1.B An Advanced Cryogenic Target-Positioning System

The past quarter has seen the completion of a difficult, multiyear project to provide a cryogenic (cryo) target capability for the OMEGA 24-beam irradiation facility.

Originally conceived in mid-1984, this project was to provide LLE with a cryogenic laser-fusion target capability based on the fast-refreeze technique pioneered by KMS Fusion[1] several years earlier at their own facility. The original plan was for KMS to develop a prototype system on a simulation chamber, which would be used to train LLE personnel in the operation of a cryo-target system and which then would be followed by a full system on the OMEGA tank. The simulation system, which was based on the old LLE ZETA tank, arrived at LLE in September 1986. A training session with KMS personnel followed after which it was decided to proceed directly to

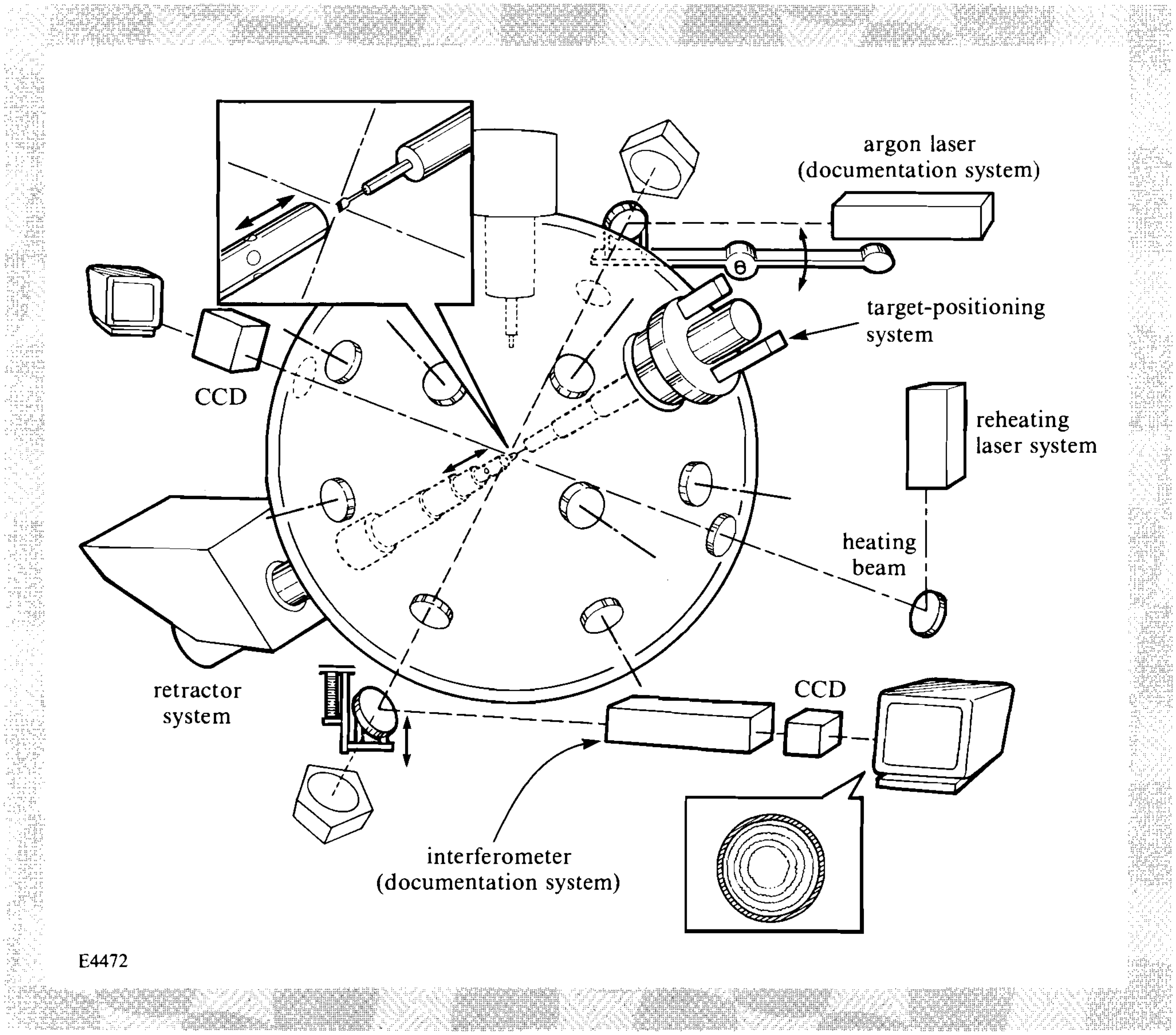

Fig. 33.8
Cryo-target subsystems on OMEGA.

the OMEGA implementation, using as much of the ZETA simulation hardware as possible. Interface hardware arrived from KMS in April 1987, and by mid-June the complete cryo system had been installed on the OMEGA tank. A number of laser shots were taken on cryo targets during the summer and early fall before it was decided to suspend cryo operations to perform a number of redesign activities. These activities substantially improved performance, and, as of this writing, more laser shots on cryogenically cooled targets are occurring. The ultimate goal is to compress a frozen pellet of DT ice to a final density of 100 times liquid hydrogen density.

There are four main parts of the cryo system. They are (1) the liquid-helium-cooled target-positioning stage; (2) the liquid-helium-cooled shroud and shroud-retractor system; (3) the reheating system; and (4) the documentation system. These subsystems are shown in Fig. 33.8 as they are arrayed on the OMEGA tank. The heart of the system is the He-cooled shroud and shroud-retraction system. In operation, the shroud, which is cooled to 16°K by liquid helium flowing through a cryostat, is also filled with cold helium gas bled off the cryostat. This cold gas is swirled around inside the shroud and around the target, refrigerating it and freezing the gas fill on the inside wall of the target balloon. The shroud, containing a stalk-mounted target, is shown in Fig. 33.9. This figure also shows the four sapphire windows inset into the gold-plated, solid-copper shroud. These four windows are for the documentation system and the heating-laser system, which will be described later. The purpose of the shroud-retraction system is to rapidly retract the shroud from around the target and leave an unobstructed path for the 24 main laser beams to be focused onto the target. Calculations and measurements of the lifetime of a solid layer of DT ice on the inside wall of a glass microballoon exposed to room temperature radiation yield times around 10 ms.[2] After 10 ms, a sufficient amount of fuel has melted and vaporized to significantly

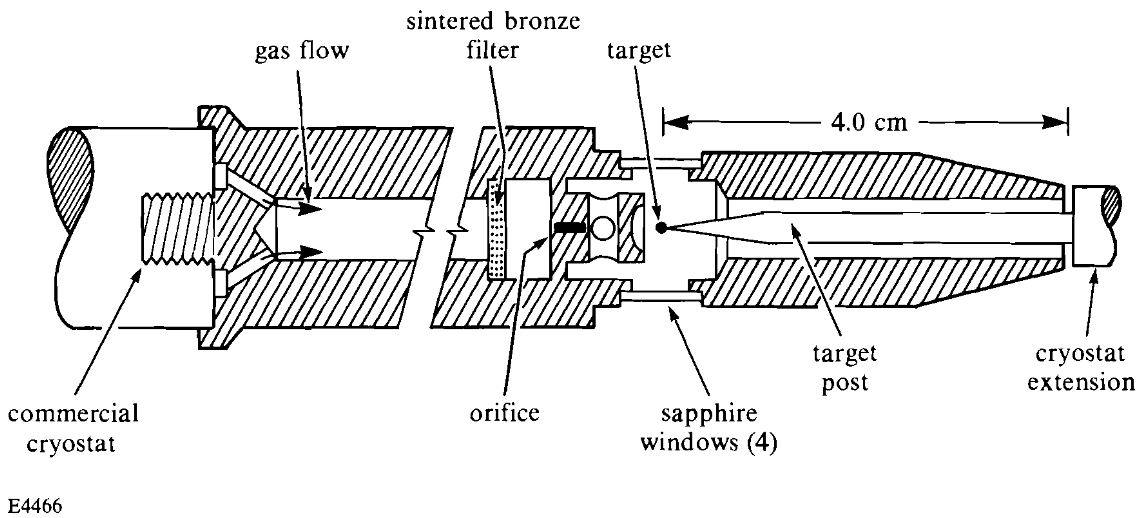

Fig. 33.9
Helium-gas shroud surrounding a cryo target.

affect the uniformity of the rest of the frozen fuel layer. In order to ensure a reasonably uniform frozen layer, exposure times—that is, the time between when the target first exits from the gas-filled shroud and the time at which the laser is fired on the target—should be much less than 10 ms. The original shroud-retraction system designed and supplied by KMS (see Fig. 33.10) used a vacuum bellows and electromagnetic release to provide the motive force for retracting the shroud. This system proved to be unreliable because the timing of the system was dependent upon the residual magnetism in the release electromagnet and was therefore prone to failure by early release.

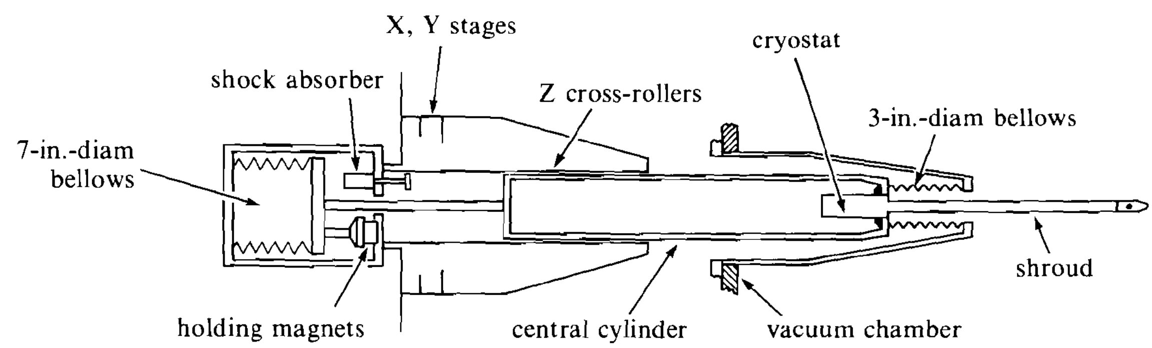

Fig. 33.10
Original shroud-retraction system showing shroud, cryostat, alignment stages, and retract mechanism.

The other major cryogenic component is the liquid-helium-cooled target positioner. While the target is cooled primarily by the cold gas from the cryo shroud mounted on the retractor, it is necessary to provide some cooling for the target mount. Because the shroud surrounds the target completely (with the exception of the four sapphire windows used for the documentation and heating systems), there is no way to view the target in two orthogonal directions for the purpose of alignment. Therefore, it was decided to align the target outside the shroud and ensure that no target motion could be induced by placing the shroud over the target. This necessitated cooling the target mount to almost the same temperature as the shroud so that all thermal contraction would have taken place before the shroud was inserted over the target.

The target positioner is unique in that it allows changing of targets between shots without breaking target-chamber vacuum. The target must be in good thermal contact with its cryostat, however, so the entire target positioner cryostat must be removed between shots. This is shown schematically in Fig. 33.11

The heart of this system is a ball-valve assembly, shown in Fig. 33.12, on the end of the re-entrant target positioner, which separates the separately pumped air lock from the main target chamber. An auxiliary vacuum system can evacuate the air lock to <1 mTorr in less than 10 min, much less than the proposed intershot time of 30 to

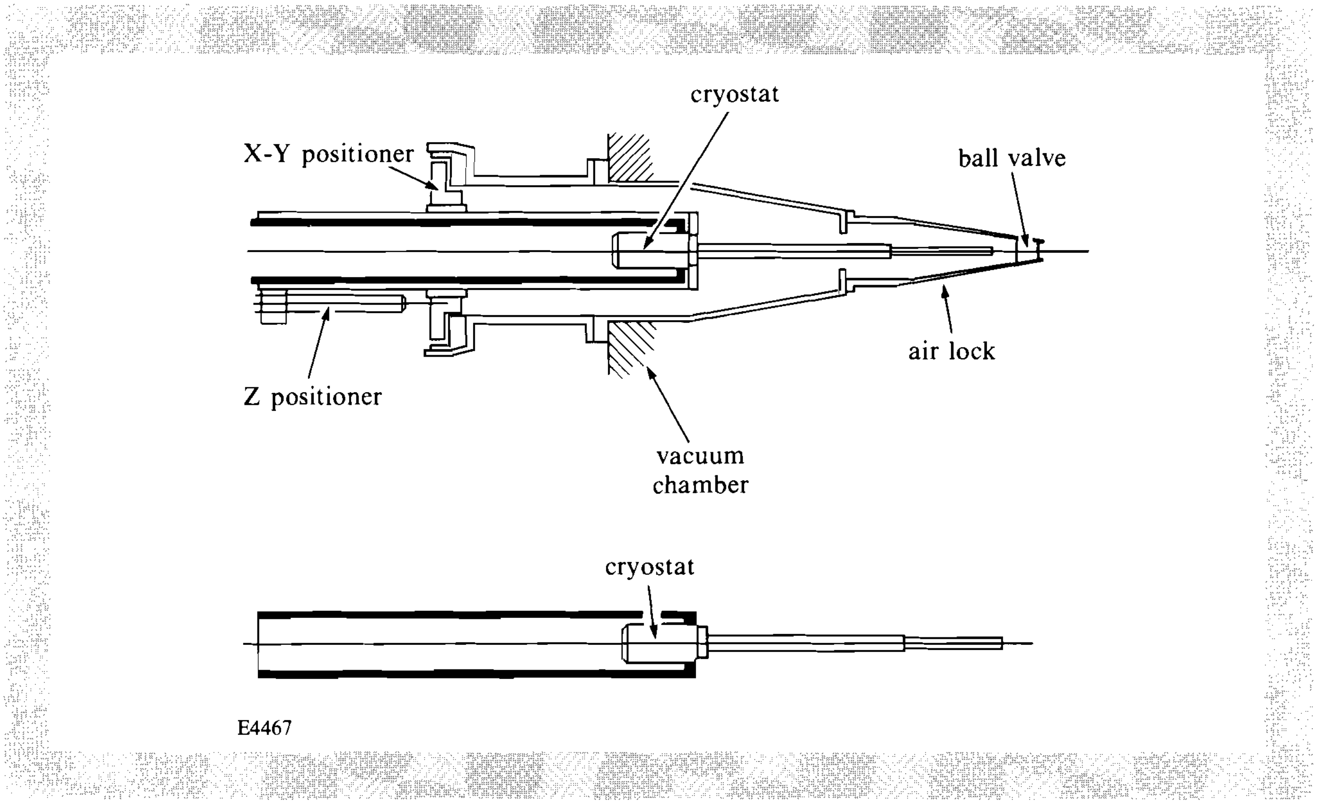

Fig. 33.11
Target-positioning system with cryostat; *X, Y, Z* stages; air lock; and ball-valve assembly.

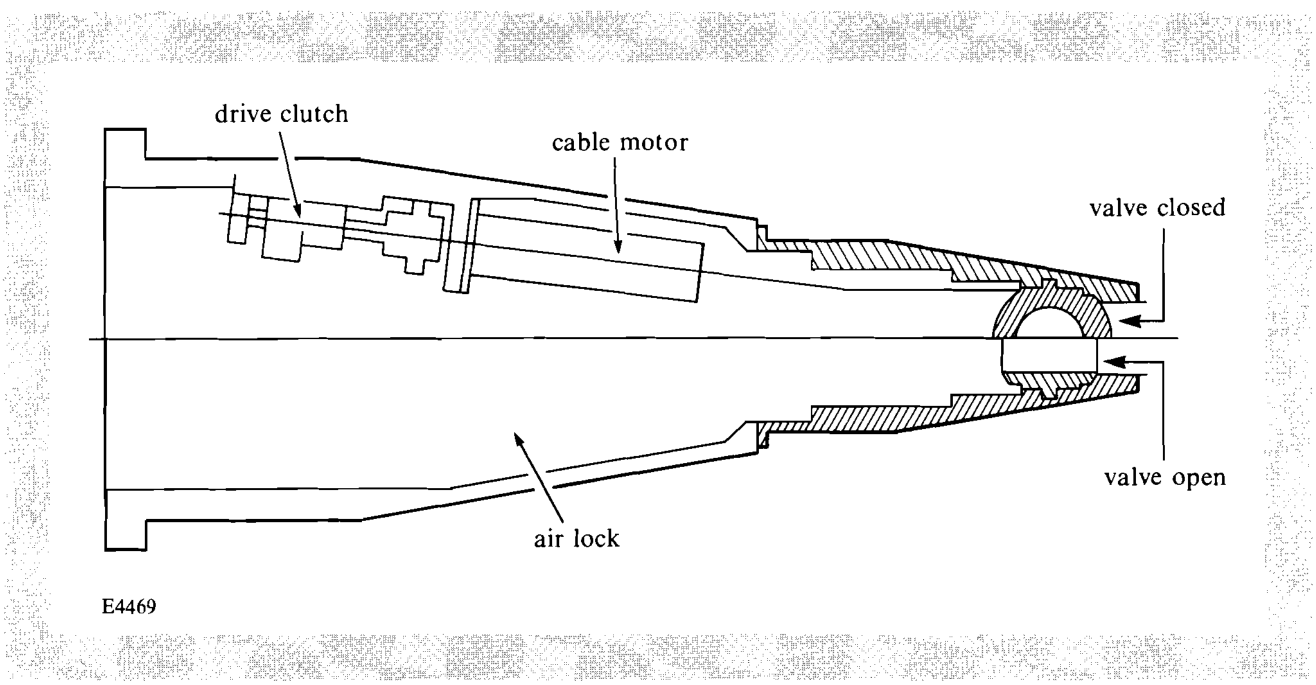

Fig. 33.12
Motor-driven ball-valve assembly, which allows interchanging targets without breaking target chamber vacuum.

45 min. The target positioning itself is done with a conventional three-axis positioning system, using computer-controlled microstepping motors to provide three uncoupled orthogonal axes of motion with 1-μm resolution and stability.

The other two major subsystems connected to the cryo-target system are the heating system and the documentation system. The heating system is a major component of the fast refreeze technique employed in this method of producing a uniform, frozen layer of DT ice on the inside wall of the target capsule. As the temperature of the microballoon is lowered slowly, the DT gas first liquefies, then forms a droplet that wets the inside wall of the balloon, and then, under the force of gravity, sags to the bottom of the balloon, where it freezes. However, if there is enough refrigeration power available to freeze the total mass of the gas on a time scale shorter than gravitationally induced sag, a uniform layer can be produced. The heating laser system attempts to do this. By focusing several watts of ultraviolet light from an argon-ion laser onto the target, it instantly evaporates the randomly frozen DT ice layer. If sufficient refrigeration is available, the ice layer will reform in a time short enough to preclude any gravitational sag and will produce a uniform, frozen layer. The purpose of the documentation system is to assure that a sufficiently uniform layer is produced.

The documentation system consists of a laser illuminator, an imaging system, an interferometer, and some method of recording and viewing the resulting interferogram. The block diagram for this system is shown in Fig. 33.13. This is a shearing-cube interferometer similar in design to the one originally used by KMS[3] but adapted to work at the longer distances imposed by the OMEGA tank dimensions. In the case of OMEGA, two opposing focusing lenses are used to illuminate the target and to image the target into the shearing cube. This means that flip-in mirrors must be used to first direct the light from the laser to the interferometer; then, a few seconds before the main laser is to be fired – after it is assured that the layer is going to remain frozen – these mirrors must retract out of the way of the main laser beams.

One of the major problems encountered during this project was the design of a nearly massless target mount. The KMS design of the gas shroud was based on the use of cylindrically symmetric stalk-mounted targets. In KMS experiments, carried out on CHROMA, the targets were mounted on thick glass or metal stalks.[4] To achieve the highest possible target performance, a very low mass target mount was needed. It was therefore decided to use a target mount that suspended a target on two or more short lengths of spider silk. Several early designs showed promise. The easiest to fabricate was a U-shaped piece of thin wire glued to a glass stalk, with spider silks stretched across the open top of the *U* and the target mounted in the center of the *U*. This worked well in tests of the shroud-retractor system, without cooling, but when the cold helium gas was allowed to cool the stalk and wire assembly, differential thermal contraction caused the assembly to twist and move the target out of the desired targeting point. Several attempts at isothermal designs were tried until the

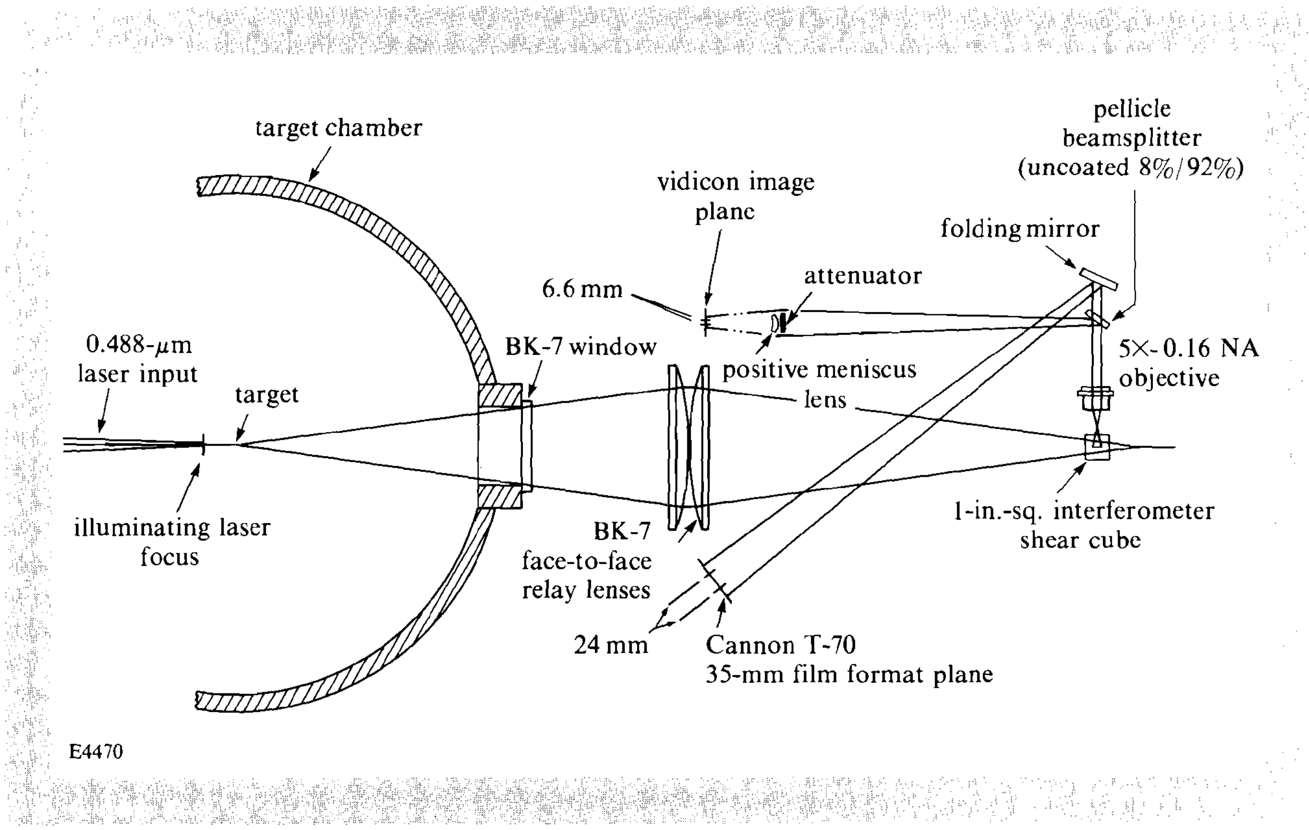

Fig. 33.13
Interferometer, as installed on the OMEGA target chamber.

design shown in Fig. 33.14 was invented. This could easily be made by photolithography and offered the advantage of a cheap, throwaway target mount. This type of target mount performed well thermally but exhibited small amplitude vibration during retraction. The shroud is normally pressurized to about 3 mTorr and is sealed at its open end by pressing against a stack of Mylar washers attached to the face of the target positioner cryostat extension (see Fig. 33.9). When the retraction begins, the gas starts to flow out through this annulus. In doing so, it causes very small amplitude flutter vibrations in the thin-copper target mount. These vibrations are soon coupled into the target-web system, setting up rather large ($>$100-μm) amplitude oscillations at frequencies $>$100 KHz. These problems were successfully diagnosed with a combination of high-speed multiframe photography, using a rotating drum camera, and single-frame photography, using a short-duration, high-power flash to illuminate the target as soon as it emerged from the shroud.

A potential solution to all of these problems is a new mount, which is currently under study. This is also an all-copper mount, soldered together using an indium/tin alloy solder but with a much thicker stem, to avoid the problems of aerodynamic movement. Tests on this mount will be conducted by the end of this quarter and cryo-target experiments, using this target mount, will begin shortly after the new year.

The most extensive redesign of the KMS-supplied equipment was in the retractor and retractor mount. As was mentioned earlier, problems

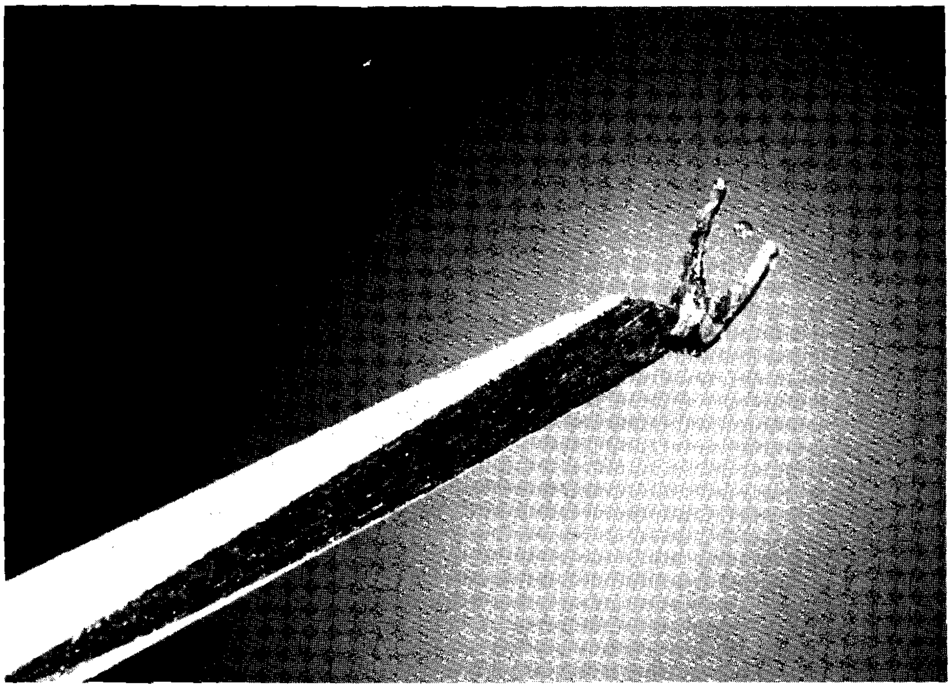

Fig. 33.14
Cryo target mounted on spider silks on thermally stable, photolithographically produced target mount.

arose early, with timing jitter and velocity uncertainty of the retractor. It was decided to replace the vacuum-powered retractor with a linear electric motor having a specification of 500 lb of pulling force and an acceleration of 10.6 g. Controlled deceleration was also specified, to minimize the impulse delivered to the mounting structure. The motor was to accelerate to maximum velocity for a distance of about 5 cm and then decelerate to zero velocity in an additional 5 cm. These specifications ensured that the shroud would be retracted to the fully clear position in less than 40 ms, resulting in a target exposure to 300°K radiation for about 4.8 ms. The motor also has an absolute positioning capability, which greatly speeds the insertion and positioning of the shroud over the target. The motor is completely computer controlled, with a standard serial interface providing the programming and hardware controls for commanding the retraction to begin. This motor was procured from Anorad[5] in slightly more than a month. New mounts were built to adapt the motor to the retractor and to the turning mirror structure. In slightly more than seven weeks after the decision to redesign, the new motor was installed and tested. It met or exceeded all specifications. LLE now has a retractor system capable of controlled, measured retractions that may lead to studies of targets in various phases of thawing. This system may be one way to achieve liquid-layer targets with a controlled amount of gas pressure in the void.

After only six months of operation, the cryo-target fabrication and positioning system has already begun to yield results in the LLE campaign to achieve high density with direct drive. Results from this campaign will be reported in a future LLE Review.

ACKNOWLEDGMENT

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