LIGO-M920002-00-M

QUARTERLY REPORT
NSF GRANT NO. PHY-8803557

CONTINUED PROTOTYPE RESEARCH & DEVELOPMENT AND PLANNING FOR THE CALTECH/MIT LASER GRAVITATIONAL-WAVE DETECTOR (PHYSICS)

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April 1, 1992

I. INTRODUCTION

This report summarizes the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from January through March 1992, 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. Measurements indicated that light-intensity fluctuations, caused by large-amplitude, low-frequency modulation of parasitic interference paths in the interferometer input optics, resulted in non-stationary noise at intermediate frequencies (300–500 Hz). A 4-Hz resonance in the vibration-isolation stack for the input optics was responsible for most of this noise. A novel vibration damper, that uses a tuned mechanical pendulum in a highly viscous medium, was developed and used to successfully damp a 4-Hz resonance in a separate experimental test. A vacuum-compatible version of this damper is being built and will be tested in the interferometer.

Experimental and analytical work were undertaken to characterize the noise induced by fluctuations in quantities (such as light intensity or RF modulation amplitude) that determine the optical gain of the interferometer servos. A model incorporating both linear and nonlinear effects of these fluctuations successfully described the interferometer response, and confirmed that the quantities investigated are sufficiently stable.

An investigation of nonlinear effects of light amplitude or frequency fluctuations, which occur at frequencies above the signal band of the interferometer, confirmed that these fluctuations do not affect the current interferometer sensitivity.

Further measurements of the mechanical quality factor Q of the test-mass suspension wires have identified some wires with Q's as high as 2.8×10^5. The large variance in measured wire Q's is probably due to variations in the connections to the wires at the test-mass and suspension point.

Mark II Prototype Interferometer. All parts for the new, larger vacuum system for the 40-meter prototype are on order or have been received. The parts on order (valves, pumps and adapters) are expected to be on hand well before we are ready to install the new system in the 40-meter laboratory, presently planned for summer.

Plans and design work for the transition of the 40-meter interferometer into the new vacuum system progressed significantly during this quarter. The successful vibration-isolation stack design was adapted to the new vacuum system and reviewed, and parts have been ordered. An optics layout was completed, and provisions for electrical functions were designed, reviewed and ordered.

A major goal of the transition planning involves preserving the present interferometer functional design, while providing for rapid future evolution of the interferometer configuration. Another significant goal is to ensure that all parts meet stringent vacuum compatibility standards. Current plans anticipate adapting the interferometer to these goals and moving into the new vacuum system envelope during summer 1992.

Suspended-Mirror Mode Cleaner. All design work was completed, and most optics, electronics, and mechanical and vacuum pieces are on hand. The vacuum system was assembled and tested. A bench "fit check" of one suspended mirror assembly was completed.

B. Stationary Interferometers

Refinement of benchtop stationary interferometers for prototyping LIGO optical topology and modulation schemes continued at Caltech and MIT. Efforts focused on the preliminary step of locking and understanding the response of two coupled cavities.

During the past quarter we have demonstrated the simultaneous resonance of the optical carrier and phase modulation sidebands in the recycling cavity of a pair of coupled cavities. The RF discriminants, needed to lock the system, behave much as expected from the theory of the interferometer. The concept of using multiple resonances in single cavities is a central element in the LIGO interferometer design that will be used in mode cleaners and recycling cavities.

C. Automatic Alignment of Fabry-Perot Cavities

The aim of this research is to develop techniques to align Fabry-Perot cavities automatically by using signatures in the light reflected by the cavity. Analytic and computer modeling of the signature for the different types of misalignments has been completed. A test setup using a Fabry-Perot cavity, frequency stabilized laser and a slit scanner has been assembled to experimentally confirm these calculations. The signature for angle misalignments has been verified experimentally. The measurements will lead to a servo strategy for control of the cavity geometry.

D. Vibration Isolation

The drift and temperature dependence of a prototype vibration isolation system for LIGO have been measured and meet the LIGO requirements. An experimental investigation has been made to determine the effect on the isolation of attaching a set of electrical leads to the stack. The wire harness is similar to that being planned in the new interferometer prototypes and the LIGO. In general, the leads do not change the stack isolation within the measurement error; in a narrow region around 70 Hz, the vibration feed through is still uncertain and is currently being investigated.

Measurements have been made of the properties of RTV elastomers as a possible replacement for the Viton which may give better stack performance in the critical 60 to 100 Hz band.

E. Thermal Noise in Mirrors

The experiment to measure the off resonance thermal noise spectrum of a quartz plate has been assembled and is undergoing tests. The quartz plate is incorporated into an optically contacted structure which contains two optical cavities to monitor the thermal vibrations of the plate. A Mach-Zehnder interferometer which will compare the lengths of the two cavities has been tested without the cavities in place and shown to have adequate contrast for the experiment.

F. Optics Testing and Development

Experiments were begun on a newly-constructed apparatus for measuring potential contamination of mirrors by materials under consideration for use in interferometer vacuum systems. Three independent vacuum chambers containing fixed-spacer Fabry-Perot cavities were constructed. Samples of two elastomers under consideration for use in vibration isolation stacks (Viton and RTV) were introduced into individual chambers, keeping one chamber without a potential contaminant as a control. Optical ringdown measurements of reflectivity of the mirrors in each chamber have shown no significant contamination due to the Viton sample after 600 hours of exposure; the data on RTV cover less time and are not yet conclusive.

III. LIGO DEVELOPMENT

A. Sites

In February, the NSF announced the selection of LIGO sites at Hanford, Washington and Livingston, Louisiana. In the LIGO Site Evaluations report, the Hanford site was designated as Site 1 for this pair. Contact has been made with representatives of both sites; environmental and geotechnical site investigations will be initiated first at Hanford.

B. Industrial Design Subcontract Development

Draft requests for proposals (RFPs) for staking, geotechnical investigations, and ambient noise measurements of the selected LIGO sites were prepared. These will be reviewed and released after initial meetings with local representatives of both sites have taken place.

Specifications for the LIGO beam tube modules was completed, and an RFP for the design, qualification testing, fabrication and installation of the beam tube modules was prepared and is being reviewed. It will be released to industry as soon as an NSF-Caltech Cooperative Agreement on funding has been completed. Work on the specification for LIGO vacuum equipment is proceeding.

C. LIGO Beam Tube Investigations

The water outgassing of the 2 ft by 40 meter spiral welded beam tube after a 140C bake has been measured as 1×10^{-16} torr liters/sec cm^2 at a pressure of 2.7×10^{-13} torr. The outgassing rate would give an average pressure of water in the LIGO beam tubes of 1.5×10^{-12} torr when pumped only at the ends. This outgassing rate provides a safety factor 10 over the goal set for the LIGO.

Tests conducted on samples of stainless steel have led to a revised annealing schedule which promises to improve the characteristics of the low-hydrogen steel for the LIGO beam tubes. Plans are underway to verify, using test chambers made from steel subjected to the revised process, that post-bakeout outgassing rates for hydrogen, water vapor and other gas constituents are acceptable.

Tests of hydrogen permeation through welds confirmed that this is not a problem for the spiral welds and stiffening ring welds used in the beam tube fabrication process demonstrations conducted last year. The LIGO beam tubes will use the same fabrication processes.

D. LIGO Scattering and Stray Light Analysis

The initial results of numerical analysis of scattering in the LIGO beam tubes performed by the Breault Research Organization were received. The comparison of these models with earlier analytic work and possible iterations of the numerical analysis are underway, and will be used to guide future work.

IV. PERSONNEL CHANGES

Madge Althouse, LIGO Subcontracts Manager, left the project in February. Irena Petrac has accepted our offer for the position of Subcontracts Manager and will start in April.

Partha Saha has joined the LIGO scientific group at MIT as a graduate student research assistant.

Pasadena, March 30, 1992

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