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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 summarizes the Laser Interferometer Gravitational-Wave Observatory (LIGO) Project activities from January through March 1991, 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. The systematic characterization of potential interferometer noise sources has continued. Several noise contributions were identified and eliminated, and improvements were made to increase system reliability. Aside from a few remaining line frequency harmonics and mechanical resonances, the interferometer displacement noise is below $3 \times 10^{-18}\mathrm{m}/\sqrt{\mathrm{Hz}}$ in the frequency decade from 500 Hz to 5 kHz.

The improvements at high frequencies (above 2 kHz), where sensitivity is limited by shot noise, resulted from increasing the input power (the quantum-efficiency corrected bright fringe power is now 45 mW) and improving the matching of the light into the 40-meter arms.

The performance at low frequencies has been improved by: (1) identifying and reducing electronics noise in the amplifiers that control the lengths of the 40-meter cavities; (2) identifying and eliminating several sources of interference at multiples of the 60-Hz line frequency; (3) analyzing the coupling between laser intensity fluctuations and the locked fringe offset, and reducing the offset; (4) measuring the noise contribution from intensity fluctuations, and reducing the fluctuations by more than a factor of ten; (5) observing noise from a vibrating cryopump cold head, and changing operating procedures to eliminate this noise source.

Vibration measurements at the test-mass suspension point show that the resulting linearly induced test-mass motion is below the observed displacement noise. The remaining excess noise at low frequency, principally below 400 Hz, may originate in the orientation control system; measurements to test this hypothesis are underway.

System Enhancements. System improvements to enhance reliability include operating with upgraded amplifiers for the primary cavity servo, replacing the argon-ion laser with another unit with a new plasma tube, and replacing a mode cleaner that exhibited degrading transmission efficiency.

Modeling of Servo System. Detailed modeling of the principal servos in the 40-meter interferometer has been initiated. The work is starting with a model for the secondary arm length control servo, and will be used to refine this servo.

Characterization of Vibration-Isolation Stack. A detailed set of measurements and calculations to characterize the seismic isolation stack of the 40-meter interferometer is being made.

New 40-Meter Vacuum System Configuration. Work at the vacuum chamber subcontractor, Mill Lane Engineering (Lowell, MA), has progressed according to plan: design and process documents have been completed, reviewed and accepted, material ordering has been completed, and test-mass chamber fabrication has begun. Pre-procurement design work for the remaining pieces of the new vacuum system has been completed and reviewed, but procurement will be delayed due to inadequate LIGO FY91 funding.

Laser Stabilization. This task includes stabilizing the frequency and output power of large frame argon-ion lasers as a precursor to the LIGO design. The conceptual design work was completed, and the designs are being tailored to a recently acquired Spectra-Physics laser.

B. Stationary Interferometer

Broadband Recycling and Optical Recombination. The stationary interferometer has successfully demonstrated the following features of recycling and optical recombination in a Fabry-Perot/Michelson interferometer. (1) The contrast of interference of the recombined beams is not compromised by unexpected optical effects and does not limit the recycling gain in our prototype measurements. (2) The measured recycling gain (a factor of 18.5) for the complete system is in excellent agreement with calculation. (3) The expected signal sensitivity increase from the Fabry-Perot cavities and from recycling is seen. (4) The reduction of unwanted spatial modes ("mode cleaning") and the temporal filtering by the recycling cavity have been observed; an unforseen improvement in the contrast of the interferometer with recycling has also been observed and a theory has been proposed to explain it. (5) A system of synchronous modulation/demodulation ("external modulation") has been demonstrated.

C. Vibration Isolation

Testing continues on the LIGO prototype passive isolation stack composed of stainless steel rings and Viton elastomer isotropic springs. A complete prototype stack has been constructed, and measurements of the system on-axis and cross-coupling transfer functions have been made in vacuum. The damping of the system is good, and the small cross-coupling terms and near-isotropy that were priorities in the design are seen. Two undesired characteristics of the transfer functions are under investigation. (1) Internal resonances in the stainless-steel rings compromise the attenuation of high-frequency seismic noise. An experiment to try a discontinuity in the stack impedance (the use of one ring of much different mass) is in preparation. (2) The poorer than expected load-stiffness product for the Viton springs, measured in initial tests, leads to a high-resonant frequency of the completed stack.

A detailed finite element model of the stack is progressing. The model predicts the resonant frequencies of the internal structure, and can incorporate realistic loss mechanisms in the Viton and in the steel.

D. Optics Testing and Development

Work has begun on the high-power test station to be located in the new optics lab. The apparatus will be used for long-exposure, high-power tests of cavities, as well as short-term testing of optical components. The necessary servo electronics and optics have been assembled and tested.

III. LIGO DEVELOPMENT

A. Sites

A competitive, public solicitation of sites for LIGO resulted in receipt of eighteen proposals from seventeen states. These proposals are being reviewed for scientific, construction and operation consequences of individual sites and pairs of sites. The proposals reflect a considerable investment of effort by the proposers, and evaluating them will require a significant, as yet unfunded, effort on our part.

B. LIGO Interferometer Design

A low-level effort in the conceptual design of LIGO interferometers is underway, but hampered by resource restrictions. These include overloads on the existing LIGO team and absence of experts in certain critical areas.

C. LIGO Beam Tube Investigations

Low-temperature bakeout of a 2-ft. diameter by 120 ft. long beam tube section was started. The thermally-insulated tube was heated to a nominal temperature of 100° C electrically, using the I^2R losses in the tube wall as the heat source. Bakeout will continue for a total of 30 days. This procedure is expected to yield outgassing rates sufficiently low to meet the LIGO pressure goals.

IV. OTHER ACTIVITIES

R. Vogt has been giving a number of agency and congressional briefings in Washington, including the March 13 testimony before the Subcommittee on Science of the House Committee on Science, Space, and Technology.

The MIT scientists have increased their involvement in the planning of the research and analysis of the data from the 40-meter prototype at Caltech. A week-long research visit was made by several scientists in January.

The paper, "A Prototype Michelson Interferometer with Fabry-Perot Cavities," by D. Shoemaker, P. Fritschel, J. Giaime, N. Christensen, and R. Weiss was accepted for publication by *Applied Optics*.

V. CONCERNS

Inadequate funding for the urgent tasks to be accomplished in the program agreed upon with NSF continues to be a grave concern. This situation has become greatly aggravated by the new task of evaluating LIGO site proposals. Generally, the lack of expert staff in some key technical areas impairs planning and implementation of critical tasks.

VI. PERSONNEL CHANGES

Dr. Stanley E. Whitcomb has joined the LIGO project as Deputy Director. In addition to his duties as a member of the LIGO management team consisting of Director, Deputy Director, and Chief Engineer, he has accepted the responsibility of directing the day-today science team efforts at Caltech and MIT and he will take on the lead role in selected technical tasks.

Dr. David Shoemaker has been promoted to the rank of Principal Scientist at MIT.

Pasadena, March 26, 1991

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