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Infrastructure works for the mitigation of environmental noises during VIRGO commissioning and plans until VSR2

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VIR-018B-09

(new release of VIR-018A-09)

May 25, 2009

VIRGO * A joint CNRS-INFN Project
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Introduction:

This document summarizes major works performed during Virgo and V+ commissioning (from September 2006 to April 2009) in order to reduce observed ITF noise driven by environmental sources. For each work a brief description is given of (1) motivation, (2) noise mitigation achieved, (3) limitations/side effects (if present) and (4) residual noise. For each work are provided links to reference documents.

List of Acronyms:

CB = Central Building
LL = Laser Laboratory
DL = Detection Laboratory
EIB = External Injection Bench
LB = Laser Bench
EDB = External Detection Bench
WEB = West External Bench
NEB = North External Bench
VSR1, VSR2 = Virgo Science Run 1 (May to Oct. 2007) and 2 (planned to start June 2009)
INJ = injection
DET = detection
HVAC = Heating, Ventilation and Air Conditioning

Summary table:

This table summarizes the works (date and gain achieved). A few works are not exactly "infrastructure" works, but as well aimed to reduce the environmental noise coupling: these are listed *in italic font* in the following table. Single items are further discussed in subsequent sections.

nr.	Item	date	notes
1	Acoustic enclosures in LL (Laser Lab)	Sep 2006	Factor 2 to 5 noise reduction above 100 Hz.
2	Acoustic enclosures for NE and WE optical benches	May 2007	Factor 2 noise reduction at 50 Hz, 4 to 15 from 100 Hz to 1 kHz.
3	Acoustic enclosure for DL (Detection Lab)	Apr 2007	Factor 2 noise reduction at 50 Hz, 4 to 15 from 100 Hz to 1 kHz.
4	*Stiffening of several mounts on external benches*	*Feb. 2007, Jan. 2008*	*Resonances moved from 100-200Hz to 500-600Hz, were coupling to dark fringe is less.*
5	Installation of acoustic panels on the	Jan 2008	Acoustic noise transmitted to

	DAQ (Data Acquisition room) windows		Central hall reduced by a factor2 above 100 Hz.
6	Relocation of the DAQ HVAC machine	Feb-Mar 2008	Reduction of noise transmitted to Central hall in the 50-150 Hz band.
7	Installation of rubber bellow in the cold water pipeline to mitigate CB pump 1 noise	Dec 2007	Not much effective. At most a factor two reduction achieved.
8	Replacement of water pump 1 with new one	Apr 2009	Noise disappeared
9	*Bellow on turbo-molecular vacuum pump at Detection*	*March 2008*	*Reduced seismic noise transmitted to Detection tower, by a factor 3-10 above 100Hz.*
10	Realization of the EE Room (Electronic Equipments Room) (acoustic separating wall, door and cooling system) to host LL electronic racks	Jul 2008; Feb 2009	Acoustic isolation of EE Room respect to LL benches is a factor ≈100 at 100 Hz, ≈ 1000 at 1kHz.
11	Modification of the CB HVAC machine air flow, reduction of fans speed by 25%	Sep-Oct 2008	Factor 2 reduction of acoustic and seismic noise below ≈ 40 Hz.
12	Mitigation of electromagnetic noise due to inductance loops in the fluorescent lighting of the CB mechanical lab	July 2008	Noise detected and eliminated by re-cabling of the circuits.
13	Improvement works on the CB electrical systems distribution (work not directly for environmental noise mitigation)	Jun-Oct 2008	Electromagnetic noise gains to be measured
14	Electromagnetic noise coming from the MC HVAC resistive heating	July 2008	Noise detected. The cure needs the installation of alternative system.
15	Electromagnetic noise from the Harmonic Corrector Unit of CB	July 2008	Noise eliminated by adding a second unit sharing the load
16	Electromagnetic noise from fluorescent lamps of the EE Room	Feb 2009	Noise detected and eliminated by substitution of the equipments.
17	Installation of dampers for electric motors and fans of the CB HVAC machine	Apr 2009	Small but sensible reduction of seismic noise, at EDB and Detection tower
18	Reduction of the WEB HVAC machine air flow, by 10%	Apr 2009	Acoustic and seismic noise RMS reduction by 30%
19	*New cover box on terminal benches*	*May 2009*	*Reduced coupling of acoustic noise to bench motion. About 25% reduction of RMS noise.*
20	*Mechanical damper for the WEB legs*	*May 2009*	*Reduction of a factor 2 of*

	resonance		*18Hz peak amplitude.*

Table 1. Major environmental mitigation works for Virgo and V+.

1. Acoustic enclosures LL benches (27-29 Sept. 2006)

Motivation: Detected large coupling of acoustic and seismic noise from LL (racks cooling fans) to dark fringe, likely via input beam jitter [1].

Implementation: Enclosures made of high-density material around EIB and LB [2].

Result: Acoustic noise at benches and seismic vibration of both benches reduced a factor 3 to 5 above 100Hz. Indication that acoustic noise is largely coupled to bench seismic noise [3].

Side effects: Some turbulent air fluxes cause increase of beam jitter below 10Hz to mHz. The situation then improved with installation of silenced openings in the enclosures [3]. But problems with air fluxes reappear from time to time. Tight space left around benches.

Residual noise: Isolation not effective below 100Hz. Residual noise from racks cooling fans starting from 30Hz. No good isolation of LL from experimental hall especially on INJ-tower side. Evidence of residual noise from racks in central hall (around INJ tower). See other actions in Section 9.

2. Acoustic enclosures around terminal benches (3-5 May 2007)

Motivation: Acoustic and seismic noise at benches excited optics mounts and coupled to dark fringe via diffused light. Peaks at the resonant frequency of the mounts were seen in sensitivity, identified with tapping tests [4].

Implementation: Enclosures made of high-density material around WEB and NEB [5].

Result: Acoustic noise and seismic motion of bench reduced by roughly: a factor 2 at 50Hz, a factor 4 at 100Hz, a factor 10-15 at 1kHz [6]. Also see concomitant mitigation action of mounts stiffening, described in Section 4.

Residual noise: No or poor isolation below 100Hz. Projection of acoustic noise above 100Hz is now slightly below VIRGO design. No measure below 100Hz [6].

3. Acoustic enclosure around detection bench (4-7 April 2007)

Motivation: as for Section 2, although noise was not limiting sensitivity.

Implementation: EDB was displaced and detached from DET tower. An acoustic enclosure made of same type (as 1 and 2) material was built around EDB to isolate it from experimental hall, the DET tower and DET racks [7].

Result: Measured a reduction of acoustic noise and bench seismic motion similar to that measured for terminal benches enclosures [8].

Residual noise: No or poor isolation below 50-100Hz. The projected noise associated to bench vibration is below VIRGO design [8]. No measurement below 50Hz. No projection done for acoustically coupling noise (difficult to excite locally only the bench).

4. Stiffening of optical mounts on external benches (Feb. 2007 and Jan. 2008)

This item is not strictly speaking an infrastructure work, but it is linked to mitigation actions of Sections 1, 2 and 3. This was done for terminal benches (Feb. 2007) and BMS mounts on EIB (Jan. 2008).

Motivation: Peaks (100-300Hz) in sensitivity were associated to mechanical modes frequency of optics mounts. Critical optical mounts were identified by tapping tests and (only in case of BMS) by noise injections on BMS actuators. The seismic motion of mounts at resonances is excited by acoustic noise and seismic motion of benches. They coupled noise via diffused light in the case of NEB and WEB [4] and via beam jitter in the case of EIB [9].

Implementation: Replacing critical optical mounts with more rigid ones [9].

Result: NEB and WEB peaks disappeared from sensitivity [6]. New BMS mounts have resonances above ≈600Hz. Input beam jitter noise largely reduced above 50Hz [9].

Residual noise: For Terminal benches acoustic noise projections above 100Hz indicated noise from acoustically induced bench and optics motion is now slightly below VIRGO design [6]. For EIB we suspect some residual peaks between 150 and 300 Hz from beam jitter on EIB, which show up in February 2009 data.

5. DAQ room acoustic isolation (January 30-31, 2008)

Motivation: Acoustic noise from electronic racks in DAQ room, coupled to dark fringe via (at least) the DET Brewster window [10]. Evidence is that Brewster vibration noise and dark fringe noise increase if DAQ room windows are opened [12].

Implementation: Installation of acoustic isolation panels at DAQ room windows. Replacement of DAQ room back door with acoustically isolated one [11,14].

Result: Acoustic noise in hall, just outside of DAQ room reduces approximately a factor 2 above 100Hz. Small, but significant, seismic noise reduction at Det. Brewster (few lines and peaks between 100 and 150Hz) [12].

Residual noise: Apparently none, after the removal of Detection Brewster window [10].

6. DAQ room new air conditioning (February 2008)

Motivation: Peaks in sensitivity (80-120Hz) likely coupling via Detection Brewster [13].

Implementation: The HVAC machine was replaced with a new one. The new machine was moved outside the DAQ room. The air flux remained roughly the same, around 5000 m^3/hour. Fan and engines were put on rubber isolating layers. Air circulation was improved adopting inlet and outlet ducts and collectors [14].

Results: About 5 times reduction of acoustic and seismic noise of floor inside DAQ room, between 30 and 20Hz. Measured a significant reduction of vibrations of EDB at 50-150Hz (acoustic noise also reduced, but less) [15].

Residual noise: The new machine produces some residual seismic and acoustic noise at EDB between 50-80Hz [15]. Intense seismic lines likely associated to HVAC fan/engine (23.8Hz) are seen on CB hall floor and at Detection. Suspect of some small noise coupling to dark fringe in February 2009 data.

7. Bellow on water pump 1 (Jan. 2008)

Motivation: Intense peaks in dark fringe at pump rotation frequency (46Hz) and harmonics, affected VSR1 data. Significant (10 times above background) acoustic and seismic noise peaks detected inside and around DL. Coupling to VSR1 dark fringe seemed to occur mainly via DET Brewster [16].

Implementation: This is the recycling pump of chilled water to the CB hall HVAC. A soft rubber bellow was added downstream of the pump.

Results: No significant reduction of seismic and acoustic emissions (about a factor two). Dark fringe coupling reduced after DET Brewster removal [17].

Residual noise: A residual noise effect in dark fringe is evidenced in February 2009 data.

8. Replacement of water pump 1 (Apr. 2009)

The pump has been replaced with one of exactly the same type and model. We verified with switch on/off tests that no noise is heard by seismic and acoustic sensors in the CB hall [18]. The noise produced by the old pump was likely due to a mechanical unbalance of the pump that might be the consequence of more than 10 years of continuous use. It has been verified that this pump is not needed in cold weather, thus its use will be reduced by operating it only during hot summer months.
Indications: Pumps should be checked periodically for noise emissions, and their balancing adjusted (by firm) if necessary.

9. Bellow on Turbo pump DET (March 19, 2008)

Motivation: The turbo molecular pump at the detection tower was found (before VSR1) to produce large noise in dark fringe (extended from 100 Hz up to 2-3kHz). Most of this noise was coupling through seismic vibrations of the DET Brewster. Until the DET Brewster was in place this pump could be switched off and replaced with a smaller, less noisy one, dedicated to the vacuum volume of the DET tower alone. After the substitution of the DET Brewster with the Cryogenic-trap, the necessity of a larger pumping capacity (the DET tower vacuum being no more separated from the rest of the interferometer) required the standard turbo-pump to be put back in operation. The pump produced still a significant residual noise in dark fringe between 80 and 200Hz [19].

Implementation: Instead being rigidly hanged to the tower vessel, as all other turbo-pumps still are, the DET turbo pump has been hanged to a rigid support (placed on a rubber isolating layer and attached to the platform) and it is connected to the tower through a soft bellow steel tube.

Results: Seismic noise to the tower is filtered significantly (factor 3 to 20) above 100Hz (eLog 22196). The noise in dark fringe disappeared [19].

Residual noise: Some residual noise between 40 and 100Hz where bellow performs no filtering action. Suspect residual seismic noise coupling through the Detection output window or the tower walls, between 100 and 400Hz, possibly via back scattering (see [19]).

10. Realization of new Electronic (EE) room (summer 2008)

Motivation: cooling fans of racks inside the LL were seen in dark fringe, lines around 200 and 400Hz [19]. Shaking tests gave indication that the interferometer operation is sensitive to intense mechanical vibrations of the last section of the MC tube [20].

Implementation: Most racks (almost all racks carrying cooling fans) have been displaced from inside LL to EE-room, about 5m away. EE-room is separated by LL by two walls (MC tube goes between them): one is the original wall made of concrete and, for a small part, of light panels; the second wall has been added and it is made of acoustically isolation material.

One acoustic isolation door separates EE-room from central hall. At the same time the laser chiller has been moved from underneath the MC tube to a separate room with concrete walls. This implementation is detailed in reference [21].
A cooling system based on fan-coils has been adopted. Preliminary tests showed this to produce very little noise, not detectable inside LL [23].

Results: Measured good acoustic isolation of EE-room from LL benches (inside acoustic enclosures): factor 100 at 100Hz, factor 1000 at 1kHz [14]. Acoustic noise in LL reduced above few hundred Hz. No evidence of coupling of noise from EE-room racks to dark fringe (February 2009 data).

Side effects: possible problems with over-heating of some laser electronic components related to not good air circulation in room.

Residual noise: Residual acoustic and seismic noise of EIB and LB above one hundred Hz is associated to the Master Laser Power Supply rack which could not be displaced. No evidence of residual noise in dark fringe from cooling fans left inside LL.

11. Slow down of fans of CB hall HVAC (October 2008)

Motivation: Low frequency acoustic and seismic noise produced by the air conditioning machines increases motion of external benches at 10-20Hz (legs resonances) which couples back-scattered light in the interferometer. Up-conversion peaks are seen in dark fringe. After VSR1 this noise was limiting VIRGO sensitivity below 100Hz [24]. The noise coupling was significantly reduced by decreasing the amount of scattered light on the benches through clean up actions (see [25]).

Implementation: Reduced rotation speed of CB hall air conditioning fans by 25% (from 11Hz to 8Hz). Instead the air flux into and out of the hall did not change (≈23000 m^3/hour), because of the opening of one air valve. The two engines (one of the inlet fan, and one of the out-let fan) were replaced with slower ones (24Hz to 12Hz) and the fans speed regulated by changing pulleys on engines and fans [26].

Results: Measured a reduced of seismic and acoustic noise RMS noise at EDB by about a factor 2 in ≈5-40Hz band for seismic, ≈0-40Hz band for acoustic.

Side-effect: Added one seismic peak at 12Hz associated to the new engines. This is potentially disturbing since it matches one main resonance of the EDB bench legs and it is thus amplified on EDB.

Residual noise: In central hall the seismic noise is still a factor 1.5 above background with AC off, acoustic noise is a factor 2 above background noise (RMS noise in same bands quoted above). In the LL the noise from this machine reduced at the level of background noise. We evidenced some residual noise coupling to dark fringe in April 2009 data [27].

12. Inductive loops in lights circuits (July 2008)

Magnetic noise at and around 50Hz was associated to the switch on of fluorescent lights in the L-room. The source was identified in the large inductive loop associated to a wrong cabling of the in and return path of this light circuit. It was then cured by re-cabling it [28].

13. New electrical net (summer 2008)

The power line distribution (IPS and UPS) and the electrical grounding in central building have been renewed. The work was mainly motivated by safety (cure not-CEE regulation complaints) and by having a more rational and thus easier to maintain electrical net. Some improvements have been made that could have ultimately reduce or prevent EM disturbances: (i) light circuits have been checked for inductive loops and cured, (ii) power cables paths are now further away from suspended mirrors and un-necessary cable loops around towers have been eliminated, (iii) the grounding connection of single racks has been checked and improved [29]. In this contest, magnetic emissions from the main electrical panels, some located at less than ~5m from suspended mirrors, have been measured and found to drop to negligible level at 1m distance.

14. Electromagnetic noise from the MC HVAC resistive heating (July 2008)

Noise detected and path understood, by final solution not implemented.
Magnetic noise at sidebands of the 50Hz power line is present in the CB and couples to dark fringe [28]. We correlated the frequency modulation of the sidebands with the correction signal (switching period) of the SRC switch which regulates the current flowing in the large resistive load (10kW) used for heating the MC conditioned air. The switching load causes a phase rotation of the 50Hz power line which is common, through the ENEL transformer, to the MC and the Central Building (eLog 22167). An electromagnetic field carrying this noise is then radiated in the CB hall by the several heavy load machines powered on the same line. Finally the magnetic noise couples to mirror magnets: indeed the measured dark fringe noise corresponds to the prediction of mirror magnets noise (eLog 22177).
It seems that the only cure is to remove the switching resistive load, which means replacing the current MC HVAC machine with one using water-based heating (as all other machines we have on site). However, we attempted to slow down the switch controller (it is possible without affecting the building temperature stability). In this way the RMS noise is reduced, but narrower higher order sidebands are more intense, and might affect pulsar search analyses (eLog 22703).

15. Electromagnetic noise from the Harmonic Corrector Unit (July 2008)

The CB harmonic corrector unit was found to pollute the CB building UPS line with a broad bump around 9kHz. The noise was present in several signals, including the dark fringe (eLog 17111, 17261). The noise path was not identified although coupling through ground loops is suspected. The excess noise seems related to the fact that the unit was overloaded, working at less than 10% of the maximum allowed load. The noise bump disappeared with the addition of a second unit working in parallel and sharing half of the load (eLog 20975).

16. Electromagnetic noise coming from the fluorescent lamps (Feb. 2009)

Evidenced RF broadband noise (1-20MHz) generated from electronic circuit that drives some neon light tubes. It has been cured by replacing the driving circuit (eLog 21812, 21869).

17. Dampers for electric motors and fans of the CB HVAC machine (Apr. 2009)

Motivation: we observe ([27] and eLog 22612) some noise reduction in dark fringe associated to the switch off of the CB hall HVAC.

Implementation: Insertion of soft springs, with nominal cut-off frequency of 5Hz (vertical) and 7Hz (horizontal) underneath the CB HVAC fans and engines blocks.

Result: Sensible reduction of seismic noise transmitted through floor [18]. Noise reduces starting from about 10Hz, more effectively along the vertical. The 8.4Hz seismic line associated to the inlet fan, reduced by a factor 2.

Residuals: Still a small residual seismic noise exists below 100Hz, mainly sensed at EDB and detection tower. Dominant residual contribution comes from the 12Hz line from the HVAC inlet engine [18].

18. Reduction of the WEB HVAC machine air flow, by 10% (Apr. 2009)

Motivation: The WEB couples a significant amount of diffused light noise, limiting the sensitivity between 20 and 40Hz. In conditions of not high sea seismic activity, the up-converted noise is associated to the large bench motion at the legs resonance (around 18Hz). A factor at least two reduction of the 18Hz mode amplitude is needed in order to meet the design sensitivity [27]. By reducing the speed of the WE HVAC fan we expect the acoustic noise in the hall to reduce and consequently a significant reduction of the WEB mode excitation. Based on the result of the work done with the CB HVAC (see above Sec. 11) we estimate a fan slow down of about 25% is needed.
Implementation: The fan has been slow down by 10%, just replacing the pulleys in order to increase the engine reduction ratio. A larger fan slow down would have brought the machine working point out of specifications, and would require the replacement of the engine and the fan (larger size fan).

Result: We measure a 30% reduction of RMS acoustic noise in the hall and seismic noise of the WEB [18]. The consequent reduction of diffused light noise projection is shown in eLog 22912.

19. New cover box on terminal benches (May 2009)

Motivation: reduce acoustic noise coupling to bench seismic motion, and better protection of beams from air fluxes.

Implementation: The plastic cover on NEB and WEB benches has been replaced with a new, more rigid and compact one, made of Plexiglas. The NEB one was installed in October 2008 (eLog 21115) the one on WEB was installed in May 2009 (eLog 22908).

Results: In both cases it is noted that the presence of the cover modifies the coupling of acoustic noise to bench seismic motion especially at the low frequencies. The new covers reduce this coupling, resulting in a reduced RMS seismic motion (-20%) of the bench below 50Hz, and in the critical region around the legs resonance. Consequently, the projected diffused light noise contribution significantly reduced (eLogs 22912, and reference [18]).

20. Mechanical damper for the WEB legs resonance (May 2009)

Motivation: reduce amplitude of WEB legs resonant mode at 18Hz.
Implementation: A mechanical resonator has been installed on WEB (eLog 22923). It consists of a suspended metallic brick (18kg) which is coupled to the bench by means of VITON rods of adjustable length. The resonance of the mass is tuned to that of the bench legs mode (by means of VITON rods of adjustable length.
Result: Amplitude was reduced by about a factor two (eLog 22923).
Residual Noise: The sum of this action, the installation of new cover (19) and the slow down of HVAC fan (Sec. 18) reduced the WEB motion at resonance of about a factor 3. The projected diffused light noise is now a factor two below the design (eLog 22932). Only in case of intense sea seismic activity the WEB noise might still spoil a bit the sensitivity at 20-40Hz (eLog 22405).

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