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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)

Rochus E. Vogt, Principal Investigator
and Project Director
Ronald W. Drever, Co-Investigator
Frederick J. Raab, Co-Investigator
Kip S. Thorne, Co-Investigator
Rainer Weiss, Co-Investigator

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I. INTRODUCTION

This report summarizes the Laser Interferometer Gravitational Wave Observatory (LIGO) Project activities from October through December, 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) reliability and sensitivity enhancements of prototypes
- LIGO development

II. PROTOTYPE ACTIVITIES

A. 40-Meter Prototype

Characterization of Interferometer Noise Sources. A systematic characterization of potential interferometer noise sources has progressed. We discovered a significant contribution to strain noise caused by amplitude modulation of light incident on the main interferometer cavities. The amplitude modulation was due to imperfections in Pockels cells used to correct the phase of the light. The laser frequency stabilization servo system was modified to eliminate the need for phase-correcting Pockels cells, thereby eliminating the amplitude modulation associated with them. Also, the rf modulator in the primary cavity servo was found to contribute to amplitude modulation noise when the laser power fluctuates; the effect is not currently a dominant contributor to strain noise, and it can be reduced by stabilizing the laser power.

New circuitry for the primary cavity locking was built, and is being tested. Compared to the circuitry currently installed, the new circuitry has improved noise and dynamic range parameters, and includes more provisions for automated operation.

Weekly telephone conferences between Caltech and MIT team members are providing additional strength to the 40-meter prototype development.

Optics Testing and Development. An analysis of reflectivity measurements made on the mirrors in the 40-meter prototype over the past three years revealed that the mirror losses increased at the rate of 10 to 40 ppm per week. Much faster degradation of the mode cleaner mirrors was sometimes observed when these mirrors were exposed to high-power resonant light. Although the degradation is reversible by cleaning, the increased losses can severely hinder operations. Investigations of the source of the loss are underway.

New 40-Meter Vacuum System Configuration. Conceptual details and requirements for new vacuum chambers for the 40-meter interferometer were completed, and competitive bids for chamber design and fabrication were solicited and evaluated. A subcontract was placed with Mill Lane Engineering (Lowell, MA), with delivery of test-mass chambers scheduled for mid-May 1991. Design and procurement of other hardware necessary for the new configuration will be completed during the next reporting period, and it is expected that all pieces needed for assembling the new vacuum system into the 40-meter laboratory will be ready by the end of next summer.

Laser Stabilization. A new task was initiated to develop and document a standard technique for stabilizing the frequency and output power level of large frame Argon ion lasers. The task will adapt existing designs wherever possible, but will emphasize reliability and reproducibility. The implementation will be closely tied to the conceptual design of the same system for LIGO interferometers. A Spectra-Physics laser recently acquired for the new optics laboratory will become the first to be modified with the newly designed hardware.

B. Stationary Interferometer

Broad-Band Recycling. Research on broad-band recycling in a pair of coupled cavities was completed. The concept of making the recycling cavity resonant at both the laser frequency and the radio frequency sidebands (needed for fringe measurement) was tested successfully but was found to be sensitive to beam alignment. Such a system will require automatic beam alignment when applied to the LIGO. A second double-cavity configuration using a short recycling cavity with lower loss optics and higher recycling gain was demonstrated, again giving recycling factors consistent with simple modulation theory. The spatial filtering action of the recycling cavity was demonstrated.

Recombination and Recycling. The stationary interferometer is currently being reconfigured into a recycled and recombined Fabry-Perot/Michelson interferometer. The initial measurements with this system are directed to investigating the contrast of the recombined and recycled cavity fields at the antisymmetric port of the interferometer—an important test to establish the compatibility of recombination with recycling.

C. Vibration Isolation

Laboratory Tests and Analytical Modeling. Testing was carried out on the prototype passive isolation stack composed of stainless steel rings and "Viton" elastomer isotropic springs. A single stage of the system with six elastomer spring assemblies and one ring was tested under varying loads. The completed system does not strictly behave as calculated from the elastomer properties or as established from measurements of a single spring element. The system is well damped ($Q < 2$), is isotropic, and exhibits the expected isolation above resonance but it has a resonant frequency two times higher than calculated and can only sustain 1/2 to 2/3 of design load. Investigations of the discrepancies are underway.

A test rig to measure the real and imaginary parts of the elastic moduli of elastomers as a function of frequency has been designed and constructed and is currently being used to measure Viton as well as the elastomers used in the 40-meter prototype isolation systems. The test data can be fit to various anelastic material models for future isolation stack design.

A test rig to measure the performance of the isolation stacks used in the 40-meter prototype has been assembled and is being used to characterize the different elastomers currently in the system.

III. LIGO DEVELOPMENT

A. Sites

Owens Valley, California. A report on the geotechnical measurements was received and reviewed. There were no significant surprises uncovered by the geotechnical survey.

Site Selection Process. The NSB approved an NSF recommendation for a site selection process, under which Caltech is to conduct a competitive, public solicitation of sites for LIGO. An announcement was published in the November 19 edition of the *Commerce Business Daily*, which specified requirements and asked for proposals by March 1, 1991. Subsequently, copies of the announcement were sent to the governors of all 50 states, and courtesy copies were furnished to all parties who had previously expressed to us an interest in LIGO sites.

B. LIGO Interferometer Design and Optics Research

Interferometer Design. The conceptual design of the initial LIGO interferometer, due to shortages in manpower and lack of experts in some critical areas, is proceeding at a slower than optimal pace.

New Optics Laboratory. Construction of the new optics laboratory space at Caltech is nearly complete, and preparations for its instrumentation and initial program are underway.

C. Experiments with the Vacuum Test Facility (VTF)

Tests of two chambers fabricated from the new batch of low-hydrogen steel manufactured for the beam tube investigations (see below) demonstrated that the new batch possesses the same low-hydrogen outgassing characteristic measured in earlier sample chambers. In another VTF setup, the feasibility of performing bulk screening tests to verify low-hydrogen outgassing properties of steel sheet was demonstrated. Previously, testing required fabricating a vacuum chamber from the material under test. The new setup, which will be developed into an apparatus suitable for industrial contractor use, involves placing cut samples of material into a specially prepared, low-background vacuum chamber.

D. LIGO Beam Tube Investigations

Three of the spiral welded tube sections were prepared and assembled into a 2-ft. diam by ~120-ft. long vacuum chamber, for demonstration of measurement and bakeout procedures suitable for use on the LIGO beam tubes. Direct measurement of hydrogen outgassing confirmed that the outgassing rate per unit area is the same low value as that obtained from sample chambers connected to the VTF. From this we conclude that none of the manufacturing, cleaning, or handling processes used in preparing the tube sections degraded the low-hydrogen outgassing characteristic of the stainless steel sheet material.

A diagnostic technique using residual gas analysis to establish if there are air leaks in an unbaked and "dirty" large vacuum system is being developed and tested in the long chamber.

A computer model of the statistical mechanics of the surface loading and outgassing of water as a function of temperature and time has been developed. The input parameters of the model have been derived from bakeout tests on the VTF. The model, which has relevance to the LIGO bakeout strategy, will be tested in the bakeout of the long chamber.

We are continuing with preparations for the low-temperature bakeout demonstration.

IV. CONCERNS

The continued shortage or total absence of staff in some key technical areas and other resource limitations, coupled with funding uncertainties, severely handicap planning and implementation of critical activities. This situation is aggravated by the requirements of the NSB approved site solicitation competition, which is placing a particularly heavy additional burden on key project management staff. In this context, the production of Quarterly Reports for an R&D program, which is the present phase of the LIGO project, although not an overwhelmingly time consuming burden, is a mental burden. R&D simply does not show results in quarter-annual steps!

V. PERSONNEL CHANGES

Dr. Lisa Sievers, who received her doctoral and postdoctoral training in computer systems and electrical engineering, has joined the LIGO team, and among her other duties will add much needed expertise in control system engineering.

Aaron Gillespie and Torrey Lyons have joined the project as graduate research assistants at Caltech, and Nervis Mavalvala has done so at MIT.

Pasadena, December 19, 1990

R. E. Vogt, P.I./P.D.