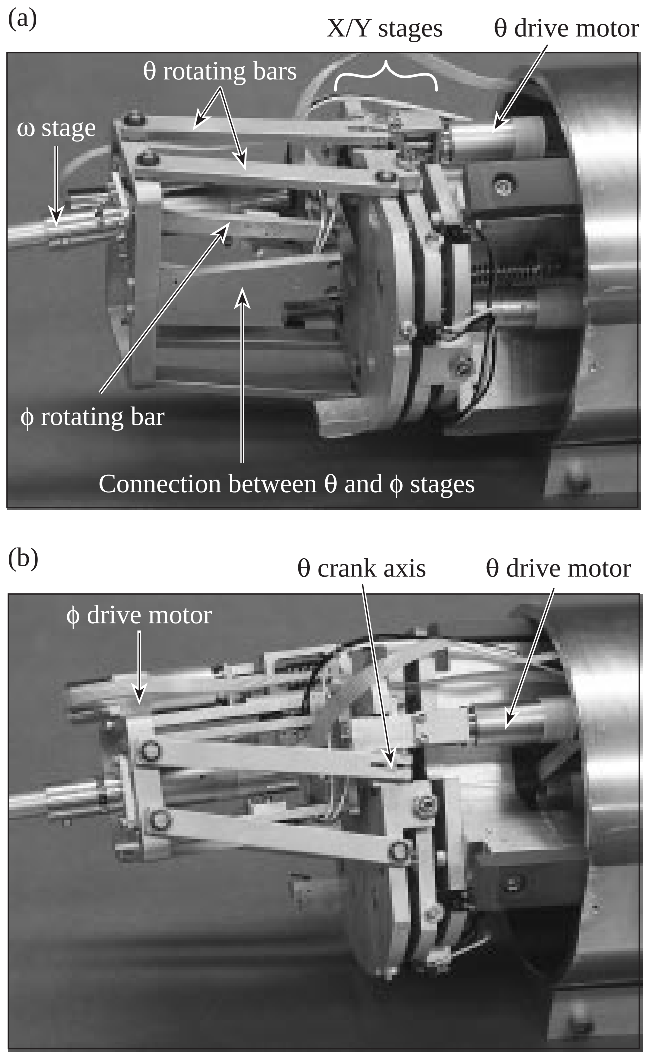


Figure 71.63
(a) θ and ϕ axial position error; (b) θ and ϕ lateral position error.



G4185

Figure 71.64
(a) θ and ϕ stages; (b) ϕ-stage drive-motor mounting.

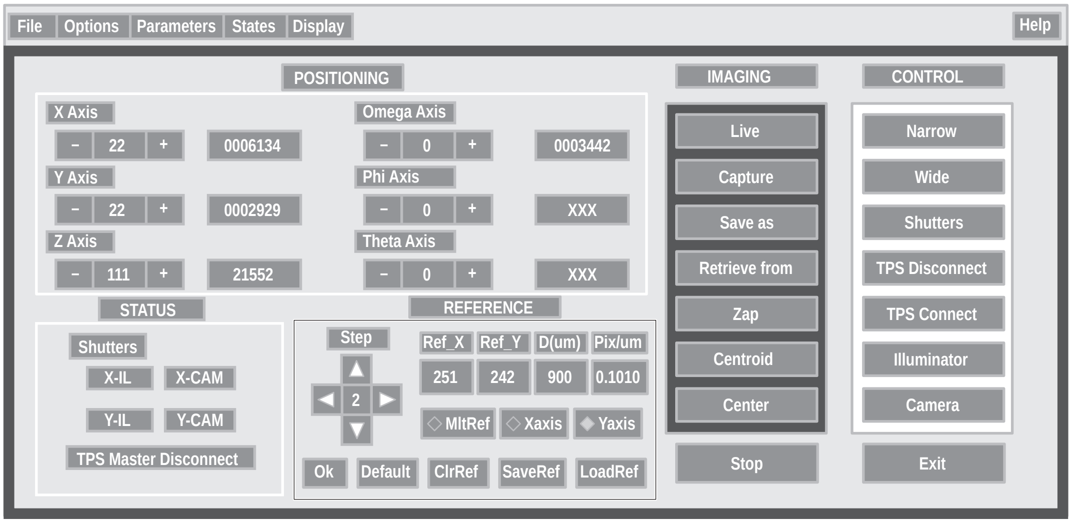
Target-Positioner Auxiliary Vacuum Controls

The primary function of the auxiliary vacuum controls is to sequence the pumps, solenoid valves, and an 8-in. gate valve such that the positioner, loaded with a target, may be inserted inside the target chamber without perturbing the chamber's high-quality vacuum condition. The process involves network communications with other auxiliary vacuum controllers to arbitrate the sharing of the roughing pump manifold resource. In addition, the auxiliary vacuum controls provide a remote control and monitor of TPS functions both in the control room and locally at the target chamber's personnel platform.

During airlock evacuation the auxiliary vacuum controls monitor a vacuum sensor to automatically sequence from rough pumping to turbo pumping operation. Once the airlock is properly evacuated and insertion has been commanded, the gate valve is opened, enabling the transport axis motion. The controls establish the "home reference position" to the transport motion axis to maintain coarse positioning accuracy to within ±0.001 in. over an 80-in. range of travel in order to arrive within the video capture range of the TVS.

Target-Positioner Precision Motion Controller

OMEGA's TPS motion controller provides the control elements for the X, Y, Z, θ, ϕ, and ω axes that provide precise alignment and rotation of the target to the center of the



X Axis – 22 + 0006134
Y Axis – 22 + 0002929
Z Axis – 111 + 21552
Omega Axis – 0 + 0003442
Phi Axis – 0 + XXX
Theta Axis – 0 + XXX

Step 2

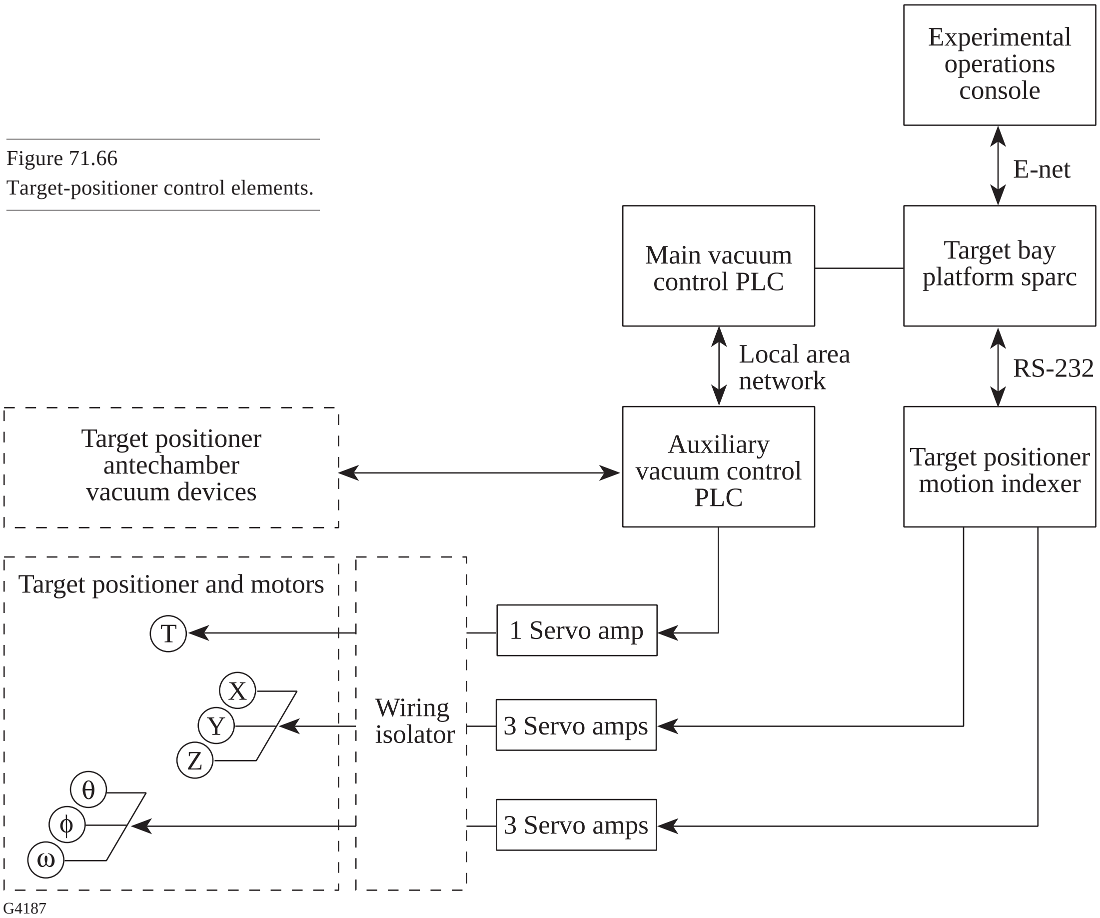
Ref_X	Ref_Y	D(um)	Pix/um
251	242	900	0.1010

◇ MltRef ◇ Xaxis ◆ Yaxis

G4186

Figure 71.65
TPS graphical user interface.

Figure 71.66
Target-positioner control elements.



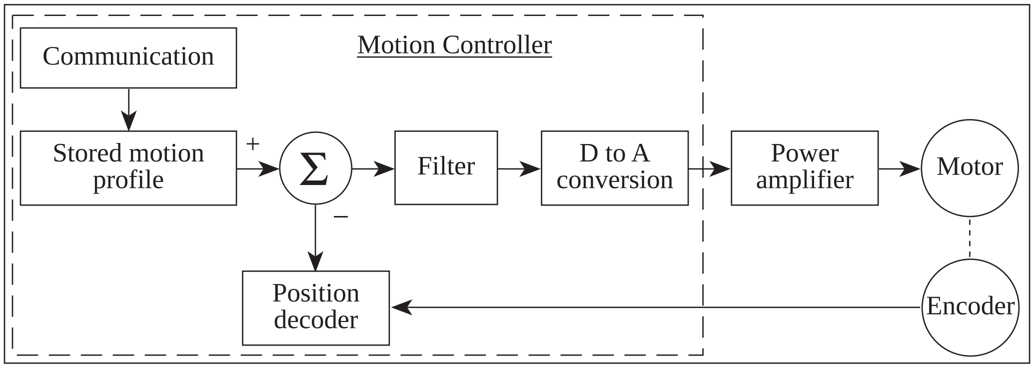
chamber. These six independent functions are provided from a commercially available unit purchased from Galil Motion Control, Inc. Motion instructions are issued via a serial data communication link from the experimental executive computer to the Galil motion controller during alignment operations. The Galil instruction set is based on an ASCII format and includes programmable variables for servo parameters such as gain, velocity, acceleration, and filter terms. These and other parameters are retained in static zero power RAM for convenience.

A motion controller is a part of a closed-loop servo system, which also includes a power amplifier, motor, and encoder. A typical closed-loop-position servo system is shown in Fig. 71.67. The controller is the element that initiates motion by generating an analog command signal that, when applied to the power amplifier, results in an electric current flowing in the motor windings. This current creates torque and subsequent mechanical motion. The encoder senses the position change in the motor and feeds this information back to the controller, which tracks the motion progress over time.

Incremental encoders operate by generating output pulses that represent the motor shaft position and include two signals that, for the case of the TPS, generate ten pulses per revolution. The two signals are displaced by 90° in phase, which enables the controller to determine the direction of rotation according to which signal leads or lags the other. Motor displacement can therefore be determined by counting the number of pulses, and the frequency of the resultant pulse train is proportional to motor velocity.

The controller performs the basic intelligent operations of the system:

- interpreting commands sent from the host computer (experimental executive) via a serial communication interface,
- generating the command signal profile,
- decoding position-feedback information into motion displacement and velocity,



E8617

Figure 71.67
Typical closed-loop-position servo system.

- closing the position loop,
- compensating the loop by filtering to achieve stability and prevent oscillation, and
- interpreting end-of-travel limit switches to prevent possible damage to the motion mechanisms.

Command Profile

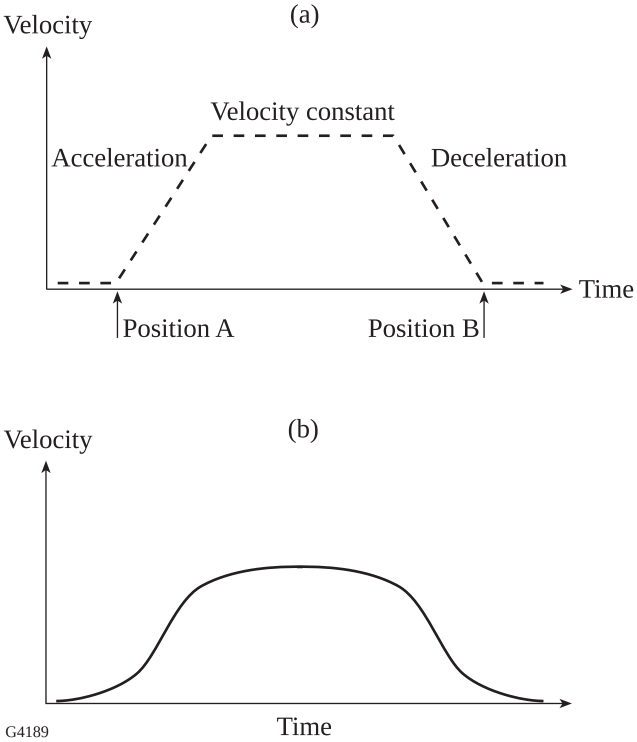
The target is suspended at the end of the target-positioner mechanism from a carbon fiber, which is several microns in diameter. The mass of the stalk is kept intentionally low, and the resultant thin structure is extremely fragile. Consequently, the controller must deliver smooth and reliable motion to minimize (lateral) forces applied to the target and its stalk during alignment procedures. Sudden TPS accelerations or decelerations must be limited to levels that ensure the stalk does not break or the target does not become dislodged from the stalk.

A “trapezoidal velocity profile” applies a linear function to the motor that provides continuous acceleration to maximum velocity and continuous deceleration to a full stop [Fig. 71.68(a)]. However, a more complex command profile known as an “S curve” [Fig. 71.68(b)] is sometimes preferred because it imparts a smoother, less-instantaneous acceleration change.

To date, the TPS controller has utilized the trapezoidal velocity profile successfully. However, should future targets or their stalks become more sensitive to acceleration forces, the controller is capable of generating S-curve velocity profiles.

Compound Coordinated Motions

The mechanical design of the ϕ and θ axes couples ϕ rotation with X and Z motions and θ rotation with Y and Z motions as discussed in a previous section. If the ϕ or θ axes are moved to the full range of motion, the target will shift outside the capture range of the TVS. For this reason a motion controller



G4189

Figure 71.68
(a) Trapezoid velocity profile; (b) S-curve velocity profile.

was selected that is capable of implementing electronic gearing where one or more axes are slaved to follow a master axis at a fixed ratio, thereby providing a motion vector.

Wiring Isolator

Early operational experience with the OMEGA target positioner confirmed that the supporting electronics systems and components were prone to damage from the laser-fusion event. During the event, laser energy is incident upon the target and the tip of the target stalk. This creates a transient high-temperature plasma comprised of charged particles, some of which recombine while others fly in all directions. The electrons, being the lightest, travel at the highest velocity to the target chamber walls. The target-positioner mechanism being the closest conductive mass near the center of the target chamber intercepts a significant portion of these charges, which can couple back into control circuitry of the TPS. The transient nature of this electrical phenomenon occurring with typically nanosecond rise times can damage semiconductor components and perturb information stored in memory devices. These effects require that the wiring and cabling in the target chamber interior be shielded from line-of-sight particles and that the remote electronics be isolated from the TPS using a disconnect switch. Just prior to the shot, relay contacts open in each of the 70+ conductors in the wiring harness to protect the control electronics. After the shot the relay is commanded closed once again, thereby enabling the TPS retrieval process.

Summary

The OMEGA target positioner has been developed to provide a means of positioning a target at the TCC and precisely aligning this target using up to 4° of freedom, X, Y, Z, and ω. A compact two-axis stage was developed to provide θ and ϕ rotation of the target, but this stage is not currently used on OMEGA.

All motions are servo controlled, and a GUI is used in the OMEGA control room to provide convenient control of the target positioner.

The OMEGA target positioner has been used to support and align a wide variety of targets in the experimental chamber including spherical implosion targets, multiple flat-foil instability targets, and hohlraums for indirect-drive experiments.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460, the University of Rochester, and the New York State Energy Research and Development Authority. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

REFERENCES

1. J. E. Shigley and C. R. Mischke, *Standard Handbook of Machine Design* (McGraw-Hill, New York, 1986).