

THE ANTARES LASER POWER AMPLIFIER*

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The overall design of the Antares laser power amplifier is discussed. The power amplifier is the last stage of amplification in the 100-kJ Antares laser. In the power amplifier a single, cylindrical, grid-controlled cold-cathode, electron gun is surrounded by 12 large-aperture CO₂ electron-beam sustained laser discharge sectors. Each power amplifier will deliver 18 kJ and the six modules used in Antares will produce the required 100 kJ for delivery to the target. A large-scale interaction between optical, mechanical, and electrical disciplines is required to meet the design objectives. Significant component advances required by the power amplifier design are discussed.

Introduction

The Antares laser is under construction at the Los Alamos Scientific Laboratory (LASL). This is a large (100-kJ) CO₂ laser for the inertial confinement fusion program. The power amplifier (Figs. 1 and 2) is the last stage of amplification in the optical chain. A cylindrical cold-cathode, grid-controlled electron gun is utilized to ionize the laser gas in the annulus surrounding the gun. Each power amplifier operates at 1800 torr of 1:4::N₂:CO₂ laser gas and requires approximately 1 MJ of stored electrical energy at an operating voltage of 550 kV. An input light energy of less than 100 J is amplified in two passes through the power amplifier to an output energy of 18 kJ. Six power ampli-

fiers operating in parallel are required to produce the 100-kJ output for the fusion targets.

This paper discusses features of the power amplifier optical, mechanical, and electrical design, and their problem areas and solutions.

Optical Design¹

A 15-cm-diameter annular input beam with an energy of less than 100 J is delivered to each power amplifier from the driver amplifier in the front end. It passes into the vacuum section through a 22-cm-diameter salt window. This input beam is divided by a central polyhedron beam splitter into 12 segments which are directed radially outward. Each of the 12 beams is reflected to a three-mirror corner cube which is used to adjust individual path lengths to obtain pulse synchronization. From the corner cube the light passes to a focus mirror then through a spatial filter. The beam enters the pressure vessel section through a 12.7-cm-diameter salt window, then through a group of four relay mirrors to the first amplifying section. The approximately 2.5-cm trapezoidal beam makes a first diverging pass through the four pumped regions to the back-reflector mirror where it is reflected for a second, near-collimated, pass through the amplifying sections. At the output of the pressure vessel the beam is transmitted through a 45-cm-diameter salt window to the two mirror periscope sections. Because of the radial geometry of the power amplifier, each amplifying sector, and therefore each beam, is a segment of an annulus. The periscope compresses the radius of the annular 12-sector beam array exiting the power amplifier to reduce the dimensions required downstream in the turning and target chambers.

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The power amplifier design is primarily dictated by optical requirements.² The damage threshold for the transmitting windows limits the flux to about 2 J/cm^2 average energy density for the nanosecond pulses. This average density provides an allowance for hot spots due to diffraction and non-uniform gain. The window damage limitation combined with state-of-the-art limits on window size means that the laser must exit through multiple output windows. For Antares this results in 12 windows per power amplifier, or 72 total output windows in the system.

An intensive development program at Harshaw Chemical Company, funded by LASL, has produced optical grade salt windows up to 45-cm diameter.³ The windows are 8.9-cm thick to withstand the 3-atmosphere pressure differential. Each window is mounted between two Viton O-rings to provide a positive seal for both the 3-atmospheres pressure operating condition and the 0.1-torr vacuum when the laser gas is exchanged.

Another development program, at the Y-12 Plant of the Union Carbide Corp. in Oak Ridge, Tennessee, has produced the large mirrors used in the power amplifier (Fig. 3). Over 200 of these large mirrors are used in the power amplifiers. These mirrors utilize an aluminum substrate plated with a 1-mm-thick copper coating. The optical surface is produced by single-point diamond-turning (SPDT). Both flats and weak spherical mirrors are produced for the power amplifier. This technology provides an optical finish on odd-shaped mirrors at a reasonable cost as well as resulting in a higher damage threshold than conventionally polished mirrors.

Antiparasitic coatings such as LiF and Fe_3O_4 have been developed which are highly absorptive at $10.6 \mu\text{m}$. These coatings will be used within the power amplifier to help eliminate harmful parasitics. Provision has been made in the power amplifier design for a saturable absorber cell to further reduce parasitics if necessary.

Mechanical

A number of difficult mechanical assemblies are required in the power amplifier. The pres-

sure vessel must operate at 3 atmospheres with a 1.65-m opening at one end for the electron gun and 12 openings, each 45 cm in diameter at the other end for the salt windows. Finite element analysis was utilized in the design of these complex elements to ensure adequate safety factors. The material is ASTM 516 Grade 70 pressure vessel carbon steel and was chosen because of good performance, dimensional stability, and low cost.

The electron-gun vacuum vessel is also made from ASTM 516 steel. This unit (Fig. 2) is 1.65 m in diameter and 7.7 m long. The vessel wall is penetrated by 48 openings for the electron beams. Each electron window opening is 75 cm by 25 cm with 0.8-cm wide hibachi ribs spaced on 6.3-cm centers down the length for window and shell support. The vacuum vessel is constructed from four finish machined cylinders each 1.65 m in diameter, 1.9 m long, with a 5-cm-thick wall. These cylinders are joined together using pulse-arc welding to give very low weld distortion, thus requiring no further machining after the welding.

The hibachi window openings are covered with 2-mil-thick titanium foil which allows the electron-beam to pass through and also provides the vacuum seal. The foil is attached to a punched-metal backing grid to form a rip-stop which prevents catastrophic window failure. Inserting and removing the electron gun posed a difficult mechanical problem. The solution was to develop special-shaped air bearings to fit the small space allowed, yet provide a reliable method for sliding the gun in and out of the pressure vessel with a minimum of force.

Electrical

The derivation of the power amplifier electrical parameters has been discussed previously.⁴ The electrical problems in the power amplifier involve the anode, anode bushings, high-voltage cable, and the electron-gun design, including gun support bushings and electrical feed.

The high-voltage cables connect the gas puffer energy storage to the power amplifier.

These cables must withstand 550-kV pulses during operating conditions, and could see a voltage as high as 1 MV during fault conditions, e.g., when the electron-gun pulser does not operate. A fault protection gap has been designed for the power amplifier in an attempt to limit the peak voltage to <800 kV during fault conditions.

A number of utility cables were tested for this duty and only dry-cure polyethylene cables rated for at least 145-kVac proved adequate. The outer semiconductive corona shield of the cable is used to grade the field distribution at the cable termination. These cables are about 7.5 cm in diameter. During the test program the cables were subjected to over 8000 shots at 800 kV and survived 100 shots at 1 MV.

An anode bushing was successfully tested at voltages up to 1 MV. This bushing uses shaped electrodes and silicon-rubber inserts to reduce the peak fields.

The cylindrical cold-cathode electron-gun concept was developed and tested in a full-scale prototype power amplifier.⁵ This prototype unit is presently being used to test actual Antares hardware components under realistic operating conditions.

Conclusion

This paper has presented the design of the Antares power amplifier and has discussed some of the key components. A number of problem areas and solutions were described.

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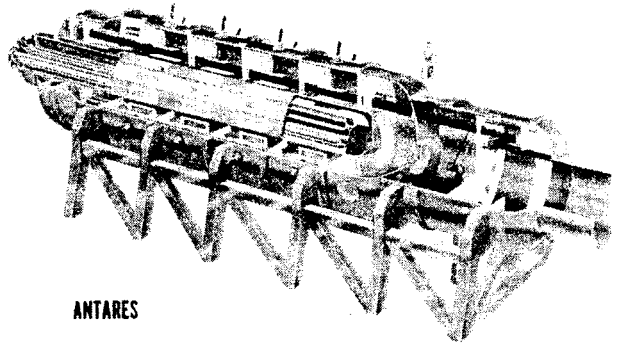


Fig. 1. The Antares Power Amplifier.

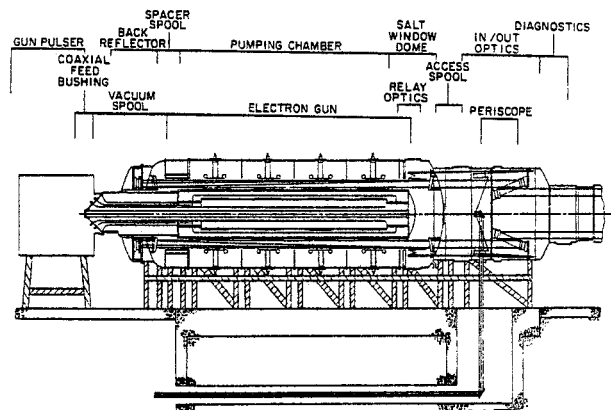


Fig. 2. Power amplifier longitudinal section.



Fig. 3. Antares power amplifier large mirror.

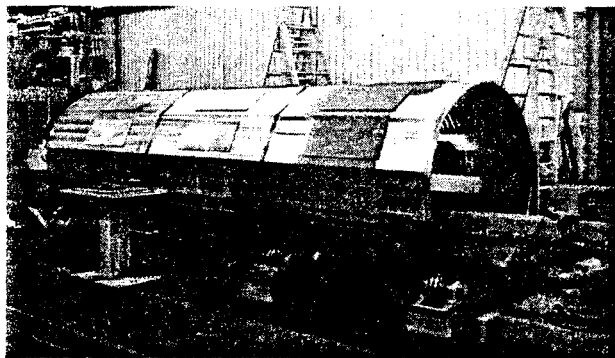


Fig. 4. Three of the four sections which make up the power amplifier electron-gun vacuum shell.