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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

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I. INTRODUCTION

This is the third quarterly progress report submitted to NSF since the beginning of the period (December 1, 1991) funded under the new Cooperative Agreement. The prior reports were submitted on January 1 and April 1, in phase with quarterly reports submitted under the preceding Grant No. PHY-8803557. The new Cooperative Agreement specifies a new phasing for quarterly progress reports, coinciding with the anniversary date of the funding period. Because of delays in signing the new Cooperative Agreement, it was not practical to shift the report period phase in time for this report. The phase will be adjusted by the time of submission of the next report.

II. LIGO DEVELOPMENT

A. Sites

Hanford. A draft land use permit, originally prepared as an agreement between DOE and Caltech, is currently under Caltech and NSF legal review for consideration as an agreement between DOE and NSF. A draft MOU between DOE and NSF to provide LIGO access to Hanford infrastructure and services is in preparation. Responses to RFPs for staking, geotechnical, topographic and environmental surveys have been received and subcontracts are in preparation.

Livingston Parish. The Louisiana legislature is expected to appropriate funds for land acquisition and road construction, with funds available on July 1. The landowner has given permission to conduct limited surveys on the property. Most detailed surveys will have to await clearing of the forested area, and the landowner prefers that a land acquisition agreement be signed prior to clearing. Clearing is expected to proceed in the fall, followed immediately by detailed site investigations.

B. Industrial Design Subcontracts

The RFP for the design and qualification testing of the LIGO beam tube modules, including an option for fabrication, installation and testing at the two LIGO sites, was released on June 19, with proposals due on September 11. The RFP for corresponding services for the LIGO vacuum equipment is expected to be released later this summer.

C. LIGO Beam Tube Investigations

As a result of prior testing of stainless steel samples, a new annealing schedule was developed which promises to improve the characteristics of the low-hydrogen steel for the LIGO beam tubes. Tests are underway on samples of newly manufactured material, using the revised annealing procedures, to verify that outgassing rates for hydrogen, water vapor and other gas constituents are acceptable.

D. LIGO Scattering and Stray Light Analysis

First results from a numerical simulation of stray light in the LIGO beam tubes using the baseline baffle design have been obtained. The goal set for noise due to scattered light is not to exceed 1/10 the strain noise associated with the standard quantum limit for a one ton mass. The noise levels predicted by the numerical simulation generally agree with prior analytic estimates. The baseline design meets the goal with a margin of several hundred in noise amplitude with a mode cleaning cavity at the output port, but falls short by a factor of about 5 without an output mode cleaning cavity. A limited number of additional runs will be made in the numerical simulation to determine the sensitivity of these results to changes in the design.

E. LIGO Interferometer Conceptual Design

A study has been performed to iterate the shot, thermal and seismic noise contributions in the initial LIGO interferometer. These have been included in the evolving LIGO Interferometer Conceptual Design Manual.

III. PROTOTYPE ACTIVITIES

A. 40-meter Prototype

Mark I: Characterization of Interferometer Noise. At high frequencies, the 40-meter interferometer has been limited by shot noise which decreases with increasing power. Recently, the optical power in the interferometer was doubled over the previous operating level, to 126 mW total bright fringe power. The interferometer sensitivity remains limited by shot noise above 2 kHz, and is better than 2×10^{-18} m/$\sqrt{\mathrm{Hz}}$ in the band 400 Hz $< f <$ 4000 Hz. The minimum observed displacement noise level is 9×10^{-19} m/$\sqrt{\mathrm{Hz}}$, near 800 Hz.

Experimental investigations of shot noise dependence on power, modulation index, visibility, and rf phase were completed. The observed noise agrees with calculation to better than 20% up to the highest power used; the major uncertainty in comparing observation with calculation is in the sensitivity calibration, which is being checked and refined. To facilitate these investigations, electronic noise in the primary photodiode preamp was reduced by narrowing the bandwidth of the rf tuned circuit, and compensating the feedback filtering to maintain the stability of the servoloop.

Earlier investigations had shown that large, low frequency motion of a set of optical components, due to a resonance in the seismic isolation stack, could be upconverted to produce noise within the LIGO operating band. Recently, a vacuum-compatible vibration damper was fabricated and installed on the plate in the interferometer vacuum system. It successfully damped the resonance and reduced this source of noise.

A seismic monitor was installed and operated to provide a continuous record of ground vibrations for comparison with interferometer performance. RMS motion is measured in four broad frequency bands with continuous, low data rate recording to magnetic disc.

Mark II: Design, Planning, and Construction of Subsystems. Work continues to develop the various subsystems needed for upgraded installation of the present interferometer into a new, larger vacuum envelope. Design work has been completed in most areas and procurement and/or fabrication has been started in all areas. Parts are on hand for the pumping system, vacuum envelope, vacuum monitor system, optical alignment system, and laboratory facility modifications (e.g., crane hoists). Deliveries of remaining parts are expected over the next few months.

Goals of the transition planning include preserving the present interferometer functional design, providing for rapid future evolutionary capability, and adhering to stringent vacuum-compatibility standards. A system assembly plan has been prepared which implements the transition to the new interferometer configuration in a staged fashion. This transition is expected to begin this summer.

Suspended-Mirror Mode Cleaner: All mechanical parts for the suspended-mirror mode cleaner have been received and are in the process of being cleaned prior to assembly into the vacuum system. The prototype unit of the orientation control electronics has been tested successfully on a suspended test mass. Problems with vacuum compatible cabling which had delayed the completion of this task, have now been resolved.

B. Stationary Interferometer

The goal of the stationary interferometer research is to investigate two candidate optical topologies that may be used in the initial LIGO interferometers. The two schemes, denoted "external modulation" and "asymmetric Michelson," are being investigated in parallel in two separate setups. The primary goals of this research are to verify the model predictions of the various control signals needed to operate the interferometer, to determine the robustness of those signals to imperfections in the interferometer, and to look for any unforeseen complications outside the scope of the numerical models.

Two stationary interferometers testing the key elements of the two topologies have been set up. Nearly all of the expected control signals have been verified individually and work is underway to test them in combination. Thus far, both systems perform as expected from prior analysis and remain viable candidates for the initial LIGO interferometers.

C. Automatic Alignment of Fabry-Perot Cavities.

The aim of this effort is to develop techniques to align the LIGO interferometers using signatures derived from the main optical beam, rather than from auxiliary methods. The initial work has centered on obtaining the signatures needed to align a simple Fabry-Perot cavity automatically by using the light reflected by the cavity. A theoretical analysis showed that appropriate signatures can be obtained from phase maps of the reflected beam at appropriate locations. An experimental demonstration in a rigid system confirmed this analysis. Work has begun on the more difficult problem of aligning coupled cavities of the type involved in the LIGO interferometers.

D. Vibration Isolation

The effort to develop a vibration isolation system for the LIGO has continued this quarter. Two elastomers (Viton and RTV) are under investigation for use as the spring elements in the LIGO isolation stacks. The drift and loading properties of RTV elastomer springs were measured for comparison with earlier measurements of Viton. RTV is softer than Viton leading to lower frequency resonances and improved isolation; however stacks made with RTV have the undesirable feature of a higher Q on resonance. The performance of a prototype stack made with RTV springs in the top layer and Viton in the lower two layers, which is predicted to combine the best features of the two materials, will be measured next.

Measurements of the transmission of a typical wire harness mounted on the stack have been completed and show that the harness does not compromise the isolation.

E. Optics Testing and Development

Tests for possible contamination of high-reflectivity mirrors exposed to RTV and Viton elastomers (candidate materials for seismic isolation stacks) continued, with over 80 days of exposure. Results are encouraging, as a test of degradation in the absence of optical power: the reflectivity change is indistinguishable from that of unexposed mirrors, and corresponds to a fractional change in power reflectivity of less than 4×10^{-7} per week.

Tests were started to look for possible degradation to mirrors exposed to high laser power in optical cavities. Preliminary data show no observable change in reflectivity after several days exposure to 100 W circulating power. The power will be increased as this experiment continues.

IV. PERSONNEL CHANGES

Irena Petrac joined the project in April as LIGO Subcontracts Manager, Karl Reithmaier, a mechanical engineer, also joined the project in April.

V. FINANCIAL STATUS

This new section of the quarterly report will endeavor to convey relevant financial status information and discuss potential or existing financial problems. We expect to report, as of the most recently available data, cumulative funding to date, cumulative expenditures and obligations to date, and to report, for each major industrial subcontract or subcontract category (e.g., site investigations), such data as necessary to provide insight into financial performance. We welcome suggestions on "tuning" the report information and format to suit the legitimate oversight needs of NSF.

Due to the delay in putting in place the Cooperative Agreement, most significant subcontract activities will not be started until the end of the current funding period (December 1, 1992).

Financial Status as of 5/1/92 ($M)

Cumulative Funding to date	19.1
Cumulative Expenditures to date	2.3

VI. GENERAL

The past year's Site Selection Activities and delays in funding and contractual agreements between NSF and Caltech have negatively affected project schedules.

Pasadena, June 24, 1992

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