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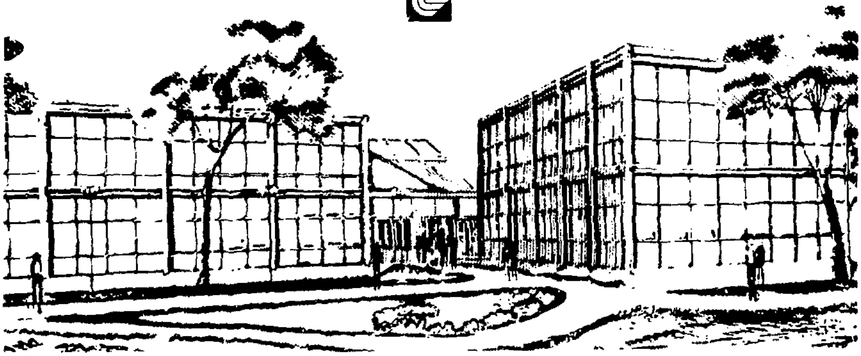

VIBRATIONAL, THERMAL, AND ALIGNMENT CONSIDERATIONS OF THE LASER SYSTEM FOR BASEBALL II-T*

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Summary

Designing the Baseball II-T laser system required addressing a number of mechanical parameters. Among them are low frequency floor vibrations, high acoustical noise levels, and large thermal fluctuations in the vicinity of the experiment. In addition, the 8-in. apertures from the 300-K environment of the laser system had to be compatible with the cryogenic environment of the superconducting Baseball magnet. This paper discusses these problems and describes their influence on the laser system design.

Introduction

The purpose of the Baseball II-T experiment (Fig. 1) is to generate a target plasma that can be heated by neutral beam injection. This is accomplished by making a frozen pellet, delivering it to the center of the Baseball magnet and irradiating it with a focused laser beam.[1] Among the necessary components are a 300-J CO_2 laser, a He-Ne alignment laser, a continuous wave CO_2 alignment laser, a He-Ne interferometer laser, an argon timing laser, and the pellet generator. Proper operation and alignment of these components dictate isolation from mechanical and acoustic vibration, thermal stability within the environment, and thermal compatibility with the existing cryogenic environment of the Baseball II vacuum chamber.

Design Parameters

In designing the structure for the laser system, consideration of its location was necessary. Mechanical vibration is present throughout the facility. Primary sources are mechanical vacuum pumps, air compressors, water pumps, building ventilator fans and the helium compressor for our liquification plant. Measurements show that these sources emit vibrations at 17 Hz, or its multiples, with amplitudes of 0.2 to 0.5 μ. Acoustical vibrations from the same sources have been measured at amplitudes of 69 dB (re 2 × 10^{-4} μbar). Finally, the experiment is situated in a large-bay area of the building, where large fluctuations in temperature, relative humidity and dust are common.

After considering alternate optical approaches,[2] a two-armed, cantilevered assembly was designed to

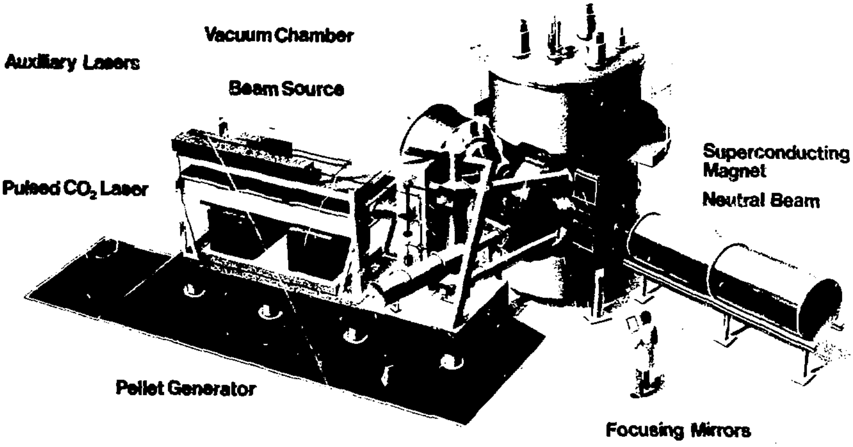

Fig. 1. Baseball II-T. target plasma buildup experiment.

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guide and focus the various laser beams, support against the vacuum load and eliminate any thermal shorts to the magnet. The cantilevers are asymmetrically oriented on the vertical axis of the Baseball magnet because of the cryogenic plumbing associated with it. Neither of the horizontal axis were available: one had too small an aperture, the other is used for neutral beam injection.

Figure 2 shows the laser system. It consists of a support structure on which are mounted the two cantilevered focusing mirror assemblies, a vertical granite slab supporting four large CO_2 laser optics and a number of smaller diagnostic optics, a mezzanine supporting the diagnostic lasers and their associated optics, the large CO_2 laser, and the pellet generator.

The support structure, vertical granite slab, mezzanine, large CO_2 laser and pellet generator are all mounted on an 10 × 6 × 1-1/2 ft granite table. The table surface has a maximum flatness runout of 0.01 in. and its thickness is sufficient to make the deflection from the supported weight negligible with respect to the surface flatness.

Vibration Isolation

The laser system, weighing approximately 45,000 lb, is supported on eight vibration isolators. They are pneumatically controlled by three independent actuators, as shown in Fig. 3, which define a reference plane. Two horizontal isolators are also mounted, each with separate actuators, along the vertical plane of the cantilevers to dampen any mechanical vibration transmitted by vacuum loading. Based upon dampening coefficients of 0.12 to 0.17 and natural frequencies of 1.5 to 3.0 Hz, simple, one-degree-of-freedom calculations showed the transmissibility to be no more than 6.3%. The amplitude of the 17-Hz vibration at each of the focusing mirrors would then be less than 0.01 μ. With estimated component weights, designed component locations on the granite table, and the 17-Hz excitation, a later dynamic computer analysis of the entire isolated laser system indicated responses as follows: a vertical natural frequency of 1.53 Hz; horizontal natural frequencies of 2.45 Hz and 2.02 Hz; a 5% transmissibility at 10 Hz; and a 1% transmissibility at 100 Hz. Tests have been run on the isolation system with almost all the equipment in place and with vacuum loading. Data show the transmissibility to be actually about 10%. A comparison of typical floor and granite table signals is shown in Fig. 4.

The support structure design was supplemented with a finite element structural analysis program, SAP IV.[3] Figure 5 shows the elemental model used in the program. Assuming 17 Hz excitation, the structure was designed not to be a mechanical amplifier. The design natural frequency of the support structure is 34 Hz, 10 Hz above the maximum frequency at which amplification occurs.

Many parts of the large CO_2 laser mirror mounts and the support structure are made of 304 stainless steel for its magnetic properties and strength. Some of the large CO_2 laser mirror mount assemblies weigh as much as 100 lb. Each of the cantilever assemblies

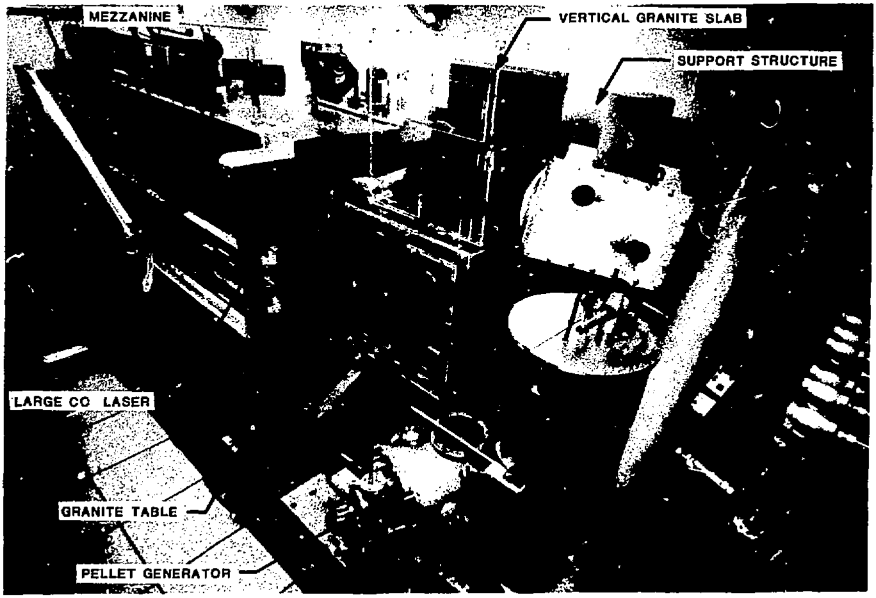

Fig. 2. Baseball II-T laser system.

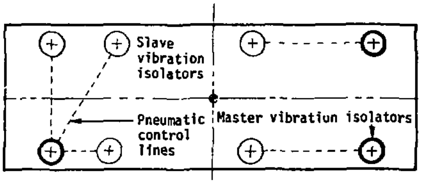

Fig. 3. Schematic of the granite table vibration isolation control.

weighs over 750 lb. The cantilevers themselves are made of 316 stainless steel because of its desirable behavior at cryogenic temperatures. The mezzanine is made of 6061 aluminum. This gives it the stiffness required to be an optical table for the diagnostic lasers, yet minimizes the change in height of the laser system center of gravity. Good machineability also lends the mezzanine deck to easy modification with changes in laser diagnostics. Its natural frequency has been measured to be approximately 150 Hz.

Environmental Control

To insure maintenance of dimensional stability of all laser paths, a temperature controlled room was built to house the entire laser structure. It is thermally stable at 72 ± 1/2°F for a designed internal load of 2.5 kW. Relative humidity is maintained at 30 ± 5%. In conformance with Federal Standard No. 209a,[4] air particulate is kept to less than 10,000 $ppft^3$ at 0.5 μ. This is necessary to minimize laser damage caused by dust on mirror surfaces. Room air is completely recirculated once every three minutes.

The room is constructed of wood, sheet rock and polyurethane panels. For added structural integrity, these panels are jacketed in either aluminum or steel sheet metal, depending on their proximity to the Baseball magnet. Removable roof panels allow access to the laser system with an overhead crane during any major assembly or disassembly. All environmental control equipment for the room is mechanically isolated and the duct work is acoustically dampened.

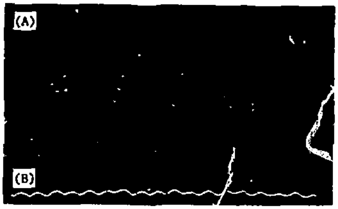

Fig. 4. A comparison of actual floor (A) and granite table (B) velocities.

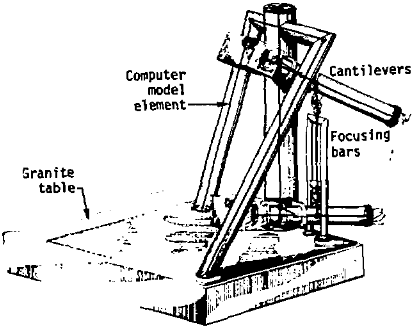

Fig. 5. The support structure and its elemental model.

Because of the 10.6-μ wavelength of the large CO_2 laser, sodium chloride windows were necessary to seal the laser gas and vacuum chamber of the Baseball magnet. These windows require a relative humidity less than 10%. For this reason, an acrylic plastic enclosure was constructed and continuously purged with dry nitrogen gas. It envelopes the sodium chloride windows and all of the large CO_2 laser optics mounted on the vertical slab.

Cryogenic Compatibility

Considerable thought was given to the mechanical stability of the sodium chloride vacuum windows, as failure would result in a catastrophic shutdown. The windows were designed with a nominal fracture safety factor of six, and were each tested to two atmospheres before use. The windows are mounted outside the cantilever turning mirrors so that in the event of failure, the shrapnel would have one collision with the turning mirror and a long flight path before impacting the focusing mirrors. This would minimize the energy of the shrapnel, and thus the damage to the focusing mirrors. Such care in protection of the focusing mirrors is important because these mirrors are off-axis parabolas, and very difficult and expensive to make. Automatically operated valves are located outside each window to minimize thermal shock and ice accumulation on the Baseball magnet in the event of window breakage.

The focusing mirrors and outer extremities of the cantilevers are maintained at 80 K. This interface with the Baseball II cryogenic system is done with long thermal paths and liquid nitrogen cooling lines. Under steady-state operations, each cantilever represents a 45-W heat load on the liquid nitrogen system. Because of the symmetrical focusing of the laser beam in the Baseball vacuum chamber, there are only negligible heat loads on the Baseball magnet from 300-K radiation through the 8-in. apertures made by the cantilevers. Each of the focusing mirrors reflects the room temperature radiation onto the other and back out the vacuum chamber. As the focusing mirrors are cooled through cantilever conduction, their alignment will be tracked with the He-Ne interferometer laser. The dimensional changes of these mirrors were considered in their design and any changes in focal length can be corrected with remote manipulators.

Optical Mount Design

All laser optical mounts are designed with 3-point suspensions. Such a design was sufficient to establish the plane of the optical surfaces. The large CO_2 laser uses eight mirror mounts[2]: four per beam path. The four mounts on the vertical granite slab operate at 300 K and 1 atm. Each mount has five degrees of freedom in adjustable motion (Fig. 6). A sixth degree of freedom is not necessary because the axis of all these mirrors must lie in the same plane.

On the inner ends of the cantilevers, the turning mirrors operate under vacuum at 300 K and have two degrees of freedom, both in rotation. More degrees of freedom were not necessary because the projected mirror surface is larger than the 8-in. aperture of the cantilever. On the outer ends of the cantilevers, the focusing mirror mounts have four degrees of freedom and operate in the vacuum at 80 K. In addition to the 8 large CO_2 laser mirror mounts, there are also approximately 20 smaller diagnostic laser optical mounts.

The large CO_2 laser mirror mounts on the vertical granite slab have an alignment resolution of 20 μrad. The turning mirror mounts on the cantilever fronts as well as the focusing mirror mounts on the cantilever ends have an alignment resolution of 50 μrad. Focusing bars can resolve a motion of 200 μ at the focusing mirrors in the direction of the focal axis. Because of the cylindrical shape of the focal zone, this should be sufficient resolution.

Conclusion

Designing the Baseball II-T laser system required addressing a number of mechanical parameters. Low frequency floor vibrations have been reduced to 10% of their excitation levels by dampening with a large granite table supported on vibration isolators. Mechanical vibration had been further suppressed by designing the various structures on the granite table to be of relatively high natural frequency. Acoustical noise levels have been reduced and environmental stability has been achieved with a temperature controlled room. A temperature of 72°F and a relative humidity of 35% have been maintained. The relative humidity is locally reduced to less than 10% for the protection of sodium chloride windows. Careful optical design, long thermal paths, and liquid nitrogen cooling lines all maintain the compatibility of the 300-K laser system with the cryogenic environment of the superconducting Baseball magnet.

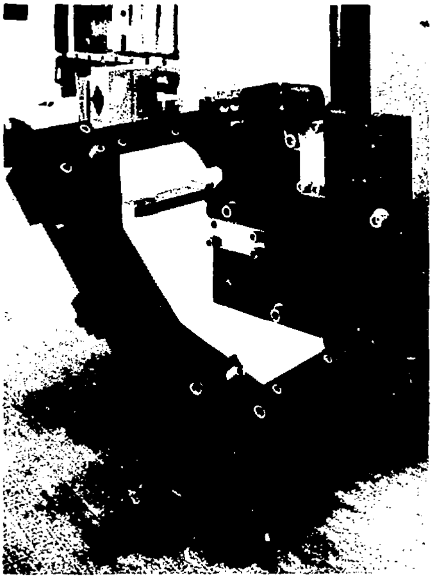

Fig. 6. Typical large CO_2 laser mirror mount used on the vertical granite slab.

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