LSC Six-Month Progress Report

Organization University of Michigan Gravity Wave Group (MGWG) **M000074-00-M**

Report Date 02/15/2000

Participation

Michigan LIGO-LSC Progress Report

Overview:

Michigan has finished its work at Caltech's 40 Meter prototype instrument (Gustafson & Dombrowski). New servo schemes for controlling the l+ and l- Michelson cavity degrees of freedom were developed and tested at the 40 Meter. Various sources of noise were identified and mitigated, and new diagnostics were developed.

Data was taken with the 40 Meter in a LIGO-like recycled Fabry-Perot Michelson interferometer configuration in two separate several-day runs. The first run was arranged to coincide with a TAMA data run and helped in further shaking down the 40 Meter; a factor of two noise improvement was achieved over the run. The second run was taken a few weeks later with roughly another factor of two improvement in noise level: a best swept sine noise of 4 x 10**-18 m/sqrt(Hz) at 1 kHz. The new l+ servo was used in part of the TAMA run and the second run. Riles and students at Michigan (Chin & Marsano) have begun analysis of the 40 Meter data, as part of a joint 40 Meter - Tama coincidence analysis effort.

Riles chairs the LSC Detector Characterization Working Group and has continued coordination of group efforts and development of particular detector characterization algorithms. Since last August, Riles has organized two teleconferences of the group, visited the Hanford site to meet with Daniel Sigg and other software developers for the Detector Monitor Tool (DMT), and has coordinated the efforts of LSC members writing code for the DMT.

Specific task reports:

Item 9 - a) Noise studies and development of lock acquisition diagnostics with the 40 Meter.

Locking and noise were improved in the 40 Meter. By the first (TAMA) run, lock was typically achieved in 10-60 seconds. Typical nighttime locks were 5-50 minutes, with alignment tweaks at 4 hour intervals. Day time locks were 20 minutes.

By the second Data Run (100 hours recorded), lock was achieved in 10-50 seconds; night time locks were hours, and daytime locks 10-100 minutes.

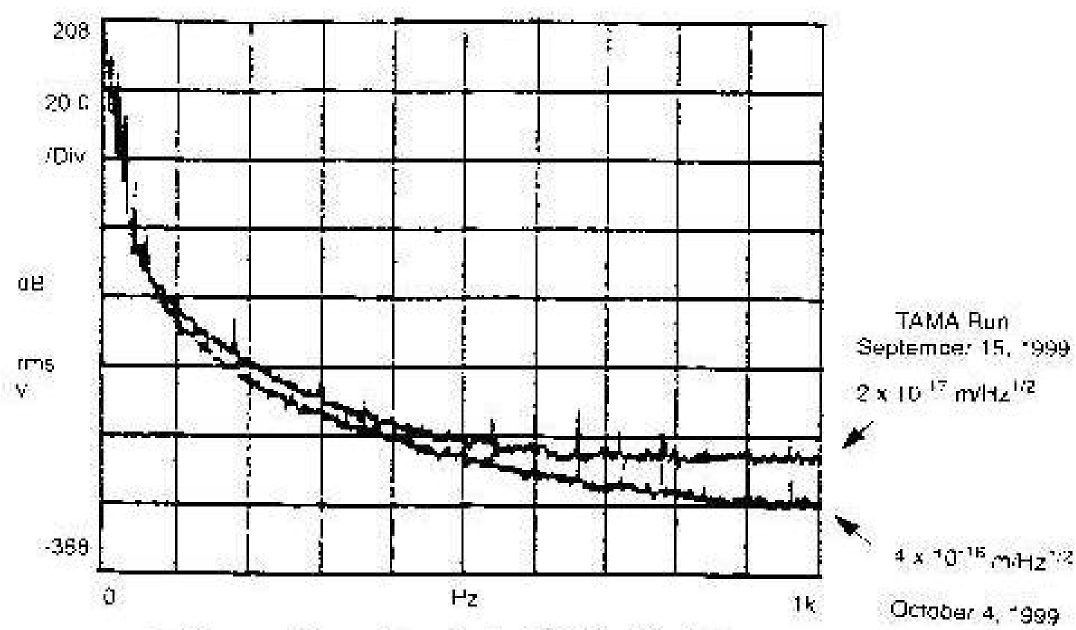
Most gratifying was reacquisition after lock break glitches in seconds or less; the only retuning done was the reoptimization of the laser and its coupling to the modecleaner-IFO system on a 12 hour visit schedule. This was usually done without breaking lock. The 40 Meter ran basically unattended. The substantive improvements are believed to be improved tuning of the collective system, continual operation of the interferometer, use of the new carrier independent l+ servo (see 9c) and a very careful setting of all the actuation drive matrices. The actuation drive matrices were optimized at DC to null pitch and yaw under length change; (this is with a relocking of a given length DOF): This yields a much larger dynamic range to length drift, AND yields a much larger lock capture "crossection". These tunings utilized all the actuation gain matrix resolution. These considerations have not been generally appreciated.

We considered tuning the actuation drive matrix relative AC gains to different values, e.g., at the pendulum frequencies, but found no simple way to implement or lash this up. Noise progress typically featured reducing oscillations in servos (which were narrowing by saturation headroom limits, hence upconverting low frequency noise), and the implementation and elaboration of low frequency boost schemes last used in the non-recycled 40 Meter era, circa 1994-96.

Item 9 - b) Test of the recycled 40 Meter

The test of the recycled 40 Meter is primarily the two data runs accomplished, and the noise levels reported. Robust operation with long locks was achieved. The best noise level at 1 kHz was about 4 x 10**-18m/sqrt(Hz), which is about 10**-19 for h_rms. There was substantial excess noise below 1kHz. We believe this was dominated by noise in the beam splitter l- servos; sustained effort might have reduced the noise at 100 Hz by a factor of perhaps 5, and 2 at 1 kHz. Naively scaled to 4 km, this would correspond to h ~ 10**-21, one of our first LIGO goals.

40 Meter Calibrated Noise Spectra



$$\Longrightarrow \quad \sigma_h \approx 1 \times 10^{-19} \quad @\ 1\text{kHz}$$

Item 9 - c) Test & refinement of "carrier-independent" servo controls for the Michelson cavity longitudinal degrees of freedom

The LIGO "Classical" Michelson cavity error signals are formed by beating Michelson cavity resonant RF sidebands which have the error encoded as a phase shift with a little bit of carrier (used as a local oscillator). The problem is unless the IFO is IN LOCK and STABLE and perfectly tuned, this is fragile, not robust, and lock acquisition becomes problematic. Experience with the 40 Meter bears this out.

We devised a new scheme wherein an additional small amount of AM modulation (2nd sideband at 70Khz) is put on the input light; this is used as the local oscillator (substituting for the carrier) for the l+ (Beam Splitter BS) servo; this beats with the standard sideband light on the SPD, yielding the l+ error signal. A subtlety is that using phase modulation (easier) sidebands for the local oscillator yields zero; the upper combination cancels the lower. The 70 kHz AM sideband is non resonant, hence primarily bounces off the recycling mirror to mix with the standard sidebands on the RFPD-SPD. We then demodulate at the sum or difference of the PM 32.7 MHz RF the AM 70 kHz sidebands. We were able to implement, test and commission this on the 40 Meter; it worked well. With both servos implemented we could switch between them on the fly; the AM l+ servo seemed indeed more robust. In our implementation, the AM l+ servo was somewhat more noisy for nonessential reasons. The AM l+ servo was used in two of the three runs with TAMA, and in the entire 100 hour October run.

We have devised a scheme similar in spirit for the l-, i.e., beam splitter; this is more subtle, but conceptually works. We did not find a simple enough implementation to test in the time available. We believe the carrier independence is an important and useful advance (this achieves what is sometimes called a "diagonal plant" in servo jargon). We will work out implementations that could be used on the LIGO IFO's. A publication of this scheme is in preparation.

Item 9 - d) Recording of 40 Meter data in a fully recycled, LIGO-like configuration

Operational improvement and Data Collection were the principal goals of the Michigan period of control of the 40 Meter. We arranged to record data simultaneously with the TAMA group in three 8-hour stretches over Sept 17, 18, 19. These runs were recorded with the full 100 channel DAQ system that had been built by B Ware, J Heefner, R Bork, and shaken down by Riles, Dombrowski, and Gustafson. Data running was done by Gustafson and S Vass.

Substantial operational improvements were made over a two week period after the TAMA run. We committed to using the AM l+ servo, and carefully tuned the length servo matrices for parallel masses. A second run was commenced and run for 100 hours, Sept 30-Oct 4, featuring substantial noise and lock improvement. Running was basically unattended. Night time locks were hours; daytime locks were ~10-100 minutes. Laser tune-up was usually accomplished without loss of lock (every 12 hours). Lock glitches usually reacquired immediately, .5-2 seconds. The Michigan group and a subset of LIGO LSC scientists have begun to analyze the fall data, as part of an international collaboration with TAMA to perform coincidence analysis of the data from the two independent interferometers.

Item 9 - e) Development & implementation of operational state characterization algorithm

Riles has written roughly half of the operational state algorithm and has begun testing it on a Sun workstation at the Hanford site, using the Data Monitor Tool. Implementation of the first release is expected to be complete by the end of February.

Item 9 - f) Development & implementation of servo instability identification algorithm

Riles has begun this algorithm, but must wait until the operational state algorithm is complete before implementing. Implementation of the first release is expected to be complete by the end of March.

Item 9 - g) Development of discrimination algorithms for periodic sources

Chin has written the skeleton of an algorithm to determine the amplitude modulation scale factor for a periodic source at a known direction in the sky. Work is underway on specifying inputs as GPS time and interferometer name. Work will begin soon on conforming to the LAL software specifications. Work has not yet begun on a wandering oscillator discriminant.

Item 9 - h) Begin analysis of 40 Meter data to test detector characterization & periodic source algorithms

Chin and Marsano have written programs for direct access of the Fall 99 40 Meter data via frames and for quick and rough characterization of data segments. This code was developed on Michigan HP workstations and is now being ported to CACR computers. In the longer term, Chin will be developing a catalog of transients in the 40 Meter data, and Marsano will be characterizing (and we hope regressing out) dominant correlations between the gravitational wave channel and other longitudinal servo channels and relevant orientational channels. Once the infrastructure is in place, Riles will search for evidence of (and we hope the source of) instability in the common mode Michelson cavity servo.