LSC Six-Month Progress Report

LIGO-M000059-00-M

Organization Oregon University Group

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Attachment

Participation

The Oregon group accomplished the following LIGO Scientific Collaboration progress during the current 6 month period (August 15, 1999 - February 15, 2000):

WEATHER MONITORING

Oregon has now achieved several milestones in weather monitoring, including the following:

1) designed, manufactured and installed a circuit to boost the relative humidity signals, compensating for the long cable lengths,

2) calibrated the stations to improve on the factory calibration.

3) designed and tested a prototype system at Hanford for running anemometer signals into fast adc channels in order to monitor wind gusts. The current weather stations count anemometer revolutions for a fixed 2.25 seconds in order to obtain a 1 mph resolution. In addition, there is a variable 0.8 to 3 second read out delay.

4) uncovered a strong correlation between wind speed and optic motion during a Hanford wind storm. Although the motion is thought to be roughly an order of magnitude below that needed to knock the interferometer out of lock, the observed motion highlights the importance of understanding the effects of gusts for this and future versions of LIGO.

5) found a very strong anti-correlation between the piezo voltage of the pre-mode cleaner and atmospheric pressure. The length of the air cavity is controlled by the piezo voltage. The range of the piezo is not enough to compensate for changes in optical path length due to atmospheric pressure fluctuations. We investigated the range of pressure fluctuations recorded by the Hanford Weather Service and, in conjunction with Rick Savage, used this information to obtain specifications for PMC re-design.

MAGNETIC FIELD STUDIES

Six permanent magnets cemented to the test masses and other interferometer optics are used to control the position of the optics. The pole strengths and orientations of the magnets are balanced to minimize the coupling of optic motion to time-varying ambient magnetic fields. Even so, the optics will shake if the pole strengths of the magnets are not identical or if different magnets are subject to different ambient fields. To estimate the displacement noise using ambient field data and to better understand this problem for current and future versions of LIGO, we have undertaken four projects. First, measurements of ambient fields inside and outside of BSC vacuum chambers. Second, development of a diagnostic system to generate forces on the optics using externally generated magnetic fields. Third, investigation of the transfer function from outside to inside of the chambers.

1) Measurements of ambient fields inside and outside of core-optic vacuum chambers

We have measured ambient magnetic fields inside of two BSC chambers, BSC-8 and BSC-7. The seismic isolation stacks and optical tables were in place but the optics and optic support structures were not. Measurements inside of BSC-8 were preliminary measurements made while R. Schofield was helping install the down-tube assembly. The door was open and the Bartington MAG03 magnetometer positioned by hand. The door was closed for measurements inside of BSC-7; two magnetometers were affixed one foot apart on a plunger and slid along inside of a 4 inch fiberglass tube connecting ports on opposite sides of the chamber.

Field measurements were recorded for all three axes of each of the two magnetometers at each location. Approximate field gradients were obtained in a second set of measurements by subtracting the magnetometer signals in a Stanford SR560 preamp. To check these gradient measurements, gradients were also calculated by subtracting 60 Hz field measurements for successive positions along the tube. The two sets of 60 Hz gradient values were in agreement.

The positioning repeatability and the relative calibrations of the two magnetometers were determined using generated fields and were both 7% or less for all axes. The absolute calibration of the magnetometers was checked by comparing measured field values and values calculated from coil geometry and current.

The average and standard deviation of the 60 Hz field at seven locations inside of BSC-7 was 3.73 (+/- 0.22) nT rms. For the three locations in BSC-8 the average was 1.64 (+/- 0.21) nT rms. The averages of the fields around these chambers were about 3 times higher. A more detailed table of measurements inside and outside of the chambers as well as a comparison with outside measurements by Savage and Weiss [4] and Coles et al. [5] are available at http://www.ligo.caltech.edu/LIGO_web/9907lsc/9907trans.html. Field noise inside BSC-7 averaged about 9.6 (+/- 1.4) pT/root(Hz) rms at 50 Hz. Magnetic field gradients at 60 Hz were 2.3 (+/- 0.92) nT/m rms and gradient noise at 50 Hz was greater than 7 and less than 20 pT/m root(Hz) rms.

A simplified model of the coupling between fields and mirror motion similar to one used by Dennis Coyne[6] but including the measured variation of magnetic fields over the distance between magnets was used to calculate displacement noise from the measured fields and gradients. The displacement noise due to the measured gradients was estimated to be below 2X10^-20 m/root(Hz) at 50 Hz. This is more than a factor of three below the allowable level for displacement noise terms in LIGO 1. The displacement noise estimated from measured fields (coupling through torques on the magnets and a 1mm assumed offset of the beam from the mirror center) was more than an order of magnitude below the estimated displacement noise due to measured field gradients. These fractions of the LIGO standard were relatively consistent over the 5-800 Hz frequency range. Magnetic positioning may play a role in future versions of LIGO, such as in the first stage of a two stage optic suspension pendulum, so continuing investigations of the ambient fields will be important for future as well as current versions of LIGO.

2) Diagnostic system for investigating the coupling between optics and ambient magnetic fields

For diagnostic driving of in-place optics, we constructed two 1m diameter coils of 12 gauge varnished copper wire wound on plywood spools. Either 10, 30, 60 or 100 turns can be selected. The coils are mounted on aluminum tripods with a 5 to 8 foot adjustable height. Two coils were built so that the coils could be placed on opposite sides of the chamber in a Helmholtz-like configuration in order to produce either fairly uniform fields or, with the current direction in one coil reversed, fairly uniform field gradients in the central region of the vacuum chamber.

We mapped out the field that the coils produced inside of a chamber for a positioning of the coils that would work for any of the variable BSC configurations. The field produced by the coils in the selected position was measured along the transept of the ambient field measurements mentioned above. The fiberglass tube was then repositioned between a second set of ports to provide an `X' shaped distribution of measurements in the plane containing the main laser beam and the center of the coils. Photographs showing the tube and the experimental set up are available at: http://zebu.uoregon.edu/~rayfrey/LIGO/LIGO_UO.html .

To map out the fields for frequencies between 1 and 1000 Hz, the coils were driven in series by a 3Vp swept sinusoidal signal from the HP 35670A analyzer. The signal analyzer recorded the ratio of the voltage from the magnetometer inside the chamber to the voltage drop across a resistor in series with the generating coils; this ratio is proportional to the ratio of the measured internal field strength to the generated field strength. At 1000 Hz, the ratio of internal to generated field strength was about 1/20 of its value at 1 Hz because of attenuation due to eddy currents in the chamber walls. Field maps for the constant gradient coil configuration showed that the measured gradients were relatively constant in the central region of the chamber, as designed.

We plan to obtain an audio frequency amplifier to boost the generated fields and to use this diagnostic system to study the sensitivity of several of the core optics to magnetic fields as soon as interferometer signals become available.

3) An approximate transfer function

As mentioned above, an extensive set of magnetic field measurements was made inside chamber BSC-7 at Hanford. Our magnetic field generating coils, placed in both Helmholtz and anti-Helmholtz configurations just outside BSC-7, were excited to produce swept-sine measurements in coincidence with field and field-gradient measurements at many positions within the chamber. Special tubes were constructed to allow the field probes to be placed at various locations within BSC-7 without disturbing chamber cleanliness. In addition to measuring the frequency dependence of the exterior-interior field transfer function throughout the chamber, ambient field measurements were also performed.

We have been working on a model for the frequency dependence. The effect of eddy currents in the vacuum chamber gives rise to a transfer function which mimics a standard low-pass filter with cutoff frequency ~ 10 to 50 Hz. However, a second cutoff is visible at higher frequency (~ 500 to 1000 Hz) which becomes significantly more pronounced for positions near the chamber wall, especially on the side near the support pillars. (These plots are available at the URL mentioned above.) The goal of this work is to produce a sufficiently detailed model to allow factor-of-2 knowledge of the field at a given position inside the chamber resulting from a measured external environmental field.

SEISMIC CHARACTERIZATION

Characterization of local and off-site sources of seismic vibrations is important for present and especially future versions of LIGO. We have begun to characterize local sources by setting up a seismometer in the corner station and attempting to identify the main peaks in the 1 - 100 Hz range. To do this we placed an accelerometer on most major pieces of equipment in order to identify their characteristic frequencies. A number of the seismic peaks seemed to be coming from the small office area air handler. Therefore, we shut it off and found that, of the equipment that will not be shut off during data runs, it produces the largest vibration peaks that we measured in the LVEA (Laser and Vacuum Enclosure Area). The much larger air handler for the LVEA is vibration isolated and comparably quiet. For future versions of LIGO, we may want to isolate the office area air handler. Our labeled seismic spectrum, our tabulation of equipment, specified frequency and measured frequency are available within the LIGO Laboratory at http://blue.ligo.wa.caltech.edu/PEM/lveaNoiseSources.html and http://blue.ligo.wa.caltech.edu/PEM/lveaNoisSrcsSpect.ps.

We have also begun a program of identifying ambient or off-site noise sources, expanding on A. Rohay's work by using two seismometers to identify source direction and setting up our electronics in a van so that we could move in the indicated direction. (http://zebu.uoregon.edu/~rayfrey/LIGO/westofroad.jpg) We shut off all large equipment at the Y-end station and found that the main remaining signal above 1 Hz was a 5-12 Hz signal coming from the direction of highway 240. Because the signal was so constant (even when cars were more than a km apart) we did not at first believe that it was coming from traffic. But time delays pointed towards the road from either side of the road and in the direction of the nearest traffic when we set up at the road. At X-end we found that the largest peak also came from the direction of the nearest road - the internal Hanford road which has traffic until well after swing shift. During the rare breaks in traffic, the peak was not evident. The traffic produced a displacement noise of roughly a nm/root(Hz) at the end stations. We did not repeat our measurements at the corner or mid-stations because we could not shut down all equipment there.

We also made measurements around the Wannawish dam, about 5 km from the Y-end station and found that it produced vibrations comparable in magnitude to passing traffic at an equal distance. However, since it is considerably further from LIGO than the roads, it is an unlikely source of detectable vibrations in the 1 - 50 Hz range. We plan to continue tracking seismic sources.

COSMIC RAY STUDIES

The cosmic ray detector consists of a pair of scintillator panels, each about 30 inches on a side and read out by two PMTs, one of which will be at high gain to clearly see single muons, and the other with lower gain to avoid saturation for the rare events of interest. After forming a coincidence trigger, the digitized signals are to be shipped, via a VME-based EPICS crate in rack CDS 2X5, directly to one of the mounted disks of the CDS system. The trigger signal, input to the VME timing module, will provide a GPS time stamp for the cosmic event record. These event records are to be inserted in the LDAS (LIGO Data Acquisition System) MetaDataBase. The event rate will be adjusted to about 100 per day by an energy threshold. It is expected that this data pathway could serve as a template for other event-type detector readouts, some of which the Oregon group is pursuing as part of the LIGO Scientific Collaboration, such as wind gusts, thunderstorms, magnetic or power line events, etc.

GRAVITY-GRADIENT NOISE

Mass motions such as density fluctuations can cause varying gravitational fields which can shake test masses; this Newtonian noise is referred to as gravity-gradient noise. Gravity-gradient noise produced by seismic waves from uncontrollable sources may limit advanced versions of LIGO. Hughes and Thorne[9] have shown that this may indeed be a limit in the 3 - 30 Hz range using a model of ambient seismic motions based on the theory of multimode Rayleigh and Love waves propagating in a multilayer medium. The magnitude of the seismic gravity-gradient noise depends on the proportions of the modes present; Love modes involve only horizontal displacements and no density fluctuations and so, in the idealized case, do not produce varying gravitational fields. The ratio of vertical to horizontal displacement measured previously by A. Rohay at both LIGO sites was used by Hughes and Thorne to constrain the possible mixtures of modes. We are working with the group set up by K. Thorne to help further constrain the possible mixtures of modes by using surface seismic arrays. The first step in this project is to obtain a dispersion relation for ambient seismic vibrations. In consultation with A. Rohay and G. Gonzalez, we have set up a trial 3 seismometer array (L-shaped with 8 and 32 foot legs) in the desert near the Y-end and collected time series data. The traffic peak was evident in the data even though we made measurements from 8 to 11 pm. We are planning on analyzing the data using MatLab and SAC (seismic analysis code) and then designing a more ideal array.

In addition to characterizing the seismic background that may be important for advanced versions of LIGO, we plan to help investigate potential non-seismic sources of gravity-gradient noise that we have identified at the out-lying stations such as vibrating roll-up doors and roof-access ladders as well as small flocks of cliff swallows and western king birds that we have seen passing near and alighting on the buildings.

DATA SET REDUCTION

We have created and circulated a first pass as to what channels might be included in a reduced data set. The total data rate is 200kB/s which is greater than the 150kB/s rate expected for Level 2 data. However, this is before any "non-destructive" data compression. For many channels, we expect a gain of at least 3 or 4 from the simplest data non-destructive data compression schemes.

TRANSIENT ANALYSIS

We have designed, developed and tested several DMT routines to perform on-line monitoring of seismic activity at the LIGO sites. One such monitor is currently running on the "stone" DMT machine at Hanford (stone.ligo-wa.caltech.edu). The purpose of these routines is to continuously watch for site-wide seismic events (i.e. earthquakes) which could disturb the optics.

Ultimately, detection of such an event will be added to the metadatabase so that data analysts can quickly look for correlations between transients in the gravity wave channel and enviromental effects. Currently, an XML file of the LIGO_LW type is written with the time and amplitude of the disturbance.

The programs monitor the seismometer signals from the X-mid, X-end, Y-mid, Y-end, and LVEA stations. We note that while the current incarnation of these routines focus on the seismometers, the code is easily extensible to other diagnostic channels which may also prove useful, such as the tiltmeters.