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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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INTRODUCTION

This report covers the Laser Interferometer Gravitational Wave Observatory (LIGO) Project activities from April through June 1989, including work of the Caltech and MIT science groups and the engineering team located at Caltech. Principal foci of research and development activities were:

a) Interferometer prototypes
  i) development and testing of technologies needed for full scale LIGO interferometers
  ii) work towards sensitivity enhancements of prototypes
b) Conceptual design of LIGO

A major effort was started on the LIGO construction proposal which is to be submitted to the NSF during the next quarter.

1. PROTOTYPE ACTIVITIES

A. 40-meter Prototype

The improved beam-injection system, which encloses all critical optics within a contiguous vacuum envelope, was completed and tested. Laser stabilization to the reference cavity was improved over previous results by a factor of 4, to 0.4 $Hz/\sqrt{Hz}$. Tests for first-order coupling from fluctuations in the laser frequency and amplitude to the interferometer output indicate that these noise sources will not limit performance. Improved circuitry to eliminate the effect of residual frequency noise by applying balanced forces to masses in each interferometer arm was developed; tests in the new optical system showed suppression of this effect by a factor of at least 500.

The optical-sensing, magnetic-forcing transducers designed to control the position and orientation of suspended components were improved by upgrading the sensors to work with 100 kHz amplitude modulation. Electronics to transform the combined signals from three sensors to a 3-degree-of-freedom readout of position and orientation, and back again to force-feedback signals, were completed and tested on the bench.

Construction of most of the mechanical and vacuum components needed for the next major modification to the prototype apparatus—subdividing the beamsplitter test mass into several separately suspended components—was completed. Preliminary plans for implementing this change in stages were developed.

B. Stationary Interferometer (5-meter System)

The stationary, in-air, interferometer became functional at the end of the last quarter. During this quarter, work has concentrated on understanding and improving the performance of the system. At the beginning of May the main interferometer, comprised of both Fabry-Perot cavities, had a noise level approximately 40 times greater than shot noise at frequencies above 10 kHz and with 30 mW of injected laser power. The Michelson interferometer, comprised of the two cavity input mirrors and the beamsplitter, was at shot noise in the same band. Since May the principal effort has been directed to analyzing the difference in performance of these two configurations. The noise in the three outputs of the interferometer, the two cavity pickoff signals and the antisymmetric recombined output signal, is strongly correlated even when the two Fabry-Perot cavities are closely matched in storage time. This implies that the excess noise at the antisymmetric output is due to a conversion of frequency noise to amplitude noise by either the phase modulating crystals or by parasitic reflections in the interferometer input optics that are different in the two interferometer arms. In the last month we have analyzed the reflections in the system and have replaced components which are sources of reflection and back scatter. Associated with this we have made measurements of the propagation of the AM and FM sidebands through the stationary interferometer. Concurrently we have been reducing the frequency noise of the laser by improvements in the bandwidth and gain of the frequency stabilization servo system. The system has now been reassembled to make overall noise measurements.

C. Optics Testing

This past quarter saw progress in the development of optical testing procedures. Because light scattering from optical surfaces may be a significant noise source in the LIGO, a facility for measuring scattered light from optical substrates and coatings is under design. An infrared technique to measure the heating by absorption in coatings and in the bulk material of optical components was tested and shows promise of distinguishing scattering from absorption loss. These measurements will be performed in vacuum using infrared imaging of irradiated components. Data on the spatial distribution of intrinsic birefringence and refractive-index inhomogeneities of fused-silica mirror blanks, collected in the last quarter, are being analyzed.

Tests of power-handling ability of low-loss mirrors continued, with encouraging results: a cavity specially constructed to exhibit thermal distortions withstood the maximum power available—corresponding to loss of 0.4 watts per mirror—without negative effects.

A cavity ring-down apparatus to measure the optical absorption loss in materials was built and used to obtain preliminary results for a superpolished fused-silica blank. An upper limit of 60 ppm for the fractional loss of light through a 1 centimeter thickness of fused silica was measured. The apparatus is readily adaptable for testing other samples and other materials, and the geometry is similar to proposed LIGO interferometer designs.

D. Suspension Research

The double-pendulum suspension system has been undergoing further tests in the suspension test vacuum chamber. Its isolation has been measured up to 250 Hz, where the transmission is −160 dB. It follows the predicted f^{-4} behavior up to about 100 Hz. At higher frequencies, resonances in the springs associated with the wire suspension of the outer mass appear.

The suspension is now being instrumented for tests of the electrostatic actuator system, which will be used to apply forces to the test masses needed to lock the interferometer.

A new effort was begun to measure the mechanical loss in tungsten wires and other candidate pendulum flexures. Mechanical loss is the parameter which determines the thermal noise in the test-mass suspension. Sample wires are placed in a small vacuum chamber, where the Q's of several of their flexural normal modes can be measured. The modes are excited electrostatically; the wire response is observed with an optical shadow sensor. So far, we have obtained Q's of about 3000 for the lowest few normal modes of a 30 cm long, 9 mil thick tungsten wire. When the systematic errors in the measurement are understood, we will measure tungsten and sapphire wires and ribbons of several different sizes.

2. LIGO DEVELOPMENT

A. Sites

The biological survey of one of the potential LIGO sites at Edwards Air Force Base, California, was completed, submitted to, and accepted by the Air Force. The preliminary archeological/paleontological survey (Phase 1) was submitted to and accepted by the California State Historical Preservation Office. This survey brings together existing applicable records and surveys, and recommends that additional survey work be performed in several specific regions to determine the impact of LIGO construction on areas of cultural significance, as defined by the National Historic Preservation Act of 1966.

B. Vacuum Test Facility (VTF)

Chamber samples #3 and #4 of special low-hydrogen content steel were pumped down, and the outgassing results confirmed the previous conclusion that steel mill processing can reduce hydrogen outgassing by a factor of 1000. We have also learned that steam cleaning effectively eliminates hydrocarbon contamination from these stainless-steel samples, and does not negatively affect water outgassing properties. Water outgassing rates from the four test chambers (one uncleaned, one cleaned with cold water and detergent, one cleaned with hot water and detergent, and one steam cleaned with a detergent solution) are essentially the same.

C. Conceptual Design

Significant progress was made in the following areas:

- Modular vacuum chamber concept:

A complete set of vacuum envelopes was designed and documented. Cost data were solicited for the input/output optics chambers (22 companies) and for the test mass/air lock chamber (8 companies).

- Beam tube design:

Cost tradeoffs for several wall thicknesses were evaluated, based upon cost data obtained from two spiral-pipe manufacturers.

We visited Pacific Roller Die, Inc. (PRD), a manufacturer of spiral-pipe-forming equipment, to investigate the feasibility of employing corrugated pipe for the LIGO beam tube application. PRD provided a cost estimate for forming the beam tubes with spiral welded, corrugated stainless steel. A stress analysis of corrugated pipe was initiated and a test using commercially available galvanized steel corrugated pipe to verify the analytical results has been planned; this test will be carried out in the next quarter.

- General vacuum system topics:

A new LN_2 pumping strategy was developed to handle the large condensible gas loads of the modular chamber concept. A conceptual design of the LN_2 pumps was developed, and an analysis of the complex spatial transient gas load was completed.

A conceptual design and a cost estimate for the monitoring and control equipment of the vacuum system was developed.

A cost estimate for leak testing the beam tubes and chambers was developed.

- Enclosures:

New floor plans for the corner, mid, and end station enclosures were developed to handle the new modular chamber concept, and cost estimates were generated. A concept for crane coverage of the station enclosures was developed. Requirements for HVAC equipment were evaluated and a cost estimate was prepared.

- LIGO Interferometers:

A servo analysis of a recombined Fabry-Perot interferometer was carried out. The results of the analysis modified the servo strategy for the initial LIGO interferometers.

The design of initial LIGO interferometers, including modulation and optical filtering techniques, was developed. A detailed study of the optical, electronic, and mechanical components required for the initial LIGO interferometers was initiated, including establishing requirements on component size and count, deciding the placement of components, and estimating the total cost.

- Additional Conceptual Design Items:

An analysis of the losses in the recoil of suspension supports was completed.

A one-dimensional analysis of the heating and associated wavefront distortion in optical materials was carried out.

3. OTHER PROGRESS

Substantial progress has been made in unifying the computing environment at Caltech and MIT with the SUN system. The system now has common software for engineering and scientific analysis at both locations.

An NSF/LIGO meeting was held at Caltech on April 10 and 11, 1989. LIGO design concepts, preliminary cost estimates, and management aspects were discussed.

The major effort to plan and write the construction proposal for the LIGO project has begun. This proposal is to be submitted to the NSF in the next quarter.

4. INTERNATIONAL COOPERATION

As agreed at the 2/14/89 NSF convened workshop at Paris, France, LIGO personnel have taken on the coordination of two international working groups: vacuum systems and control systems. The LIGO team also has assigned members to all other working groups coordinated by European scientists.

Full engineering and science briefings on the LIGO project were given, over the period of several days, to Drs. Hough and Leuchs, the respective leaders of the British and German gravity wave research groups. Similar courtesies were extended to Dr. Blair, who is organizing a new laser interferometer program in Australia.

Information on engineering advances also is being provided to Britain's Rutherford Laboratory on a continuing basis.

5. PERSONNEL CHANGES

Richard Benford, who has provided engineering and technical support to the laboratory for over 15 years, has taken a new technical/management position in the MIT Center for Space Research.

Nelson Christensen, a fourth year graduate student who has been working on the stationary interferometer, will do his PhD research on a theoretical problem concerned with the detection of a stochastic background of gravitational radiation by a network of interferometric detectors.

Pasadena, June 28, 1989

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