LIGO-T890031-00-R

#57

List of 3/15/89

"ENVIRONMENTAL SPECIFICATIONS

7 MARCH-88

ALEX

1.1.1 Drift Requirements

1. Buildings

In principle, the structure of instrumentation buildings should be designed to satisfy criteria like the ability to provide thermal insulation, sufficiently low acoustic noise, etc., while drift and creep should not be design drivers.

One should require that the connection between the building and the pipes be compliant, in order to avoid stress on the pipes.

It seems reasonable that the building be subject to a drift requirement similar to that of the pipes, that is the long term movement of the building should not exceed 1 cm.

2. Vacuum Tanks

Vacuum tanks are connected to the beam pipes and therefore should be subject to a similar limit on long term drift: 1 cm.

1.1.2 3. Test Mass Suspension Supports

The relative motion of two points on the ground is dominated by the solid Earth tide, as long as the space between them is filled with a continuous and relatively homogeneous material (see R. Weiss, Memo on Thermal Considerations for LIGO Tubes, December 1989). For a separation of 4 km, the change in spacing due to the tide is:

4x10**(-2) cm

The best case is when the supports are firmly anchored to the ground and therefore move with the Earth tide, while a compliant connection between the supports and the vacuum chambers ensures that no additional drift is caused by the movement of the tanks. The design of supports and their connection with the ground should be such that their drift is indeed not larger than the Earth tide, over the time span of one day.

It seems likely that one can design coil magnet systems for test mass position adjustment, which would develop a force of 1 N. For a 1 ton test mass suspended as a 1 m pendulum, that would provide a servo range of 0.1 mm. This range would allow to keep the 4 km resonators in lock for several hours before hopping a fringe due to Earth tidal motion, which seems adequate.

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Temperature Requirements Inside Instrumentation Buildings

1.2 a

1. Tanks, Supports and Interconnecting Tubing

- Assumptions

  - Various vacuum tanks in the instrumentation buildings are connected together rigidly either directly or with sections of pipe;
  - Tanks and pipe supports are connected to the foundation through industrial rubber-metal shock absorbers which allow for horizontal motions of at least 2 mm;
  - The distance between two points on the floor is not affected by the temperature variations inside the building;
  - Vacuum tanks are connected to test mass (or other) vibration isolation supports through compliant elements (bellows).

- Under the above assumptions, thermal expansion leads to some relative motion of the tanks with respect to each other and with respect to the ground. Since the vacuum enclosure is weakly coupled to either the vibration isolation supports or the ground, the latter do not impose restrictions on vacuum system expansion, as long as it does not become too large. One can get a feeling of the scales involved by noting that a 50 m steel structure expands 0.75 mm for each °K.

- Following the previous discussion, it is suggested that the temperature inside the instrumentation building be maintained at:

20°C ± 1.5°C

2. Lasers

- Assumptions:

  - Laser length: 2 m
  - Range of PZT used for tuning the laser length: 10**(-5) m (20 wave lengths)
  - Laser resonator spaers are made of invar, α=1.5x10**(-6) /C

- The temperature variation corresponding to the assumed PZT range is:

$$\Delta t = \frac{1}{\alpha}\frac{\Delta \ell}{\ell} = 3.3°C$$

- It is suggested that the temperature in the laser area be maintained at:

20°C ± 1.5°C

NOTE: Implementation of this requirement will allow, in principle, to keep the lasers locked to the interferometer for as long as the 4 km resonators can be kept under control.

1.2 b

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Power Dissipation by Electronics Instrumentation

1. Assumptions

- 2 racks, 4 scopes per test mass (TM) or beam splitter (BS)
- 1 rack, 3 scopes per beam conditioning optics tank serving one interferometer (BC1)
- 2 racks, 6 scopes per beam conditioning optics tank serving 2 interferometers (BC2)
- 4 additional racks, 5 additional scopes per interferometer in the corner building (I)

- Power dissipation per rack: 1.2 kW, resulting from fitting the rack with five 120 w NIM bins and two 500 W HV power supplies, all loaded at 75% of capacity
- Power dissipation per scope: 200 W

- 3.2 kW dissipation per test mass or beam splitter
- 1.8 kW dissipation per BC1
- 3.6 kW dissipation per BC2
- 5.8 kW additional dissipation pre interferometer

- The beam conditioning optics is housed in a succession of 6 chambers

2. Comments

- The total estimate for the power dissipated by the electronics in various type of buildings in Phase A and Phase B is given below.
- The number of interferometers, test masses, etc., used for the present estimate, are taken from LIGO: Mission, Evolution, Configuration and Early Operation, 1 March 1989, by W. Althouse, R. Drever, F. Raab, R. Vogt.
- The result of this estimate, which is no more than a somewhat educated guess, exceeds a previous estimate (LIGO Engineering Staff, LIGO Electrical Power, 30 November 1988) by approximately a factor of two.
- The present estimate refers to electronics instrumentation only and does not contain power dissipated by machinery and data processing equipment.
- It would be interesting to compare the present estimate with the estimated heat contributed by solar radiation. If, as it seems likely, the power dissipated by the electronics is comparable or higher than the one contributed by the Sun, a more accurate estimate will be required in order to specify the air conditioning system.

Table 1. Power dissipated by LIGO electronics

PHASE A

SITE 1		SITE 2	
- Corner building:		- Corner building:	
(8TM +4BS)x3.2 =	38.4 kW	(4TM + 2BS)x3.2 =	19.2 kW
2x6BC2x3.6 =	43.2 kW	2x6BC1x1.8 =	21.6 kW
4IX5.8 =	23.2 KW	2IX5.8 =	11.6 KW
TOTAL.............	104.8 KW	TOTAL...............	52.4 kW
- Mid/End building:		- End building	
2TMx3.2 =	6.4 kW	2TMx3.2 =	6.4 kW

PHASE B

SITE 1		SITE 2	
- Corner building:		- Corner building:	
(12TM + 6BS)x3.2=	57.6 kW	(6TM + 3BS)x3.2 =	28.8 kW
6x6BC1x1.8 =	64.8 kW	3x6BC1x1.8 =	32.4 kW
6Ix5.8 =	34.8 kW	3Ix5.8 =	17.4 kW
TOTAL.............	157.2 kW	TOTAL...............	78.6 kW
- Mid/End building:		End building:	
3TMx3.2 =	9.6 kW	3TMx3.2 =	9.6 kW

Environmental Specs relating to vibration and sound

1.4

Introduction

Engineering specifications related to vibration and sound deal mainly with what we have called ''imported noise". Once a site has been selected, giving due weight to how noisy it is (along with many other factors), its ambient noise spectrum is not under our control. Much work for the scientists will go into attenuating this noise before it reaches the critical parts of the interferometers, but this will be local isolation where it counts. No practical scheme exists to substantially attenuate the noise across the whole site or even throughout a whole building.

The spirit of imported noise specifications is that we should not bring in enough noise to make a noticeable difference to the sensitivity of the interferometers. For imported vibration, it is easy to cast this spec in terms of the pre-existing ambient spectrum. For imported sound, the specification is, of course, in different units. A physical model of the interaction between sound and the vibration which it causes is needed to justify the spec.

(There is a methodological problem with specifications set in this way. Ambient noise spectra are typically characterized as broad-band distributions of power. The specifications we will impose are also naturally given for the broad-band spectral component. But some noise sources, such as rotating machinery and electrical equipment such as transformers, produce a substantial amount of noise in rather narrow spectral lines. These can stand out in Fourier transforms of high resolution, even if the total power in the lines is small. For this reason, we will have to make a separate allowance for narrow-band noise.)

Vibration Specification

The total imported broad-band vibration power shall be small enough so that the vibration spectrum near any test mass is increased by less than 3 dB at any frequency from 0.3 Hz to 10 kHz, compared to its value before the site was developed. (For planning purposes, the spectrum can be estimated as 10**-7 cm/rHz independent of frequency below 10 Hz, falling inversely with the square of the frequency above 10 Hz.)

Imported narrow-band vibration power shall be limited in the following way:

Narrow-band noise is defined as having a characteristic frequency width narrower than one-fifth of its peak frequency.

The sum of the broad-band and narrow-band imported vibration shall be less than 3 dB greater than the pre-existing level, in any octave from 0.3 Hz to 10 kHz.

In a high resolution spectrum, fewer than 1 percent of the frequency bins in any octave may be allowed to exceed the pre-existing spectrum by greater than 3 dB.

Rationale

This specification spells out in detail the meaning of our desire not to increase our interferometer noise problems by a substantial amount.

I think it will not be difficult to meet this spec. (For detailed justification, see the Report on Imported Noise by PRS, a draft of which is presently circulating.) Most small pieces of equipment can be used without special care. Large items like laser power supplies should be placed on compliant isolators, but the isolators can be made quite effective. Free-standing air-conditioning units should probably be avoided, in favor of quiet units such as the chilled-water fan-coil type (or equivalent). Items on which the LIGO team needs more information are noise from large transformers, and from the pumps and other gear for the laser cooling system. In addition to choice of quiet equipment and use of isolators, siting heavy equipment (such as the power sub-station) some distance from the instrumentation buildings should be considered where it is appropriate.

1.5 Sound Specification

The sound spectrum in the vicinity of any instrumentation chamber shall be limited in a manner like the vibration spectrum, except that the threshold''3 dB greater than the pre-existing spectrum" should be replaced by ''10**-3 dyn/cm**2-rHz".

Rationale

The choice of this particular spectral density is justified by two lines of argument.

Firstly, this noise level roughly corresponds (above 1 kHz) to the sound level of +45 dBA specified as the maximum recommended level in the ISA ''Recommended Environments for Standards Laboratories". This is justified mainly on psychological, rather than physical grounds. The document notes that this is a typical noise level for private offices. The MIT 1.5-meter lab had a noise level about 10 dB higher than this when all equipment was running. Most people thought it was unpleasantly noisy. There seems to be no reason that the lower noise level should be hard to achieve. The Caltech lab is considerably quieter (to the ear, anyway). This is due in large measure to banishing the laser power supplies and computers to a separate room.

Secondly, sound at the level of our spec is small enough so that the vibration it induces in our appartus should be small compared with the level caused by the pre-existing vibration spectrum. Detailed justification of this statement will appear in a forthcoming document.

1.6

Yekta; March 8, 1989

Cleanliness Specifications

(a) Global Building Specifications:

(i) The building should be sealed against insects and and small animals (None allowed).

Any of these could get into a vacuum chamber or into a high intensity laser beam. In either case, high precision optics can be contaminated.

(ii) The building should be over-pressurized with at least a positive pressure of 10 pascals. (10^{-4} ATM)

This is necessary to stop dust from entering the building through cracks and door ways.

(iii) The part of the building which houses the vacuum chambers and lasers should not have any fenestration (No windows or sky lights which let the sun shine on the equipment).

(iv) There should be no water leakage into the building from outside.

1.3

(v) The relative humidity level in the building should be 40 percent plus or minus 5 percent.

This level of humidity has sufficiently low dew point temperature at the ambient temperature of 75 degrees Fahrenheit in order not to cause condensation on the laser coolant hoses and tubes. If the level humidity is lower, static charges build up very fast and the air is uncomfortably dry.

(vi) There should be no visible or concealed condensation in the building. Any part of the building with a temperature below the dew point for the specified relative humidity must be thermally insulated to prevent condensation.

(vii) There should be no detectable (by humans) unpleasant odors in the building.

(viii) The levels of toxic dusts, fumes and mists must be below the federal standards (ASA standards MAC, and ACGIH 1959).

(ix) There should be no radioactive contaminants in the building.

(x) There should be NO aerosols or mists of oils in the ambient air in the building. Mechanical pumps that produce such mists must have vent hoses which carry the mist out of the building to a condensation chamber.

(xi) The global air quality of the building should be Class 50,000 (50,000 particles per cubic foot).

The cleanest part of the MIT lab is Class 15,000; the shuttle assembly bay at Cape Caneveral is Class 100,000.

(xii) The ventilation of the building should be within the comfort levels for humans with sufficient number of air exchanges to keep the air healthy. This is extremely important if dry nitrogen is used to fill and purge the vacuum tanks.

(xiii) The infiltration of outside air into the building should be regulated to keep the global air quality within the specified limit.

(xiv) There should be no concealed or visible growth of fungi or moss in the building.

(b) Local Cleanliness Issues:

(i) Hazards and Advantages of Cleaning high-precision Large Optics:

Although successful cleanings of super mirrors which are 2 inches in diameter have been achieved at Caltech Gravitational Physics Laboratory, successful in-place drag wiping of larger super mirrors have not yet been demonstrated.

In place cleanings of large diameter mirrors can be extremely difficult especially with the tight and space saving designs under consideration.

The chances of stirring up settled dust is large when in place cleaning is attempted.

Cleaning at a remote location with specially designed equipment has the largest chance of being successful. This requires a design which allows the main optical components to be removed from suspensions. In the designs under consideration such an operation will be extremely difficult.

Dust caps are required when the interferometer components are assembled. Once the components are in place, removable remotely-controlled dust caps are required. Unless a very ingenious design is developed, these caps will be difficult to use and they waste valuable vacuum chamber space. No such design is available at the present time.

We conclude that keeping the LOCAL environment around the chambers clean when the tanks are open to air is the only feasible solution. This can be achieved by using removable and portable clean rooms which are lowered in place once the tank covers are removed. Such clean rooms are commercially available and one can be designed to seal against the main flange of the chamber when the top is removed. These clean rooms have air cleaners in them to keep the air free of dust at all times.

(ii) The Local Clean Room Specifications:

The LOCAL air quality in the portable clean rooms should be Class 200.

A calculation performed by Rai Weiss indicates that for exposure times of the order of a day, the air quality in the clean rooms should be Class 20 for HORIZONTAL surfaces. Measurements by R. P. Young (Degradation of Low scatter mirrors by particle contamination, AEDC Air force station, 1975) and by R. P. Ruel, et al. (A forecasting technique for accumulated particle contamination on spacecraft assemblies, TRW systems, 1977) indicate that the amount dust accumulation on vertical surfaces is 0.0023 to 0.10 times the the amount of accumulation on the horizontal surfaces.
The calculations performed by Yekta Gursel show that the amount of dust accumulation on the vertical surfaces as measured by the people above can be accounted for by estimating the static charges on the cleaned surfaces. For a value of the electric field which is at the breakdown level for ordinary air, the amount of dust accumulation on a vertical surface is comparable to the amount of dust accumulation on a horizontal surface under the influence of gravity. Since the amount of accumulation is proportional to the square of the electric field, a field which is one third of the breakdown field will cause 10 times less accumulation.

RW
3/7/89

1.7 POWER CONDITIONING IN THE FACILITIES AND GROUNDING FOR DISTRIBUTION SYSTEM

THE INSTRUMENTATION BUILDING POWER DISTRIBUTION SYSTEM HAS NO SPECIAL REQUIREMENTS THAT WOULD NOT BE THE STANDARD FOR A RESEARCH LABORATORY WITH DISTRIBUTED APPARATUS

THE SERVICE SHOULD INCLUDE:

440	3ϕ	LASERS, ROTATING MACHINERY
220	3ϕ	POWER SUPPLIES, MACHINERY
110		GENERAL LABORATORY INSTRUMENTATION

SINCE ALL CRITICAL INSTRUMENTION IS RECOMMENDED TO HAVE LOCAL VOLTAGE REGULATION, THE SPECIFICATION FOR GLOBAL LINE VOLTAGE VARIATION ARE LOOSER THAN FOR A STANDARDS LABORATORY

1.7.1 $\Delta V/V \big|_{RMS} < 0.02$ LONG TERM $t >$ MINUTES
ZERO TO FULL LOAD

1.7.2 $\Delta V/V \big|_{PEAK} < 0.001$ TRANSIENTS $t < 10^{-2}$ SECONDS

1.7.3 HARMONIC CONTENT

$$V(t) = \sum_{n=1}^{\infty} V_n \sin(n\omega_1 t + \varphi_n)$$

$$\frac{\left(\sum_{n=2}^{\infty} |V_n|^2 \right)^{1/2}}{V_1} < .05$$

GLOBAL SPECIFICATIONS

1.7.4 GROUNDING AND NEUTRAL LINES

1) EARTH GROUNDING CONSISTENT WITH LIGHTNING SAFETY IS ASSURED. [illegible] A [illegible]

2) SINCE THE INSTRUMENTATION IS DISTRIBUTED OVER A SUBSTANTIAL AREA IT WILL BE IMPORTANT TO HAVE A WELL DEFINED GROUND CONNECTION AT EACH LOCATION.

A RECOMMENDED GOAL IS TO ESTABLISH A STAR GROUND SYSTEM IN EACH BUILDING USING AN EARTH CONNECTION WITH RESISTANCE TO GROUND OF LESS THAN 1 Ω.

INTERCONNECTION BETWEEN THE LOCAL GROUND AND THE STAR SHOULD BE MADE WITH LOW INDUCTANCE AND LOW RESISTANCE LEADS

$$L/\ell = \text{INDUCTANCE}/_{\text{METER}} < 0.05 \ \text{HENRYS}/_{\text{METER}}$$

$$R/\ell = \text{RESISTANCE}/_{\text{METER}} < 10^{-4} \ \text{OHMS}/_{\text{METER}}$$

A SUGGESTED TECHNIQUE IS TO USE COPPER TUBING FOR THE GROUND NETWORK

3) NEUTRAL POWER LINES SHOULD BE SEPARATE FROM GROUND LINES

4) INDIVIDUAL LOCATIONS, — AT EACH INSTRUMENTATION TANK OR SEPARABLE COMPLEX — SHOULD DERIVE POWER FROM A SEPARATE SUB TRANSFORMER THE INDIVIDUAL TRANSFORMERS SHOULD HAVE ELECTROSTATIC SHIELDS BETWEEN PRIMARY AND SECONDARY WINDINGS WHICH ARE GROUNDED

5) UNBALANCED NEUTRAL CURRENTS IN Y TRANSFORMATIONS SHOULD NOT EXCEED 1% OF THE AVERAGE LOAD CURRENT IN ANY OF THE LEGS

6) THE INSTRUMENTATION TANKS AND VACUUM TUBES SHOULD BE GROUNDED BY KNOWN CONNECTIONS USING LOW INDUCTANCE CIRCUITRY. (THE GROUNDING LINE SHOULD BE REMOVABLE FOR DIAGNOSTICS)

* UNCERTAIN → 7) THE OVERALL GROUNDING AND INTERCONNECTION BETWEEN STATIONS ESPECIALLY THE CURRENTS RUNNING ALONG THE BEAM TUBES

MUST BE STUDIED FURTHER. THE LARGE INDUCED EMFS FROM MAGNETIC STORMS AND LIGHTNING MAY REQUIRE INSULATED SECTIONS AND ARC SUPPRESSION BETWEEN SECTIONS. THE REQUIREMENTS FOR THIS ARE SITE DEPENDENT

8) IT IS WORTH CONSIDERING INDIVIDUAL ELECTROSTATICALLY SHIELDED ISOLATION TRANSFORMERS AS A MEANS OF FREEING EACH SEPARABLE INSTRUMENTATION COMPLEX TO FURTHER REDUCE THE CHANCE OF LARGE GROUND CURRENTS

1.8

MAGNETIC FIELDS IN THE INSTRUMENTATION BUILDINGS FROM THE POWER DISTRIBUTION SYSTEM

1) THE DISTRIBUTION SYSTEM WIRING SHOULD BE ARRANGED SO THAT LINE FREQUENCY AND HARMONIC MAGNETIC FIELDS AT MASS SUSPENSION LOCATIONS ARE LESS THAN 1 MILLIGAUSS rms.

THIS SPECIFICATION REQUIRES SOME CARE IN TRANSFORMER PLACEMENT AND THE GEOMETRY OF THE DISTRIBUTION LINES. IN MOST CASES IT WILL BE SATISFIED BY STANDARD PRACTICE

SOME COMMENTS MORE RELEVANT TO THE SECTION ON RECEIVER / FACILITY INTERFACES

1) INTERCONNECTION OF SIGNALS BETWEEN INSTRUMENTATION COMPLEXES (INSTRUMENTATION STATIONS, TANK COMPLEXES etc) WOULD BE BEST DONE DIGITALLY USING OPTICAL FIBRES TO AVOID INDUCED GROUND CURRENT TRANSIENTS

2) ELECTROSTATIC SHIELDING IS REQUIRED ON ALL INSULATORS IN THE INSTRUMENTATION TANKS

FOR EXAMPLE:

CONDUCTING COATINGS ON VIEW PORTS

CONDUCTING COATINGS ON PLASTIC OR GLASS PARTS

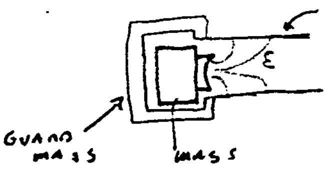
FARADAY SCREENS ON THOSE PARTS WHICH CANNOT BE CONDUCTING

NATIONAL 42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE

THE FIELD LINES FROM UNCONTROLLED STATIC CHARGES MUST NOT GET TO THE SUSPENSION MASS

* ⟹ UNCERTAIN

A SPECIAL PROBLEM ARE THE DIELECTRIC COATING ON THE MIRRORS THEMSELVES, <u>THIS NEEDS FURTHER THINKING</u>. I HAVE OFTEN IMAGINED A TUBULAR SHIELD ATTACHED TO THE GUARD (OR RECOIL) MASS ASSOCIATED WITH THE SUSPENSION



NOTE ON LOW INDUCTANCE CONNECTIONS

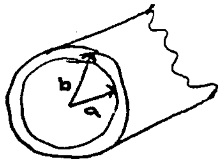
$$L/\ell = \frac{\text{INDUCTANCE}}{\text{LENGTH}}$$

STRAIGHT SOLID CYLINDER $\frac{\mu_0}{4\pi}$

BRAID $\sim \frac{\mu_0}{4\pi N^{1/2}}$

N: # OF STRANDS

TUBING $\frac{\mu_0}{4\pi}\left[1-\frac{2a^2}{b^2-a^2}\ln b/a\right]$



$\approx \frac{\mu_0}{8\pi}\left(\frac{b-a}{a}\right)$

$\frac{b-a}{a} \ll 1$

NATIONAL
42 381 50 SHEETS 5 SQUARE
42 382 100 SHEETS 5 SQUARE
42 389 200 SHEETS 5 SQUARE