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# Modal Testing and Analysis
## of
## Nova Laser Structures

*MASTER*

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## DISCLAIMER

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## NOVA LASER STRUCTURES*

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## ABSTRACT

NOVA, currently the world's most powerful laser system, is an ongoing project at the Lawrence Livermore National Laboratory in California. The project seeks to develop a feasible method of achieving controlled fusion reaction, initiated by multiple laser beams targeted on a tiny fuel pellet. The NOVA system consists of several large steel framed structures, the largest of which is the Target Chamber Tower. In conjunction with design engineers, the tower was first modelled and analysed by sophisticated finite element techniques. A modal test was then conducted on the tower structure to evaluate its vibrational characteristics and seismic integrity as well as for general comparison to the finite element results. This paper will discuss the procedure used in the experimental modal analysis and the results obtained from that test.

## INTRODUCTION

The NOVA laser system is entering its final stages of construction at the Lawrence Livermore National Laboratory. (See fig. 1). In order to achieve fusion ignition, 10 large diameter (74 cm.) laser beams are focussed on a small diameter (200 $\mu$m) fuel pellet in a $4\pi$ symetrical pattern. To accomplish this goal, three large structures are integrated together to facilitate the amplification, turning and targeting of the laser beams. The structures are constructed of 6" square tubing welded together in a spaceframe configuration. The first structure, the Laser Spaceframe, is a long, narrow rectangular frame (20 ft. x 200 ft. x 25 ft. high) used to mount the laser amplifiers, spatial filters and optical isolation equipment. The second structure is the Switchyard Tower. This is a series
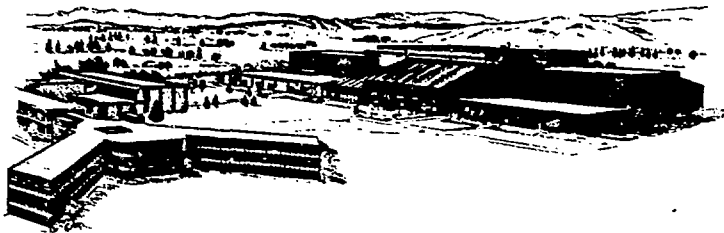


figure 1. NOVA Laser Fusion Facility

of smaller rectangular towers clumped together (10 ft. x 15 ft. x 25 ft. high) and used to mount large optical turning mirrors and laser beam diagnostic equipment which take the amplified beams from the first structure and steer them to the final structure, the Target Chamber Tower. This is the largest and vibrationally, the most crucial of the three structures (25 ft. x 75 ft. x 60 ft. high). During this final stage, the beams are received from the Switchyard Towers and directed into the target chamber mounted in the center of the structure at which point the fusion ignition is initiated.

The fact that each beam must travel long distances and be redirected several times, coupled with a target size barely visible with the naked eye, has provided ample reason for a focalized investigation into the vibrational characteristics of the NOVA system. Initially, the structures were modelled using sophisticated finite element techniques. The models were used to examine both the static and dynamic load conditions under which the structure might operate. Once the main construction was completed, each of the structures were dynamically tested. This report discusses the dynamic test results for the largest and most complicated of the structures, the Target Chamber Tower.

## TARGET CHAMBER TOWER TEST PLAN

Generally described, the Target Chamber Tower is an elevated rectangular platform upon which is mounted a 14 ft. diameter, 5 inch thick, multi-ported, spherical aluminum chamber which will house the target pellets used in the fusion reaction. Surrounding the platform are four towers, connected transversely and longitudinally by long rectangular box frame systems. (See fig. 2). In these towers are located the final turning mirrors which direct the laser beams to their desired target in the chamber.

The complete structure has over 50 thousand degrees of freedom, making it inconceivable to obtain experimental results at each member joint. A simplified frequency response function model was constructed using 148 nodal points located at main vertical and horizontal beam connections.



*figure 2. NOVA Target Chamber Tower*

Whenever possible, the nodes were located on the outside perimeter of the structure. (See fig. 3 Note: The target chamber is not included in this model as a seperate modal test is being completed on the spherical structure). The X and Y orthogonal directions were aligned with the East/West and North/South construction of the facility. The Z-direction (vertical) modes were not examined in this test as their contribution was considered insignificant with respect to the other orthogonal directions.

The Target Chamber Tower structure was excited by means of an electro-magnetic shaker. The shaker was suspended from an overhead construction crane, independent of the structure itself and was attached horizontally about 3/4 of the way up the structure at the east end. (See fig. 4). The shaker was mounted to a non-orthogonal (to X or Y) structural member, thereby allowing bi-directional input excitation from the single location. A load cell was placed between the shaker pusharm and an aluminum mounting plate to measure the input
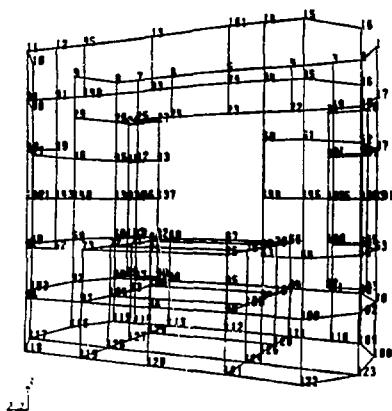
*figure 3. Frequency reponse model*

signal from the shaker to the system. (See fig. 5). The whole configuration was then C-clamped to the structural member. The output, at each of the designated nodes was measured using piezo- resistive accelerometers. The accelerometers were mounted such that measurements were always taken in the global X and Y directions. (See fig. 6). The shaker was driven by a periodic random Gaussian noise signal. The



*figure 4. Shaker suspended from crane*

input range of evaluation was between 0 and 45 Hz. To increase the frequency resolution, the overall bandwidth (45 Hz.) was divided into nine subdomains of approximately 5 Hz. each. This increased the frequency resolution from 0.35 Hz. to 0.04 Hz. .To improve the signal-to-noise ratios and to aid in removing non-linearities, standard averaging techniques were employed. Due to construction activity, constant watch over the quality of the collected data was maintained by the operator. Any spurious data which might have contaminated the data was thrown out and new measurements were
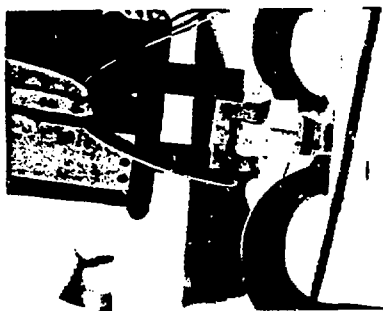


*figure 5. Shaker mounting scheme*

taken. In general, 4 averages were sufficient to obtain reasonably clean frequency response functions.

After verifying the quality of the frequency response functions, the data was transferred to a floppy disk by way of an IBM Personal Computer. In all, 2664 frequency response functions were collected- and stored. The subsequent processing, as well as the data collection, was done using a modal analysis software package developed by Modal Test Associates (MTA) of San Jose.

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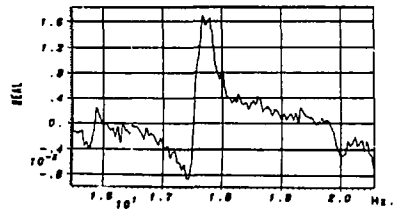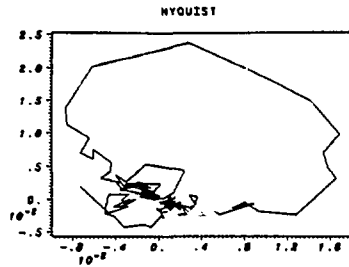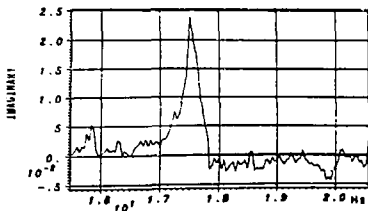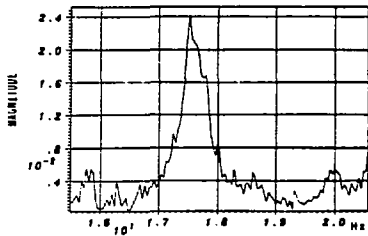
Typical response function data for tower

| Mode # | Frequency (Hz) | Damping (%) |
|---|---|---|
| 1 | 5.60 | 0.41 |
| 2 | 6.40 | 0.42 |
| 3 | 7.40 | 0.45 |
| 4 | 8.30 | 0.40 |
| 5 | 11.45 | 0.45 |
| 6 | 11.88 | 0.34 |
| 7 | 12.28 | 0.37 |
| 8 | 13.03 | 0.45 |
| 9 | 14.25 | 0.42 |
| 10 | 15.77 | 0.40 |
| 11 | 16.99 | 0.45 |
| 12 | 17.56 | 0.70 |
| 13 | 17.62 | 0.90 |
| 14 | 19.95 | 0.60 |
| 15 | 20.63 | 0.43 |

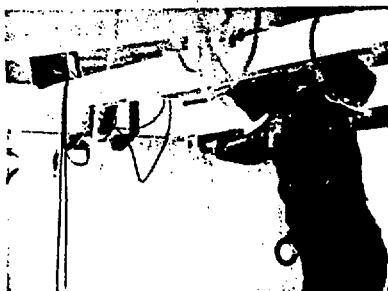TABLE 1. Target Chamber Tower — first fifteen modes

*figure 6. Mounting accelerometers*

## RESULTS AND CONCLUSIONS

Listed in Table I are the frequencies and damping for the the first fifteen modes. The most significant and useful results obtained from the modal test were the modal damping parameters. In most structural systems, mass and stiffness values can be calculated easily by knowing physical specifications or by using generalized expressions. On the other hand, methods of computing energy loss in structural systems are not fully understood. Trying to evaluate damping coefficients by using generalized damping expressions is at best an educated guess. For this reason, modal analysis tests provide a viable means of experimentally determining the damping parameters. These damping coefficients are of great value to those in finite element analysis for it gives them a "real world" parameter to use in their models.

Using MTA software, nearly all of the modeshapes proved to be complex in nature. The travelling wave patterns throughout the structure and the large number of members in this complicated structure make spatial comparisons with the finite element results very difficult, time consuming and hence, costly. The finite element code used to model the structure (Gemini) uses normal mode analysis techniques and therefore, does not compute complex modeshapes. Because of this, only broad, qualitative comparisons have been made to date. Both methods of analysis yielded many closely spaced modes below 20 Hz. This tells the NOVA engineers that any outside input (ie. cryo-pumps, air conditioning, workmen) is likely to excite a mode. Currently, a modal test is underway to examine the vibrational characteristics of the chamber itself. Results from the tower test will be input to determine what kind of sensitivity the chamber has to dynamic input for the frequency range found to be of most interest in the tower test. Knowing the kind of response the tower will transmit to the chamber will be of great importance in determining the targeting of the laser beams on the tiny fuel pellet. Finally, looking at the animated modeshapes allows for the pin-pointing of problem areas in the structure. As expected, the top portion of the structure has far more motion than does the chamber platform area. One phenomena, possibly adding to the complex behavior of the structure was a slab-like motion of each of the floor levels in the tower. This uniform floor level motion may have a detrimental effect on ability of the turning mirrors to accurately bounce the input laser beam. Knowing this, designers and analysts can further evaluate sensitive areas like the mirror mounts, lens positioners and beam tubes to see if any structural modification is necessary to insure the success of the NOVA laser system.

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