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QUARTERLY REPORT
NSF COOPERATIVE AGREEMENT NO. PHY-9210038
THE CONSTRUCTION, OPERATION, AND SUPPORTING RESEARCH AND DEVELOPMENT OF A LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

R. E. Vogt, Principal Investigator and Project Director
S. E. Whitcomb, Deputy Director
W. E. Althouse, Chief Engineer

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I. INTRODUCTION

This report summarizes the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from December 1992 through February 1993.

This summary includes work of the Caltech and MIT science groups and the engineering team located at Caltech. The principal areas of activity are:

- LIGO development, including sites, facility design and development of the initial interferometers.
- Prototype laboratory activities aimed at improved understanding of interferometer noise sources or at development of key interferometer techniques.

II. LIGO DEVELOPMENT

A. Sites

Livingston Parish, Louisiana. Funds for land acquisition were released by the State in late January to Louisiana State University (LSU), who will purchase the land and lease it to NSF. LSU has formally authorized the land acquisition, and is proceeding with the necessary steps. LSU will in parallel develop a proposed lease agreement between LSU and NSF. We will pre-review the proposed lease before putting LSU in direct contact with NSF.

The alignment staking survey of the site was completed by a contractor. In response to our solicitations, contractor proposals have been received for geotechnical, environmental (NEPA-related), wetland permitting, topographic and hydrological investigations. Evaluation of geotechnical, environmental and wetland permitting proposals has been completed and awards are pending. Evaluation of proposals for topographic and hydrology investigations is underway, and negotiations should begin soon.

Hanford. We have completed review of the latest draft DOE/NSF land use permit and MOU, and forwarded extensive comments to NSF for further consideration.

Contracted field work for the geotechnical investigations was completed and the final report has been received. Environmental investigations by a contractor continued and draft sections of the environmental assessment (EA) report were submitted to the project for initial review and comment. The topographic survey (using aerial photography) has been placed on hold upon recommendation of the subcontractor due to extraordinarily bad weather and ground snow cover; work is expected to resume during March.

B. Industrial Design Subcontracts

Although evaluation of proposals for the beam tube modules has moved forward (e.g., site visits to proposers were conducted in December), continued outside distractions have seriously impacted management involvement and hampered progress. Preparation of specifications and RFPs for the rest of the LIGO vacuum system and remote facilities has been similarly affected.

C. LIGO Beam Tube Investigations

Laboratory work on steel sample testing was completed, and an internal report summarizing the results and the analysis of the results is in preparation.

Development continues on techniques and equipment suitable for industrial subcontractor use in screening steel outgassing properties.

D. LIGO Scattering and Stray Light Analysis

The phase noise due to scattering and stray light in the LIGO beam tubes as a function of surface conditions of the steel has been analyzed to establish the tolerance we have for different surface preparations of the beam tubes. The results show that for the critical backscatter paths changes in the scattering properties of the beam tube surface cause only small changes in the noise due to scattered light.

Discussions with the VIRGO project about scattered light have led to modifications in prior estimates of the reduction of phase noise from scattered light by placing spatial wave front cleaning cavities between the main photodetector and the gravitational wave interferometer. These changes have increased the possible importance of reducing the scattered light by blackening the baffles.

E. LIGO Interferometer Conceptual Design

The work to study wave front distortion from imperfect optics and to establish specifications for interferometer optical components continued. The numerical and analytic techniques developed in the prior quarter have been compared and agree with each other. These theoretical tools have been incorporated into the process of development of the initial LIGO interferometer optics. Data from sample large diameter mirrors have been analyzed and show that the current techniques for the surface grinding and polishing are adequate for the optics of the initial interferometer. The wave front perturbations due to large area coatings are currently under study.

III. PROTOTYPE ACTIVITIES

A. 40-Meter Interferometer

Mark I — Characterization of Interferometer Noise Sources

Development of strategies and programs for analyzing interferometer data for burst signals continued, using a 24 hour long record of interferometer and environmental data taken before the Mark I interferometer was decommissioned. The data are being analyzed to characterize the bursts and to look for clues to their origin. This exploratory investigation will influence the design of future data acquisition and analysis with the Mark II interferometer.

Mark II Interferometer

Assembly of the Mark II prototype vacuum system continued. Concerns about potential trapping and outgassing of condensable hydrocarbons, suggested by some recent results from the LIGO beam tube investigations, led us to decide to interrupt the assembly and to expose the Mark II beam tubes to a "bead blasting" process for removal of oxide surface. The tube sections were subsequently recleaned, and assembly continues.

After the vacuum system is certified, the new vibration isolation stacks will be installed and tested. Drift tests and transfer function measurements were done using an assembled stack to check certain aspects of the design, such as the response of the stack under an unbalanced load. New Viton springs are being processed by a new method to replace the initial batch of springs which were damaged during vacuum preparation.

Suspended-Mirror Mode Cleaner

Construction of all parts has been completed but integration has been delayed as effort and equipment have been dedicated to Mark II construction.

B. Stationary Interferometers

The goal of stationary interferometer research is to investigate two candidate modulation and optical topology schemes that may be used in the initial LIGO interferometer. Experimental and analytical studies of the servo signals, both before and after the servosystems acquire lock, are underway.

The stationary interferometer for testing the external modulation scheme has been locked successfully. Current work is dedicated to comparing experiment with the theory of the interferometer with sufficient detail to give confidence in scaling to the LIGO interferometer. The major control signals (common and differential mode cavity, common and differential mode Michelson arm, optical path length in the external modulation interferometer) agree with theory. The cross-coupling of the control signals and the frequency response of the system are currently under investigation

The stationary interferometer for testing the scheme using asymmetric Michelson arms has been reassembled with mirrors which more closely match the parameters required for LIGO. The interferometer locks for short periods of time (a few seconds), and work is underway to improve the robustness of the servo-loops so that detailed verification of the control signals can be made.

C. Development of Techniques for Interferometer Alignment

This research is aimed at developing techniques for sensing the alignment of the LIGO initial interferometer. In the past quarter the analytic and numerical techniques developed to predict the discriminants for the angular and translational alignment of the optic axis relative to an input beam have been compared and found to agree for both single and double cavities. The theoretical analysis is necessary to allow scaling to the LIGO. An experimental verification of the discriminants in a breadboard system for a single cavity was accomplished two quarters ago. The demonstration for a double cavity is in process.

During the last quarter work has begun on a demonstration in a suspended cavity. The experiment will take place in the central tank of the 5 meter facility using suspension designs developed for the suspended mode cleaner for the 40 meter interferometer. Currently, the suspension cages and input light conditioning optics have been assembled.

D. Vibration Isolation

Efforts to develop a vacuum-compatible RTV silicone spring for vibration isolation stacks continued. Stacks containing some layers of silicone springs have shown improvements in vibration isolation over the current stack design, which uses Viton springs. Although small silicone springs (cleaned by a solvent soak followed by baking) passed a test for mirror contamination, attempts to adapt the processing for the larger springs needed for full size stacks have not yet succeeded. The effectiveness of different cleaning procedures is being evaluated by residual gas analysis of the treated samples.

E. Optics Testing and Development

The development of test masses for the initial LIGO interferometer continued with the delivery of several 10–kg, 25–cm diameter, fused silica test mass blanks. These will be used in a pilot program to develop and evaluate vendors for supplying the material, and the polishing, coating, and metrology services for the large mirrors for LIGO. A program of testing mechanical and optical properties of the test masses will proceed throughout the fabrication process.

A method of measuring the small surface deformation of a mirror which absorbs a few parts-per-million of incident light was demonstrated as part of a program to investigate heating effects in mirrors under high light illumination.

The reflectivity of mirrors in an optical cavity used for laser stabilization has degraded as a result of light exposure. Since we have successfully operated mirrors at power levels and intensities that are several orders of magnitude higher, we suspect that this is due to a so far undiscovered source of contamination. Testing of the vacuum environment and the surfaces of the mirrors are being pursued to identify the cause of this problem.

F. Suspension Development

A new tower for suspending test masses was constructed to allow the measurement of high Q pendulum modes at approximately 1 Hz frequencies. This tower is stiffer than the earlier tower to reduce the effect of losses in the tower structure as it recoils from the swinging test mass. Measurements with the new tower indicate that it should allow the measurement of pendulum Q's of several million.

A model for thermal noise from internal vibrations of the test mass, which allows the use of different mechanical Q's for the different internal modes, has been developed. This model will be used to interpret data obtained from measurements of the Q of internal vibrational modes of the test mass.

IV. OTHER ACTIVITIES

A paper ("Mirror Orientation Noise in a Fabry-Perot Interferometer Gravitational Wave Detector" by S. Kawamura and M. Zucker) was submitted for publication to Applied Optics.

The administrative arrangements for the LIGO project within Caltech have been restructured. Dr. Lew Allen has been appointed as Special Assistant to the President for LIGO and will assume primary responsibility for LIGO in the Caltech administration. Dr. Allen will chair an oversight committee composed of representatives from both Caltech and MIT which will review and advise the project.

V. FINANCIAL STATUS

Cooperative Agreement No. PHY-9210038 Financial Status as of 1/1/93 ($M)	
Cumulative Funding to date	19.1
Cumulative Expenditures to date:	
Site Investigations	0.3
In-house	6.2
TOTAL	6.5

VI. ACTION ITEMS — CALTECH/NSF RESPONSIBILITIES

	Topic	Status
1.	Hanford land use permit	In process
2.	DOE/NSF Memorandum of Understanding	In process

Pasadena, March 1, 1993

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