NanoBeam2002

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THE EFFECT of COOLING WATER on MAGNET VIBRATIONS

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Overview of my talk:

1. Introduction
2. Simple theory of water induced vibrations
3. Experimental set-up
4. Results of the measurements
5. In-situ measurements (vibrations of CTFII quads)
6. Conclusions

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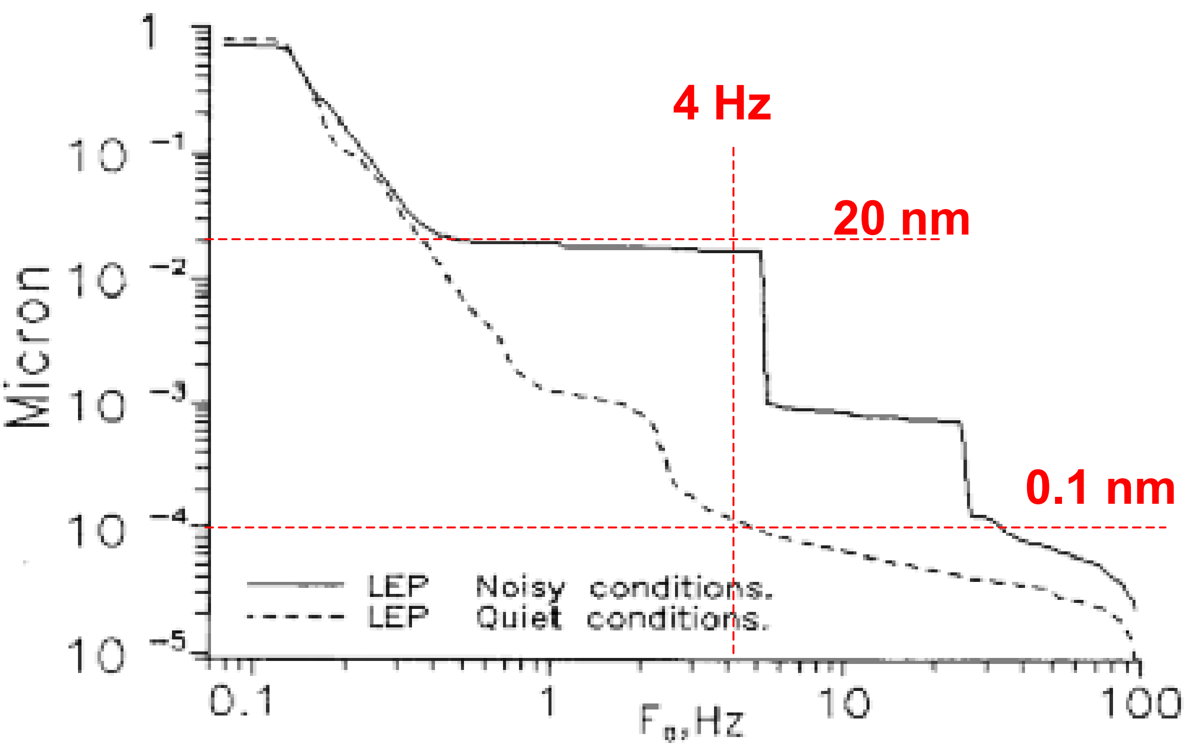
1. Introduction

Performance of future Linear Colliders like CLIC will be limited by the vibrations of the focusing quadrupoles

CLIC tolerances for uncorrelated motion above 4 Hz

Quad type	Number	Horizontal	Vertical
Linac	2600	14 nm	1.3 nm
Final Focus	2	4 nm	0.2 nm

(Work done in the CLIC Stability Group)



On earth exist places quiet enough for CLIC!

But the noise of the accelerator environment disturb this quietness!

Measurements in the LEP tunnel
(W. Coosemans *et al.*, 1993)

Why do quadrupoles move?

- Natural ground motion
- Resonances of the support structures.

⇨ Amplification of the ground motion level.

- Acoustical noise
- Air currents
- Mechanical vibrations
- **COOLING WATER**

Cultural noise from equipment in the tunnel (cooling system, vacuum pumps, air conditioning, particle detector,...).

This is what we are going to discuss!

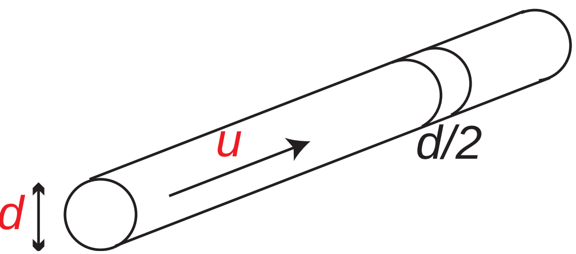
2. Simple theory of water induced vibrations (1)

Theory first proposed by W. Schnell (*CLIC Note 468 – Landau-Lifshitz, Vol.* **VI**)

Vibrations supposed to by induced by **TURBULENCE**

Reynold's number: $$Re = \frac{ud\rho}{\eta}$$

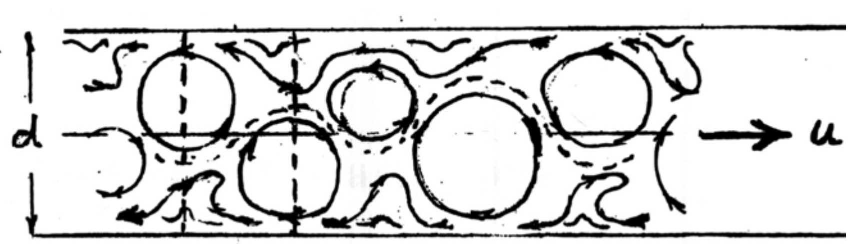
u: water velocity
d: pipe diameter
$\rho = 10^3$ kg m^3: water density
$\eta = 0.89\,10^{-3}\,\mathrm{kg\,m^{-1}\,s^{-1}}$: viscosity



Turbulence onset: ***Re* ≈ 2000**

↓

Eddy-like local motion superimposed to drift *u*



Length of larger coherence domains ~ *d/2*

⇩

Intrinsic frequency associated to turbulence: $$f_c = \frac{u}{d}$$

Turbulence induced vibrations expected **above f_c**

Simple theory (2) – Energy released in turbulent regime

In turbulence, pressure drop ~ u^2:

Weak dependence on *Re (Blasius' formula)*

$$\Delta p = \frac{\rho\lambda}{2}\frac{l}{d}u^2$$

$$\lambda \approx 0.316 Re^{-1/4} = 0.04$$

Power pump completely converted in irretrievable kinetic energy:

$$\frac{\partial V}{\partial t}\Delta p = \frac{\partial V}{\partial t}\frac{\rho v^2}{2}$$

v = mean-square of local turbulence velocity

Isotropy ⇒ Local momentum density:

$$v_y^2 = v^2/3$$

$$\rho v_y^{RMS} = u\rho\sqrt{\frac{\lambda l}{3d}}$$

Assumptions: kin energy concentrated in cells of coherence length *d*/2

All energy released at f_c

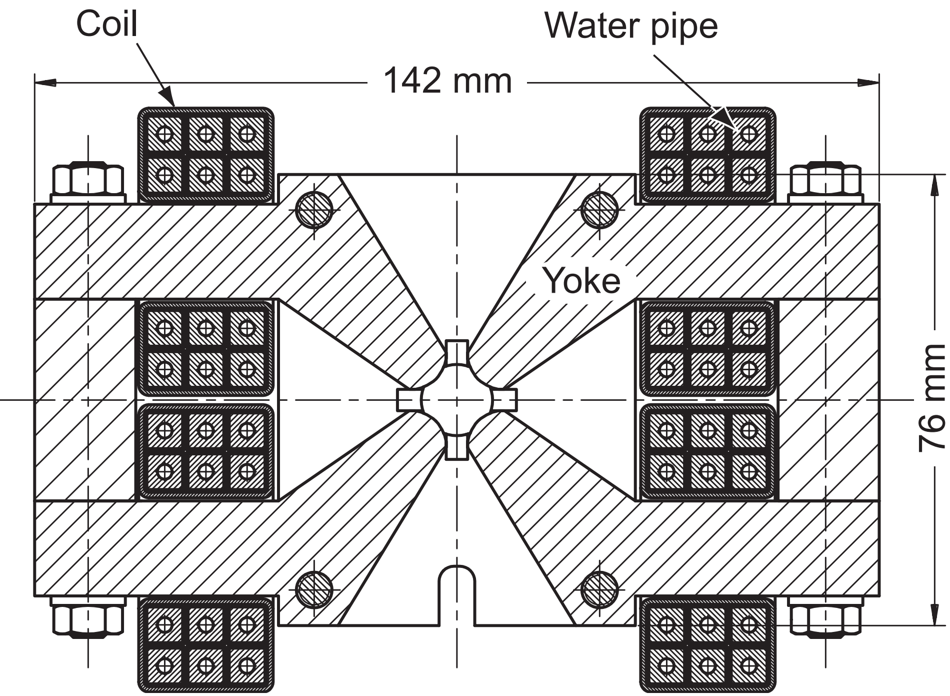
Small dependence of motion on water flow!

$$y^{\mathrm{RMS}} = \sqrt{n_c n_q}\frac{d}{2\pi}\frac{m_{\mathrm{water}}}{M_{\mathrm{Tot}}}\sqrt{\frac{\lambda}{6}},$$

Sum in quadrature of all cells (and magnet coils)

(*nc*, *nq* = number of coils/quads)

3. Experimental set-up (1) – The CLIC linac quadrupole

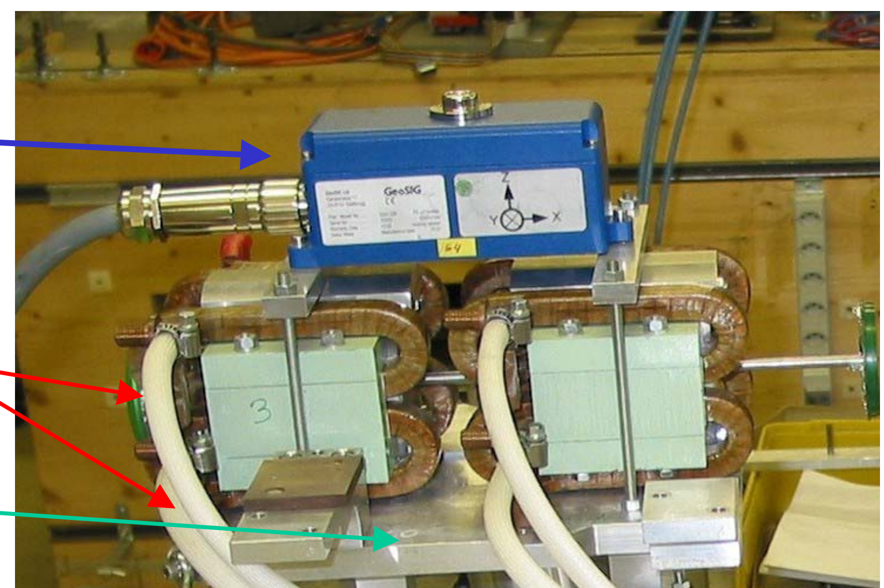


- CTFII quadrupole - similar for CLIC
- Resistive quadrupoles (copper coil)
- Coils with 6 cables
- Cooled with water (d = 3 mm)
- 80mm(long)x76mmx142mm; 6.7 kg
- Two quads on one support plate

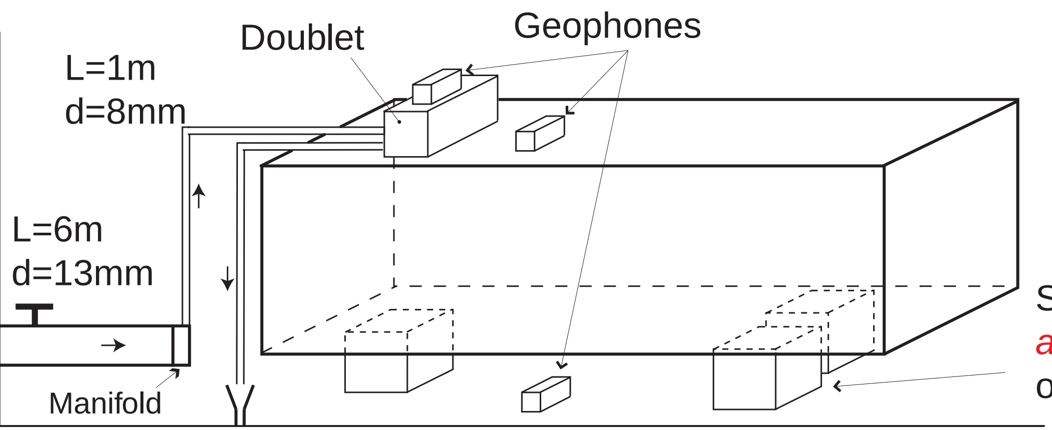
Geophone for vibration measurements

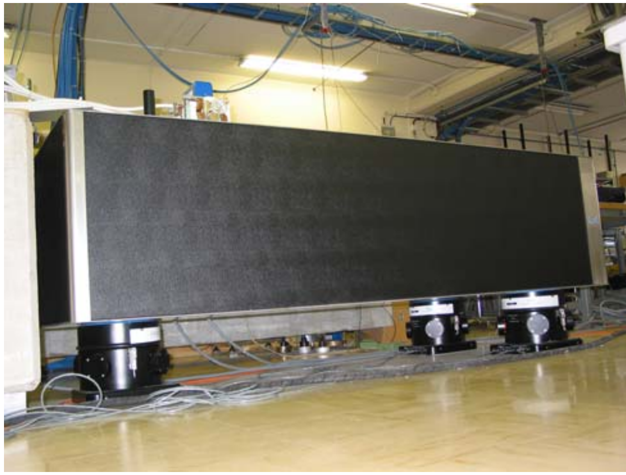
Water feeding pipes

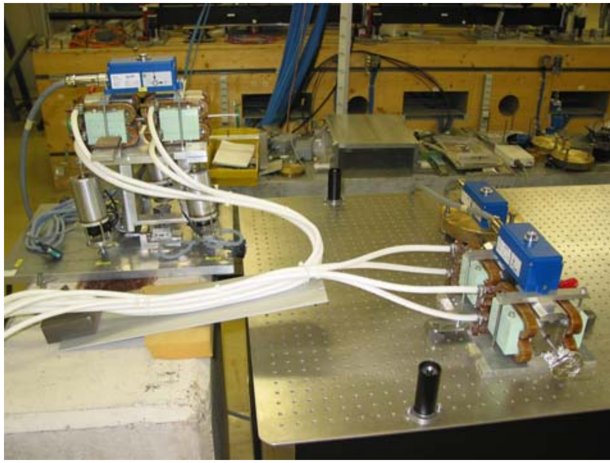
Steel plate



Experimental set-up (2)







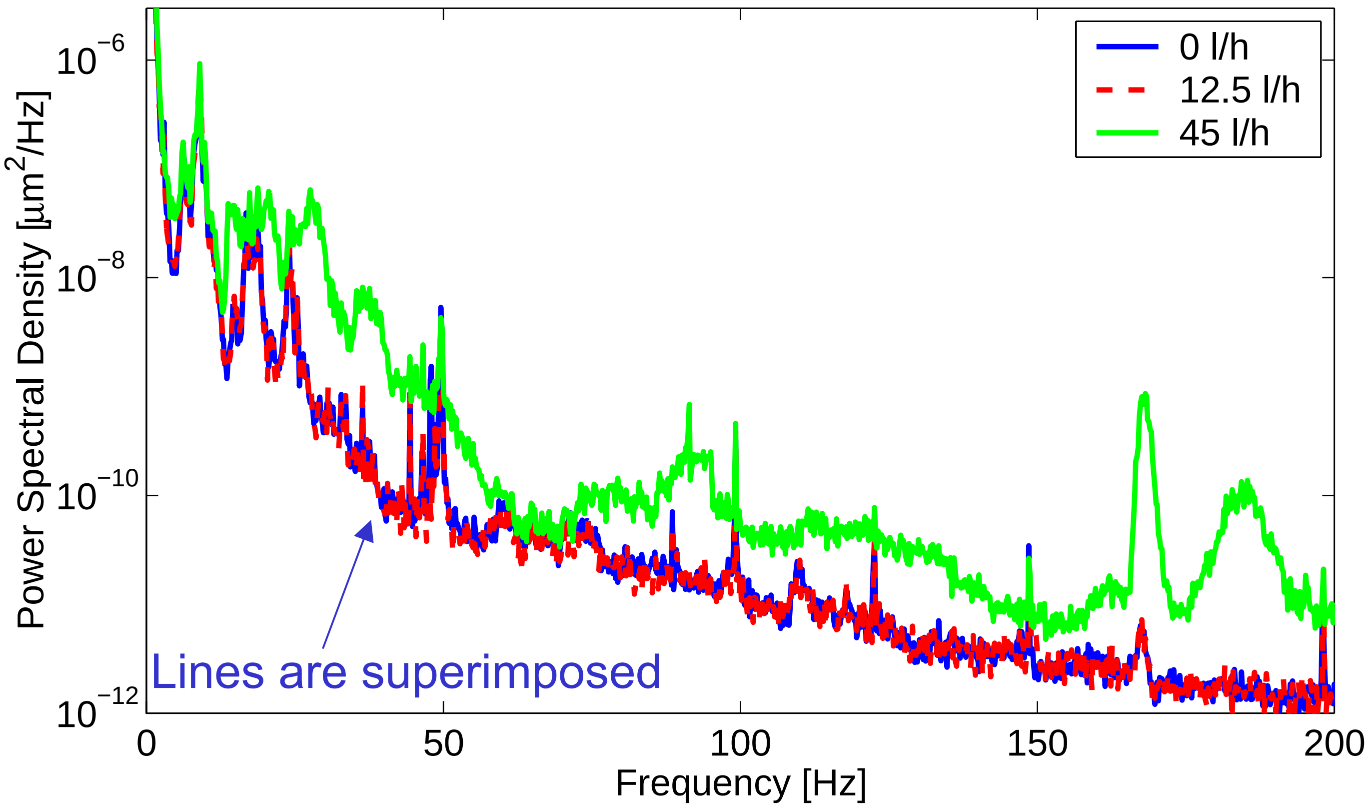
- Active system *isolates from ground motion*, does not actively damp vibration on table top
- Tap water, no pumps
- Quadrupole doublet screwed on table top
- Floor and table also measured simultaneously
- Pipes of different diameter – all relevant for vibration!

Pipe	Re	d [m]	Flow [l/h]	f_c [Hz]
Tap→Manifold	2000	0.013	16.4	10.5
Manif.→Quad	2000	0.008	40.3	27.9
Quadrupole	2000	0.003	15.1	198

$$f_c = \frac{u}{d}$$

4. Results of the Measurements – Turbulence onset

Quadrupole vertical vibration (same feature for horiz)

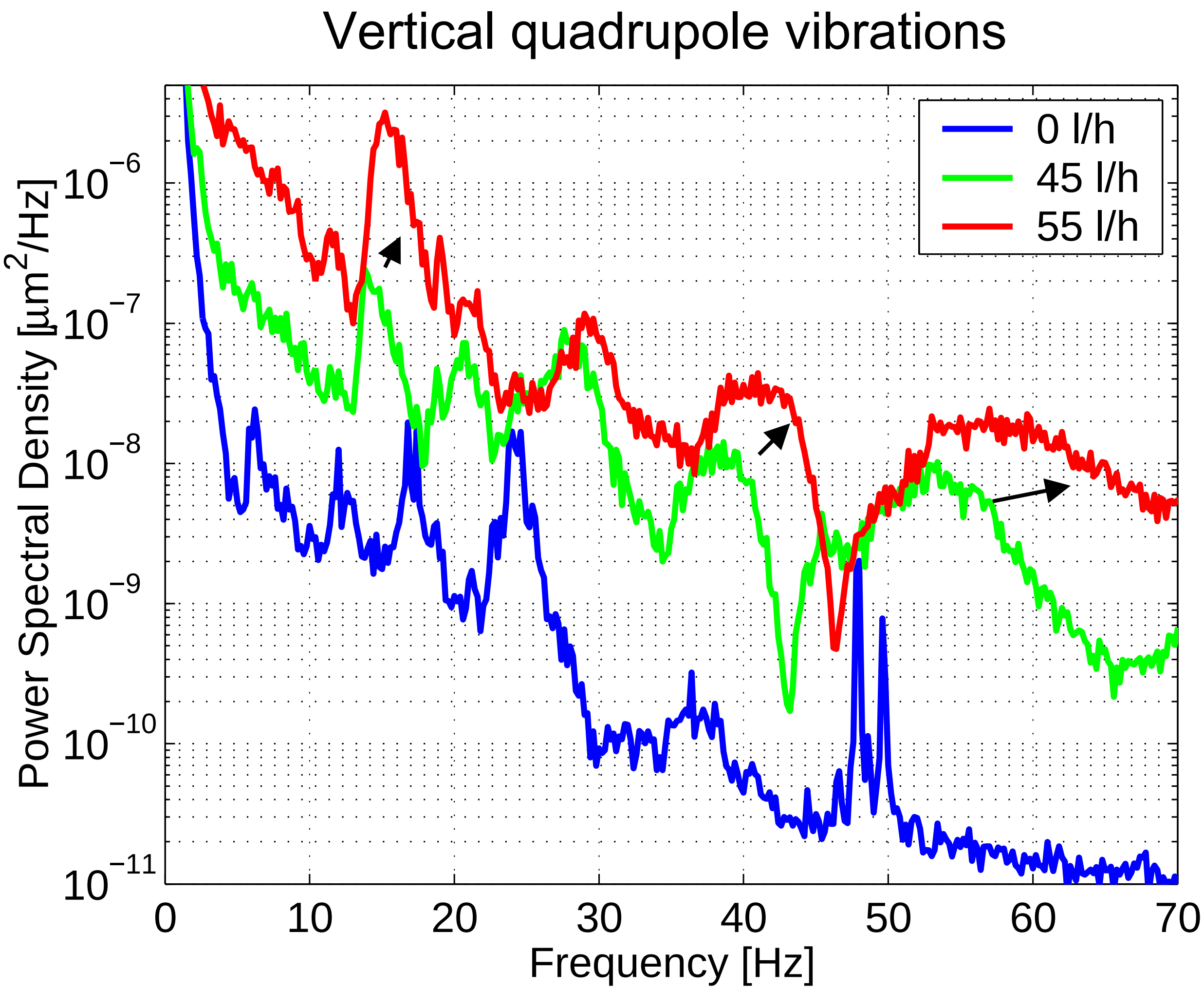


Turbulence is a threshold phenomenon, effects for flow ≥ **15 l/h**

Pipe	*Re*	Flow [l/h]	f_c [Hz]
Tap → Manifold	2000	16.4	10.5
Manif. → Quad	2000	40.3	27.9
Quadrupole	2000	15.1	198

This value corresponds to turbulence onset in the pipes feeding the quadrupole and in the quadrupoles themselves

Low frequency content of the vibrations



Pipe	*Re*	Flow [l/h]	f_c [Hz]
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Overall **increase of noise** level + **new peaks**!

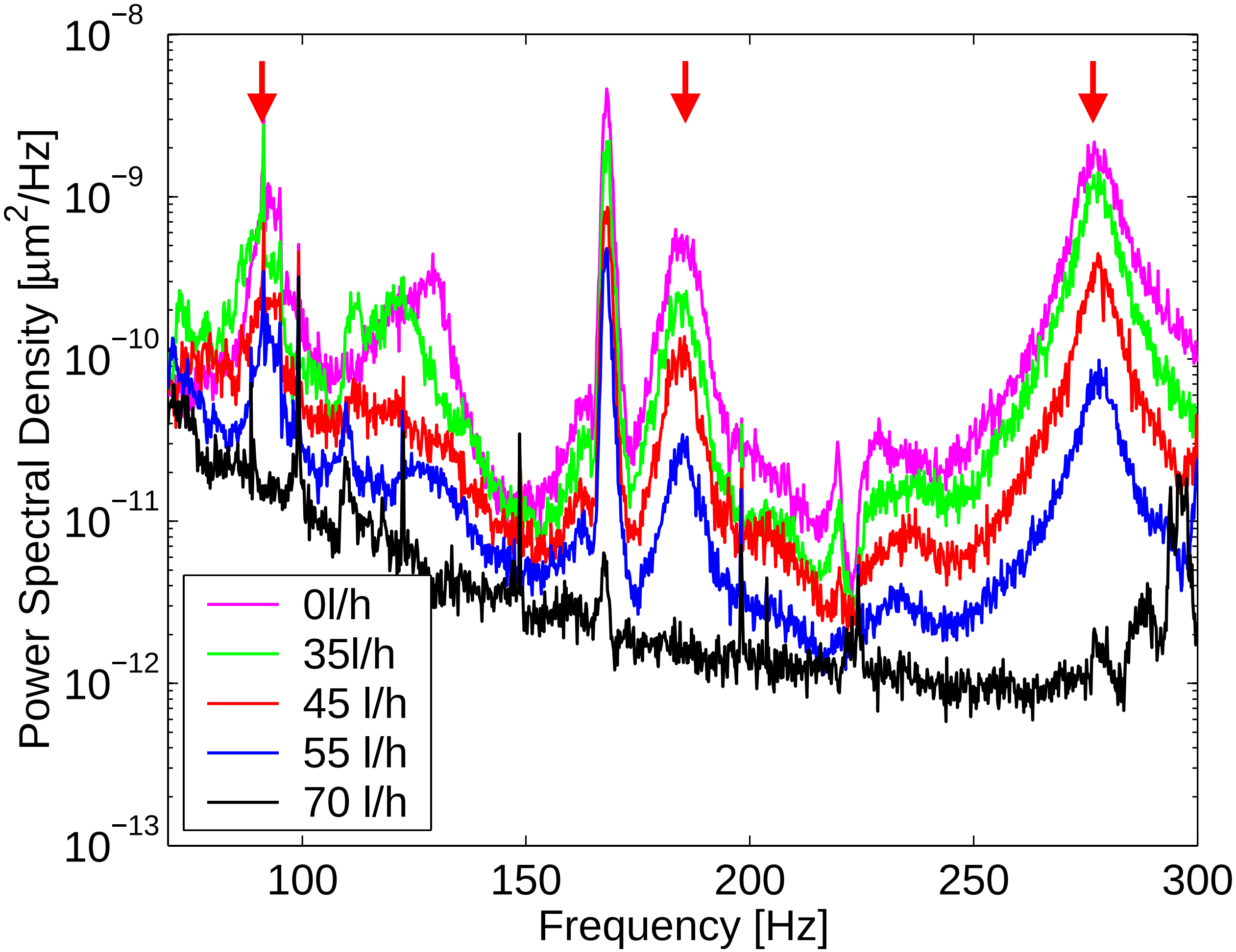
Main contribution to vibration at low frequency from the **FEEDING PIPES.**

Small quadrupole pipes induce much higher frequency

Peaks moving with *u*?

$$f_c = \frac{u}{d}$$

High(er) frequency content of the vibrations



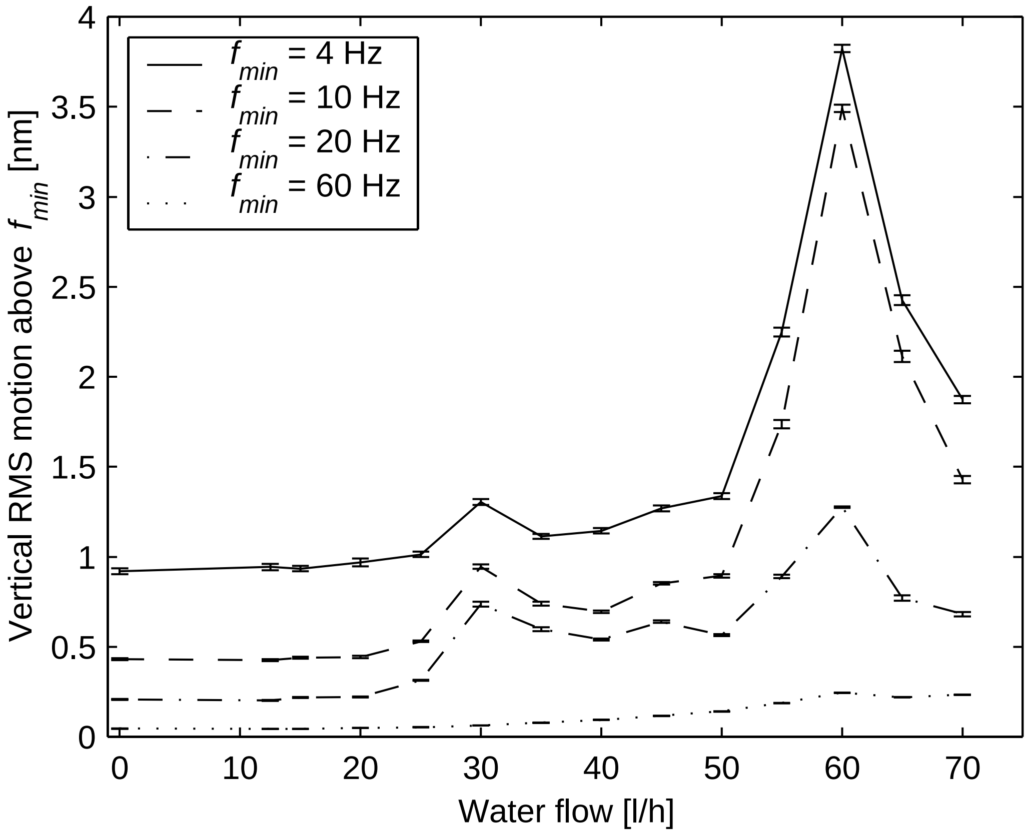
Again: Amplification of existing peaks + new peaks arising

Increase of power spectral density of 1000 times!

But what about the total motion?

Integrated RMS motion

Vertical RMS motion



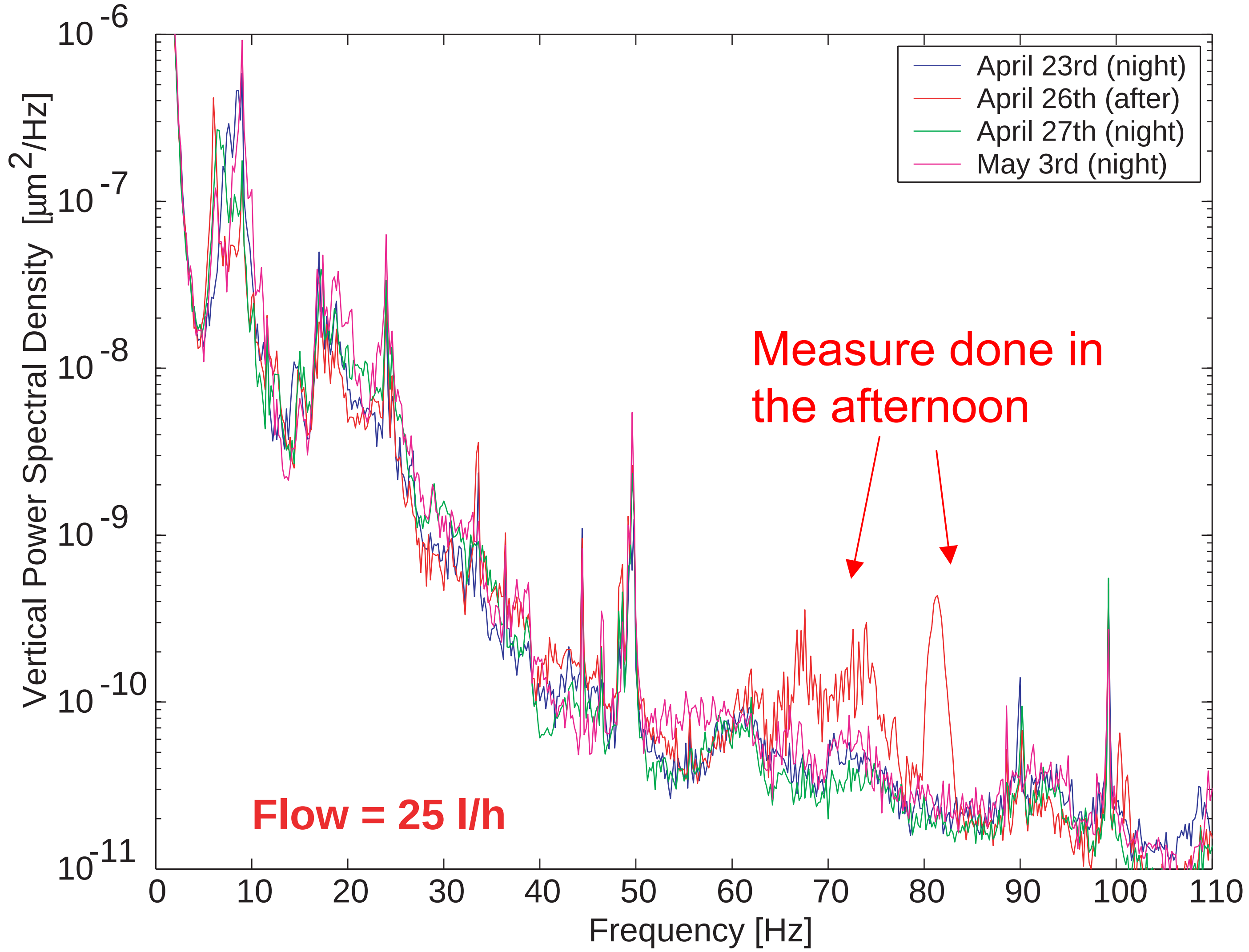
Nominal of CTFII

Vertical displacements			
f	Floor	Doublet 0 l/h	Doublet 30 l/h
4 Hz	3.62 nm	0.92 nm	1.30 nm
20 Hz	1.29 nm	0.21 nm	0.74 nm
60 Hz	0.07 nm	0.05 nm	0.06 nm
Horizontal displacements			
4 Hz	2.33 nm	0.35 nm	1.33 nm
20 Hz	0.43 nm	0.18 nm	0.80 nm
60 Hz	0.04 nm	0.04 nm	0.17 nm

Effect of water: increase motion above 4 Hz by **~ 3 nm**

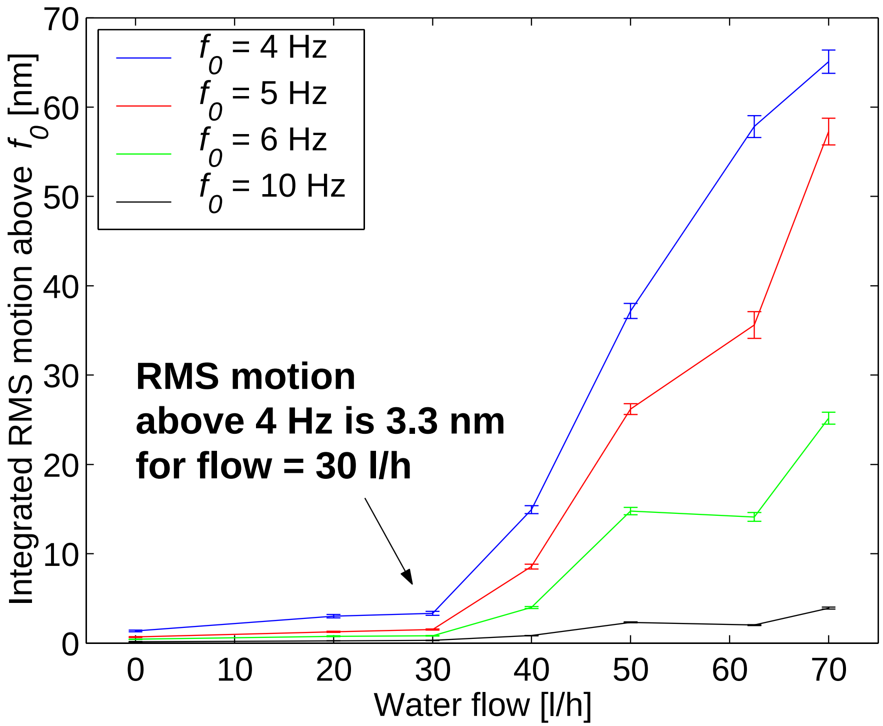
- CLIC tolerances are met!! **Quad stabilized at 1.3 nm above 4 Hz**
- Main contribution induced by vibrations **below ~60 Hz** (~15Hz peak)
- Strong dependence of motion on water flow → careful design!

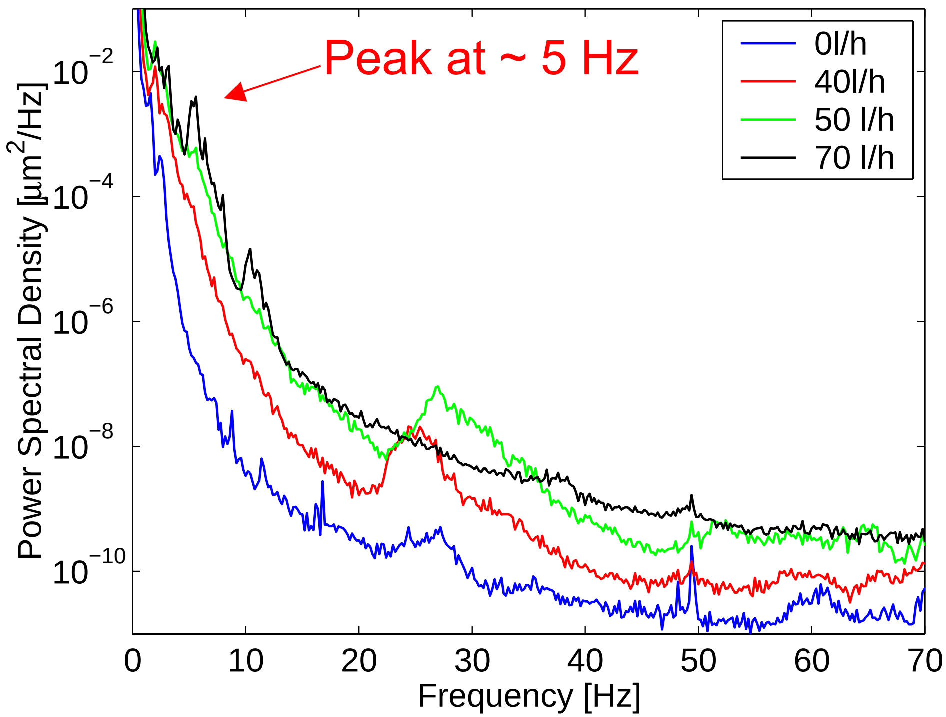
Reproducibility of the measurement



Measurements reproducible – similar results over 10 days

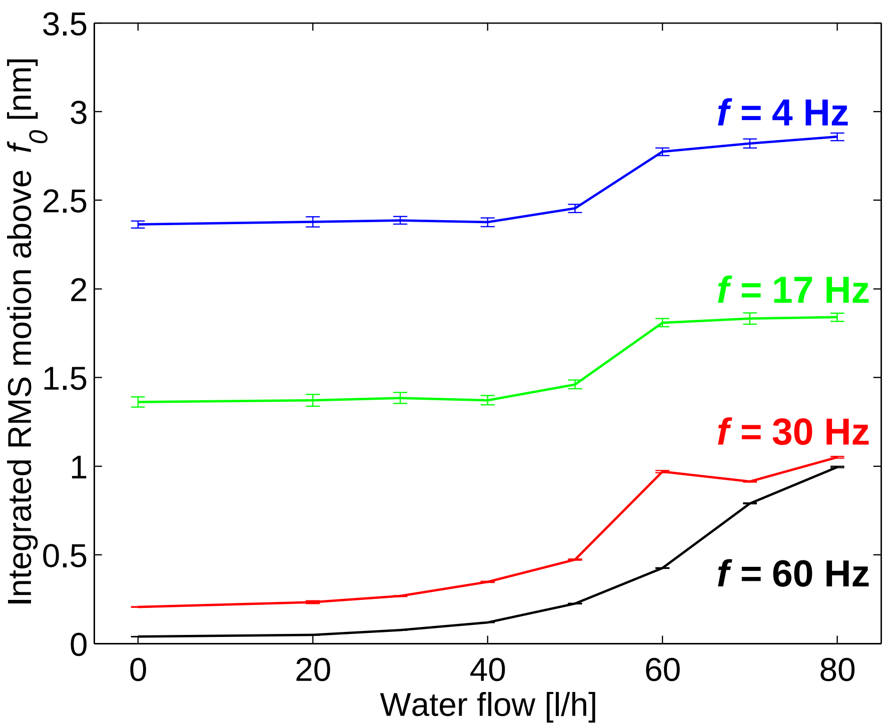
Vibration measurement on air pressure stabilization system

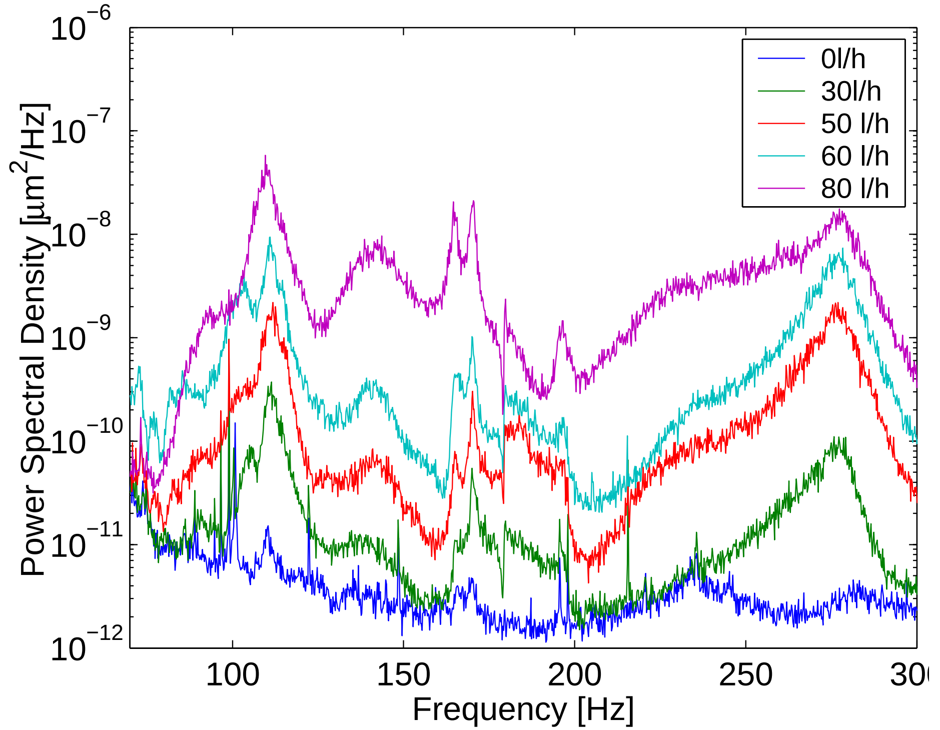




- Much larger displacements – system less stiff, larger amplitudes below ~20Hz
- RMS motion above 4 Hz at flow = 30 l/h is 3.3 nm
- Monotone increase of displacement (at 4 Hz) with flow, driven by ~ 5 Hz peak
- Still reduction of vibrations from 20 Hz to 40 Hz for flow above ~ 60 l/h

Recent measurements of stiff stabilization system





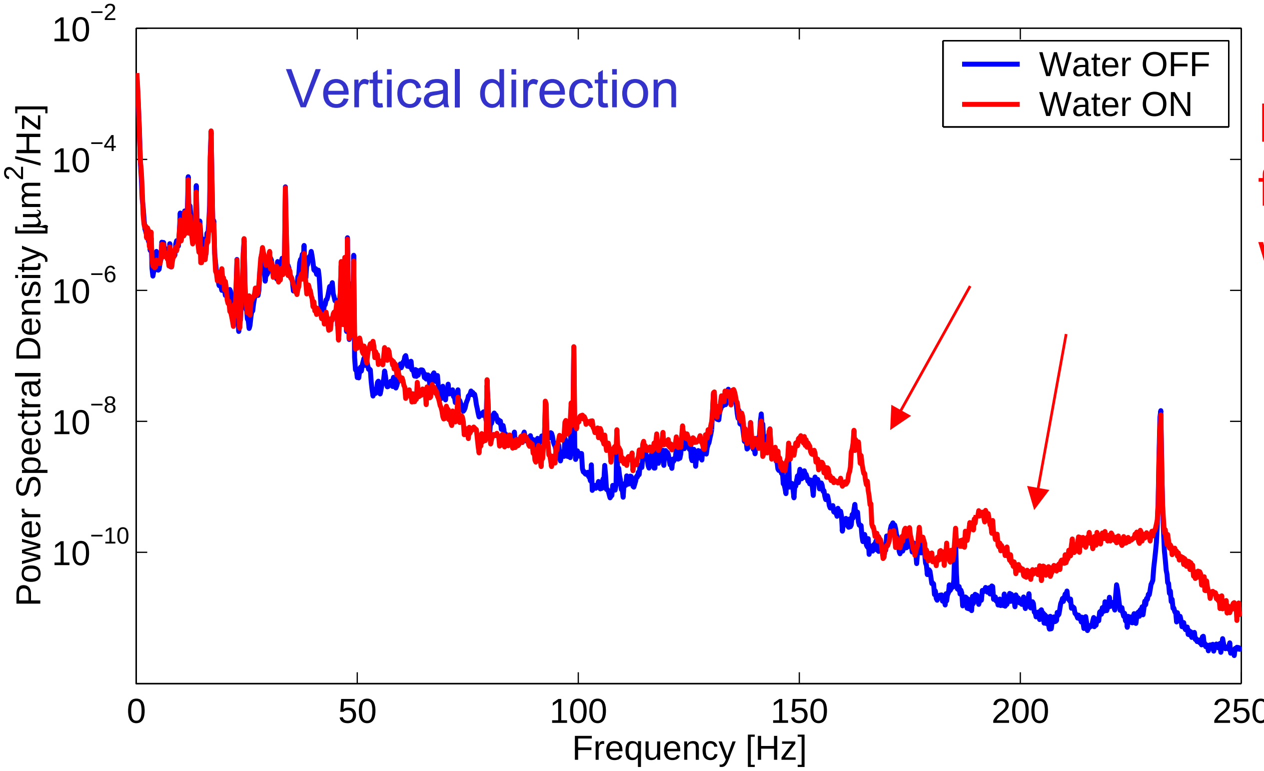
- System with four feet (before three) – active feedback not yet optimized
- Larger vibration without water (~ 2.5 nm instead of ~ 1 nm)
- Smaller contribution from water to overall motion
- Relevant contribution from high frequency vibrations (~ 1 nm above 60 Hz)

5. In-situ measurements – Vibration of CTFII quadrupole

Same quadrupole doublets, installed on the main line of the CTFII accelerator

No measure of water flow

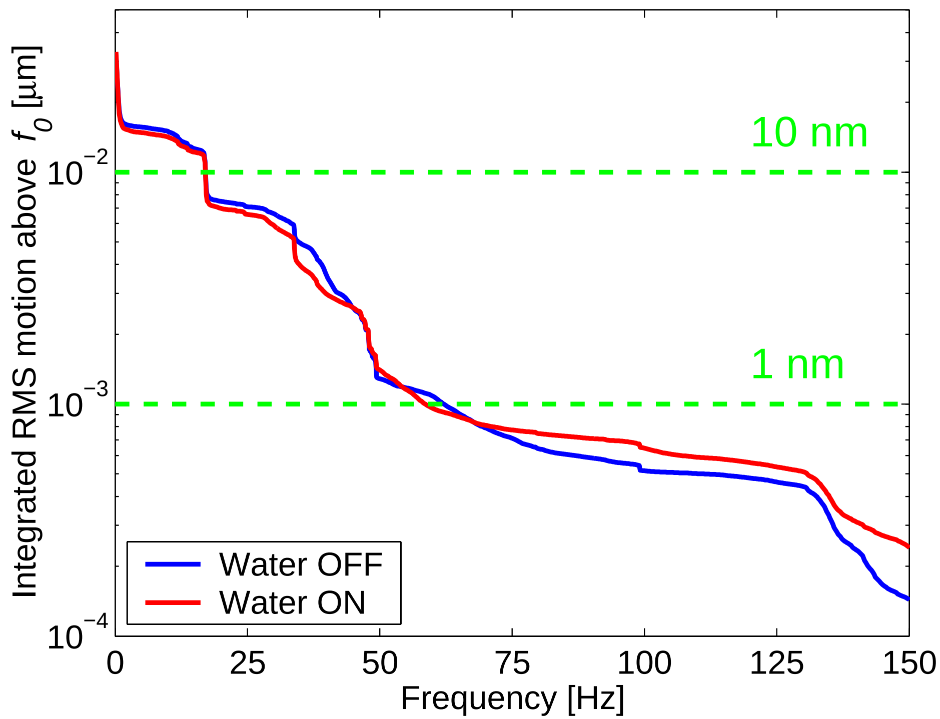
Measurements in *noisy conditions* (afternoon of a working day)



No big effect from cooling water!

Horizontal

Vertical



- *Effect of water quite small!* Background too high to see water effect?
- Quadrupole stability: Vert → **~ 15 nm** above 4 Hz (CLIC tol = 1.3 nm)

  Hor → **~ 26 nm** above 4 Hz (CLIC tol = 14 nm)

6. Conclusions

- Results of water induced vibration of CLIC quadrupoles presented
- First measurements encouraging – CLIC linac tolerances are met!

  Linac quad stabilized at **1.3 nm above 4 Hz** with nominal water flow
- Simple theory – good order of magnitude for vibrations frequency, not good the estimate of vibration amplitudes
- Importance of the pipes feeding the magnets
- RMS motion above 4 Hz driven by vibrations up to ~ 60 Hz → could excite structural resonance

} **Vibration studies have an effect on magnet design!**

- Vibration properties of quadrupoles depends on stabilization device
- Studies on going to improve theoretical understanding