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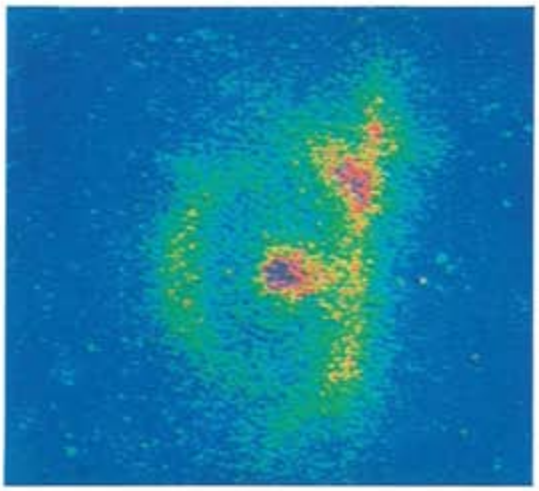

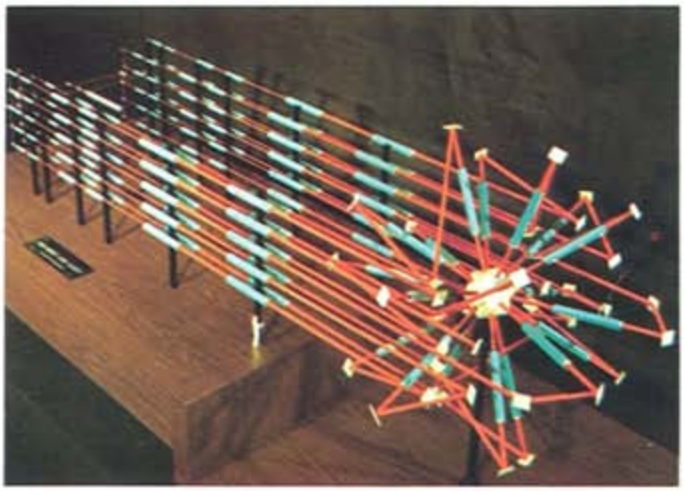

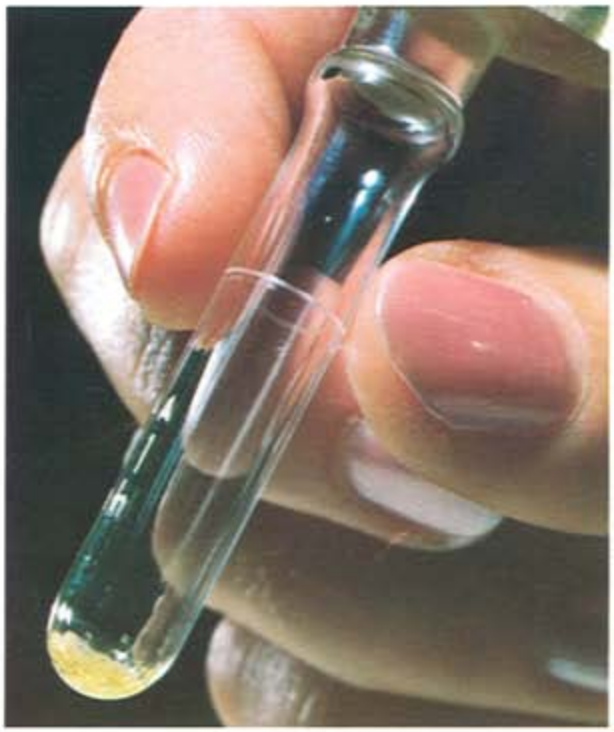

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LLL LASER PROGRAM

Construction of the building and support frame for Shiva, our 20-beam laser irradiation facility, is now under way. Completion of the frame is expected this fall. The space frame is a rigid, open-grid matrix of 6 × 6-in. steel tubing onto which the laser-chain and target-chamber components are mounted. The open structure provides flexibility in mounting hardware and compatibility with the building's environmental-control system. Although this design requires 8 km of steel tubing, it is more stable and much less costly than either solid steel or concrete structures.

The Shiva laser system will have both the precise illumination uniformity and high power needed to demonstrate significant thermonuclear burn. Very simply, the plan for Shiva is to irradiate a microscopic D-T pellet with 20 laser beams arriving simultaneously at the target along 20 different axes. This requires very precise alignment and high stability to maintain alignment. The 20 laser chains, composed of amplifiers, spatial filters, polarizers, rotators, and mirrors, must be arranged in an optimum geometry and held there.

We have designed a high-stability space frame to accomplish this. The frame will support some 600 individual component assemblies while maintaining a tolerance of ±4-μrad rotation between any two points over a period of 100 s. This stable support requires a design approach different from that normally used in conventional machine-support structures. The usual loads must be considered, but the dominant considerations in this case are vibrational and thermal disturbances. The sizing of structural elements to minimize motion requires that we strive for maximum stiffness, sufficient size and mass for high thermal inertia, and minimum weight to keep resonant frequencies high. The frame must provide structural rigidity and good access for maintenance. It must also be simple enough to allow good air flow around the frame and components for dust and heat control. Finally, the design must be cost-effective.

Shiva Support System

After considering several alternatives, we decided to make the structure in two sections, as shown in Fig. 12. One section will be an H-shaped laser support frame for the oscillator, amplifiers, polarizers, rotators, beam splitters, and folding mirrors. The other will be a five-segment icosahedral target support for the target chamber, turning mirrors, and possibly the radial amplifiers (Fig. 13). These sections will be physically separated by a shielding wall. The amplifier section will be 40 m long, 12 m wide, and 7.6 m high. The target section will be approximately 15 × 15 × 15 m.

The frame will be hard-mounted to the floor without vibration isolation. Although spring-mounting would be useful because it attenuates vibration, it is not attractive because the laser and target support structures would have to be one single inflexible unit, 8 × 12 × 70 m. This configuration is extremely difficult to achieve, especially since shielding is required between the laser and target sections. Other disadvantages exist, including the cost and space requirements of such large springs.

The basic construction material for the frame will be 6 × 6 in. square tubing with 4 × 4 in. tubular diagonals, made of 0.25-in.-thick steel. This allows fabrication of clean, simple welded joints and flat surfaces for mounting hardware; it also presents the most uniform rigid cross section, with no possibility of flange or web buckling. The square tubing will form the basic structural unit: an open grid box, 1.2 × 1.2 × 1.2 m, with short spans to provide maximum stability. This unit also allows ample space for channeling cables and pipes and for the flow of room air. One important advantage of this boxlike structure is the ease with which it can be modified.

Laser components will be cantilevered from the outside vertical faces of the structure by stiff brackets at each end. The brackets are designed with the same stability criteria as the frame and have damping features at the frame interface for shock loads from flashlamp firing and magnet pulses. They support the components in a manner that will allow alignment repeatability during installation and replacement. The components will have tamperproof and lockable alignment adjustments, which will be used for gross alignment and will allow the amplifiers to be rotated easily to a number of positions around the beam axis. This support method is simple and allows good air flow around components for dust and heat control. The air system is designed to limit dust particles and maintain the Shiva system environment as a Class 10 000 clean room.*

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*Clean rooms are defined in terms of the number of particles, such as dust, per cubic foot. A Class 10 000 clean room has no more than 10 000 particles/ft^3. The three major classes are 100, 10 000, and 100 000.

Components will normally be accessible for inspection and light maintenance through a system of movable and elevator platforms, or in the target-room frame, by means of catwalks and stairways. Major maintenance will require the removal of a whole unit by means of an overhead crane and special handling equipment; the unit will then be serviced in a separate clean room.

Power cables and gas pipes will be routed through ports in the building floor, distributed under the raised floor, and fed up to each component through the open-grid structure of the space frame.

System Stability

The main sources of motion in the structure are acoustic vibration, stress relief, load deflection, ground vibrations, and thermal changes. The building that houses the laser is being designed to minimize acoustical noise, and little disturbing input is expected. Residual stresses from welding will be relieved by mechanically vibrating the structure in a low-frequency range during and after welding. Load deflection is taken care of during component installation by adjusting the brackets.

Determining ground-vibration effects requires considerable calculational effort. We are using the dynamic analysis code SAP IV, with ground vibrations measured near a similar building at the site as input. Our initial calculations involved the concrete laser bay floor on which the amplifier frame will be mounted.

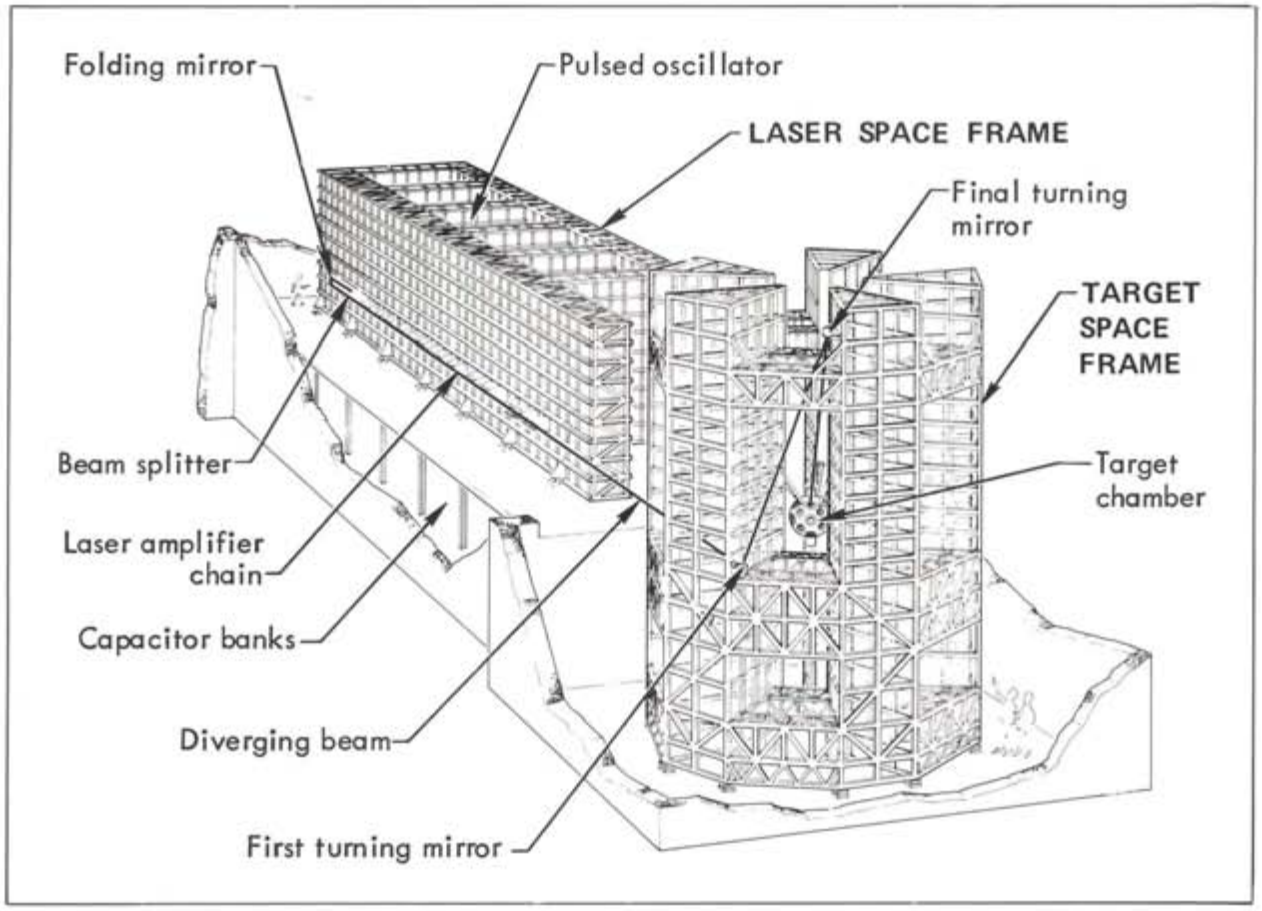

Fig. 12. Open-grid, steel-tubing space frame for Shiva onto which the laser-chain and target-chamber components are mounted. In this design, the beam is projected from the oscillator through preamplifiers, beam splitters, and folding mirrors. The folding-mirror assembly has three functions: to correct for beam path length, to center the beam on the apodized aperture, and to point the beam down the amplifier chain. The beam is spatially filtered and expanded several times to fill all amplifiers; at the last filter, it reaches a 23-cm diameter. When the beam passes through the last stage of amplifiers (still mounted on the laser space frame), it is slightly divergent. Then it passes through the turning mirrors on the target-chamber space frame and proceeds to the focusing lens elements of the target chamber itself. To upgrade Shiva, more laser chains can be added on the existing frame, and final-stage amplifiers can be positioned in line on the frame or radially around the target where space has been reserved for this purpose.

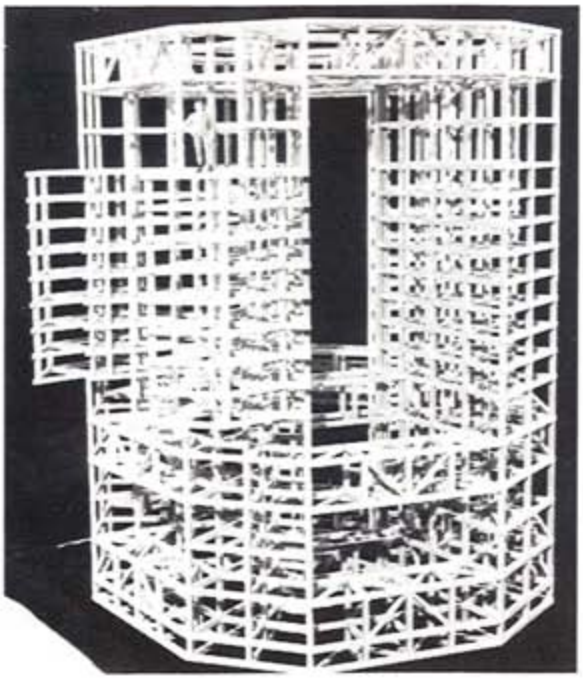

Fig. 13. Engineering model of the target-chamber space frame. Once the beams reach this chamber, they follow complex reflection paths to the target. We constructed the model to verify our engineering drawings and determine precisely where structural members had to be cut out to avoid interference with the beams.

Because the amplifier frame consists of a number of repeated identical sections, we could consider a small portion of the frame, defining boundaries by appropriate symmetry or asymmetry conditions. Calculations showed magnification of peak ground displacements ranging from 1.7 to 2.0 at the frame. We used computer graphics routines to visualize the low vibration modes of the amplifier frame. These enabled us to choose the most appropriate locations to add diagonals for extra stiffness.

The target frame does not have such a convenient form. It is basically cylindrical, with the only symmetry involving five equal sectors around the center of the cylinder. Because SAP IV requires the boundary conditions to be defined in Cartesian coordinates, the problem becomes too large to handle. Several initial attempts to get around this problem were unsuccessful. At present we are representing each distinct section of the frame (involving many members) by a simple beam. The required stiffness characteristics of such a beam are determined by treating the corresponding section of the frame as a cantilever with a point load or moment applied at the end. The code is then used to determine the resulting deflection or rotation so that the appropriate bending and shear stiffnesses can be calculated. This technique will enable us to model the complete frame without having too many frame members.

We are also calculating the horizontal movement of the laser bay floor; interaction with other parts of the building makes this a more complex problem.

For thermal stability, we must choose structural elements of a suitable size and mass to be compatible with the building environment. Air-temperature stability at any point in the laser bay, including the allowable drift of the mean temperature, is specified to be less than ±0.5°C peak to peak, with a period not exceeding 15 min; the floor-to-ceiling differential will be less than 1°C. The room has vertical air flow, providing a complete air change once every 20 s. We find that frame motions resulting from these conditions will not hamper laser operations.[9] In the unlikely event that our building air system should not provide adequate thermal control, we also have the backup capability of flowing temperature-controlled water through the frame tubing.

The effect of environmental temperature changes is decreased by the thermal inertia of the structure. When the air temperature varies 1°C over a 15-min period, the steel temperature varies accordingly but with a time lag and an amplitude of only 0.0159°C. This temperature variation causes a negligible sinusoidally varying strain of 0.4×10^{-6} and a stress of 82.7 kPa.

Supports for the space frame are designed to accommodate thermal growth without strain during periods when the air conditioning system is not operating. Roller bearing supports will allow the frame to move in an accurately guided manner from a fixed point.

Construction Schedule

The space frame for Shiva is being shop-fabricated in large sections concurrent with building construction. The size of these prefabricated sections is determined by handling and space restrictions. They will be welded together for final assembly in the laser building. Total weight of the steel is 272 155 kg, with 13 600 weld joints and a total of 8535 m of weld.

We expect the building and support frame to be completed by this fall. The first irradiation of a laser target pellet with the Shiva system is scheduled for the summer of 1977.

Key Words: lasers – Lawrence Livermore Laboratory; Shiva; solid state lasers; space frame.