RESULTS OF VIBRATION MEASUREMENTS ON LA SILLA TELESCOPES

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Abstract

With reference to **VLT Interferometer** requirements relating to mechanical vibrations, we describe the instrumentation and procedures used for telescope testing at La Silla (1989). A picture of conventional (3.60 m) and less conventional (NTT & CAT) telescope vibrational behaviour becomes clearer from a very large number of samples. Guidelines are presented for telescope design and for the selection of instrumentation adapted to vibration measurements.

Introduction

This paper describes the results of a mission performed at ESO-La Silla in 1989 on large telescopes. A number of issues are tackled here :

a) Will the VLT 8m telescopes be stable enough to be used in an interferometer ? Up to now, all interferometers (in operation or being implemented) make use of specially designed telescopes for interferometry, *except the VLTI* : the VLTI structure is very large (see figure 1) and can accommodate a number of foci and instruments. Even though stiffness is a driving parameter for other reasons (first eigenfrequency > 8 Hz), it is not known how the structure will behave at submicrometer level.

b) Why do vibration measurements on large existing facilities ? 1) to identify main sources of perturbation (drives, wind loading, effects due to nearby transformers, motors or fans...) 2) to obtain an estimate of the power spectrum of optical path variations in a telescope after integration of mirror distance variations along the whole path under different conditions.

c) Longitudinal OPD stability requirements for the VLTI [4] : the budget allocated to vibrations within one telescope in terms of Optical Path Difference (OPD) *versus* exposure time is :

OPD fluctuations =	14	nm rms	for a	10	ms exposure time
OPD fluctuations =	50	nm rms	for a	48	ms exposure time
OPD fluctuations =	225	nm rms	for a	290	ms exposure time

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GOALS

Investigate vibrational behaviour of telescopes

The PRIMARY goal of the testing mission was to obtain some numbers on the actual level of mechanical vibrations found on existing telescopes.

The SECONDARY goal was to identify some of the sources of vibrations.

An important TERTIARY goal i.e. "how to possibly improve the vibration status on these existing telescopes" is much more difficult and was beyond the scope of the work.

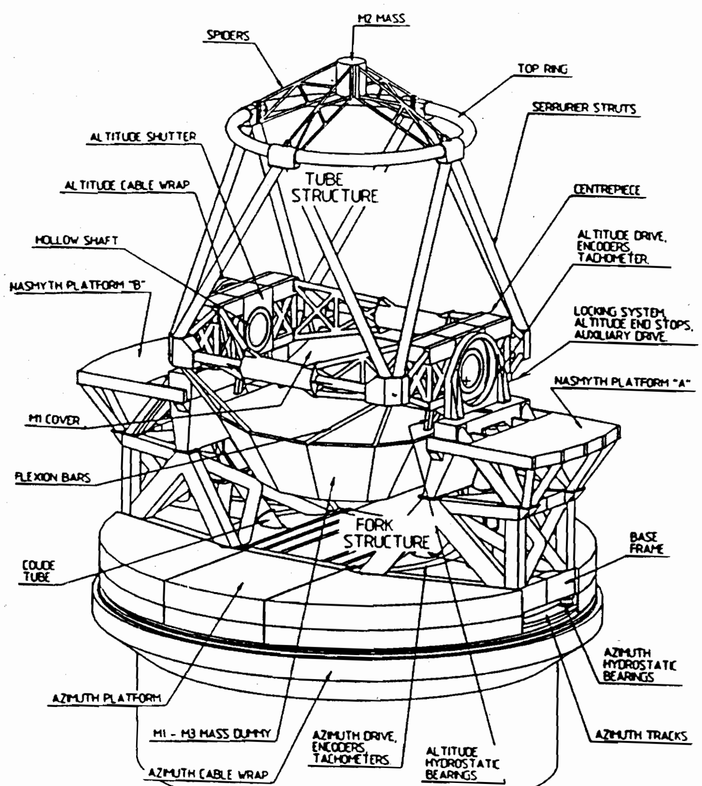


Fig. 1 : the VLT 8 m Telescope Structure

1) Instrumentation used. Noise limitation and Calibration

a - Hardware and software

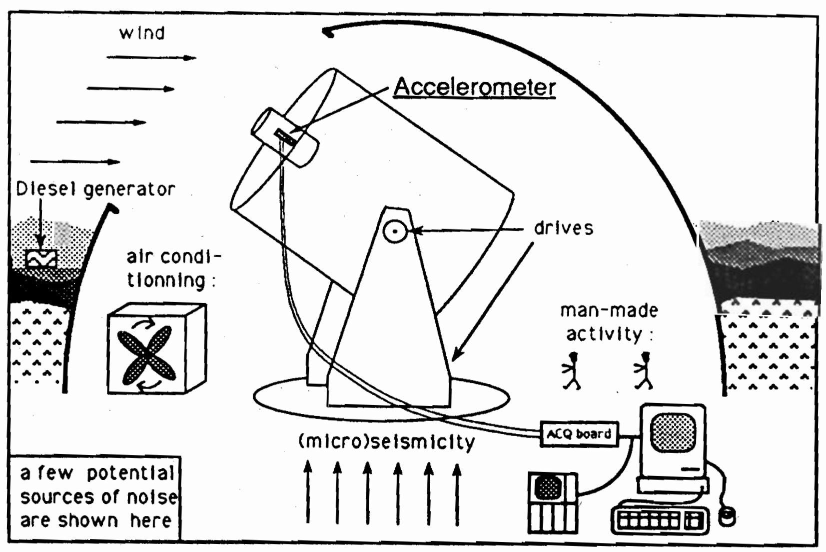
* 2 accelerometers Bruel & Kjær 8306 (Piezo), working in push-pull mode with booster amplifiers

* high-pass filter to eliminate the DC component

* second order filter for antialiasing (transforms accelerations into positions)

* acquisition board from "GW Instruments". Sampling rates used : 260.1, 360.9 and sometimes 5218 Hz.

* Data acquisition and processing with Macintosh computer



b - Noise limitations

We identified the following sources of noise in our push-pull set-up :

* sensor random noise

* electrical common mode (power supply drifts, 50 Hz...) are almost negligible

* electrostatic low frequency fluctuations, especially troublesome on electrically insulated structures under wind load

The *usual noise level* is plotted on each graph. The measurements were very often "noise limited" below 3 Hz, for quiet telescope conditions.

c - Calibration : we checked our system response against : 1) other accelerometers with their own data acquisition system 2) a HP interferometer.

2) Vibrations from oil pumps

The oil pump frequencies (azimuth oil bearing of the NTT, hour-angle oil bearing of the 360) appear clearly on almost all of the corresponding samples. The resulting amplitude remains small but is certainly not negligible in terms of interferometric requirements.

On the other hand there is a possible filtering effect by the oil support on some of the mechanical resonance lines. (The following numbers are orders of magnitude, given in nm rms over a 0.2 Hz band)

NTT @ 85.9 Hz & 86 Hz (the 2nd harmonic components are visible but very small) :

M2 (parallel to the optical axis)	approx. 3 nm rms
Nasmyth, vertical	approx. 2 nm rms
M1 (parallel to the optical axis)	approx. 0.1 nm rms
Fork base, horizontal	approx. 0.3 nm rms

3.60 m telescope @ 173 Hz (the 2nd & 3rd harmonic components are visible but very small) :

M2 (parallel to the optical axis)	approx. 0.2 nm rms
M1 (parallel to the optical axis)	approx. 0.02 nm rms
Horse-shoe, vertical :	approx. 0.6 nm rms

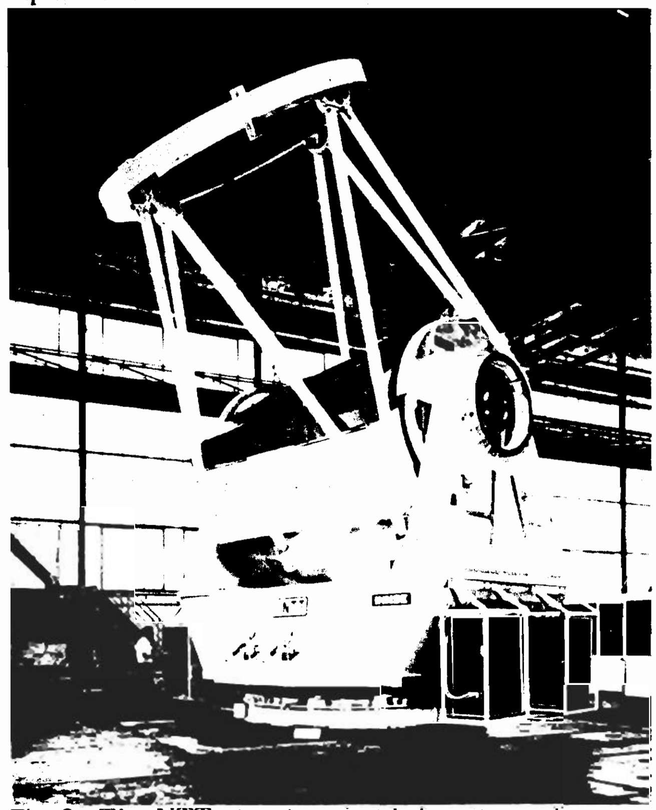


Fig. 2 : **The NTT structure** just before it was disassembled and shipped to Chile; last time it could be seen entirely.

3) Vibrations from the M2 spider support on the NTT

Surprisingly, most of the measurements, at various places over the NTT, displayed a similar spectral signature in the 43 to 50 Hz range. After some investigation the source was identified to be the transverse vibration of the secondary mirror support spider, transmitted through the telescope structure.

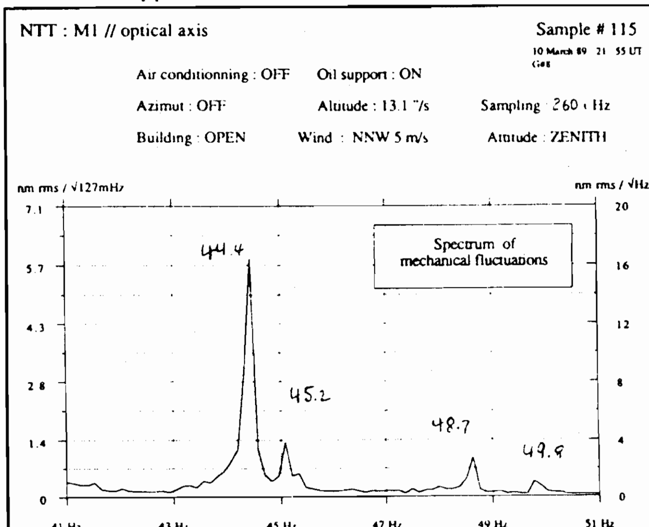


Fig. 3 : Vibrations coming from the **Mirror 2 support spiders**, seen on **Mirror 1**.

Figure 3 : the accelerometers were installed on the side of the primary mirror of the NTT, which produced this typical PSD under quasi normal observing conditions.

rms fuctuations *versus* exposure time τ

From measured Power Spectrum Densities (PSD), the rms position errors σ during the exposure time τ were computed using the following[3] :

$$\sigma^2(\tau) = \int_{1\,Hz}^{Nyquist} PSD(Signal + Noise)\,[1 - sinc^2(\pi\tau f)]\,df$$

The "reference" on Fig.4 to 10 corresponds to the requirement given in Int.(c) with $\sigma=\sigma_{opd}/2$

Ideally the integration should be from 0 to infinity and applied to the signal above the measurement system noise. Since our PZT accelerometers are less sensitive at low frequency (cf. §7), measurements were detector noise limited below ≈ 5 Hz when the environment was quiet (especially on Fig. 9). In this paper the PSD corresponds to (Signal + Noise) and is integrated from 1 Hz (measurements valid above ≈ 1 Hz) to the Nyquist frequency.

4) Contribution of the wind to mechanical vibrations

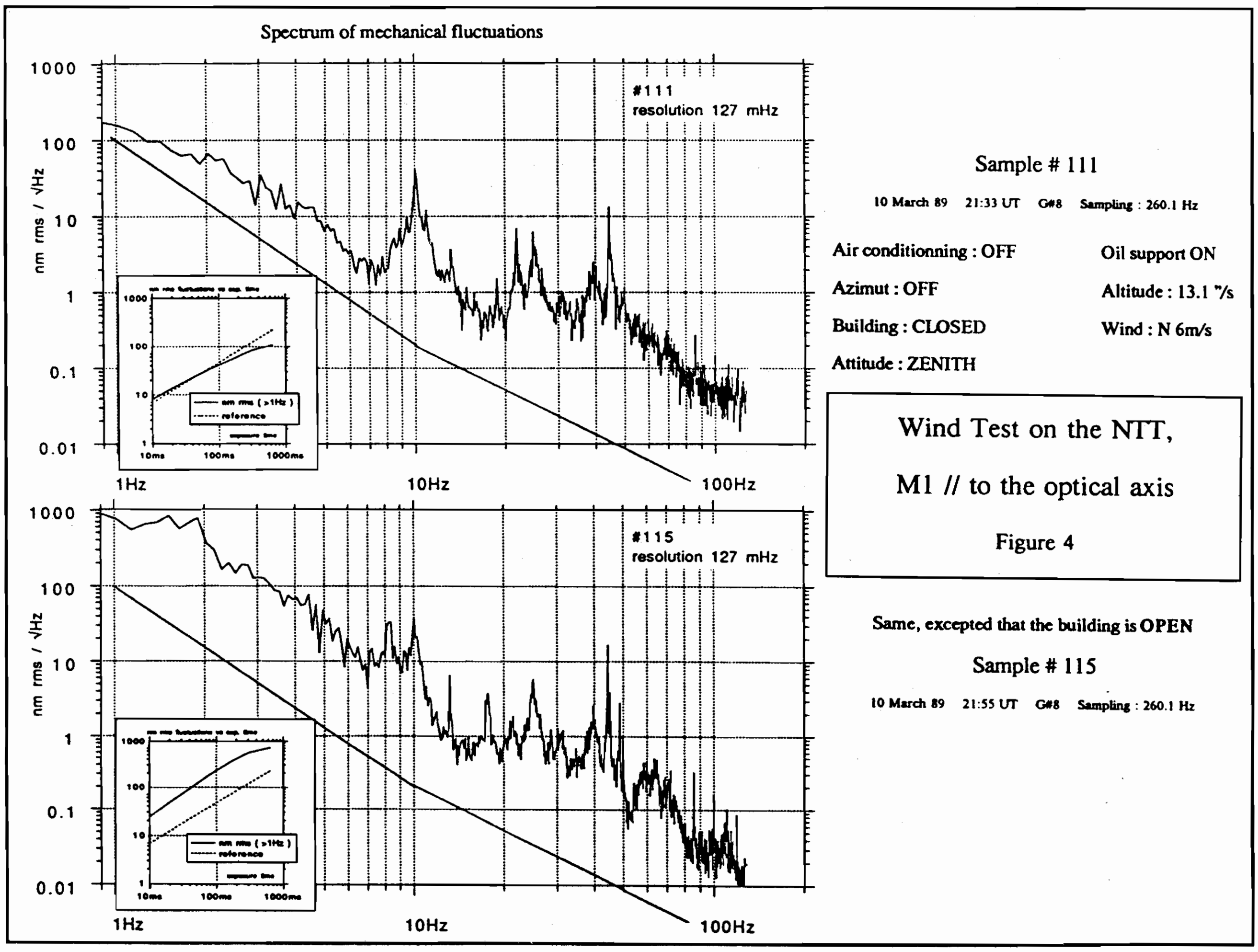
(rms fluctuations given below are computed for a 15 msec exposure time)

a - On the NTT ; measured on the side of M1, along a direction parallel to the optical axis

see fig. 4 : sample # 111 (building closed) and sample # 115 (building open).

Average over 5 samples building closed : **14 nm rms** for a 5 m/s open air North wind

Average over 3 samples building open : **42 nm rms** for a 5 m/s open air West-North-West wind



Wind Test on the NTT,

M1 // to the optical axis

Figure 4

Conclusions from this test : the vibrations on the side of M1 increase by a factor of 3 at 15 ms exposure time, when the NTT building is opened, for a 5 m/s open air wind. This increase, when the building is opened, occurs mainly at frequencies below 10 Hz. The 14 nm rms value (building closed) would certainly be lower under a no-wind (and closed building) condition because of suspected wind influences on the telescope through the foundations even with a closed building.

<u>b- On the CAT</u> (3.60 m telescope, Coudé Auxiliary Telescope)

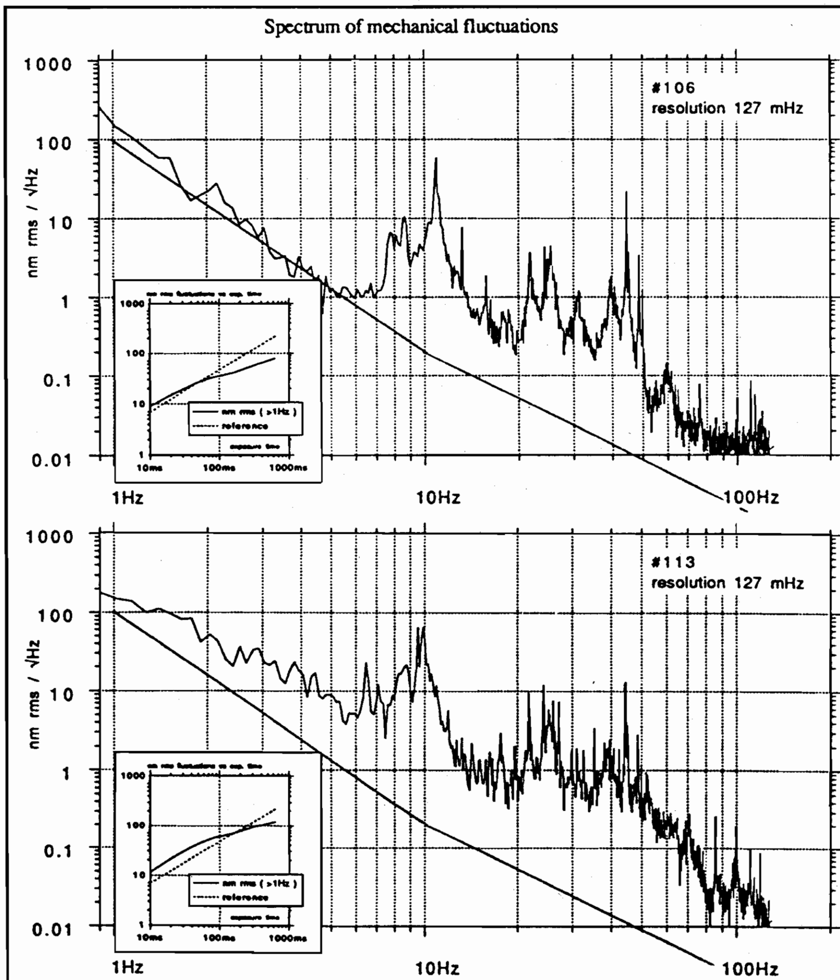
Two samples are available to estimate the wind effects on the secondary mirror (vibrations are measured along a direction parallel to the optical axis) : these samples do not show any significant variations between an OPEN dome and a CLOSED dome, for a *7 m/s open air North wind*. The measurements done on the CAT do not distinguish wind effects on the tall tower or through the opened dome (cf. above, § 4 a).

5) Contribution of drives and bearings to the mechanical vibrations

*(The rms fluctuation given below is computed for a 15 **ms** exposure time.)*

<u>a - NTT : effects measured on the side of M1, along a direction parallel to the optical axis (see fig. 5)</u>

average over 3 samples (drives OFF) : **14 nm rms**
average over 2 samples (drives ON) : **16 nm rms**



Sample # 106

10 March 89 21:13 UT G#8 Sampling : 260.1 Hz

Air conditionning : OFF Oil support : OFF
Azimut : OFF Altitude : OFF
Building : CLOSED Wind : N 5 m/s
Attitude : ZENITH

Drive Test on the NTT,

M1 // to the optical axis

<u>Figure 5</u>

Same, excepted that : Azimut : 1350 "/s
Altitude : 13.1 "/s

Sample # 113

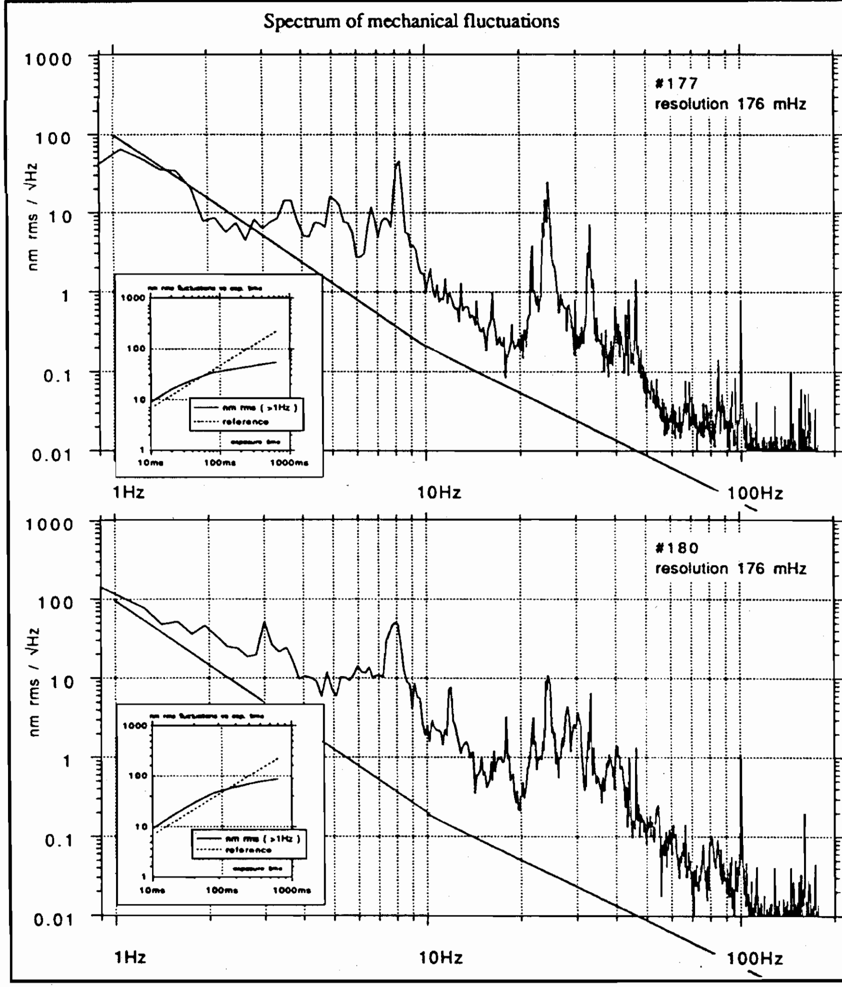
10 March 89 21:55 UT G#8 Sampling : 260.1 Hz

- The difference on the rms value for short exposure times is negligible .
- There is a clear difference in spectral signature, when the drives are applied : the mechanical noise increases markedly in the 1 to 10 Hz band and a second line appears at 8 Hz.

b - NTT : effects measured on the side of M2, along a direction parallel to the optical axis

The difference between : DRIVES ON (with the tracking rate set for a small zenithal distance, ie Az : 1350 ″/s ; El : 13.1 ″/s) and DRIVES OFF, is hardly significant in terms of rms fluctuation for short exposure times. These effects were certainly shadowed by the fairly strong wind (7 m/s) with the building open at the time of the measurement.

c- **3.60 m telescope** : effects of the drive measured on the side of M1, along a direction parallel to the optical axis (fig. 6)



Sample # 177

14 March 89 14:07 UT G#9/2 Sampling : 360.9Hz

Air condition'g : OFF Oil support : ON

Air : ON

Hour-angle : 0 ″/s Declination : 0 ″/s

Dome : OPEN 45 ° Wind : NNW 5m/s

Attitude : ZENITH

Drive Test on the 3.60 m Tel.,

M1 // to the optical axis

Figure 6

Sample # 180

Same, excepted that :

Hour-angle rate is : 150 ″/s

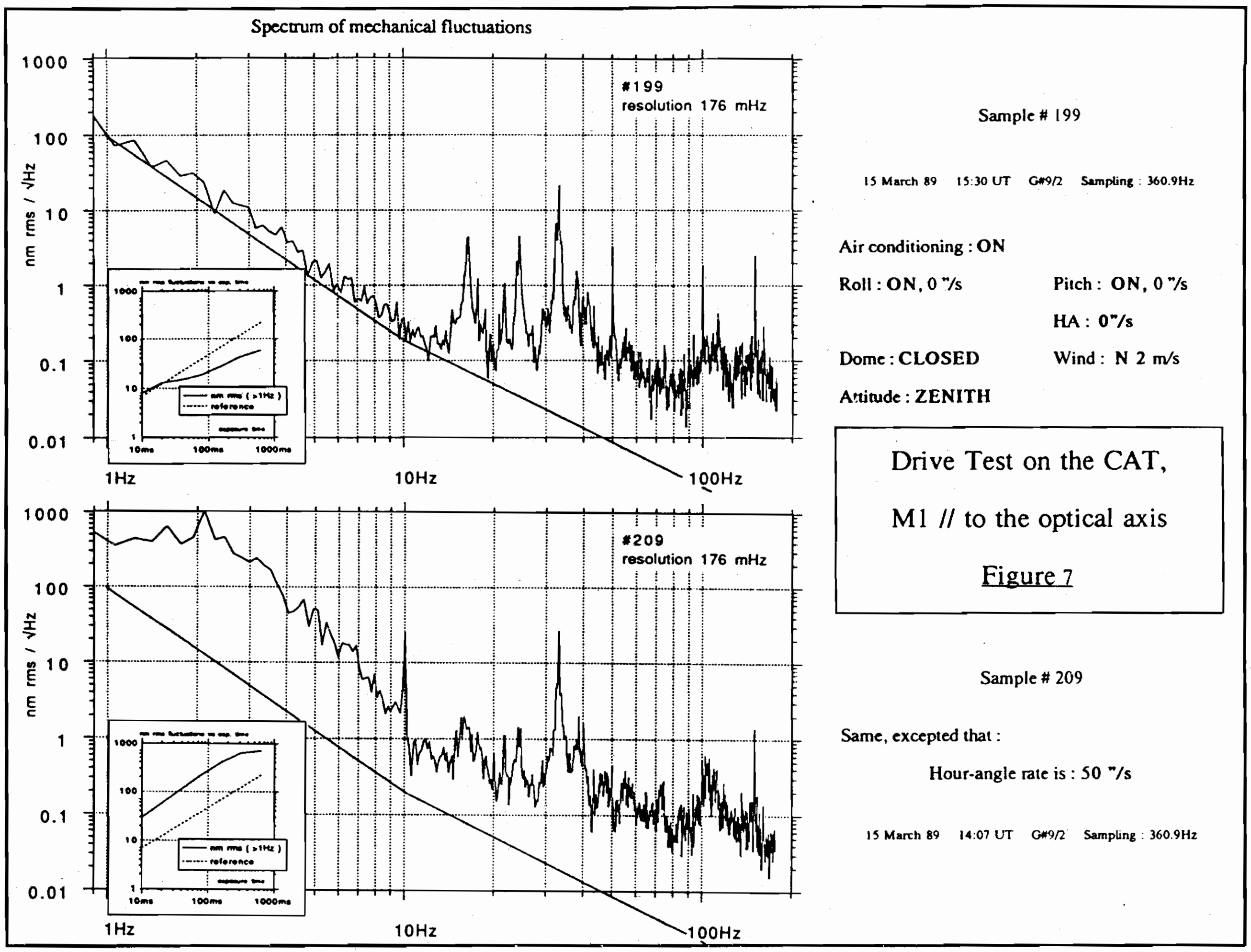
14 March 89 14:07 UT G#9/2 Sampling : 360.9Hz

Tracking in hour-angle at a rate up to 150 ″/s does not show any significant changes with respect to the OFF status in terms of rms fluctuation. Nevertheless, with increased tracking rate, new lines are visible on the Power Spectrum.

d - CAT : effects measured on the side of M1, along a direction parallel to the optical axis (see fig. 7)

Average over 3 samples (drives OFF) : **12 nm rms**
Average over 4 samples (drives ON) : **36 nm rms**

There is a clear increase of the level of mechanical vibrations, mainly for frequencies below 10 Hz, when the hour-angle tracking speed is increased.



Drive Test on the CAT,

M1 // to the optical axis

Figure 7

6) Estimated cumulated mechanical fluctuation along the NTT optical path :

The intention is to derive, from point accelerometric measurements, an estimate of the contribution of the NTT to optical path fluctuations as if it were used for interferometry. (fig. 8)

We used measurements on the primary mirror (M1), on the secondary (M2) and at the Nasmyth focus. These measurements were performed under normal observing conditions ; the fluctuations were assumed to be uncorrelated, which is most probably true except for the lower frequencies, and therefore were added quadratically. The result *does not* incorporate air index contribution and refers to mechanical fluctuations (not optical path *differences).*

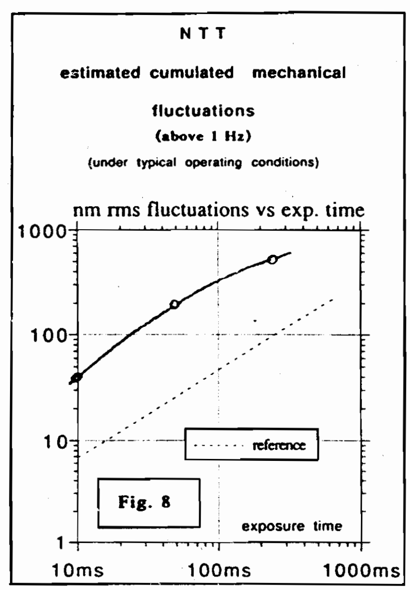


Fig. 8

7) Validity of the measurement technique and possible improvements

- the hardware and the software were extensively tested and calibrated ; the *overall response* (fluctuation values in nm) is estimated to be correct within ± 20 % between 3 and 110 (or 140 Hz) ;

the lower boundary comes from possible slight changes in the high-pass filter ; the higher boundaries take into account the rather low sampling frequency.

- in quiet conditions, measurements were in most cases limited by the system noise up to a few Hertz (typically 5 Hz).

- single point measurements make it impossible to distinguish between *translation and rotation* of the mirror under test ; we assumed in this paper that the motion was mostly translation but this needs further investigation, for example with more accelerometers at proper locations near the mirror under test.

- the method used neglects the effect of *air index* fluctuations in the telescope. The lack of phase information does not allow to *add linearly* the contributions of each mirror. Therefore one would need laser measurements provided a very stable reference is available. We strongly recommend that this be considered for further investigations (the drawback is that the set-up for laser measurements takes a lot more time than point accelerometric measurements).

- when the environment is noisy, as it was often the case at the time of our measurements, an evaluation of the contribution of each source of vibration is difficult.

CONCLUSIONS

1- Conclusions on wind

We noticed a small increase in rms fluctuations -by a factor of 1 to 3 (computed for a 15 ms exposure time)- for wind speeds of 5 m/s. Wind influence through the outside building and the telescope foundations may be of importance.

2- Conclusions on drives - we found :

- a small increase in rms fluctuations, by a factor of 1 to 3 (computed for a 15 ms exposure time). The increase is spread over the 1 to 180 Hz frequency range, especially below 10 Hz.

- a clear but not striking change in spectral signature

- a difficulty in distinguishing between drive errors in acceleration (spectral lines at lower frequencies?) and bearing / gear noises (wide band noise at higher frequencies ?).

3- Conclusions on overall behaviour

See fig. 9 *(quiet* conditions) & fig.10 *(typical observing* conditions) for measurements on M1 *(left column)* & on M2 *(right column)*, for the NTT *(upper row)*, for the 3.60m *(middle row)* and for the CAT *(lower row)*.

- no striking differences between telescopes ; the 3.60m telescope may be a little quieter than the NTT ; the impression is that vibrations are less on secondary mirrors than on primaries.

- the NTT, considered as one component in an interferometer, would probably be above the provisional specs by a factor of 3 for "normal observing conditions", but the **secondary mirror** by

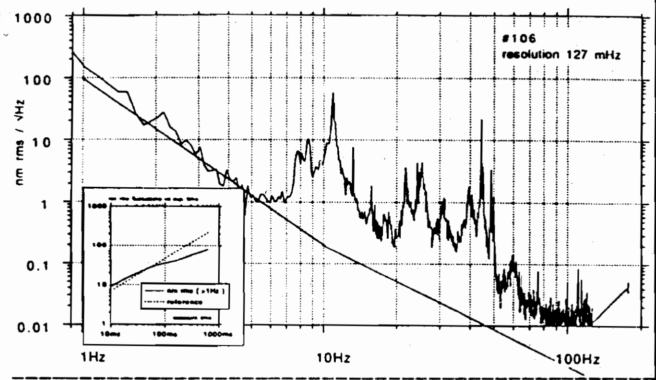
QUIET CONDITIONS (Fig. 9)

NTT : M1 // optical axis

Sample # 106
10 March 89 - 21 : 13 UT
G#8

Air conditionning : OFF   Oil support : OFF
Azimut : OFF   Altitude : OFF   Sampling : 260.1 Hz
Building : CLOSED   Wind : N_5 m/s   Attitude : ZENITH

Spectrum of mechanical fluctuations

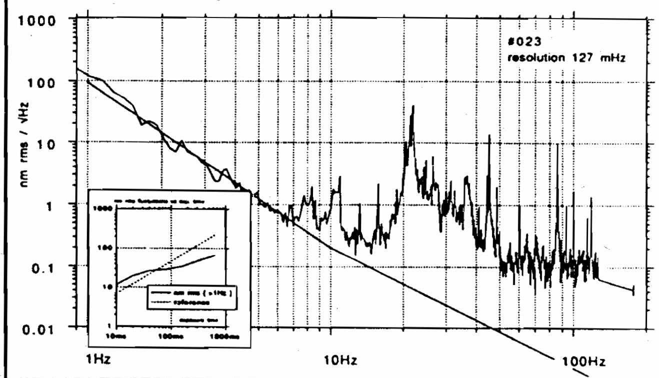


NTT : M2 // optical axis

Sample # 23
4 March 89   21 : 52 UT
G#7

Air conditionning : ON   Oil support : ON
Azimut : OFF   Altitude : OFF   Sampling : 260.1 Hz
Building : CLOSED   Wind : ESE 2 m/s   Attitude : z = 45°

Spectrum of mechanical fluctuations



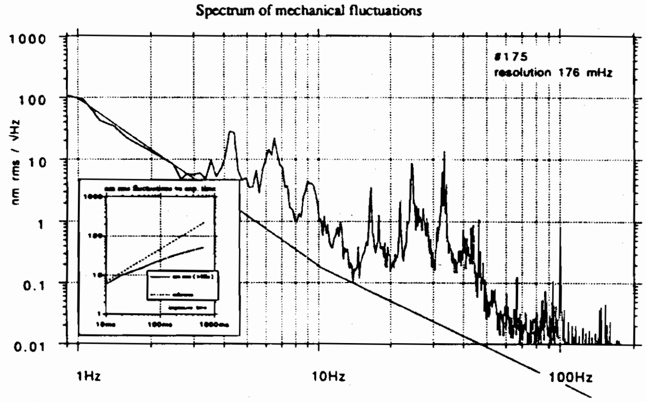
360 : M1 // optical axis

oil boost pump OFF

Sample # 175
14 March 89 - 13 : 56 UT
G9/2

Air cond. : OFF   Oil pads : OFF   Air : OFF
HA : LOCK   Dec : LOCK   Sampling : 360.9 Hz
Dome : OPEN 45°   Wind NNW 3 m/s   Attitude : ZENITH

Spectrum of mechanical fluctuations



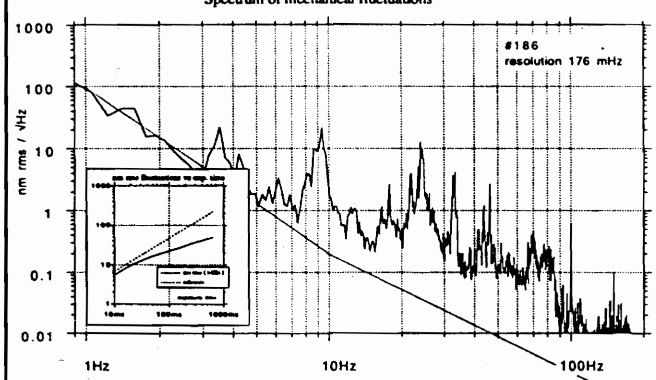
360 : M2 // optical axis

oil boost pump OFF

Sample # 186
14 March 89 - 17 09 UT
G9/2
5.2 kHz OK

Air cond. : OFF   Oil pads : OFF   Air : OFF
HA : LOCK   Dec : LOCK   Sampling : 360.9 Hz
Dome : OPEN 45°   Wind N 9 m/s   Attitude : ZENITH

Spectrum of mechanical fluctuations

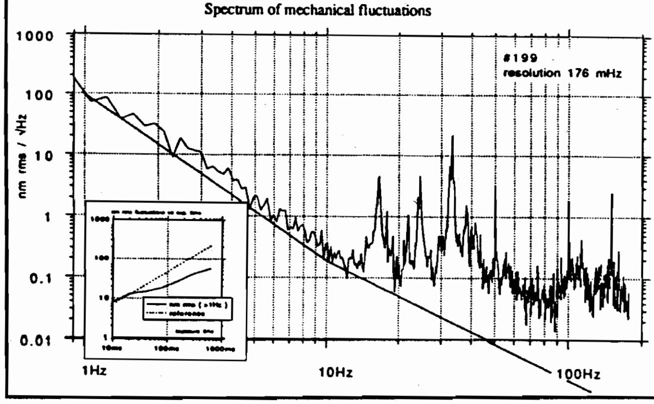


CAT : M1 // optical axis

Sample # 199
15 March 89 - 15 : 30 UT
G9_2
Sampling : 360.9 Hz

Air cond. : ON
Roll : ON, 0 "/s   Pitch : ON, 0 "/s   (HA : 0 "/s)
Dome : CLOSED   Wind : N 2 m/s   Attitude : ZENITH

Spectrum of mechanical fluctuations

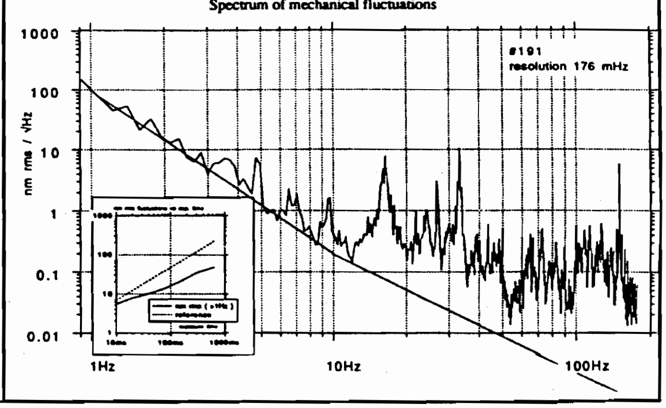


CAT : M2 // optical axis

Sample # 191
14 March 89 - 20 : 38 UT
G9_2
Sampling : 360.9 Hz

Air cond. : ON
Roll : GUIDE   Pitch : GUIDE   (HA : 50 "/s)
Dome : OPEN   Wind : N 9 m/s   Attitude : ZENITH

Spectrum of mechanical fluctuations

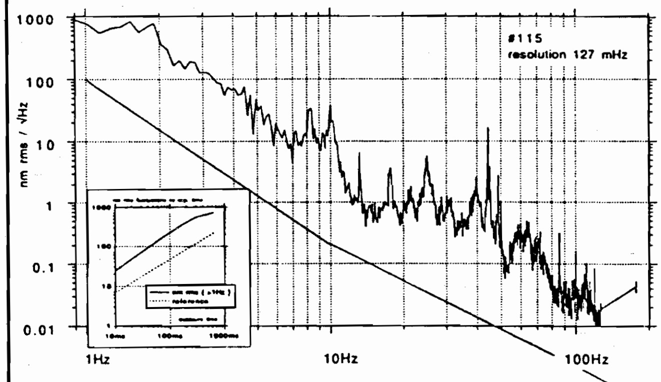


TYPICAL OBSERVING CONDITIONS (Fig. 10)

NTT : M1 // optical axis — Sample # 115
10 March 89 - 21 : 55 UT
G#8

Air conditionning : OFF — Oil support : ON
Azimut : OFF — Altitude : 13.1 "/s — Sampling : 260.1 Hz
Building : OPEN — Wind : NNW 5 m/s — Attitude : ZENITH

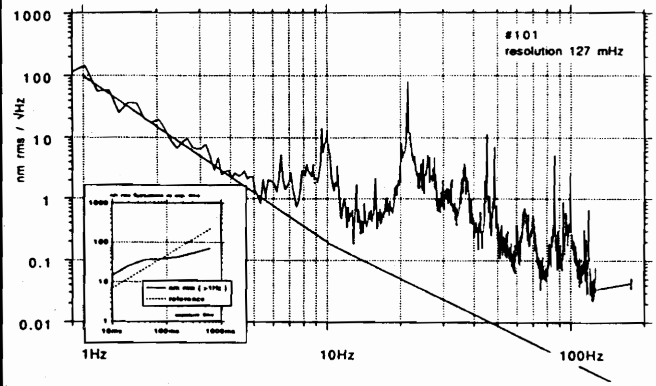
Spectrum of mechanical fluctuations



NTT : M2 // optax — Sample # 101
10 march 89 - 20 : 19 UT
G#8

Air conditionning : ON — Oil support : ON
Azimut : 1350 "/s — Altitude : 13 "/s — Sampling : 260.1 Hz
Building : Open — Wind NNW 7 m/s

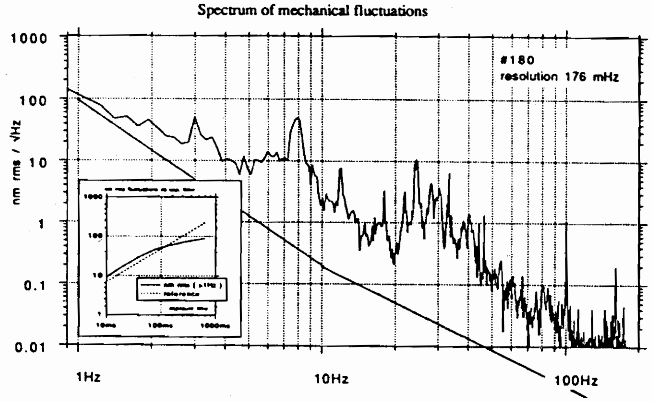
Spectrum of mechanical fluctuations



360 : M1 // optical axis — Sample # 180
14 March 89 - 14 : 29 UT
O9/2

Air cond. : OFF — Oil pads : ON — Air : ON
HA : 150 "/s — Dec : 0 "/s — Sampling : 360.9 Hz
Dome : OPEN 45° — Wind N 5 m/s — Attitude : ZENITH

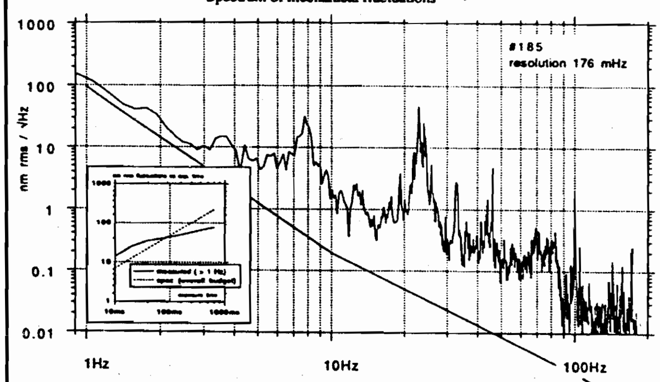
Spectrum of mechanical fluctuations



360 : M2 // optical axis — Sample # 185
+ oil boost pump
14 March 89 - 16 : 48 UT
O9/2

Air cond. : ON — Oil pads : ON — Air : ON
HA : 15"/s ->S — Dec : 15 "/s ->W — Sampling : 360.9 Hz
Dome : OPEN 45deg — Wind N 7 m/s — Attitude : ZENITH

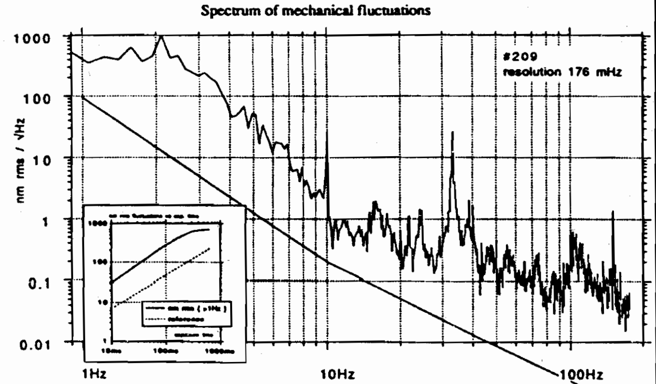
Spectrum of mechanical fluctuations



CAT : M1 // optical axis — Sample # 209
15 March 89 - 22 : 31 UT
O9_2
Sampling : 360.9 Hz

Air cond. : ON
Roll : ON — Pitch : ON — HA = ∂ = 50 "/s
Dome : CLOSED — Wind : SW 3 m/s — Attitude : z = 20°

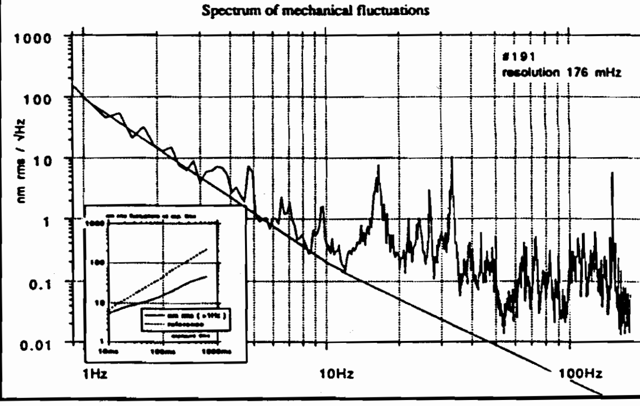
Spectrum of mechanical fluctuations



CAT : M2 // optical axis — Sample # 191
14 March 89 - 20 : 38 UT
O9_2
Sampling : 360.9 Hz

Air cond. : ON
Roll : GUIDE — Pitch : GUIDE — (HA : 50 "/s)
Dome : OPEN — Wind : N 9 m/s — Attitude : ZENITH

Spectrum of mechanical fluctuations



itself would meet our requirements for exposure times > 100 ms, i.e. for wavelength approximately larger than 3.5 μm.

- The vibration level of the tested telescopes -which were not designed for interferometry- is above, but still close to, the tentative specifications and we can be reasonably optimistic for the future of the VLTI in that respect.

4- Conclusions on vibration testing methods

Accelerometers are a good choice for an extensive survey of telescope vibrations, but their low frequency response should be improved. For deeper and more accurate measurements on actual *Optical Path Distances*, accelerometers and laser metrology should be combined.

5- Recommendations for engineering

- investigate the respective influence of errors in tracking speed smoothness and of the noise generated by solid bearings and drive actuators.
- introduce damping in the structures of buildings and telescopes
- evaluate the ground transmission of vibrations induced by the wind on buildings around or in the vicinity of a telescope.
- avoid pulsating oil pumps
- compressors, air conditioning fans, etc... should be "far" away
- select carefully the location of power supplies for instrumentation and telescope control

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