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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 covers the Laser Interferometer Gravitational Wave Observatory (LIGO) Project activities from April through June 1990, 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) work towards reliability and sensitivity enhancements of prototypes
- LIGO development

II. PROTOTYPE ACTIVITIES

A. 40-meter Prototype

Servo Refinements. Cascaded, high-Q resonance-cancelling circuitry was added to the mode cleaner feedback loop, resulting in higher gain feedback to the piezo-mirror that adjusts the mode cleaner length.

Installation of Improved Mode Cleaner. A replacement 90-cm-long mode cleaner, with improved optical efficiency and mechanical properties, was installed. The replacement mode cleaner design eliminates a mirror degradation problem due to contamination from a bonding material used on mirrors and piezos.

Investigations of Interferometer Noise. Shot-noise limited performance at a bright-fringe power of 60 mW and at frequencies above 2 kHz was verified by measurements of system response to incandescent light sources, and corroborated by comparison of observed sensitivity with calculations.

Several noise sources below 2 kHz were identified, including late-stage electronic noise, spurious interferometers (likely due to inadequate rejection of beams reflected between the input cavity mirrors and the mode cleaner output mirror), second-order polarization modulation from Pockels cells, and possible nonlinear effects in the photodiodes converting out-of-band laser frequency noise to frequencies of interest. These noise contributions will be studied in detail in the new interferometer configuration (see "Separate Suspension of Beam-Splitter Components," below).

Test Mass Orientation Coupling Coefficients. Measurements were made of the coupling between test mass angular displacements and interferometer output. The results are in agreement with a static displacement of less than 2 mm between the center of rotation of the mass and the cavity beam axis. Measurements indicated that with the orientation control system tested in the previous quarter, this effect contributes less than 3% to the total observed noise, at all frequencies above 300 Hz.

Separate Suspension of Beam-Splitter Components. Previously, the 40-meter interferometer system included a large, complex suspended mass to support the beam splitter and other optical components. Plans and preparations to remove the complex mass and provide separate suspensions for these optical components were completed. All parts and assemblies required to implement this task were received and tested, and integration into the 40-meter system was begun. Several interferometer measurements were made for documentation purposes before installation of new components, including parameters of seismic isolation stacks and orientation fluctuations of the beam splitter.

Transmitted Light Monitors. Photodiodes to monitor light transmitted through the 40-meter cavities were installed, to aid in alignment and the measurement of optical storage times.

Planning for Rebuild of Interferometer. Design work for new chambers, tubes, pumps, and facilities modifications to provide the 40-meter interferometer laboratory with expanded capabilities was started. The plans—still in the conceptual design phase—provide greatly increased space within the vacuum system. This will improve the efficiency of operations with the current interferometer configuration, and will permit testing of selected full-scale LIGO components and techniques. The planned configuration will use the 60-cm-diameter tube sections being prepared for the LIGO beam tube investigations (see below).

B. Stationary Interferometer

Research on a rigid recombined Fabry-Perot interferometer using in-line internal modulation has been completed. The results of the research have been submitted for publication ("A Prototype Michelson Interferometer with Fabry-Perot Cavities").

The interferometer has been reconfigured for broadband recycling and external modulation, a candidate system for the initial LIGO interferometer. The mechanical, optical and electronic components for this test have been assembled and installed. The sequential steps in the research program are:

1) Operation of a single Fabry-Perot cavity coupled to a recycling cavity using an external optical phase modulator to develop the sidebands for locking both the Fabry-Perot and the recycling cavity. This is currently being tested and will give information on the coupling efficiency, mode filtering and power gain in a broadband recycled interferometer.

2) The addition of a second Fabry-Perot cavity and a beam splitter to establish a recombined and recycled configuration.
3) The addition of an external reference beam derived from the optical field within the recycling cavity to complete the configuration.

C. Vibration Isolation and Thermal Noise Studies

Vibration Isolation. Design and construction is proceeding on a prototype passive vibration isolation system for the 5-meter and the rebuilt 40-meter interferometer prototypes and as a candidate for the initial LIGO interferometer. Procurement and machining has begun on a straightforward design using unencapsulated "Viton" elastomer conical springs and dampers supporting 5 isolation stages in series. The stages are isotropically supported with fundamental resonances between 5 to 10 Hz. Each stage has a mass of approximately 70 kg. The calculated isolation factor is sufficient to meet the proposed goals for operation of the initial LIGO interferometer at frequencies above 100 Hz.

Instrumentation has been developed to measure the isolation performance of the system, including low noise electronics to improve PZT accelerometers and a newly-designed prototype laser cavity interferometric accelerometer that is undergoing test.

Thermal Noise. Analysis and preliminary experiments are being carried out to determine the feasibility of measuring the off-resonance thermal noise in the internal modes of a mirror using an interferometric measurement of the mirror-motion induced optical phase fluctuations in two optical modes of the same rigid cavity. The two cavity modes are chosen to sample different parts of the mirror. The measurement is important in estimating the thermal noise, especially in advanced LIGO interferometers.

III. LIGO DEVELOPMENT

A. Site Selection

A proposed site selection procedure, including selection criteria, was prepared and submitted to the NSF. In conjunction with this proposal, we furnished a history of site searches conducted to date. Site related activity this quarter included three candidate sites:

Hanford, Washington. USGS topographical maps of the Department of Energy Hanford facility with four proposed alignments for the LIGO were received. The site properties of this nuclear facility have been well characterized and documented, and the DOE contractor furnished us with a substantial amount of relevant data. The site appears to be a promising candidate for a LIGO installation.

Owens Valley, California. The Los Angeles Department of Water and Power granted permission to carry out limited geotechnical surveys of the property. These surveys are planned to be conducted during the next quarter.

Stennis Space Center, Mississippi. USGS maps and other technical data regarding this western Mississippi site were received. The area suggested for the LIGO lies partially outside the boundaries of the government-owned facility, in an area which is flat but crossed by streams. The data have been placed on file for future reference.

B. LIGO Interferometer Design and Optics Research

Interferometer Design. A team was formed to begin design of the first interferometers to be used in LIGO. Initial work is focusing on producing a hierarchical description of the interferometers.

Low-loss Mirrors. A new batch of mirrors was manufactured (two of which were assembled into the new mode cleaner) to test the effectiveness of new substrate cleaning procedures and to establish procedures for obtaining very high quality antireflection coatings (R $<$ 100 ppm, necessary for obtaining high recycling factors in planned interferometers). The new cleaning procedures, developed as a result of improving our optical inspection and testing capabilities, resulted in a significant improvement in mirror quality.

Expanded Laboratory Space. The Caltech administration allocated funds to provide more than 2000 ft^2 of additional laboratory space to support optics testing and development for LIGO. We expect to occupy the new facility (located in the West Bridge building) after completion of renovations near the end of this year.

C. Experiments with the Vacuum Test Facility (VTF)

The low temperature (90°C), extended (700 hr) bakeout of a steam-cleaned chamber achieved acceptable outgassing rates for water vapor and hydrogen. We now feel confident in adopting a low temperature bakeout strategy for the LIGO beam tubes, with considerable reduction in costs compared to standard bakeout techniques (our December 1989 Construction Proposal anticipated and incorporated this cost reduction). We are testing the same bakeout method on an uncleaned chamber, and plan to use the low-temperature technique for the beam tube investigations (below).

D. LIGO Beam Tube Investigations

Preparatory work for testing of techniques for construction of LIGO beam tubes is underway. Objectives of the beam tube investigation are: 1) to demonstrate that the annealing process for low-hydrogen steel is reproducible; 2) to show that the spiral welding process introduces no surprises; 3) to show that the baked tubing meets LIGO outgassing rate requirements.

A coil of low-hydrogen steel from a fresh production run was received and spiral welding of 60-cm-diameter tube sections is in process. We are testing two weld processes. The test section is expected to be set up and pumped down by mid-summer. After completion of the tests, the tube sections will be reserved for installation in the new vacuum system for the 40-meter prototype interferometer.

E. LIGO Procurement Documents

Draft procurement documents for the major LIGO subcontracts (facility A&E design, facility construction, vacuum equipment design and construction, and beam tube design and construction) were prepared. Our schedule calls for release of RFPs for A&E design work and vacuum system elements during the summer.

IV. OTHER ACTIVITIES

The LIGO project has continued to support NSF with technical data and analyses needed for planning and congressional activities.

N. Christensen's PhD thesis (MIT) on the detection of a stochastic background of gravitational waves using a network of interferometers is in draft form. He will defend his thesis at the end of July 1990.

A paper, "Thermal Noise in Mechanical Experiments," by P. Saulson, has been submitted for publication.

V. CONCERNS

The uncertainty of ultimate approval of the LIGO construction proposal continues to make it essentially impossible to recruit urgently needed, high quality senior staff to support ongoing tasks. Project schedules, nevertheless, must be maintained, resulting in a heavy overload on key members of the project. This serious problem cannot be resolved until the NSF accepts some form of long-term institutional responsibility for the LIGO.

The budget reductions imposed on the 1990 program at MIT negatively affected activities both at MIT and at Caltech. At MIT, the procurement of long-lead items for interferometer optics and vibration isolation systems cannot be initiated, and prudent additions to technical and scientific staff cannot be considered. When project decisions are made to standardize on tools and techniques, MIT is often unable to respond. For example, after agreeing to establish common data-acquisition hardware in the 40-meter and 5-meter laboratories, the equipment for the 5-meter laboratory ($100K) had to be covered from the budget reserved for Caltech tasks. Thus, the budget reduction impacts the entire LIGO project. A full or partial restoration of the sequestered funds for MIT would be most helpful.

VI. PERSONNEL CHANGES

E. Franzgrote, Assistant to the Director, has left the LIGO project to accept a position at JPL. An important factor in his decision was the uncertain future of LIGO.

Dr. Seiji Kawamura (the key scientist for the Tokyo 10-meter delay-line interferometer), who spent the past 9 months as a Japan-sponsored Research Fellow at Caltech, has joined the project as a staff scientist.

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