MECHANICAL VIBRATION MEASUREMENTS ON TTF CRYOMODULES

(Using WPMs as Detectors)

Summary with integrations and revisions of the FOAA005 talk at

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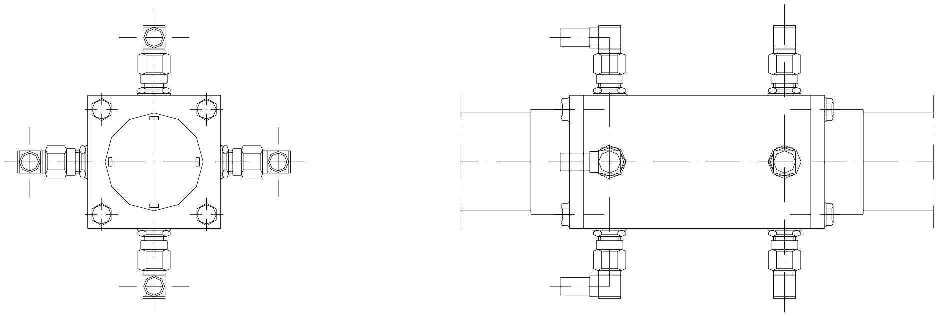
A. Bosotti, C. Pagani, R. Paparella, P. Pierini, D. Sertore
INFN LASA, Milano, Italy
R. Lange, DESY, Hamburg

R. De Monte, M. Ferianis, ELETTRA, 34012 Trieste Italy

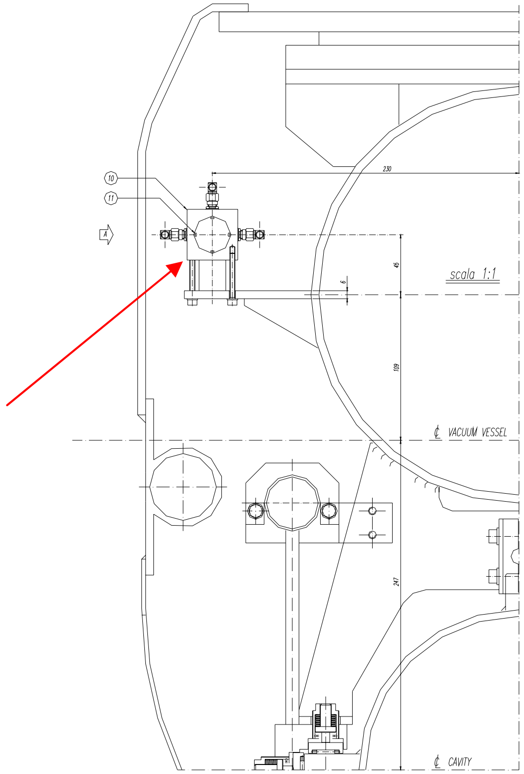
WPM Main Features And Evolution 1/2

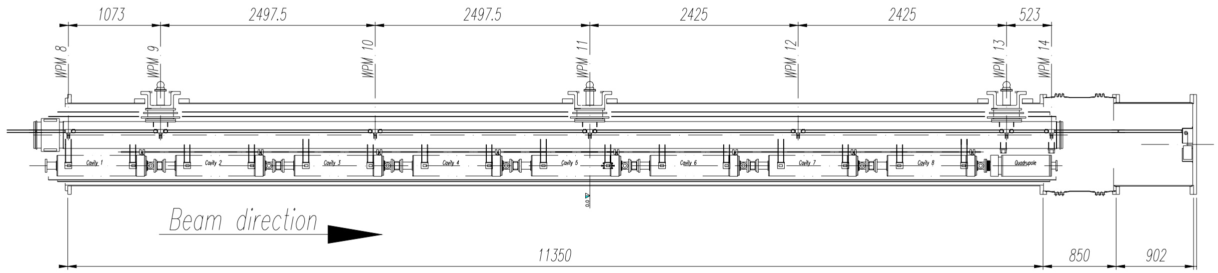
- A Wire Position Monitor (WPM) system has been developed for on-line monitoring of the cold mass during cooldown and operation. The analysis of the WPM measurements allows checking the alignment reproducibility between successive cooldown cycles.
- A WPM is a sort of microstrip four channel directional coupler. A 140 MHz RF signal is applied on a stretched wire placed (nominally) in the center of the monitor bore.



WPM Main Features And Evolution 2/2

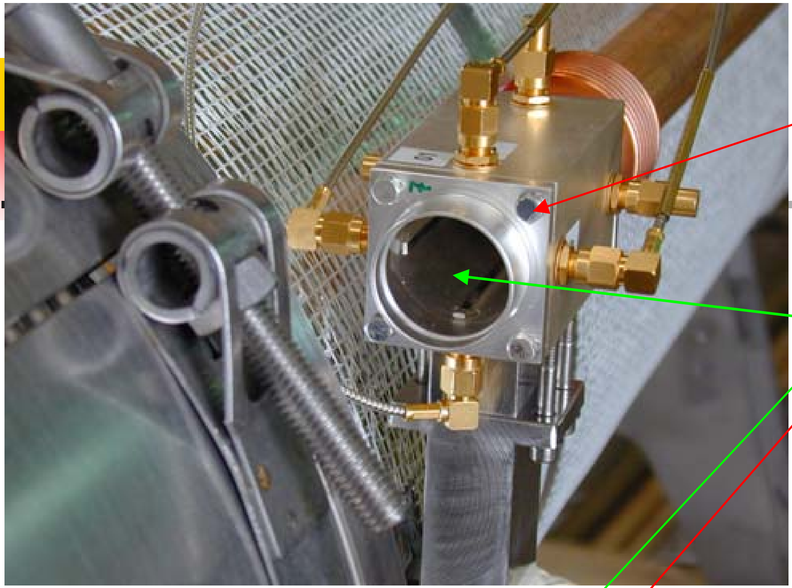
The analysis of data taken by the WPM system during thermal cycles contributed to the upgrades that brought to the actual generation of cryomodules. Furthermore, together with the cryomodule evolution, the WPM system sustained substantial modifications and simplifications, starting from the two chains of 18 detectors of the first generation of cryomodules, to the current one of a single chain of seven detectors (placed in critical positions: at each end, at the three posts and between the posts), screwed through a support to a stainless steel arm which is welded to the gas return pipe (GRP).





Longitudinal positions of the WPM sensors in cryomodule # 5

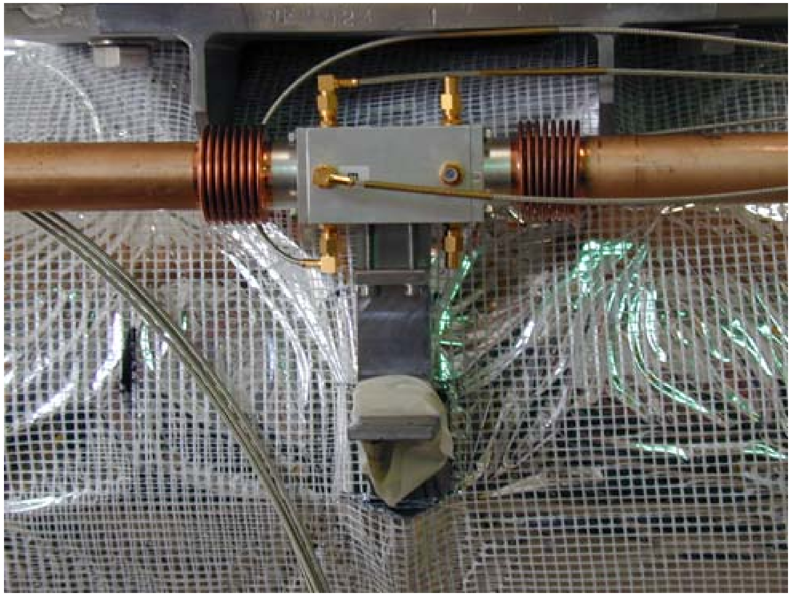
WPMs Assembled Into The Modules



WPM during assembly at ZANON

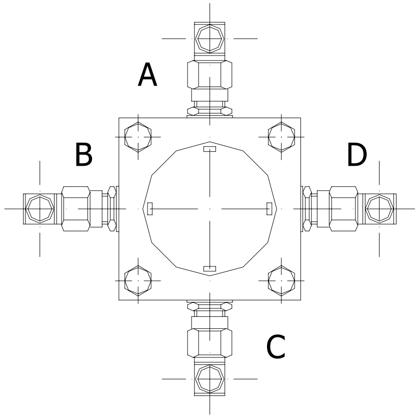
The stretched wire for the 140 MHz RF signal transmission is inserted here

WPM assembled on 3rd generation cryomodule



WPM as vibration detector 1/2

- Four of the WPMs of module # 5 are used as vibration detectors.
- The low frequency vibrations of the cold mass, amplitude modulate the RF signals picked up by the microstrips.
- The microphonics (and the sub-microphonics) can be recovered de-modulating the microstrip RF signal.
- The de-modulated signals are converted into positions via the same two dimension 3rd order polynomial, used to convert the WPM electrical signals (D_x and D_y) into cold mass displacements (x and y).
- Only transverse vibration in the horizontal and vertical planes can be detected.



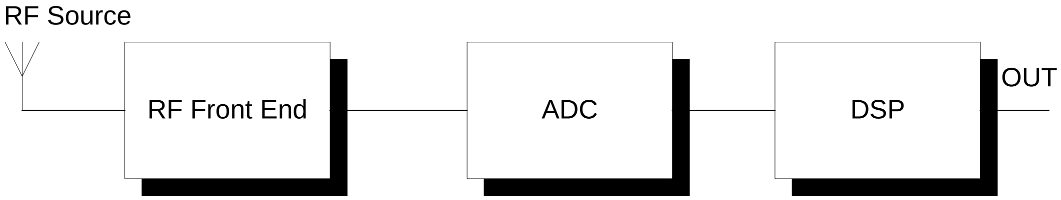
$$D_x = \frac{V_B - V_D}{V_B + V_D} \qquad D_y = \frac{V_A - V_C}{V_A + V_C}$$

$$x = a_{10} D_x + a_{30} D_x^3 + a_{12} D_x D_y^2$$

$$y = a_{01} D_y + a_{03} D_y^3 + a_{21} D_x^2 D_y$$

WPM as vibration detector 2/2

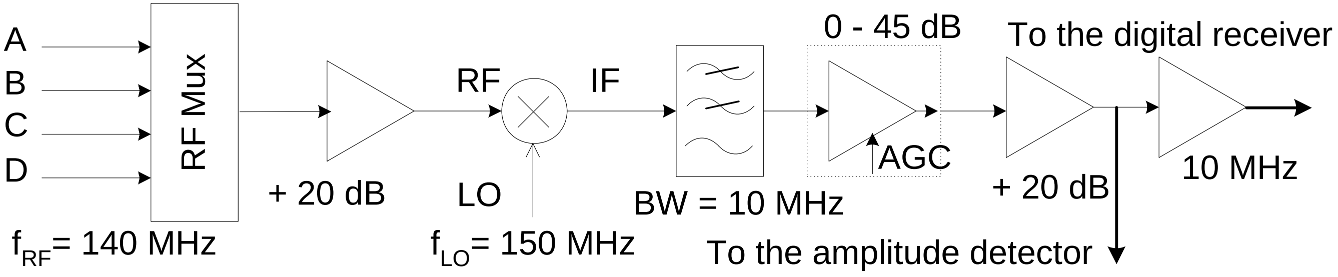
- Vibration measurement is a field well advanced at DESY (and in all the other laboratories with big accelerators), specially in the field of ground vibrations.
- http://ground-vibrations.desy.de/index_eng.html
- Results from tests using geophones, seismometers and piezos are reported in literature.
- Our effort in this field is to integrate the WPMs in the vibration sensor family.
- A nice feature of the WPMs is that they work in the same way at cold and warm conditions and are well distributed along the cryomodules.
- The WPM control electronics has been upgraded inserting a 4 channel Digital Receiver Board, which recovers the base-band signal like a sort of AM software radio.



Digital receiver concept

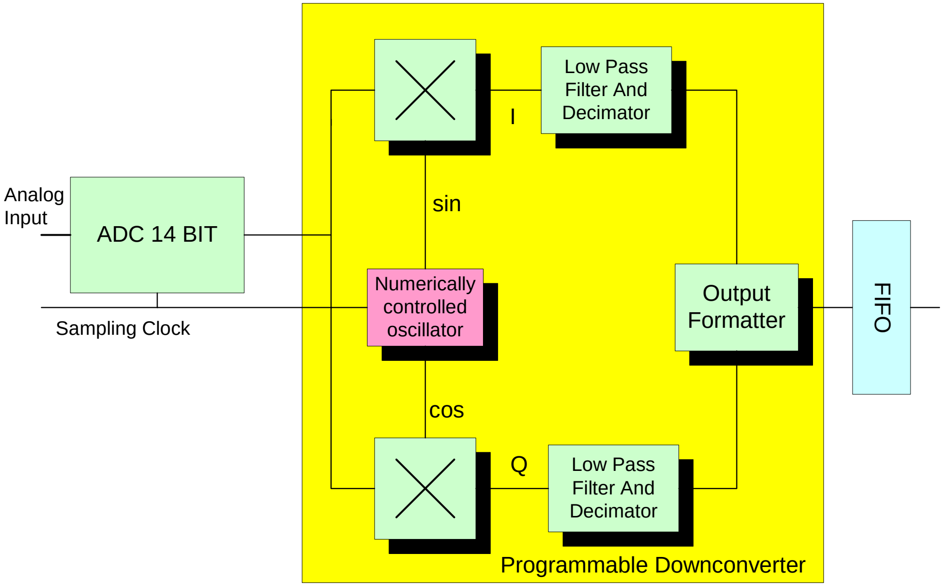
System Description – RF Front End

- The vibration detection system is a super-heterodyne receiver, where the base-band demodulation is made digitally.
- Two WPM readout electronics boards have been modified to work as the RF front end circuitry for the digital receiver.
- The function of the RF front end is to read the four microstrips of the selected WPM, and to down-convert the RF signal to the 10 MHz IF signal, together with amplifying and filtering.



RF input stage

System Description – Digital Receiver



Digital Receiver functional Diagram

- The IF signals from the RF front end enter the QDR, where they are first filtered, and then sampled.
- The Analog Devices 14 bit AD9644 analog to digital converter, mounted on a mezzanine board is used for the A to D conversion.
- The rest of the processing is done in a digital way. The Digital Downconverter (DDC) translates the carrier to base-band and then applies filtering and decimation, gain scaling, resampling and Cartesian to polar coordinate conversion.

The Quad Digital Receiver module is from Instrumentation Technologies

Vibration Measurements

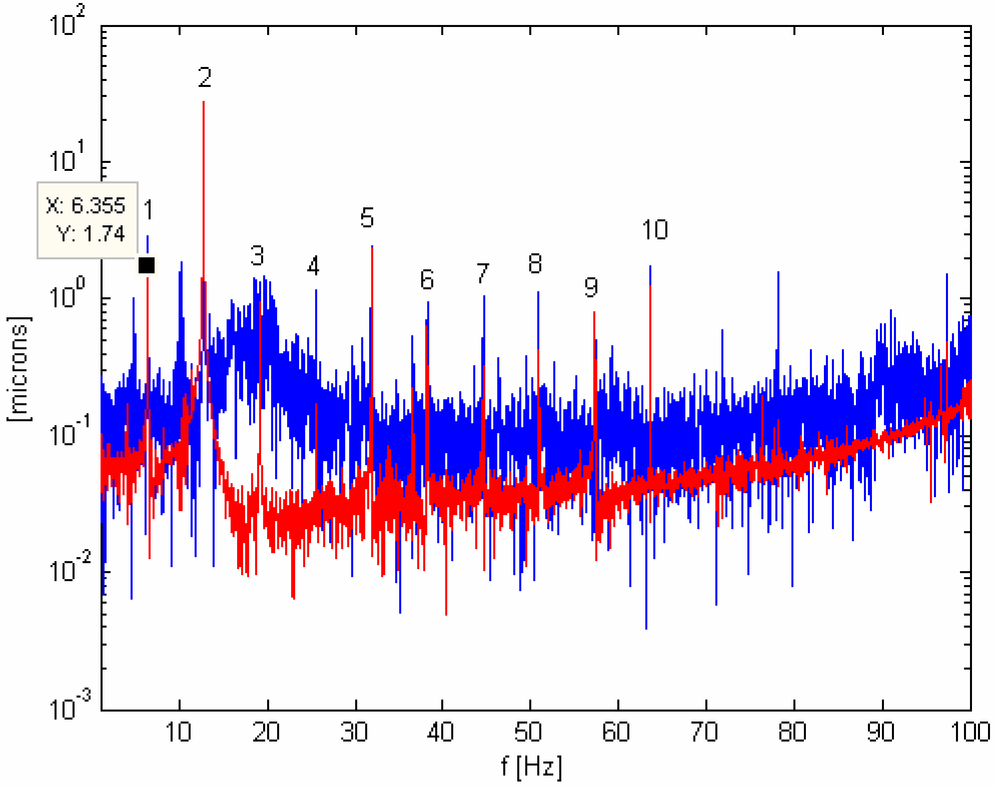
- WPMs # 11, 12, 13, 14, i.e. the last four monitors of the module # 5, has been connected to the digital receiver via the modified electronic boards.
- The monitor # 11 is placed close to the central post, where we expect to find the minimum of the noise, while the monitors # 13 and # 14 are placed on the quadrupole.
- A possible limitation to the detection of the vibration spectra could be the amplitude of the stretched wire proper oscillations.
- The frequencies of such oscillations can be found using the vibrating string equation.

$$f_n = \frac{n}{2\ell}\sqrt{\frac{F}{\rho A}} = n \cdot 6.4\ \mathrm{Hz}$$

Vibrating string equation (VSE)

- **Wire: (CuBe) Berylco-Cabot BERYLCO 25**
- Density (ρ): 8.25 g/cm3 = 8250 kg/m3
- Cross Section (A): 0.196 mm2
- Stretched Wire Length (ℓ) 25.950 m
- Tensile Strength: 18 kgp = 176.58 N

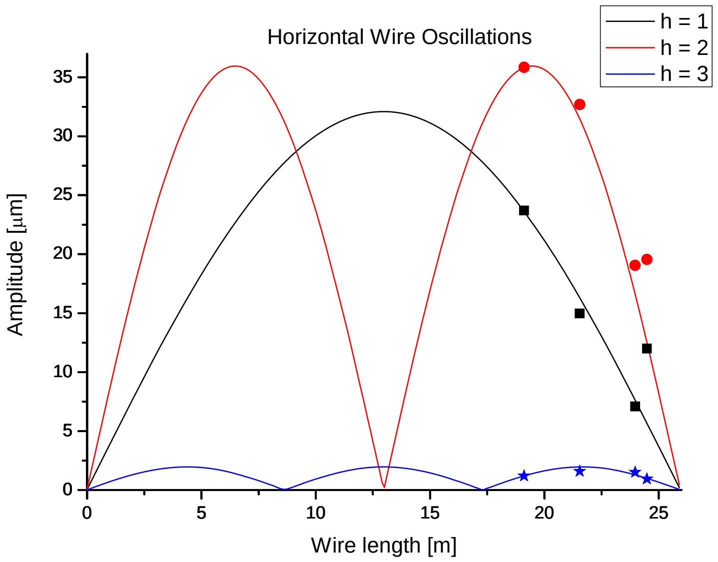
Wire Oscillations Spectra

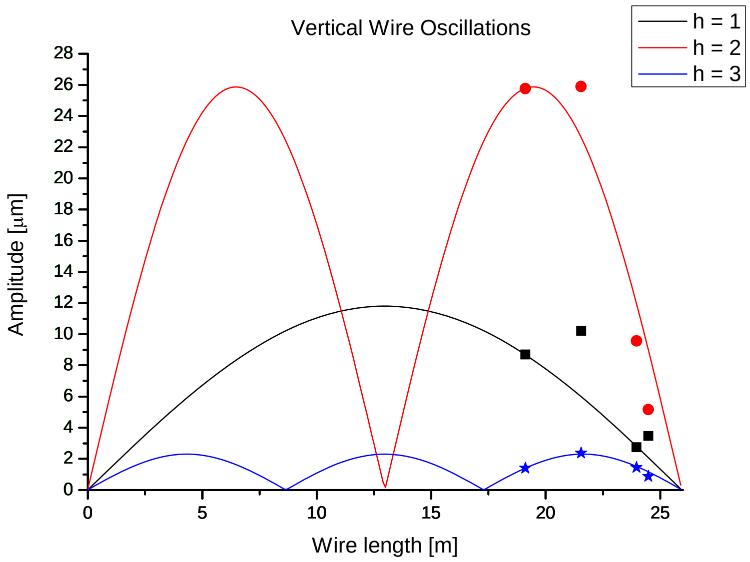


Wire oscillations in the horizontal plane, detected by WPM # 11 and # 14, superimposed to the cold mass vibration spectra. The harmonic number is reported close to each spectral line.

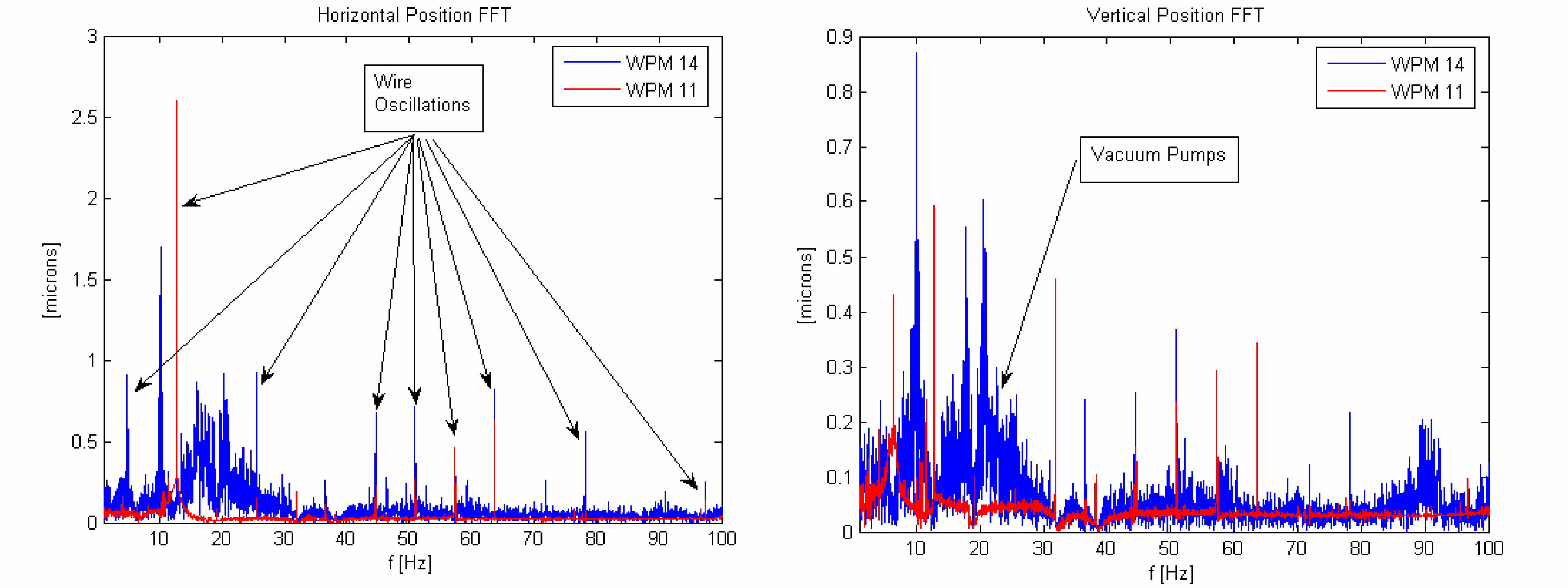
Wire Proper Oscillations

- The wire proper vibration spectral lines (fundamental and harmonics) overcome the cold mass mechanical vibration lines.
- On the other hand, being their frequencies well predictable by VSE which completely agrees with the experimental data, it’s easy to filter them when processing the data.





Filtered Vibration Frequency Spectra 1/4

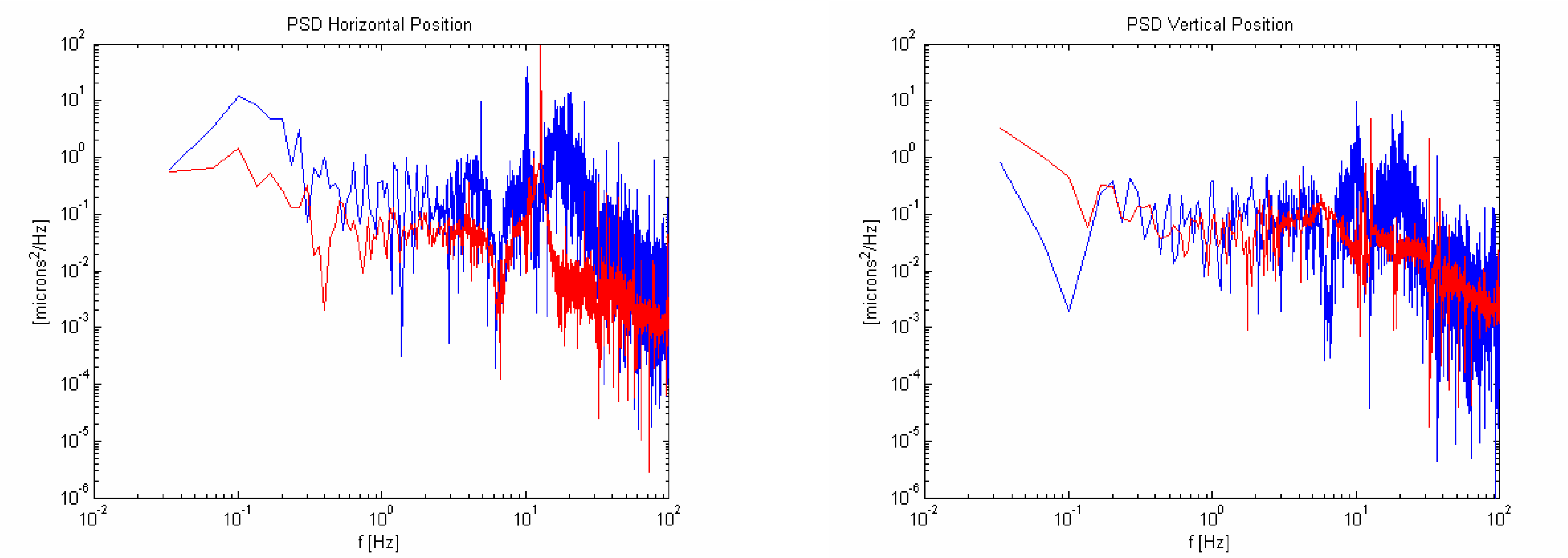


Cold mass vibration spectra in the horizontal and vertical planes detected by WPM # 11 and # 14. A residual of wire proper oscillation (after filtering with notches) is still present. The data comes from T = 30 s acquisition time at f_s = 5 kHz (nominal) sampling frequency.

Filtered Vibration Frequency Spectra 2/4

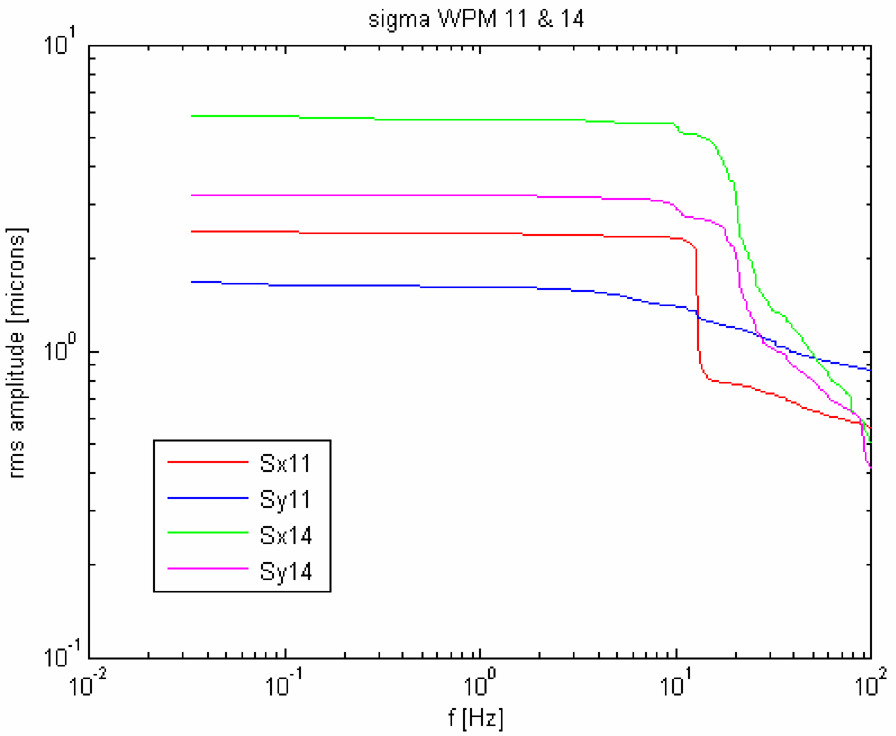
- As expected the vibration noise is considerably low close to the central post (WPM # 11), compared to the cryomodule end (WPM # 14).
- Looking to the blue line spectra, coming from WPM 14, one can see that significant amount of noise is present between 10 Hz and 30 Hz, due to the proximity of vacuum pumps and similar devices, and under 10 Hz, possibly due to the cryogenic system.
- On the contrary, the spectra of the WPM 11 signals, which is at the central post position where all the cold mass is constrained, show only the harmonics (filtered) of the wire oscillations.
- The differences in the vibration noise is again more evident looking to the power spectral densities, where if one excludes the wire oscillations, the PSDs of the signal coming from the central sensor are at least one order of magnitude lower with respect to the other at the cryomodule end.

Filtered Vibration Frequency Spectra 3/4



Power Spectral Density of the cold mass vibrations in the horizontal and vertical planes detected by WPM # 11 and #14.

Filtered Vibration Frequency Spectra (Variance) 4/4



Spectral bandwidth df ≈ 0.034 Hz

Equations:

FFT coefficients

$$G\left(\frac{n}{N\tau}\right)=\frac{2}{N}\sum_{k=0}^{N-1} g(k\tau)\cdot e^{-j\frac{2\pi}{N}nk} \qquad n=1\ldots\frac{N}{2}-1$$

$$G(0)=\frac{1}{N}\sum_{k=0}^{N-1} g(k\tau) \qquad n=0$$

Power Spectral Density

$$PSD\left(\frac{n}{N\tau}\right)=\frac{\frac{1}{2}\left|G\left(\frac{n}{N\tau}\right)\right|^{2}}{df}; \quad df=\frac{f_S}{N}=\frac{1}{T}$$

Variance

$$\sigma\left(\frac{n}{N\tau}\right)=\sqrt{df\cdot\sum_{l=n}^{\frac{N}{2}-1} PSD\left(\frac{l}{N\tau}\right)}$$

Conclusions

- The spectra taken with this non optimized preliminary set up, show that the WPM can be used to detect low frequency vibrations.
- Wire oscillations, that “dirt” the data, can be removed by filtering the spectra.
- Higher resolution, towards nanometers, can be achieved by properly setting the digital receiver input channel gains and electronics performance.
- Further work and experiments are planned, to explain the source of noise associated to most of the spectral lines detected, and to extend the tests here reported to the complete chain of monitors.