S-AA-M-12

OMEGA
System Operations Manual
Volume I–System Description

Chapter 3: Laser Amplifiers

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Chapter 3
Laser Amplifiers

3.0 INTRODUCTION

The power amplifier section of the upgraded OMEGA laser has a 6.4-cm input aperture and a 20-cm output aperture. The output aperture of the final amplifier was established by the number of beams, the total energy requirement, and the damage thresholds of the available optical coatings. The staging, shown in Fig. 3.0-1, comprises four stages (A–D) of rod amplifiers and two stages (E and F) of disk amplifiers, all separated by spatial filters. The final aperture of the beam is increased to 28 cm to reduce the fluence on the ultraviolet (UV) transport optics.

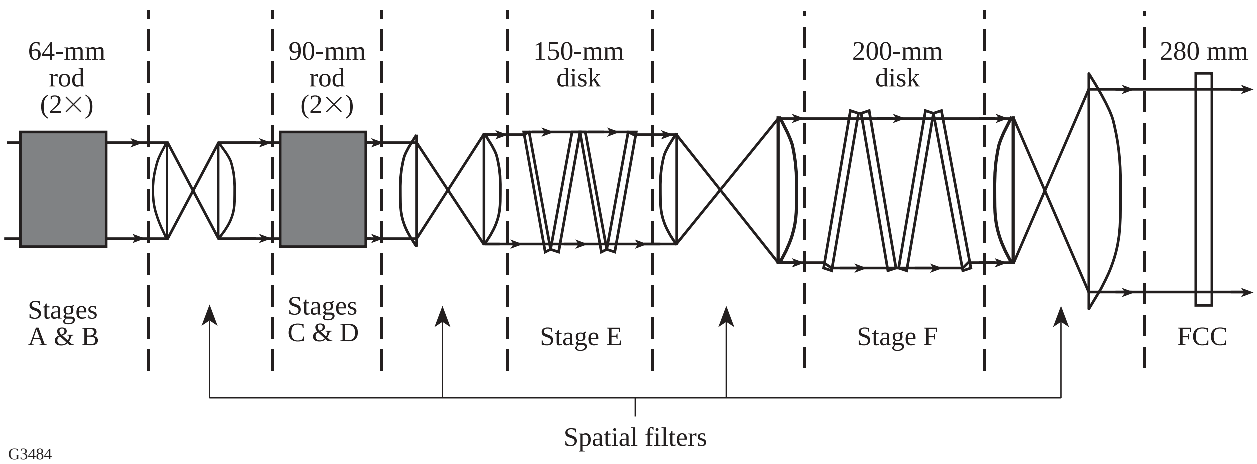

Fig. 3.0-1
The amplifier staging of the upgraded OMEGA laser consists of four stages of rod amplifiers and two stages of disk amplifiers. The early stages compensate for the 1:60 splitting; the last three stages provide ~97% of the beamline energy.

The stage A–D amplifiers are conventional flash-lamp pump units used on the original OMEGA, and the disk amplifiers are of conventional box geometry[1,2] utilizing a 15-cm aperture at stage E followed by a 20-cm aperture at stage F. Each amplifier contains four Nd:glass laser disks. The disk amplifiers use water-cooled flash lamps that facilitate operation at a high storage efficiency. Both amplifier stages utilize the same power-conditioning and pulse-forming network. The cooling times for the disk amplifiers are sufficiently short to permit a 1-h shot cycle. The modular nature of the design allows for the rapid change of flash-lamp pump modules within this shot cycle.

3.1 AMPLIFIER STAGING

The final aperture of OMEGA was determined by the decision to use 60 beams (for high irradiation uniformity) and the requirement for 30 kJ of UV energy on the target. The IR beam size was set by the damage threshold of the sol-gel coating on the input lens of the final spatial filter. The OMEGA laser has a final (amplifier) infrared (IR) aperture of 20 cm.

Rod Amplifier Staging

The rod amplifier staging design was dictated by the energy needed to compensate for the beam splitting required to generate 60 beams from a single driver line and, as with other designs, by budgetary considerations. The splitting, performed in steps of 3×, 5×, and 4× (actually two steps of 2×), in that order, was chosen (instead of say 10× and 6×) because high-quality polarizer/splitter elements using thin-film technology may be used when the split is less than 6×. This particular ordering was chosen because it produced a system configuration that fits inside the existing LLE laser bay. In addition, the splitting matches the saturated gain of the rod amplifiers to the energy partition. For example, the saturated gain of the rod amplifiers minus the losses in the beamline's applicable segment nearly equals the split multiple. This holds for the five-way split before stageB (6 cm) and the four -way split before stage D (9 cm). The three-way split was placed first because it minimizes the total number of rod amplifiers needed.

Power Amplifier Staging

The final three amplifiers—a 9-cm rod, a 15-cm Brewster-disk amplifier, and a 20-cm disk amplifier—produce ~97% of the IR energy in each beamline. The area ratios of the last stages are 1:2.78:5, a standard, short-pulse staging configuration entirely appropriate for OMEGA's main-pulse performance.

Spatial Filters

The B-integral is a measure of the phase retardation accumulated as a beam propagates through a medium possessing a nonlinear index of refraction. This phase retardation can cause self-focusing of optical noise in the beam, creating intensity modulations that can result in severe damage to a laser system. Spatial filtering removes these intensity modulations and essentially resets the wavefront distortion to an acceptable level. The laser designer is therefore concerned with the phase retardation accumulated between spatial filters, termed Delta B (ΔB), which is typically kept below 2 rad. Moreover, practical constraints prohibit the complete elimination of phase retardation by the spatial filters. The resulting accumulation of residual retardation is termed Sigma B (ΣB). The effect of ΣB on laser performance is a complicated function of spatial frequencies and the estimates of optical noise in the system. OMEGA has an overall ΣB of 4.5rad. No single stage has a ΔB greater that 1.4 rad.

As is typical of a medium-pulse-width (~1-ns) laser, the system performance is limited by damage fluence rather than by B-integral effects. It is expected that if ΔB rose to 2 rad, the nominal laser obscuration fractions (i.e., dirt) would yield a maximum spatial modulation of 1.8:1. Subsequent modeling has confirmed this expectation. All system fluences have been chosen such that the optical coatings can survive localized spikes in laser fluence 1.8 times higher than the average beam fluence. Recent experimental results indicate that if high cleanliness is maintained in the system, the 1.8:1 modulation is, indeed, conservative.

3.2 ROD AMPLIFIERS

The ninety-four 64-mm and 90-mm rod amplifiers needed for the upgraded OMEGA laser system are fabricated from a design that reuses parts of the 54 amplifiers from the original OMEGA system. Refinements to the original design have been implemented as a result of 12 years of experience using these amplifiers and are aimed at improving performance, serviceability, and conformity to the rest of the system. The rod amplifier assembly, shown in Fig. 3.2-1, consists of a frame, a rod module, a pump module, and the various electrical and coolant connections.

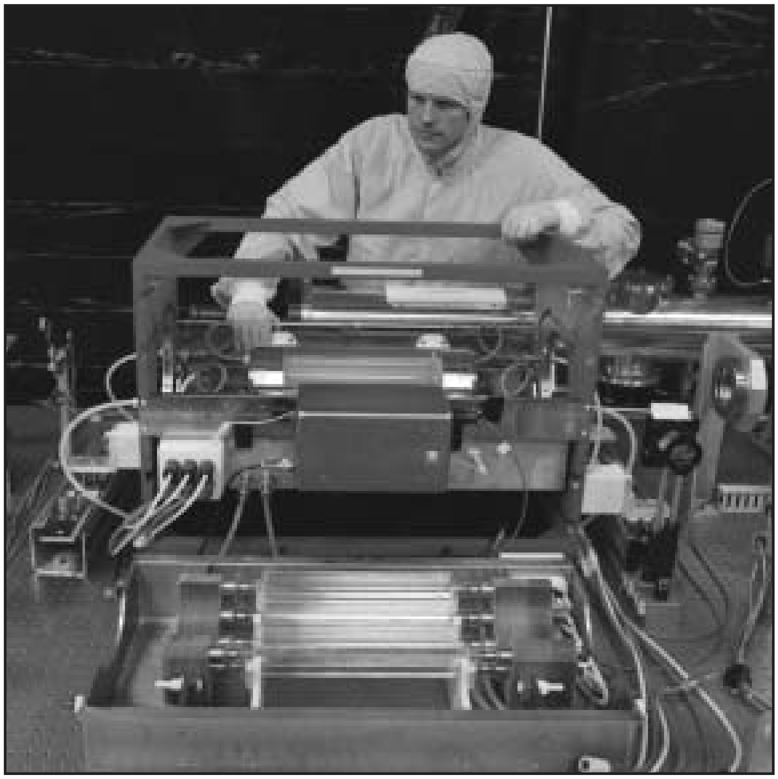

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Fig. 3.2-1
The OMEGA rod amplifier. The pump modules (top and bottom) are open, showing the flash-lamp assemblies.

Rod Amplifier Structures

The stage-A rod amplifiers are supported in individual pedestal-style structures, with a box covering. These units were used in the original 24-beam OMEGA laser. The stage-B, -C, and -D rod amplifiers are supported in rigid box-beam structures with X-bracing that stack the amplifiers five-high. The stage-B and -C structures, shown in Fig. 3.2-2, are identical and hold five amplifiers each in a single vertical column. The stage-D amplifier structure (Fig. 3.2-3) holds ten amplifiers in a five-high by two-wide "cluster" configuration. Electrical and coolant services run up into the structures through openings in the laser bay floor. Coolant manifolds and amplifier facility controllers (AFC's) are located at the base of the structures. High-voltage cabling from the power conditioning to the flash lamps and plumbing is routed along the structural support members. Within the structure each amplifier is supported by a structure-to-device interface package (SDIP) that provides for horizontal/vertical alignment adjustment and electrical isolation.

Rod Amplifier Frame

The rod amplifier frame is unchanged from the original OMEGA design. It is simply a welded/painted aluminum frame that holds the rod module and pump modules together rigidly and allows the unit to be serviced. The frame is designed to remain in place and aligned during change-out of either the rod module or the pump modules.

Rod Module

The rod module consists of a laser rod (64-mm or 90-mm diameter), two precision-machined stainless steel yokes and plenums, and a Pyrex coolant jacket, all held together with two spacer bars. The yokes and plenum serve the dual purpose of holding and sealing the laser rod with an O-ring and providing for the uniform flow of deionized (DI) water/ethylene glycol coolant around the laser rod.

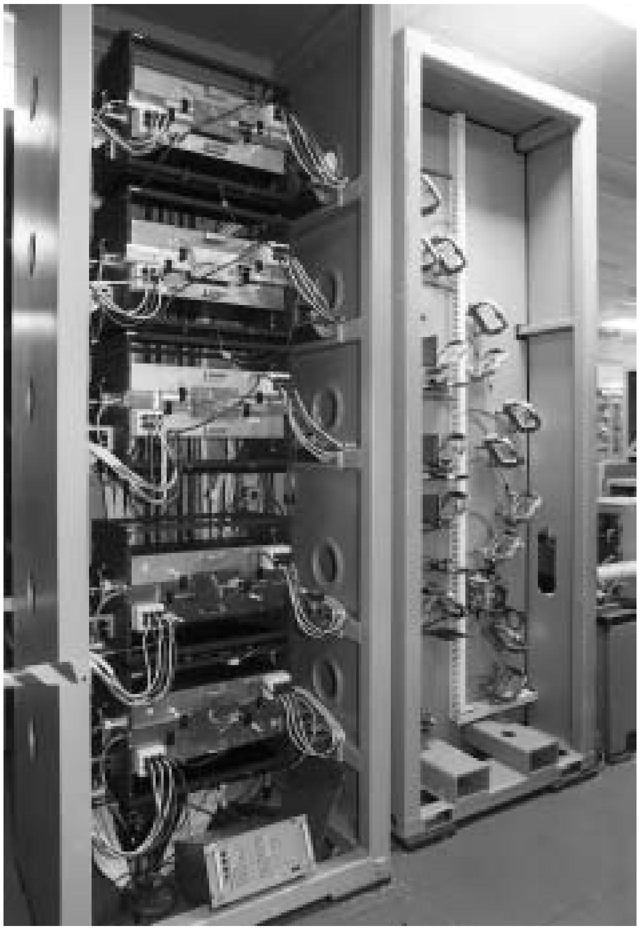
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Fig. 3.2-2
The five-level, stage-B amplifier structure, shown with amplifiers installed. (The B-split structure is on the right.)

Fig. 3.2-3
The five-level, stage-D amplifier structure supports ten 90-mm rod amplifiers.

The original OMEGA rod module was redesigned to reduce the number of parts in order to cut cost and improve coolant flow and serviceability. The material used for all parts was selected for high resistance to corrosion by the DI water/glycol solution used to cool the rods. The flow pattern for this coolant is designed for uniform heat extraction, thereby reducing thermal-stress-induced birefringence in the rod. The plenum is also designed to provide the O-rings with maximum protection from direct flash-lamp radiation.

The Nd-doped phosphate glass laser rods (64-mm and 90-mm diameter) are 370mm in length to accommodate the improved O-ring seals and provide some margin for future refinishing of damaged ends. The rods have a 6° angle on the faces, and the 64-mm rod faces are parallel. It was found, however, that if the ends of the 90-mm rods were made parallel, an internal, end-to-end reflection would propagate unwanted energy just outside the laser aperture. To inhibit this reflection, the 90-mm rods are finished with a 0.6-mrad wedge that prevents retroreflection within the rod. The rod module assembly is designed to allow for off-line rotational alignment of the rod in the module. Thus, a complete module can be built and easily installed in a rod frame with little or no realignment in the beamline.

Pump Module

Each rod amplifier has two pump modules consisting of a rigid aluminum external shell containing six flash lamps and a reflector. The pump-module design maintains the original OMEGA philosophy of being capable of a complete replacement between shots (≤30 min) if a failure occurs. A new reflector configuration has been implemented to improve the cavity transfer efficiency of the rod amplifiers. It is a simple searchlight reflector geometry designed using the ZAP Monte Carlo ray-trace code.[3] Prototype testing of this module demonstrated the achievement of the increased performance required to overcome absorption losses due to increased ionic platinum in the laser glass. The rod amplifiers use 19-mm bore, 305-mm (12-in.) arc length, 300-Torr xenon flash lamp, and the same connectors used on the disk-amplifier pump modules. The flash-lamp assemblies have been designed to also incorporate a mounting/ connecting configuration similar to the disk-amplifier bricks. The high-voltage connectors for the amplifier are to be identical to the ones used for the disk amplifiers.

Rod Amplifier Basic Maintenance

The basic maintenance plan for the rod amplifiers includes periodic visual inspection of the laser rod, checking for O-ring leakage, and flash-lamp performance monitoring. Maintenance of the rod module will occur every 400 shots and will include cleaning and mapping of the rod faces, checking/ replacing O-rings, cleaning the rod jacket, and checking the rotational alignment of the rod. Maintenance of the pump module, which will occur only when a flash lamp fails, includes cleaning the reflector, checking both electrical lines and connections, and plumbing lines and connections.

3.3 DISK AMPLIFIERS

The amplifiers for stages E and F are modern, 15- and 20-cm-clear-aperture, Nd:glass Brewster-disk amplifiers. The amplifiers are termed modern because they incorporate several unique features as well as a number of improvements suggested by others[4] who have extensive experience in building disk amplifiers. These improvements include minimization of total amplifier volume[5] for better coupling of pump light to the laser glass, transversely pumped rectangular design to avoid obscuration of flash lamps by disk supports,[6] water-cooled flash lamps,[7] and polymerically bonded edge cladding.[8]

Each amplifier contains four Nd:phosphate glass (3-wt% doping), 3-cm-thick disks.[9] The number of disks was chosen to obtain adequate gain using the 3-cm-thick disks—a thickness chosen to minimize the B-integral. The pump pulse width was then optimized [$3\sqrt{LC} = 550\,\mu s$, where L and C are the pulse-forming-network (PFN) inductance and capacitance values, respectively] for high gain per unit path in the disks. Pump radiation is supplied by water-cooled xenon flash lamps mounted on either side of the cavity.

Because of the relatively short (~1-ns) pulse, an optimization of focusable power per amplifier dollar was more appropriate than total stored energy per amplifier dollar. The results of this design optimization, plus a wavefront budget analysis for the system, yielded optical requirements for the 20- and 15-cm amplifiers that are summarized in Table 3.3-1.

These requirements impose constraints on the mechanical and electrical design of the amplifier. As an example, the gain requirement results in pump-light fluences capable of incinerating any contamination within the amplifier. Since this could result in possible damage to the laser disks, high levels of cleanliness are required. These constraints are summarized in Tables 3.3-2 and 3.3-3.

Table 3.3-1
Amplifier Performance Optical Requirements

Clear aperture (cm)	15	20
Number of disks per amplifier	4	4
Thickness per disk (cm)	3.0	3.0
First-photon center-line gain	4.2	3.0
Gain uniformity across aperture	±10%	±10%
Average stored-energy density (J/cm^3) (assuming a stimulated emission cross section of 3.5×10^{-20} cm^2)	0.54	0.41
Cavity transfer efficiency	>1.14%	>1.14%
Nd_2O_3 doping (wt%)	3.0	3.0
$3\sqrt{LC}$ pump-pulse width (µs)	550	550
Passive transmission	>96%	>96%
Wavefront, waves rms at 1054 nm	1	1
Repetition rate (shots per hour)	1	1

Table 3.3-2
Mechanical Requirements

- Only organics that can survive intense UV irradiation
- Disk cavity isolated from the external environment
- Nitrogen purge for disk and pump cavities
- Maintainable on a 1-h shot cycle
- Class-100 compatibility a minimum, Class-10 a goal (permissible cleaning techniques, ultrasonic bath, high-pressure Freon or water spray, solvent wipe)

Table 3.3-3
Electrical Requirements

- Negligible contribution to 120-mΩ resistance budget of pulse-forming networks
- Materials compatible with deionized (18 MΩ•cm) water
- 40-kV dc standoff
- Electrically insulated in case of fault
- Provide ground plane for flash lamps

A consistent and well-reasoned design philosophy is essential to meet all performance requirements and maintain safe design. To effect this, the philosophy addresses three aspects of the design: reliability, maintainability, and producibility.

The amplifiers have been designed for a 15-year, 20,000-shot lifetime. Reliability is driven by a number of factors such as system lifetime, maintenance intervals, and gain stability. Assuming one of the 120 disk amplifiers is maintained each week, the maintenance interval will be approximately 2.5 years. The degradation of the amplifier optical performance during this interval must be minimal.

Maintenance of the disk amplifiers has been approached in three ways: First, the amplifier must require minimal maintenance. Second, the most probable maintenance tasks (e.g.,flash-lamp replacement) must be performed in place and be completed within a 60-min shot cycle. To facilitate this, the tools required must be minimal. Amplifiers are removed only for full maintenance or catastrophic failure. Third, repairs on subassemblies are conducted off-line, i.e., new assemblies are swapped in and the old ones repaired off-line.

To ensure the amplifiers are produced in a cost-effective manner, considerable manufacturing engineering has been incorporated into the amplifier design. Conventional manufacturing methods that permit mass production have been used in addition to purchased parts whenever possible.

The 15- and 20-cm amplifiers consist of four major subassemblies: pump modules, flash-lamp bricks, disk-frame assemblies, and the amplifier frame assembly. The 20-cm disk amplifier is depicted in Fig. 3.3-1 and the 15-cm disk amplifier in Fig. 3.3-2. The amplifier frame supports the various subassemblies. Hinged to the side of the frame are the pump modules that house the flash lamps and serve as the outer face of the optical cavity. The laser glass disks are mounted in disk frame assemblies within the amplifier frame.

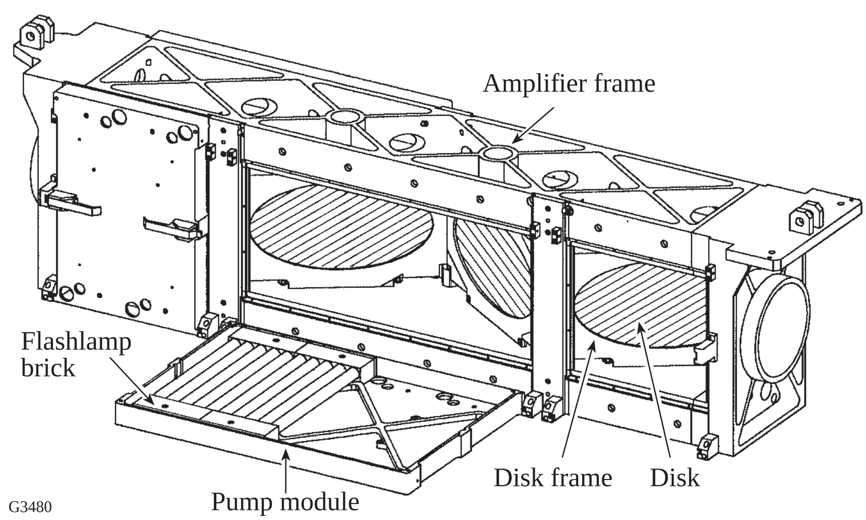

Fig. 3.3-1
The major components of the 20-cm disk amplifiers. The 15-cm disk amplifier is smaller but has longitudinal flash lamps rather than transverse.

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Fig. 3.3-2
The 15-cm disk amplifier has 132-cm-long longitudinal flash lamps, each equivalent in arc length to a five-lamp brick used on the 20-cm disk amplifier.

Amplifier Frame Assembly

The frame assembly consists of seven major components that form the structural backbone of the amplifier. All components are machined from solid pieces of 6061-T6 aluminum, stress relieved and electroless nickel plated. The plating prevents oxidation and seals the exposed surfaces for operation in a class-100 clean area.

The amplifier frame design is nearly identical (except for scale) for the 15- and 20-cm amplifiers. The disk frame assemblies kinematically mount within the frame assembly to avoid inducing stresses in the disk. The pump modules are held flush against the frame by spring-loaded hinges to minimize light leaks. Inside the frame the top, bottom, and ends of the optical cavity are constructed of separate, highly polished, silver-plated reflectors to maximize cavity transfer efficiency. The pump modules form the sides of the cavity and are separated from the laser glass by 6-mm-thick blast windows.

Blast windows serve three functions in the amplifier design: First, they isolate the class-100 interior from the class-1000 laser bay environment when the amplifier is opened for servicing. Second, the blast windows stop flash-lamp-generated acoustic disturbances that would degrade the transmitted-wavefront quality. Third, they prevent laser disk damage in the event of an explosive failure of a flash-lamp brick assembly.

Mounted on each end of the amplifier frame is an optical-quality fused-silica window that is antireflection coated with an ammonia-hardened sol-gel. These windows are plane parallel and mounted at a 6° angle to the beam. The windows serve to keep the laser glass free from contamination and to reduce the required nitrogen flow through the amplifiers.

Pump Module Assemblies

The pump modules containing the flash-lamp bricks and reflectors have been specifically designed to permit *in-situ* replacement of flash-lamp brick assemblies. A novel mechanical design with quick-release electrical and coolant connectors allows the replacement of a flash-lamp brick within a 1-h shot cycle.

To maximize the cavity transfer efficiency, the pump modules contain a highly polished, silver-plated, flat reflector placed within 1 mm of the flash-lamp water jacket. The proximity of this reflector provides the electrical ground plane essential for flash-lamp triggering. To prevent degradation of the silver surfaces, the pump modules are kept in a slightly pressured (<1-psi) nitrogen environment. As a secondary feature, the nitrogen environment reduces acoustic noise generation from the absorption of the lamp light in Schumann-Runge bands in oxygen between 175 and 195 nm.[10]

Flash-Lamp Brick Assembly

The 15-cm and 20-cm disk amplifiers are pumped by (12) 132-cm-arc-length (52 in.) and (80) 25-cm-arc-length (10 in.), 19-mm-bore, water-cooled xenon flash lamps, respectively. The flash lamps are mounted on 34-mm centers for a packing fraction of 1.75. The flash-lamp bricks are driven by (12) or (16) 19-kJ pulse-forming networks (PFN's) for the 15-cm and 20-cm disk amplifiers, respectively. This results in total bank energies of 227 and 300kJ at nominal bank voltage with the lamps operating at a 26% explosion fraction. These bank energies are based on 1.14% cavity transfer efficiency. The pulsed-power system also includes a pre-ionization and lamp check (PILC).[11] (See Chap. 4.)

The flash-lamp brick assembly consists of a flash lamp or group of flash lamps, their water jackets, the electrical connections, and water connections. For the 15-cm amplifier a brick consists of a single flash-lamp assembly. Five flash-lamp assemblies are used in a brick for the 20-cm amplifier. In both cases, the total flash-lamp arc length is about 132 cm. The five flash-lamp assemblies are connected in series electrically and for coolant flow.

The flash lamps are cooled with deionized (DI) water, which has a number of advantages. The DI water used in the closed-loop cooling system has a resistivity of 10 to 18 MΩ•cm. At this resistivity level the DI water serves as an electrical insulator.[12] Water cooling has been demonstrated to improve flash-lamp reliability, especially when lamps are operated at higher fractions (20%–35%) of explosion energies. As opposed to air-cooled flash lamps that fail in an explosive manner depositing glass and metallic debris over a large area, water-cooled flash lamps fail in a noncatastrophic manner by simply filling with water. A catastrophic failure that generates debris is not acceptable for amplifiers operating in a class-100 environment.

Each flash-lamp assembly consists of a flash lamp, a water jacket, and two flash-lamp connectors. The flash-lamp assemblies are 300-Torr xenon flash lamps of either 132-cm or 25-cm arc length. To reduce UV emission, the flash-lamp envelopes (22-mm-diam. × 1.5-mm-wall-thickness tubes) are made of cerium-doped quartz (CDQ). Because metallic ions are highly soluble in DI water, the flash-lamp lugs are passivated 316 stainless steel. In addition, all components of the flash-lamp connector directly exposed to DI water are made of 316 stainless steel. The remaining components of the flash-lamp connector are made of 20%-glass-reinforced Ultem[13] to provide electrical insulation. The water jackets are made from 27-mm × 1.5-mm Corning[14] 7740 Pyrex tubing.

Disk Frame Assemblies

Except for scale, the disk frames of the 15- and 20-cm amplifiers are identical. Each assembly has two pieces (frame and cover) machined from solid plates of 6061-T6 aluminum, stress relieved and silver plated. Care is taken to center the laser disks within the frame and to ensure a 5.1-psi, "continuous" elliptical ring contact on the laser glass surface. The metal-to-glass contact area never overlaps the laser glass to cladding glass bond line. Modeling of this design has shown that the induced Hertzian stresses[15] decay outside the disk's clear aperture.

Disk Amplifier Support Structures

The 15-cm and the 20-cm disk amplifiers are supported in groups of 30 each on the disk amplifier support structures, as shown in Fig. 3.3-3. Each of these four structures supports three ten-beam clusters of disk amplifiers. The cluster structures are connected by the rail system of the overhead service crane. There are six swinging door assemblies that can move one to five amplifiers at a time for installation/removal, inspection, or flash-lamp replacement. The door can lift one or more amplifiers off their

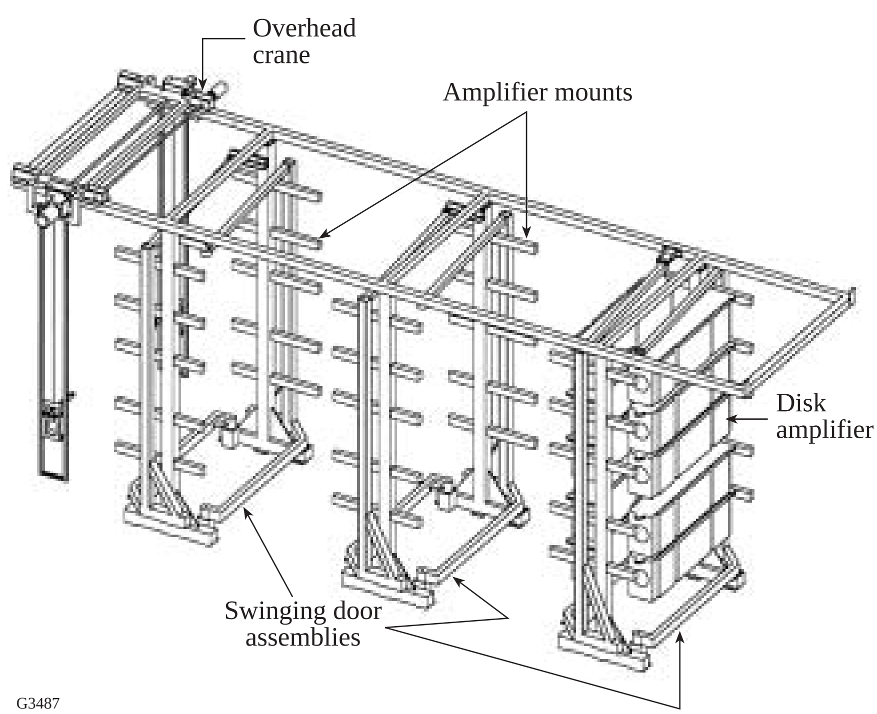

Fig. 3.3-3
One of the four structures that support the Stage-E and Stage-F disk amplifiers. Each structure has six doors, each of which can swing out any or all of the associated five amplifiers. A crane on each structure can lower an amplifier to floor level to facilitate routine maintenance.

SDIP's, swing them away from the structure, and allow for inspection of the inside flash-lamp bricks. Amplifiers are installed/removed from the structure using the overhead crane. Amplifiers are transported to and from structures and amplifier assembly areas (AAA's) using die carts.

Parasitic Oscillations in the 15-cm SSA's

The gain provided by any laser amplifier is ultimately limited by either amplified spontaneous emission or parasitic oscillations.

Whenever the inverted population necessary for lasing is produced, a certain number of the excited molecules (Nd^{+3} ions in our case) revert spontaneously to lower energy states, emitting photons in the process. These can stimulate the emission of other photons and lead to amplified spontaneous emission (ASE). At sufficiently high inversion levels, the rate at which ASE depletes the inversion can match the pumping rate. Under these conditions, no further gain increases can be obtained by means such as increasing the PFN voltages.

Parasitic oscillation occurs when the gain in the medium is sufficient to amplify the reflections from any suitably aligned nearby surfaces. In severe cases, this unintended oscillation can prevent an amplifier from reaching the gain for which it was designed and/or inject unwanted light into the laser chain. Care must be taken in the design and operation of high-gain amplifiers, such as all of the amplifiers used in the OMEGA laser, to prevent parasitic oscillation.

The silver-plated reflectors behind the flash lamps have the potential of causing parasitics. When new, these have an IR reflectivity of 98% or better. In the OMEGA SSA's, large, flat regions of these reflectors face each other with a disk of the amplifier located between them at the complement ($90°-\theta_B$) of Brewster's angle. The oscillation condition is

$$\text{Single pass gain} > \frac{1}{\text{Single pass loss}}.$$

Where the single-pass gain is given by

$$\text{Single pass gain} = \exp\{\text{specific gain coeff} \bullet \text{stored energy density} \bullet \text{path in glass}\}.$$

For the specific case of the 15-cm amplifier:

$$\text{Single pass gain} = \exp\left\{0.212\frac{\text{cm}^2}{\text{J}} \bullet 0.434\frac{\text{J}}{\text{cm}^3} \bullet 3.240\text{ cm}\right\} = 1.347.$$

The single-pass loss is given by

$$\text{Reflector reflectivity} \times \text{Window Fresnel loss} \times \text{Disk Fresnel loss} \times \text{Window Fresnel loss}.$$

$$\text{Single pass loss} = 0.98 \bullet 0.96^2\ 0.975^2 \bullet 0.96^2 = 0.791,$$

so the oscillation condition becomes

$$1.347 \geq 1.264$$

and oscillation may be expected where the geometry allows.

In the 15-cm disk (stage-E) amplifier the flash lamps are horizontal. While a large fraction of the area of the reflectors is obscured by flash lamps that are highly opaque in the IR, a small, horizontal region between the flash lamp assemblies is unobscured: The 15-cm amplifier has the potential to oscillate in a direction transverse to the amplifier axis. This was, if fact, observed in fluorescence measurements made to establish trigger timing during activation of the OMEGA system. The oscillation does not occur in the 20-cm (stage-F) amplifiers because in that design the flash lamps are vertical and opposing unobscured strips cannot “see” each other due to the longitudinal offset caused by the Brewster-angle laser disk.

The solution to the parasitic problem in the 15-cm amplifier was quite simple. The pump modules that contain the side reflectors were tilted slightly by installing “voodoo wedges” at the top of the amplifier, where the module would normally contact the amplifier frame. This slight tilt or wedge of the side reflectors with respect to each other causes reflected rays to “walk off” into a highly opaque flash lamp, thereby frustrating oscillation.

Disk Amplifier Basic Maintenance

The basic maintenance plan for disk amplifiers consists of regular monitoring of flash-lamp brick performance, routine *in-situ* inspection of amplifier glass for laser damage, and routine inspection of the cavity for degradation of nickel coating or other defects.

The PILC diagnostic circuits built into the PCU’s report back through the Power Conditioning Executive the triggering status of every flash lamp (brick) in the disk amplifier system. Failure of a flash-lamp brick to trigger indicates that the brick should be changed out prior to the next shot. The design of the disk amplifier and support structure provides for this event, and a brick can be changed (or simply inspected) during the one-hour shot cycle. The installation and usage status of all flash lamps and bricks is tracked with a computer database and facilitated by a bar-code tag on every lamp.

All of the disk amplifiers are visually inspected for laser damage, or other problems that may affect laser performance or amplifier safety, on a weekly basis. The laser glass and windows are inspected for general cleanliness and for laser-damage tracking. Either of these would indicate that the unit should be serviced. If there is laser damage, the source of the damage must be determined.

The base-line operational plan called for at least one disk amplifier to be taken out for refurbishment each week. As a result, every unit would be rebuilt once in 120 weeks, including

- complete tear-down of the amplifier’s optical and mechanical parts;
- inspection and cleaning of the silver reflectors, replacement replating if necessary;
- inspection and mapping of damage in the laser glass;
- cleaning of the laser glass, or replacement if necessary;
- inspection and cleaning of the flash lamps and reflectors;
- replacement of flash-lamp bricks if necessary, based upon PILC data and database history; and
- rebuilding the amplifier and interferometrically testing for wavefront performance.

The base-line rebuild cycle has not been implemented because the routine periodic inspections have shown no progressive degradation that would warrant the complete overhaul. Instead, damaged or degraded components are replaced on an as-needed basis.

3.4 LASER GLASS

In keeping with the philosophy of using proven, low-risk technologies, LHG-8 laser glass[16] was chosen as the active medium for the upgraded OMEGA laser. It is a well-characterized, athermal phosphate laser glass that provides a high cross section for stimulated emission, extremely low 1-μm absorption, and a reduced nonlinear index of refraction when compared with the silicate glasses. LHG-8 can be melted in production quantities while maintaining sufficient homogeneity and low particulate platinum content.

The 60-beam OMEGA laser uses Nd:glass laser rods in three diameters: 40, 64, and 90mm, all 370 mm long. The basic properties of the three sizes are listed in Table3.4-1 and refer to Fig. 3.4-1. The disk amplifiers utilize Nd:glass laser disks referred to in two sizes of clear apertures: 15 cm and 20 cm. Figure 3.4-2 shows the comparative size of the 15-cm and 20-cm disks, and a 90-mm rod shown in its rod module. The laser disks are actually octagonal in shape (when viewed at Brewster's angle along their optical axis) and are somewhat larger in dimension than their clear aperture.[9] The basic properties of the laser disks are listed in Table 3.4-2 and refer to Fig. 3.4-3.

Table 3.4-1
Laser Rod Properties (Refer to Fig. 3.4-1)

Item No. 3.3.6.X	*Attribute*	Specification		
	Option Number	**–1**	**–2**	**–3**
1	Nd-Oxide doping ±10% of wt%	0.40	0.55	0.55
2	D, Diameter in mm, TOL. ±0.0, –0.1	90	84	40
3	L, Overall length in mm, TOL ±1.0	370	370	370
4	CA, Clear aperture in mm, TOL ±0.3	87	61	37
5	A1, Face angle in degrees, TOL ±0.5°	6	6	6
6	A2, Face angle in degrees, TOL, ±0.5°	6	6	5
7	Wedge, parallelism, S1 to S2, in minutes, ±10 seconds	2	0	0
8	S1 surface wavefront quality, see Note 1 and Note 2	–	–	–
9	S2 surface wavefront quality, see Note 1 and Note 3	–	–	–
10	Single-pass transmitted wavefront quality, see Note 1	Note 4	Note 4	Note 4
11	S1, S2 Scratch/dig in clear aperture, minimum level	20/10	20/10	20/10
12	Maximum birefringence in clear aperture in nm/cm	1.0	1.0	1.0
13	Bubble/inclusion cross section in any 100 cc., in mm^2, maximum	0.02	0.02	0.02
14	Dimension of any bubble/inclusion in mm maximum	0.10	0.10	0.10
15	Volume of laser glass in cc	2353	1190	485
16	R, Radius or 45° bevel in mm	1.0±0.5	1.0±0.5	1.0±0.5

Note 1: P–V at 633 nm within the clear aperture.
Note 2: Hand figured as required to meet item 10 with 1 λ/cm maximum gradient within the clear aperture.
Note 3: λ/10/cm maximum gradient withing the clear aperture.
Note 4: λ/4 with λ/10/cm maximum gradient within the clear aperture.
Note 5: λ/6 with λ/10/cm maximum gradient within the clear aperture.

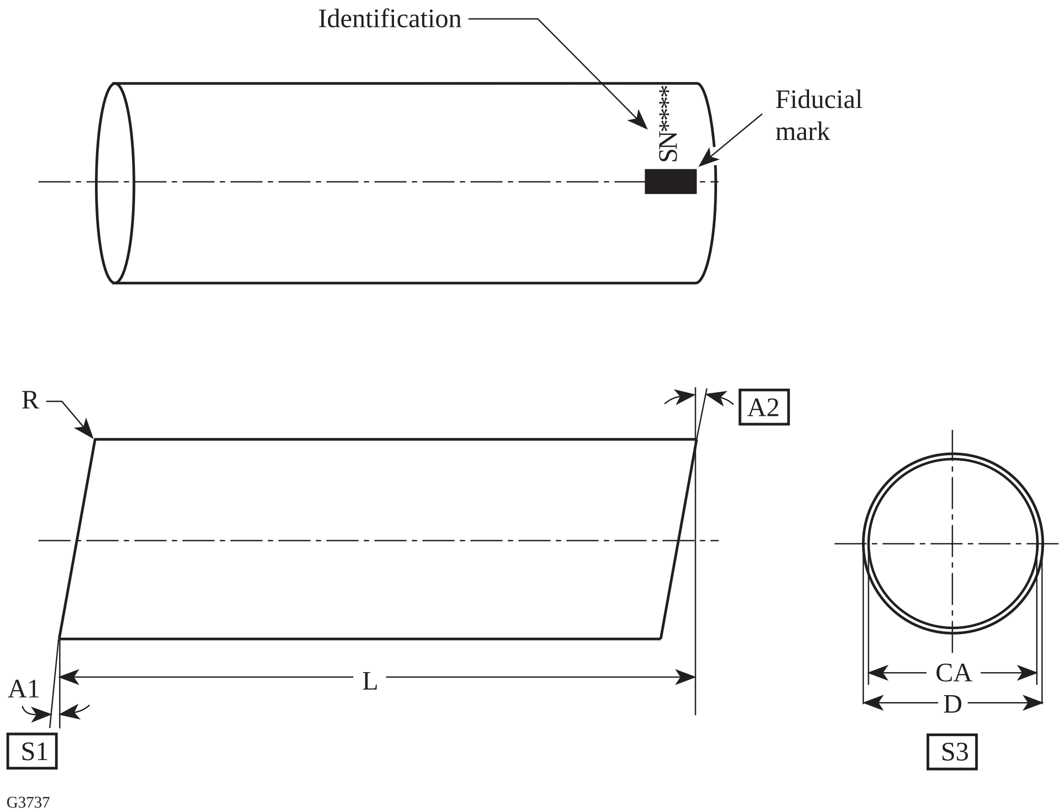

Fig. 3.4-1
OMEGA laser rods.


G3652

Fig. 3.4-2
UR/LLE-developed LHG-8 laser glass is used in two basic shapes and several sizes. Shown are the hexagonal elements for the 15- and 20-cm disk amplifiers and a 90-mm rod (inside the module assembly).

Table 3.4-2
Edge Clad Disk Properties (Refer to Fig. 3.4-3)

Item No. 3.3.6.X	Attribute	Specification	
		15-cm Disk	**20-cm Disk**
1	L, Overall length in mm, TOL. ±0.3	357	448
2	W, Overall width in mm, TOL. ±0.3	226	276
3	T, Thickness in mm, TOL. ±1.0 –0.0	30	30
4	C, Cladding thickness in mm, TOL ±0.5	8.0	8.0
5	B, Length of clear aperture in mm, TOL ±0.5	327	399
6	A, Width of clear aperture in mm, TOL ±0.5	160	210
7	I, Length of corner in mm, TOL ±0.5	114.7	140.0
8	w, Width of corner in mm, TOL ±0.5	66.2	80.8
9	Wedge, parallelism, S1 to S2, in minutes, ±10 seconds	0	0
10	R, Radius of curvature, cladding option 2, in mm, TOL ±1	15	15
11	Single-pass transmitted wavefront quality, see Note 1	See Note 2	See Note 2
12	S1, S2 scratch/dig in clear aperture, minimum level	20/10	20/10
13			
14	Maximum birefringence in clear aperture in nm/cm	3.0 (See Note 3)	3.0 (See Note 3)
15	Bubble/inclusion cross section in any 100 cc. in mm^2, maximum	0.3	0.3
16	Dimension of any bubble/inclusion in mm, maximum	0.2	0.2
17	Volume of laser glass in cc	1759	2766
19	Volume of laser glass and cladding in cc	1965	3030

Note 1: P–V at Brewsters angle at 633 nm withing the clear aperture.
Note 2: $\lambda/9$ with $\lambda/30$/cm maximum gradient within the clear aperture for both “A” and “B” orientations shown on this drawing.
Note 3: For *p*-polarized radiation at Brewsters angle within the clear aperture at 1054 nm.

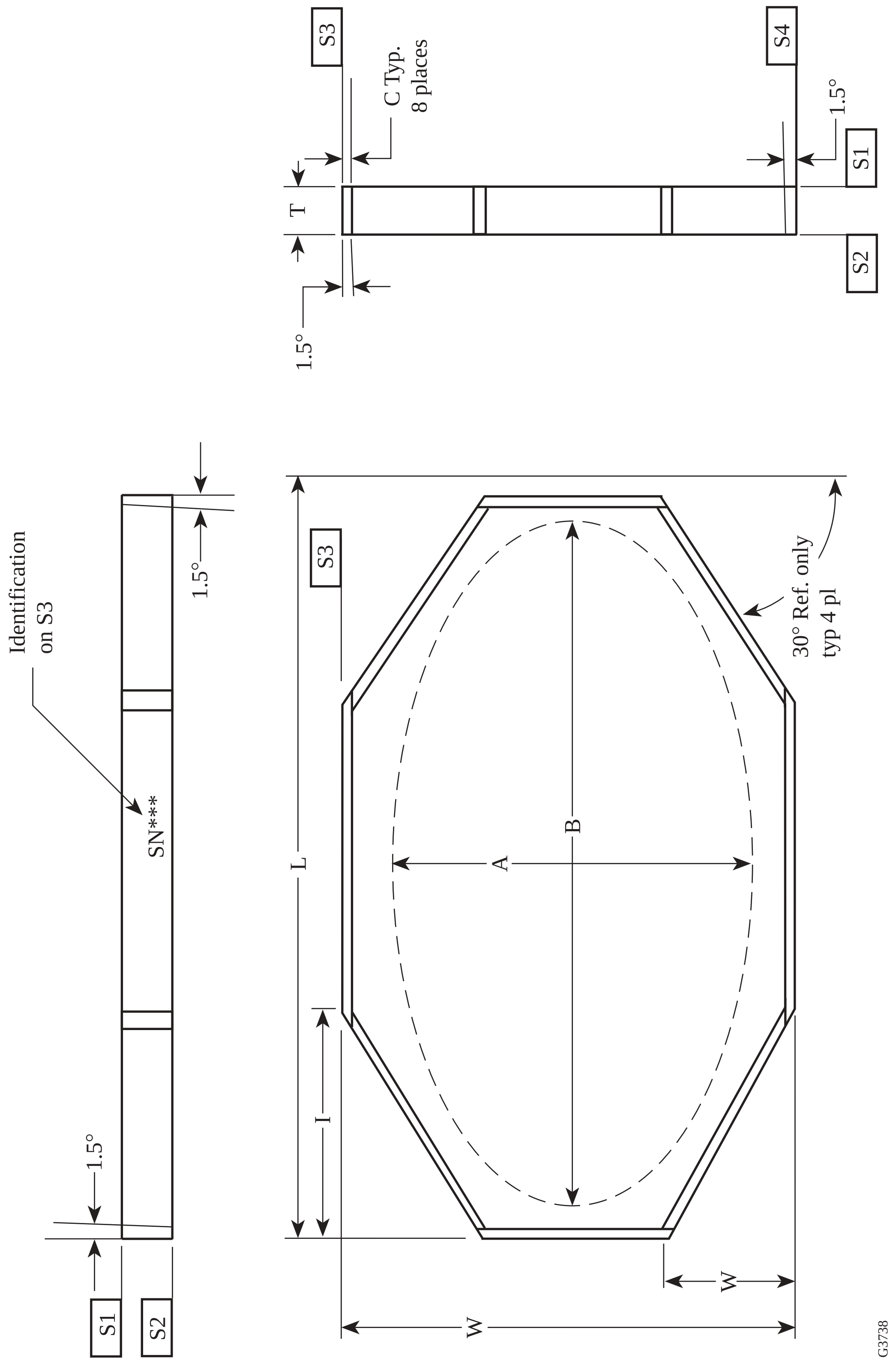

Fig. 3.4-3
Details of the OMEGA laser disks.

The disk-cladding technology used for the OMEGA disks was developed at LLNL[8] utilizing a polymer bond to attach copper-doped LHG-8 glass to the disk edges in a stress-free manner. This cladding effectively reduces parasitic oscillations.

At the recommendation of LLE, the vendor utilized phase-shifting interferometry and polished-homogeneity-testing[17] technology to monitor the homogeneity of the production laser glass. This quality-control step assisted in the production of glass that exceeded the specifications for homogeneity.

3.5 FLASH LAMPS

The 218 laser amplifiers in OMEGA require nearly 7,000 flash lamps. These units are 19-mm-bore, 300-Torr, xenon flash lamps and have arc lengths of 25, 132, and 30 cm for the 20-cm single-segment amplifier (SSA), 15-cm SSA, and rod amplifiers, respectively. Other than the arc length, all other features of the flash lamps are identical.

All OMEGA flash lamps are water cooled. This feature provides a number of advantages over air-cooled flash lamps: The lamps can run at a higher explosion fraction. (This is the operational energy divided by the maximum energy a lamp can survive and not explode.) The lamps are operated at 26%–34% explosion fraction, whereas air-cooled lamps are normally operated at 20%–25%. The deionized water used to cool the lamps has high resistivity, which eliminates electrical arcing. The water also provides mechanical support allowing the use of lower-cost, industry-standard, 1.5-mm-thick jackets rather than custom, heavy-wall jackets favored on other laser systems. Lastly, water-cooled flash lamps increase the transfer of thermal energy out of the amplifier after a shot. Air-cooled lamps, which dissipate thermal energy by radiation, ultimately heat the laser glass after a shot; water cooling removes this heat without heating the laser glass.

Along with the visible light used to pump Nd lasers, xenon flash lamps produce large amounts of UV light. The solarization of phosphate laser glass when exposed to intense UV light is a problem in high-power-laser designs. In the design of amplifiers for OMEGA, the desire to eliminate as much UV light as possible has led to the use of CDQ envelopes that absorb much of the UV radiation from the flash-lamp discharge. Recently, an additional attenuation of the UV radiation has been achieved using a new manufacturing process for the envelopes. The use of cerium-doped quartz and the new process for producing that quartz are the most significant improvements to these flash lamps relative to their predecessors.

3.6 AMPLIFIER FLUID AND INTERLOCK SYSTEMS

The utilities and interlocks required to operate the laser amplifiers are readily divided into four (sub)systems: power conditioning, cooling, nitrogen, and interlocks. The power conditioning system provides the energy for the flash lamps within the amplifiers and is fully described in Chap. 4. The cooling systems consist of a closed-loop DI water system and a closed-loop DI water/glycol system. These systems provide cooling for the flash lamps and laser rods respectively. The nitrogen system provides a purge environment within disk cavities and flash-lamp pump modules. The amplifier interlocks are associated directly with amplifier hardware that ensures safe operation.

Cooling System

The DI water and DI water/glycol cooling systems are both closed-loop, centralized systems of similar design. Figure 3.6-1(a) shows the schematic of the DI water system and Fig.3.6-1(b) shows the glycol system. DI water cools the ~7000 flash lamps in both rod and disk amplifiers. The DI water/

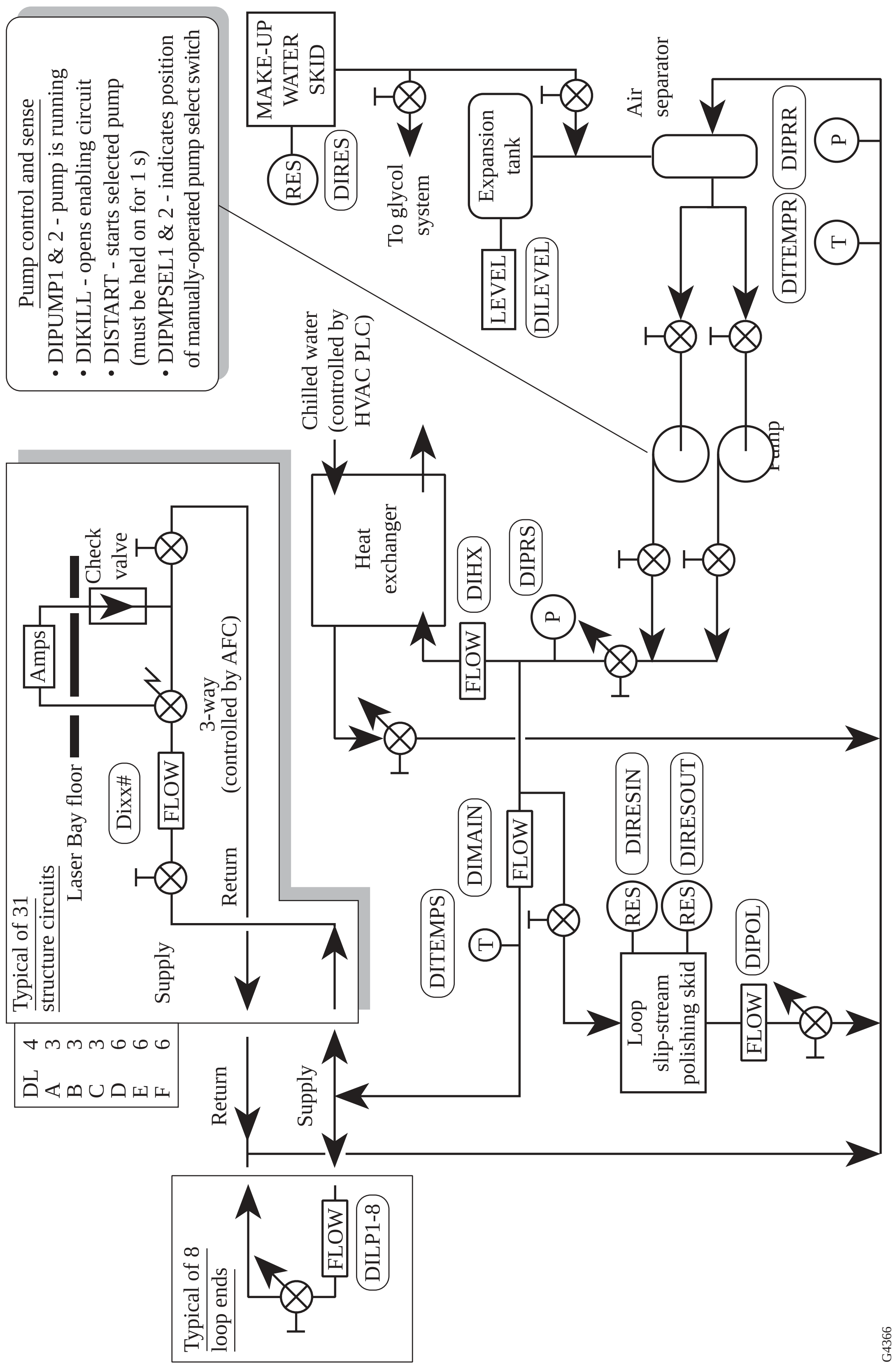

Fig. 3.6-1
(a) Deionized water cooling loop schematic/cooling system monitor control points..

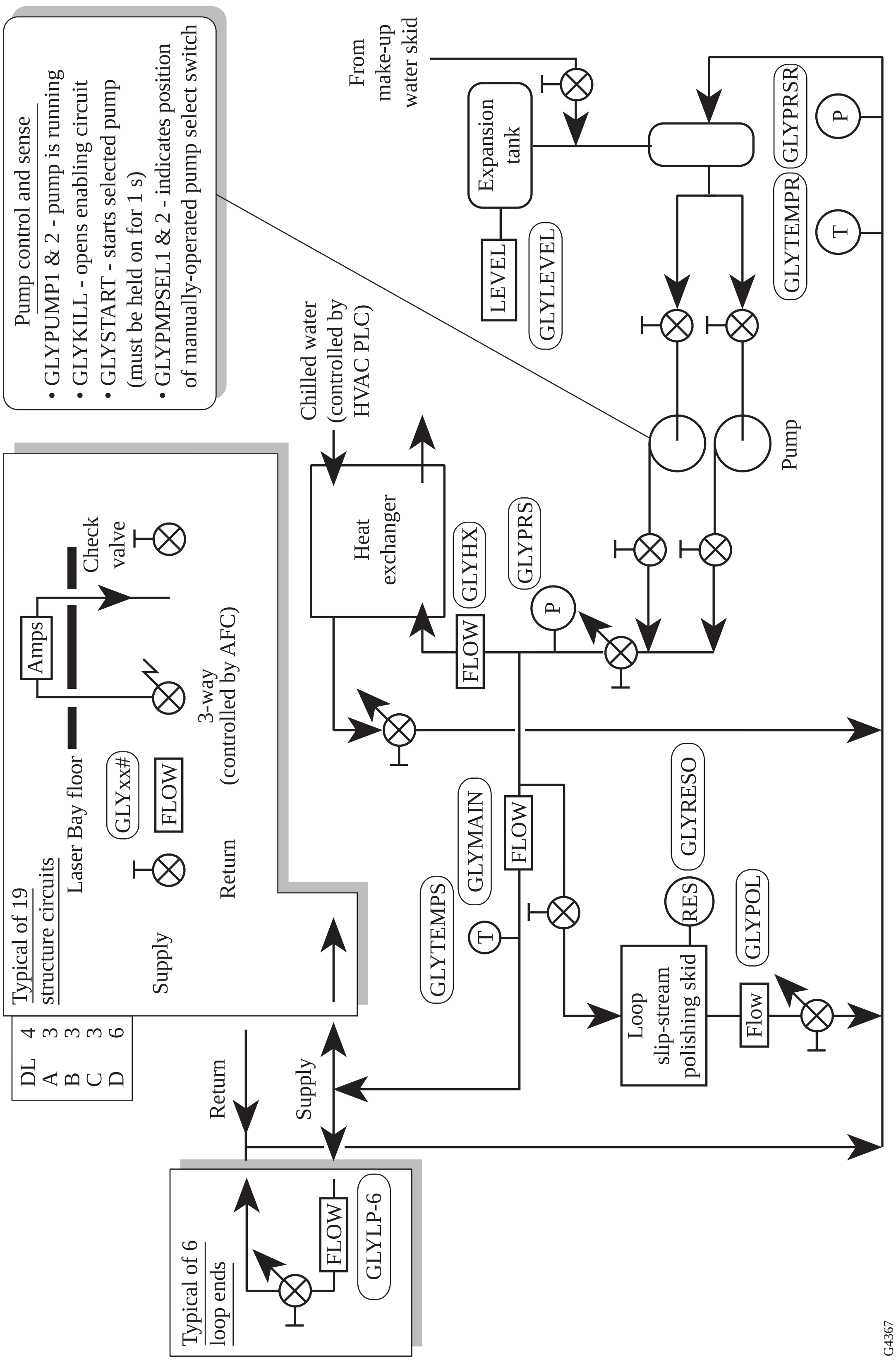

Fig. 3.6-1
(b) Glycol cooling loop schematic/cooling system monitor control points.

glycol system circulates a 50/50 mixture of DI water and ethylene glycol to the rod-amplifier rod modules. (Phosphate-based laser glass dissolves in pure DI water but is relatively unaffected by DI water/glycol.) The pumps and heat exchangers are located in the north air plenum below the Laser Bay, next to Capacitor Bay 1. Fluids are conducted through CPVC piping under the Laser Bay floor and up through the appropriate floor hole to the structures. The same type of piping is used in the structures to each of the amplifier heads, but final connections to the heads are done with polypropylene tubing. The DI water system maintains a flow of 30 gal per hour (gph) to the flash lamps at a temperature of 70±2°F. Flow to the heads is monitored by Proteus™ flow sensors that incorporate local operating network (LON) microprocessors and are interfaced to the control system. The piping system also includes a host of valves and gauges that provide for balancing water flow through the entire system. The DI water/glycol cooling system for laser rod modules is similar in design to the DI water system but circulates the 50/50 mixture and serves only the 97 rod amplifiers in the system. It maintains a flow of 2.0 gal per minute (gpm) to each laser rod at a temperature of 70±1°F.

Nitrogen System

Nitrogen gas flows into the disk-amplifier disk cavity and the flash-lamp pump cavities. In the rod amplifiers it flows only into the flash-lamp pump cavities. Nitrogen is required to prevent/reduce two effects within the disk amplifiers: First, the nitrogen purge displaces air in the cavities that contain trace amounts of sulfur. The airborne sulfur causes the silver plating on the reflectors in the cavities to tarnish, thus causing a reduction in amplifier gain performance. Second, the nitrogen displaces oxygen that has absorption bands between 170 and 210 nm. Absorption of flash-lamp energy by those bands causes a shock wave within the amplifier.

The amplifier disk cavities require a dry nitrogen purge of ≤0.1 standard cubic feet per minute (scfm) at laser bay ambient temperature (70±1°F). With the addition of the fused-silica end windows on the disk amplifiers, nitrogen flow is minimal. The flash-lamp pump cavities for both rod and disk amplifiers require a nitrogen purge of ~3.0 scfm at ambient temperature for a minimum of 60 s prior to a shot.

The nitrogen gas purge system to the amplifiers is supplied by the building's dry nitrogen system that is piped via under-floor copper piping throughout the Laser Bay and in the Target Bay. Valved connections are made to the piping manifold through the appropriate hole in the Laser Bay floor; final connections to the amplifiers are made through plastic tubing. Figure 3.6-2 shows a typical amplifier nitrogen purge schematic for an amplifier structure. Note that the disk-cavity purge is controlled by a manual valve, whereas the pump-cavity purge is controlled by the AFC. The building's dry nitrogen is produced from gas blowoff from the building's liquid nitrogen supply tank. The gas is filtered through Molsieve™, which removes any residual sulfur. These units are located in the supply line at each amplifier structure.

Amplifier Facilities Controller and Interlocks

Stage-A through stage-F amplifiers have one AFC to handle the fluids, interlocks, and warning beacons for the entire amplifier structure. There is a single AFC for all of the driver-line amplifiers. A diagram of the AFC interconnect is shown in Fig. 3.6-3.

The AFC controls the flash lamp and rod coolants and the pump cavity purge mentioned above. It also receives leak-detection signals, which come from detectors in the amplifier drip pans. Coolant leaks of less than 1 gal are easily detected. In addition to the flow rate and leak detection "go/no go"

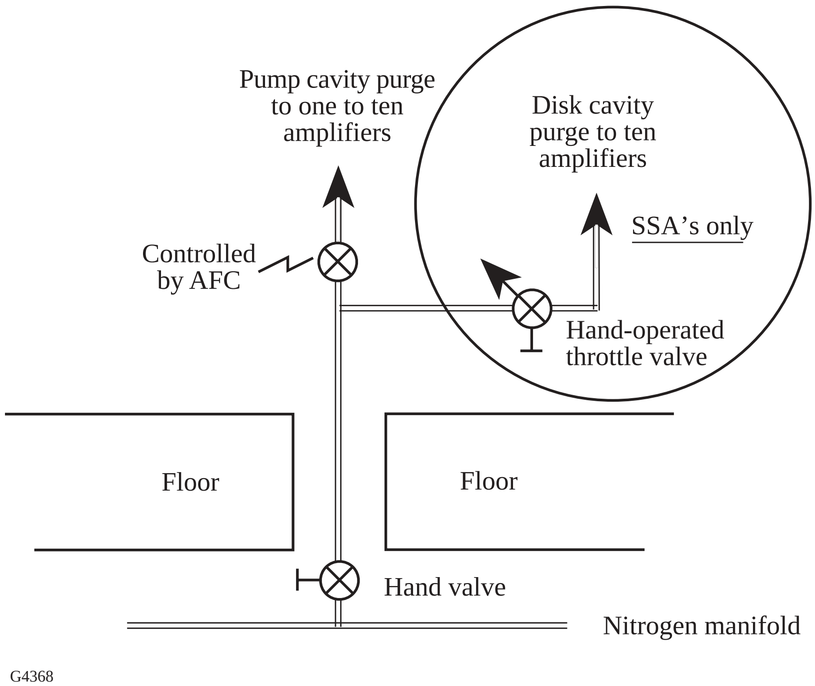

Fig. 3.6-2
Amplifier structure nitrogen purge schematic.

signals, the AFC's on the SSA structures enforce physical configuration interlocks. These are intended to assure that all of the amplifier pump modules are in place, that the swing door on the structure is in the correct position, and that the service crane is parked out of the beams. The status of the crane power is also included in this interlock loop.

A hardwire "Amp OK" signal from the AFC indicates to the PCU that an amplifier and its associated structure are ready for a shot. This signal combines all the flow and interlock indicators into one signal for each amplifier. If all of the indicators are good, the AFC closes a contact that is sensed by the power conditioning module (PCM). If the contactor remains open, the PCM will not proceed until the fault is cleared. If this occurs during a charge sequence, the PCU dump relay is closed and the PCU charge sequence is halted.

AFC logic is done in programmable logic array (PLA). This method was selected as a result of a trade-off between the hardness of relay logic and the flexibility of software logic. The AFC also incorporates neuron firmware that, through a LON connection via the PCM, reports the details of the "Amp OK" signal to the PCE and allows for the remote control of the warning beacons, DI, glycol, and N_2 flows. The firmware also monitors the front panel switches. The AFC's share the LON channel with their respective PCU's.

The front panel of a typical AFC (shown Fig. 3.6-4) contains manual switches to turn the flows on and off and sense indicator lights for the DI, glycol, N_2, and pump module location, and "Amp OK" for each amplifier on the structure. There are also indicators for the structure warning beacon, the amplifier crane power and location, and the SSA structure swinging-door assembly status. Individual amplifier bypass switches allow one or more amplifiers to be bypassed if the amplifier is not to be used due to maintenance or structure population. An AFC bypass switch can be used to lock out usage of the AFC during maintenance. The AFC bypass does not allow the "Amp OK" contactor to be closed; therefore, all associated PCU's will not charge. The front panel also contains the LON connection ports

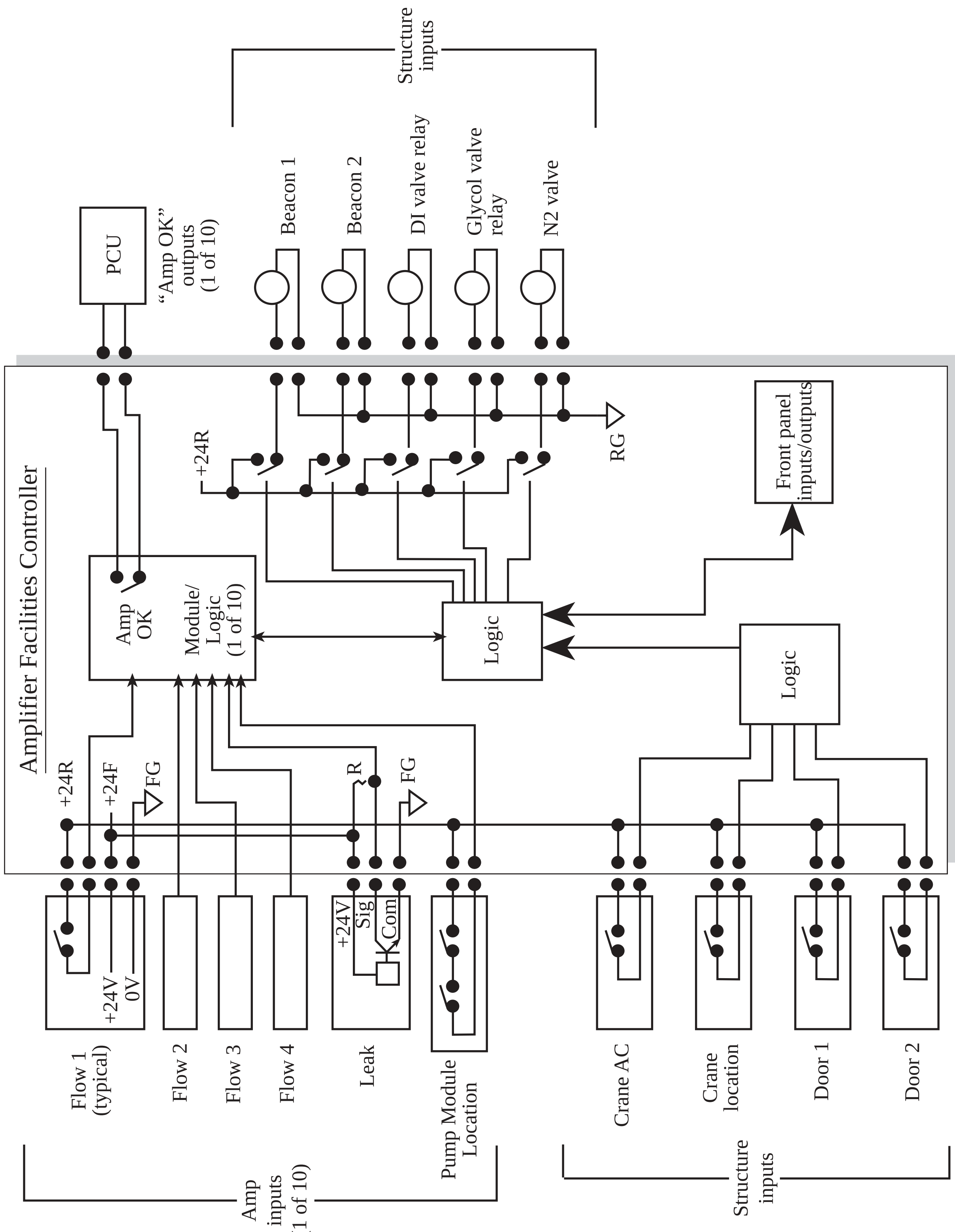

Fig. 3.6-3
AFC interconnect diagram.

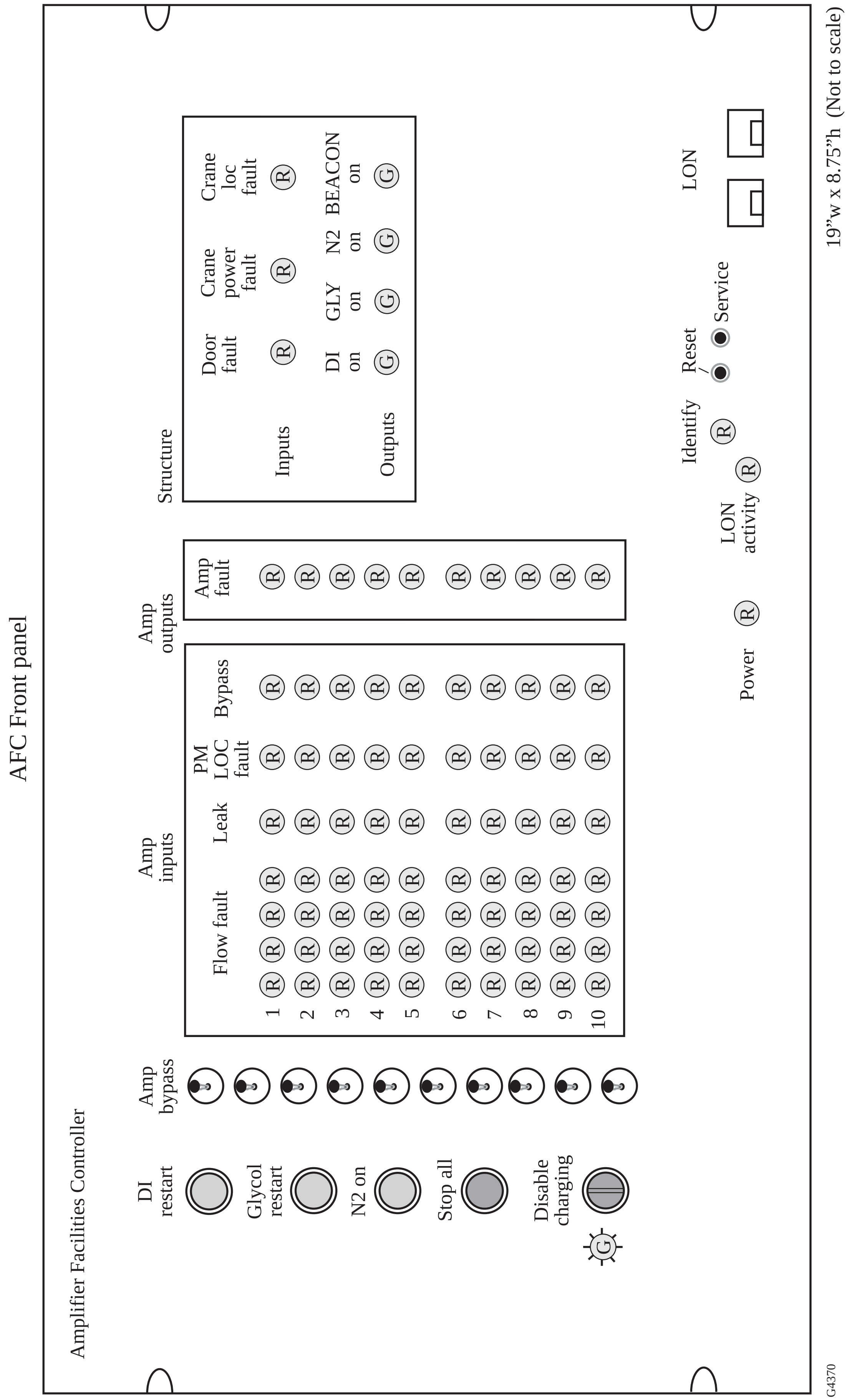

Fig. 3.6-4
AFC front panel.

and a LON activity indicator. When all flows and interlocks are in their ready state, the “Amp OK” light will indicate the amplifier/structure is ready for the shot. If there are any problems, the problem can be located using the indicator lights. The AFC is connected to an ac power outlet located beneath the floor of the amplifier structure. Table 3.6-1 describes the maximum physical I/O points in the AFC’s.

Table 3.6-1 **AFC Maximum Physical I/O Points**
40 flow-detector inputs
10 leak-detector inputs
10 pump-module “in position” switch inputs
2 structure door-interlock switch inputs
1 crane-location input
1 crane AC disconnect input
10 amplifier “OK” contact-closure outputs
2 warning beacon outputs
1 DI valve output
1 glycol valve output
1 N_2 valve output

3.7 AMPLIFIER SUPPORT FACILITIES

The OMEGA laser facility has two dedicated support areas for the construction and maintenance of laser amplifiers: the amplifier assembly area (AAA) and the flash-lamp test facility (FTF). The AAA is located adjacent to the Laser Bay on the north wall, west of the control room, and directly accesses the laser bay. The FTF is located on the first floor of the building, adjacent to the north wall of Capacitor Bay 1, and directly below the AAA.

The AAA has four adjoining rooms: the disk amplifier assembly room, the interferometry room, an entrance anti-area, a gowning room; and a separate rod amplifier assembly room. The rod amplifier assembly room is accessible from the hallway and also leads out to the laser bay; it is maintained as a class-1000 cleanroom. It contains a class-100 DI water-production system, capable of producing 1200 gal/day, which is used for amplifier cleaning. The disk amplifier assembly room, maintained at class-100 cleanliness, contains an aqueous ultrasonic cleaning system that is large enough to handle the amplifier frames, a high-pressure freon cleaning system, and a class-10 laminar flow clean bench. All disk amplifier parts (except the laser glass) are cleaned and then assembled (disassembled) in this room. After final assembly, the amplifiers are tested for transmitted wavefront performance ($\leq 1\ \lambda$ @ 633 nm) in a 12-in.-aperture Zygo phase-measuring interferometer, prior to delivery to the Laser Bay.

Flash lamps are inspected and flash-lamp bricks are built in the FTF room. All lamps are bar coded, and their statistics are kept in a relational database. Lamps are inspected for conformity to the dimensional and cosmetic specifications. When the lamp bricks are built up, they are normally tested for infant mortality in the flash-lamp tester. This unit has a complete power conditioning unit that can be fired at a repetition rate of once per minute to determine the initial performance of any lamp brick.

The flash-lamp database tracks all flash lamps within the OMEGA system and contains both manufacturing and shot data. The manufacturing data permits traceability back through the entire manufacturing process. The shot data contains the entire history of the flash lamp, including receipt, assembly, installation, location, and number of shots. The shot history is automatically updated after a shot.

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