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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 July through September 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) work towards reliability and sensitivity enhancements of prototypes
- LIGO development

II. PROTOTYPE ACTIVITIES

A. 40-meter Prototype

Separate Suspension of Beam-Splitter System Components. The removal of the previous central mass (a complex structure supporting the beam splitter and other optical components) in the 40-meter interferometer and the introduction of separately suspended beam-splitter components was completed. Newly developed position and orientation control systems for these elements were installed. The new installation greatly enhances our capability for diagnostic studies. For example, it makes possible the determination of the effects of optical component motion on interferometer performance, in a carefully controlled manner, which was not possible with the previous configuration. Additionally, this modification will permit a stringent test of the newly developed control systems under actual interferometer operating conditions.

This task required temporary shutdown of 40-meter interferometer operations, and entailed significant modifications to the vacuum and mechanical components of the 40-meter system. Two additional vacuum chambers, for a total of three, were installed at the interferometer vertex. These chambers now house the vertex test masses and peripheral optical components. Previously these components were largely inaccessible and cumbersome to work with. The beam-splitter and test-mass chambers at the vertex were equipped with new vibration-isolation systems which include the introduction of a bottom stack for isolation of non-suspended components and the use of elastomers that are more vacuum-compatible. Residual gas analyzer measurements indicate a significant reduction of gas-phase hydrocarbons in the vertex area.

Installation of lower loss optics and removal of contamination in the system, accompanying this work, resulted in more than a factor of two increase in optical efficiency and dramatically improved fringe visibility (now approximately 90%) in the interferometer. The interferometer has been restored to operation, and systematic diagnostic work on sensitivity enhancements of the interferometer has been resumed.

New Vacuum System Configuration. Design work for new chambers, tubes, pumps, and facilities modifications to expand the capabilities of the 40-meter interferometer laboratory continued to evolve. A pumping system concept was developed and adopted, and conceptual details of a new test-mass chamber configuration were worked out. A Request For Proposal (RFP) for design and fabrication of the new 40-meter laboratory vacuum chambers was prepared and will be released shortly. We expect to place a subcontract for production of these chambers during the next reporting period, with delivery expected in Spring 1991.

B. Stationary Interferometer

The stationary interferometer is now configured for broadband recycling and external modulation, a candidate system for the initial LIGO interferometer. The properties of a single Fabry-Perot cavity in line with a folded recycling cavity were measured to demonstrate broadband recycling with cavities. The expected recycling power gain (commensurate with the losses in the optical components) was achieved. This is the first recycling experiment to be done with coupled cavities.

A computer code to analyze the propagation and detection of modulated beams in interferometric optical systems composed of cavities with optical feedback was written and used to analyze the two-coupled-cavity system. The code has general applicability to all interferometric detectors.

C. Vibration Isolation and Thermal Noise Studies

Vibration Isolation. The fabrication of components for a prototype passive vibration isolation system for the 5-meter, 40-meter and LIGO interferometers is completed. The system, consisting of four stages of stainless-steel-ring masses and Viton elastomer springs, is currently being assembled in a test tank. The elastomer springs are isotropic using both compression and shear in a conical configuration of elastomer rods. The spring constant, drift under load and damping of a sample spring were tested and found to be within 30% of design values.

Initial measurements of the isolation and cross coupling of a single stage will be followed by tests of the complete assembly. The instrumentation (PZT accelerometers, drive motors, drift meters) for these tests has been developed over the last two quarters and will use the new laboratory computer for data collection and reduction. A sensitive laser cavity accelerometer to measure the small motions (large isolation) expected from the system has been developed. The device uses a fiber coupled Nd:YAG laser to convert the motions of one suspended cavity mirror into a frequency change of the laser.

A finite element analysis code, Abaqus, has been installed and will be used to characterize the vibration isolation system and to guide further development.

Thermal Noise. The design of an experiment to measure the thermally induced motion of the normal modes of a mirror is progressing. In this experiment a single cavity will be excited in two modes which illuminate the same mirror in different places. These optical modes are then compared interferometrically to detect mechanical modes of the mirror.

III. LIGO DEVELOPMENT

A. Sites

Owens Valley, California. A staking survey and profile of a potential LIGO site was carried out and geotechnical measurements will be performed shortly. A report of geotechnical results and preliminary foundation recommendations is due in October.

Site Selection Process. At the request of NSF, we prepared a draft site solicitation announcement for use in a competitive site solicitation and selection process. The NSF plans to carry out the public solicitation and site selection, with technical support from the LIGO project. This plan is presently under review and will be submitted to the National Science Board for approval.

Site Geometries. A study of the burst coincidence sensitivity for a pair of interferometers as a function of separation and alignment was completed. This is applicable to determining the relative merits of site pairs.

B. LIGO Interferometer Design and Optics Research

Interferometer Design. The organization of the conceptual design of the initial LIGO interferometer leading to a systematic approach to specifications, requirements and testing of interferometer subsystems was begun in this quarter.

Optics Testing and Development. Work has continued with an optical coating contractor (PMS, Boulder, Colorado) to improve the reliability and quality of mirrors manufactured for prototyping, testing programs, and eventual use in LIGO. A recently acquired batch of 120-ppm-transmission mirrors, intended for use in power-handling tests and vacuum-contamination testing, exhibit typical total losses of 20 ppm or less. We are investigating the possible use of these mirrors for improved mode-cleaning cavities.

New Optics Laboratory. Renovation work has begun on the new laboratory space to support optics testing and development work for LIGO.

Development of Numerical Optical-Simulation Capability. Initial testing and verification studies using the (commercially-available) numerical optical-simulation code GLAD V have uncovered a number of subtle (and previously undetected) errors and inadequacies associated with using the code for simulation of resonant optical cavities. These problems have now been overcome in a cooperative effort with the vendor (Applied Optics Research, Tucson, Arizona); the latest GLAD V release is now being used for actual simulation studies.

C. Experiments with the Vacuum Test Facility (VTF)

Bakeout tests of the fourth (uncleaned) of the original four VTF test chambers were completed and showed results consistent with earlier measurements. The VTF is now being configured to perform outgassing measurements of test chambers made from the recent batch of low-hydrogen steel manufactured for the beam tube investigations (see below).

D. LIGO Beam Tube Investigations.

Spiral welded tube sections made from a fresh production coil of low-hydrogen steel were received and leak tested, using a setup similar to that proposed for leak-testing LIGO tube sections. No leaks were found associated with either of the two spiral weld processes employed for the 160 meters of 60-cm-diameter tubing produced, enhancing confidence that the standard industrial processes can be used for the LIGO ultra-high vacuum application. Two of the twelve tube sections exhibited leaks associated with stiffening ring installation, showing that more attention must be given to this process; this conclusion is not expected to have any cost impact for the LIGO. Three of the tube sections have been selected for more detailed measurements of outgassing and for bakeout testing. After completion of these tests, the tube sections will be reserved for installation in the new vacuum system for the 40-meter prototype interferometer.

E. LIGO Procurement Documents

After the House budget action to delete LIGO FY91 construction funding, work on subcontract procurement documents was moved to a low-priority activity. RFP drafts were put aside; a draft of a document providing information for potential industrial subcontractors was prepared and is being reviewed.

IV. OTHER ACTIVITIES

A paper, "A Double Pendulum Vibration Isolation System for a Laser Interferometric Gravitational Wave Antenna" by M. Stephens, P. Saulson and J. Kovalik has been submitted for publication.

Nelson L. Christensen completed his PhD work in Physics with a thesis: "On Measuring the Stochastic Gravitational Radiation Background with Laser Interferometric Antennas" (MIT, August 1990).

V. CONCERNS

The project continues to be understaffed or not staffed at all in some key technical areas (data and control systems, electronics, management). These and other resource limitations (see July 1, 1990 Quarterly Report), combined with the uncertain future of the LIGO project, continue to negatively impact the work of the LIGO team.

VI. PERSONNEL CHANGES

J. Harman resigned as Principal Electronics Engineer for the LIGO project to pursue independent consulting. He is being succeeded by J. Chapsky.

Pasadena, September 19, 1990

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