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 October through December 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. Measurements of interferometer response to artificially increased motion of the test-mass vacuum chambers indicated that interferometer sensitivity is limited by background seismic noise below about 120 Hz. Isolation stack performance was measured in-situ and showed a shortfall from the performance of an idealized, simplified model, by a factor greater than 100.

Interferometer performance continued to improve in the band 100 to 500 Hz, a consequence of (i) reducing harmonics of the line frequency in the orientation control system, and (ii) adjusting the positions of the optically resonant light beams in both 40-meter arms to coincide with the test mass axes of rotation. (Remote controllers for test mass orientation were installed, speeding alignment.) The sensitivity near 500 Hz is now $2 \times 10^{-18} \mathrm{m}/\sqrt{\mathrm{Hz}}$. This noise level is in excess of shot noise by a factor of 3. Several candidates for the source of excess noise have so far been eliminated by measurements (assuming linear coupling mechanisms): electronic noise in orientation or damping servos, seismic noise, laser frequency or intensity noise, and several types of noise that might arise from scattered light participating in spurious interferometer paths.

The sharp lines in the interferometer output spectrum at the test-mass suspension wire resonances now have amplitudes consistent with thermal excitation of these modes. Measurements of the mechanical quality factor Q of several of these resonances ranged from 1.7×10^4 to 6.5×10^4. The internal vibrational modes of the test masses were also measured: the frequencies agree with predictions of a finite element model, but the Q's (between 2000 and 2×10^4) are significantly lower than measurements done before the masses were suspended. Models indicate that losses at the level inferred from the Q measurements could introduce significant thermal noise in LIGO interferometers.

An experiment was conducted to test if stresses induced in the glue used to affix small magnets to the test masses could be a source of noise. Forces were applied to the magnets to increase the stress by a large factor, compared with the normal operating value. No change in the interferometer noise was observed (at the sensitivity level of $1.5 \times 10^{-18} \mathrm{m}/\sqrt{\mathrm{Hz}}$, f = 800 Hz), indicating that stress-induced glue noise is not currently a problem.

Tests were made of interferometer sensitivity with increased levels of N_2, Xe, and CO_2 in the beam lines, to experimentally check the formulae used to derive partial pressure goals for the LIGO beam tubes. Interferometer noise increased, as a function of pressure and molecular polarizability, in excellent agreement with calculation.

New 40-Meter Vacuum System Configuration. The new vacuum chambers have been received from their manufacturer, Mill Lane Engineering. All other vacuum envelope hardware for the new 40-meter vacuum system has been ordered. All parts should be ready for installation in the 40-meter laboratory by second quarter 1992.

Mark II Prototype Interferometer. Work has been initiated to plan and implement the transition of the existing 40-meter prototype interferometer to the new vacuum envelope. The work involves new vibration isolation stacks, new mechanical supports for most optical components, and new cabling for all electronics.

Laser Stabilization. The task of stabilizing the frequency and output power of a large-frame Spectra-Physics argon-laser was completed. The new laser exhibits significantly improved long-term stability compared to previous designs.

Suspended-Mirror Mode Cleaner. Procurement of the vacuum system and most electronics modules for a 12-meter triangular mode cleaning cavity was completed. Conceptual design of the vibration isolation stack and suspension hardware is complete.

B. Stationary Interferometers

Prototyping of LIGO optical topology and modulation schemes advanced with the setup of benchtop stationary interferometers at MIT and Caltech. A scheme for generating a single-frequency shifted sideband of incident laser light was tested successfully, and a 6-meter interferometer was locked to a prestabilized laser.

C. Automatic Alignment of Fabry-Perot Cavities

A new program was begun to develop techniques to automatically align and position optical beams in LIGO.

Computer modeling of the effect of misalignments on the intensity pattern reflected from a cavity has been performed, and a test setup with fixed mirrors is under construction.

D. Vibration Isolation

A full-scale isolation stack was tested in vacuum. The system exhibits horizontal and vertical to horizontal cross coupling isolation of greater than −110 db at 100 Hz and −130 db above 250 Hz, in good agreement with finite-element and lumped-circuit models.

E. Thermal Noise in Mirrors

The construction of an experiment designed to measure the off-resonance thermal noise in the lowest flexural mode of a fused quartz plate is nearing completion. The main optical element has now been constructed, and the vacuum system and specialized translation stages are ready to receive it.

F. Optics Testing and Development

An apparatus for making calorimetric measurements of mirror absorption was tested. A value of 11 ± 2 ppm of absorption was obtained for the input mirror of a Fabry-Perot cavity at a circulating power level of 1.5 kW.

Assembly has begun on an apparatus for measuring potential contamination of mirrors by materials under consideration for use in interferometer vacuum systems. Three rigid Fabry-Perot modules are being constructed, one of which will be used as an experiment control; mirror reflectivity (as a contamination index) will be monitored by optical ring-down of cavities containing material to be tested.

III. LIGO DEVELOPMENT

A. Industrial Design Subcontract Development

Work was initiated to prepare specifications and request-for-proposal packages for the design and fabrication of LIGO beam tubes, vacuum chambers and supporting equipment.

B. Sites

A report, "LIGO Site Evaluations," was completed and submitted to NSF. The report documents evaluations of 19 sites proposed as the result of a competitive, public solicitation, and identifies seven pairs (composed of eight individual sites) as being technically preferable for LIGO. Prior to submission, the report was reviewed by a committee of outside experts who affirmed the adequacy of the evaluation procedures and compliance with the criteria and guidelines approved by the National Science Board. We are awaiting the tentative selection of the LIGO site pair by NSF.

C. LIGO Beam Tube Investigations

The 2 ft by 40 meter spiral welded beam tube was baked to 140° C for 43 days. The water outgassing during the bake was satisfactorily accounted for by the surface adsorption model developed from data in prior bakes. On cooling to room temperature, the system has a water pressure between 4 to 7×10^{-13} torr, the lowest water pressure yet attained in this system which corresponds to an outgassing rate 1 to 3×10^{-16} torr liters/sec cm^2.

The research on hydrogen outgassing in the Vacuum Test Facility and in outside testing laboratories has established that the special stainless steel contains approximately 1 ppm of dissolved hydrogen, smaller than typical stainless but much larger than had been inferred from initial outgassing measurements. Work is in process to develop a commercially applicable annealing schedule that will reduce the bulk hydrogen concentration.

Hydrogen permeation of welds is under investigation using test chambers with the same welds as the beam tube.

D. LIGO Scattering and Stray Light Analysis

A subcontract was placed with Breault Research Organization (BRO), Tucson, Arizona, to carry out computer simulations of the scattering from LIGO beam tubes, vacuum chambers and interferometer components. BRO will submit an initial report in early January, with subsequent work guided by the early results.

IV. PERSONNEL CHANGES

Richard Prout, optics engineer, left the project in October. Yekta Gürsel, staff scientist, left the project in December. Douglas Jungwirth and Timothy Howard joined the project engineering staff in November and December, respectively. Jungwirth serves as an engineering specialist in optics and optical systems. Howard will be responsible for coordinating and managing a broad variety of engineering support activities within the project.

Peter Fritschel received his Ph.D. degree in physics for studies of interferometer topologies. He has taken a position with the gravitational research group in Paris directed by A. Brillet to work on solid state lasers. Michelle Stephens received her Ph.D. degree in physics for work on suspensions and theoretical studies of gravitational-wave burst detection with large baseline interferometric detectors. She has taken a position at JILA with C. Weimann in atomic physics.

Pasadena, December 27, 1991

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