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QUARTERLY REPORT
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CONTINUED PROTOTYPE RESEARCH & DEVELOPMENT AND PLANNING FOR THE CALTECH/MIT LASER GRAVITATIONAL-WAVE DETECTOR (PHYSICS)

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I. INTRODUCTION

This report summarizes the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from July through September 1991, including work of the Caltech and MIT science groups and the engineering team located at Caltech. Principal foci of research and development activities were:

- Interferometer prototypes
  1) development and testing of technologies needed for full-scale LIGO interferometers
  2) reliability and sensitivity enhancements of prototypes
- LIGO development

II. PROTOTYPE ACTIVITIES

A. 40-Meter Prototype

Characterization of Interferometer Noise Sources. The characterization of interferometer noise sources was disrupted by an earthquake which struck near Pasadena on June 28. Although there was no direct damage to the vacuum system or the interferometer optical surfaces, the shaking did collapse several vibration isolation stacks, and caused minor damage to some of the optics suspensions in the form of broken suspension wires, actuator magnets, etc. Motion limiters, which had been installed around some suspended components to protect them from such events, passed a significant test; motion limiters were installed around the remaining suspended components as repairs to the interferometer proceeded. Normal interferometer operations resumed three weeks after the earthquake. Unfortunately, the laser for the 40-meter interferometer failed in late July, requiring replacement of the laser's plasma tube.

In spite of these setbacks, a number of improvements to the prototype were made this quarter. The input optics to the interferometer were rebuilt, replacing components which either degraded beam quality or introduced significant losses. This resulted in a twofold improvement in efficiency of coupling light into the interferometer. New, lower noise electronic controllers for the test-mass orientation system were constructed and installed. The electronics for damping the 1 Hz pendulum motion of the test masses were improved, resulting in greater efficiency in interferometer operation.

Measurements with the new test-mass orientation and damping control systems indicate that noise introduced by the current servo systems should not prevent the interferometer from achieving displacement noise below $2 \times 10^{-19} m/\sqrt{\mathrm{Hz}}$.

Interferometer measurements concentrated on noise mechanisms which affect performance below 500 Hz. Experiments were performed to understand, in detail, the mechanisms by which seismic motion affects interferometer noise. We initiated measurements of the transfer functions from ground motion to interferometer output. An important preliminary result implies that a number of peaks in the interferometer noise are associated with resonances in the test-mass suspensions.

New 40-Meter Vacuum System Configuration. Fabrication and testing of the new vacuum chambers has been completed by the subcontractor, Mill Lane Engineering (Lowell, MA). Acquisition of other long-lead items for the new system has begun to ensure that the vacuum envelope can be assembled as soon as budget and ongoing prototype work permit.

Laser Stabilization. The task of stabilizing the frequency and output power of a large-frame Spectra-Physics argon-ion laser is nearly complete. Construction and shakedown have been completed and initial measurements of laser frequency stability are in progress.

Suspended-Mirror Mode Cleaner. Development of a triangular 12-meter mode-cleaning cavity which uses separately suspended and controlled mirrors has begun. This cavity is designed for use as the input-optics filter cavity in LIGO. The suspension, position-, and orientation-control systems for the mirrors will incorporate new knowledge gained from the 40-meter prototype and will test key features of LIGO designs. Initial development and testing of this cavity will be done in the LIGO Optics Laboratory; final testing will be done after installation into the 40-meter prototype.

B. Stationary Interferometers

Experiments have begun to test optical topologies and modulation schemes for the initial LIGO interferometer. Two options have been analyzed and will be prototyped.

In the first topology, the optical modulation required for signal extraction is applied externally to the main interferometer, in a manner similar to earlier stationary interferometer experiments. This earlier setup is being modified to more realistically test a possible LIGO design. This requires that the interferometer, which is located at MIT, be moved to a larger experimental space. This has necessitated the rebuilding and frequency stabilization of a new laser, establishment of a clean and quiet environment, and the duplication of some control electronics. Once the interferometer is installed, a series of tests will be performed to determine the suitability of various aspects of the scheme.

The second topology being tested uses an imbalance in the lengths of the two interferometer arms to allow a modulation of the input light to be passed through the interferometer. An interferometer using this scheme is being assembled at Caltech to allow a parallel set of measurements.

The information from these two sets of tests will be combined to choose an optical topology for the initial LIGO interferometers.

C. Vibration Isolation

A stack composed of elastomer springs and concentrated masses with lowest internal resonance frequency above 1 kHz has been designed and modeled with finite element analysis. The stack is expected to meet the goals of the initial LIGO interferometer.

A scale model of the stack was assembled and tested in air and exhibited the anticipated isolation and horizontal stability. A full-scale vacuum compatible stack is currently being assembled and will be tested in vacuum.

D. Optics Testing and Development

A set of monolithic test masses (in which the mirror surfaces are ground, polished, and coated directly onto the fused-silica test masses) were completed this quarter. The 4-inch diameter test masses are available to replace the present composite test masses (in which the mirror is joined to the mass by an optical contacting technique) in the 40-meter prototype. The new masses are nearly identical in construction to the masses which will be used in the initial LIGO interferometer (although compatibility with current test masses determined the physical size).

An apparatus for measuring total integrated scattering from mirrors at the part-per-million level has been completed.

An experiment to measure the effects of high light levels on mirrors has achieved circulating power levels of 3.5 kW (intensities of 1.2 MW/cm^2) in optical cavities, and calorimetric measurements of mirror absorption at these power levels are planned. The scattering and absorption data, along with transmission and reflectivity measurements, will provide complete mirror characterizations to guide future optics development.

III. LIGO DEVELOPMENT

A. Sites

Technical evaluation of proposals submitted in response to the public solicitation for LIGO sites continues. An implementation plan for the site selection process was approved by NSF, and work has begun to assemble an independent review committee. Additional information or clarifications have been gathered for 13 of the 19 proposed sites through site visits or letter requests, and visits to two more sites are planned. A final report on site evaluations will be completed in October, and reviewed by the committee in November.

B. LIGO Beam Tube Investigations

An empirical model of water vapor outgassing after low-temperature bakeout, based upon data derived after a 100°C 30-day bakeout of a 2 ft. diameter by 120 ft. long beam tube section, was formulated. The model fits the data well and highlights the importance of water readsorption in determining the ultimate water pressure and of relaxation times in the vacuum system. Tests are currently underway to verify predictions of the model. The model will be applied to the full scale LIGO vacuum system to establish bakeout times and temperatures as well as to confirm the pumping strategy.

The hydrogen outgassing of the demonstration beam tube behaves differently from earlier test chambers. A possible cause is the reintroduction of hydrogen or increased permeability of hydrogen by the welding process used in tube fabrication. This and other hypotheses are currently being tested both in the vacuum test facility and in material science laboratories.

C. LIGO Scattering and Stray Light Analysis

A subcontract is being developed to carry out computer simulations of the optical scattering properties of LIGO interferometer components and the LIGO beam tubes. The numerical analysis is intended to check the results of prior analytic work and to give assurance that no important scattering mechanisms or stray light propagation paths have been overlooked.

IV. OTHER ACTIVITIES

The following papers, summarizing talks given at the Marcel Grossmann Conference in Kyoto, Japan, were submitted for the conference proceedings: "The U.S. LIGO Project," by R. Vogt; "The LIGO 40-Meter Prototype Laser Interferometer Gravitational-Wave Detector," by M. Zucker; and "Test Mass Orientation Noise in the LIGO 40-Meter Prototype," by S. Kawamura.

An article, "Prototype Michelson Interferometer with Fabry-Perot Cavities" by D. Shoemaker, P. Fritschel, J. Giaime, N. Christensen, and R. Weiss was published in *Applied Optics*, **30**, 3133–3138.

An article, "LIGO: A New Initiative in the Exploration of the Universe," by R. Vogt, was published as an opinion piece in National Geographic's *Research & Exploration*, Spring 1991.

An article, "Lasers, Mirrors, and Gravitational Waves," by F. Raab was published as a feature article in *Engineering and Science*, **54**, 3, (1991), a Caltech periodical.

A review of the book, "The Detection of Gravitational Waves," edited by David Blair was written for *Nature* by R. Weiss.

V. PERSONNEL CHANGES

The search for a new Research Scientist at MIT, replacing Mike Burka, has ended with an offer to Yaron Hafetz, who began working on the LIGO project on September 23.

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