NLC - The Next Linear Collider Project

Vibrations caused by cooling water in LINAC components

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Why do we care ?

Because we keep pushing the limits of the designs

Dissipating heat caused by RF power (4kW/m):

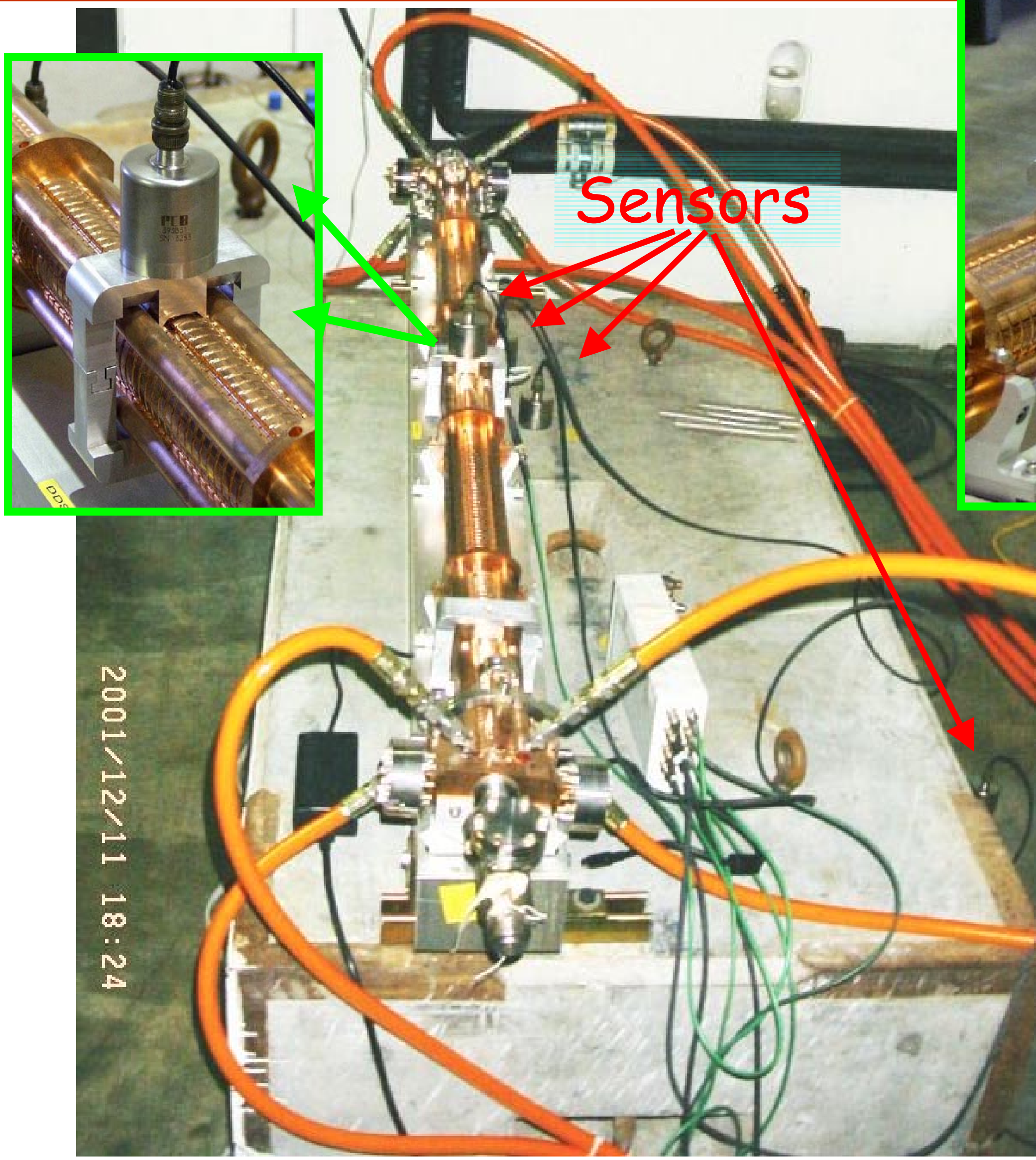
=> need large flow of cooling water (1 l/s at 70 MV/m)

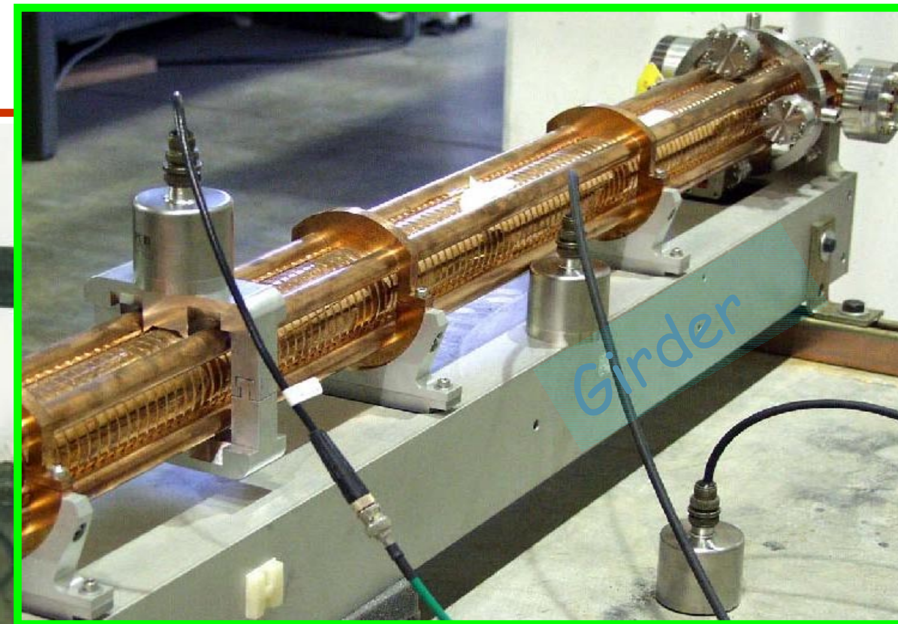
=> this cause vibrations

- Tolerances for structure vibration are rather loose (μm scale)

- **More worrisome issue:**
    - **vibration coupling, even tiny, from RF structure to a quadrupole (10 nm tolerance)**

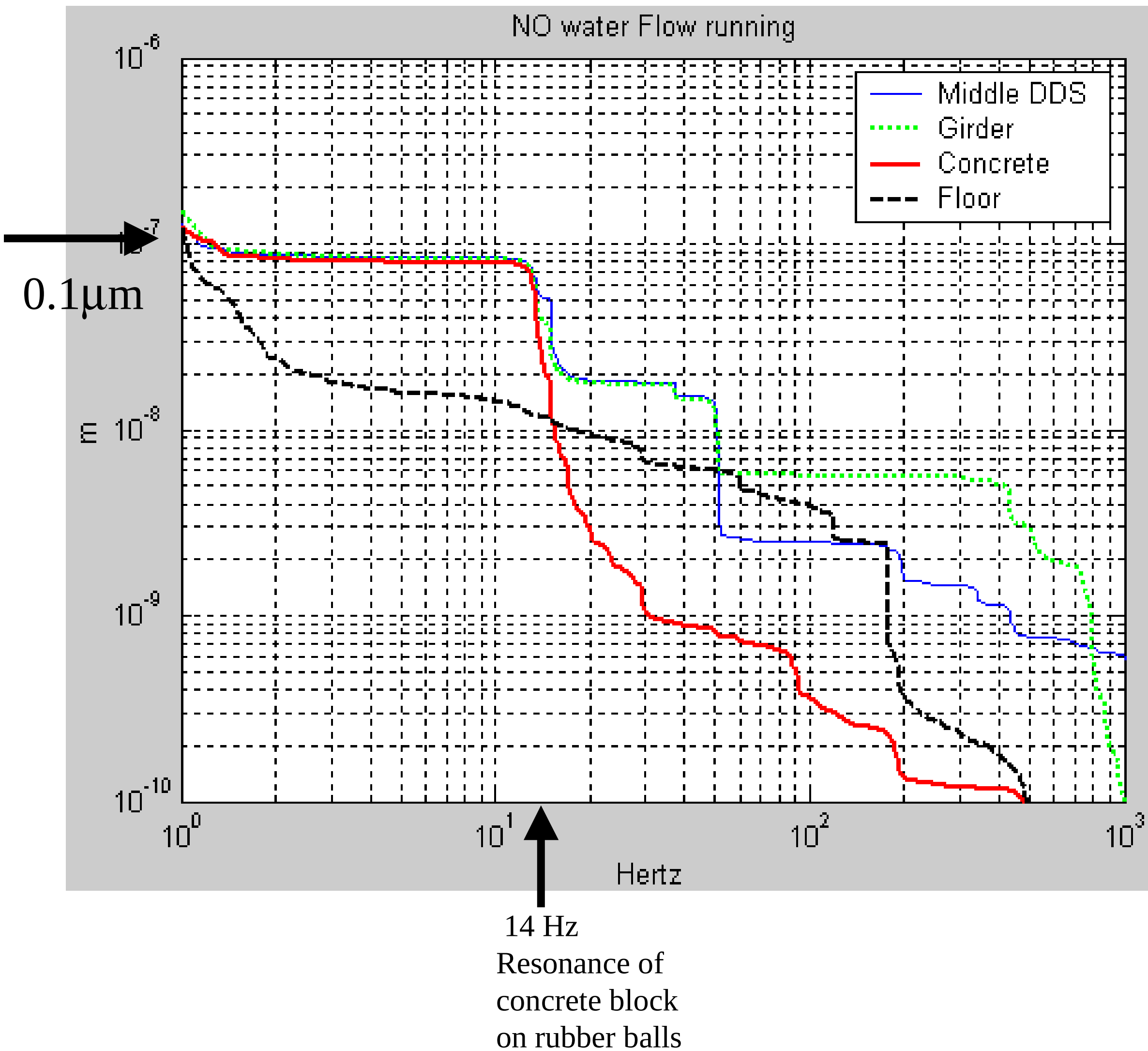
Structure vibration tests at NLCTA





- **1.8m Long RF structure DDS1 (~100 Kg)**
- **Installed on Hollow Aluminum girder**
- **Girder is connected to concrete block**
- **The block is installed on rubber balls (~14Hz resonance) to isolate from noisy NLCTA floor**
- **Nominal total flow is 16GPM (~1 liter/s)**
- **Sensors: four piezo-accelerometers; one piezo-transducer to measure water pressure fluctuations (not shown)**

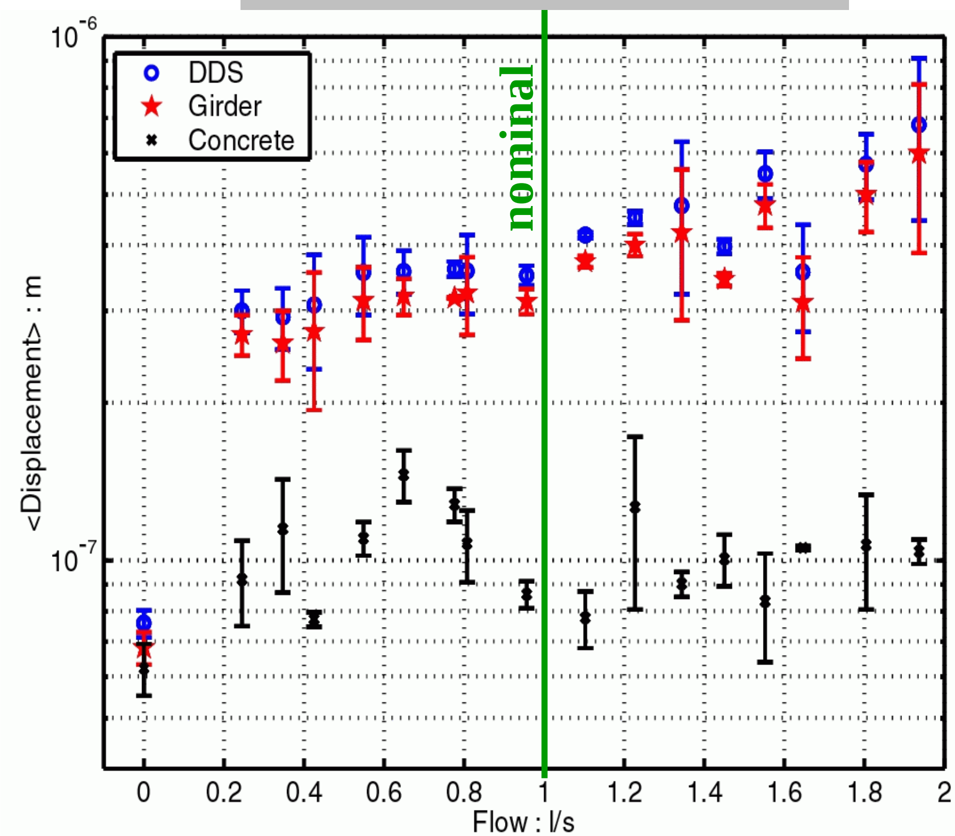
Results on cooling water induced vibration of RF structure at zero l/s



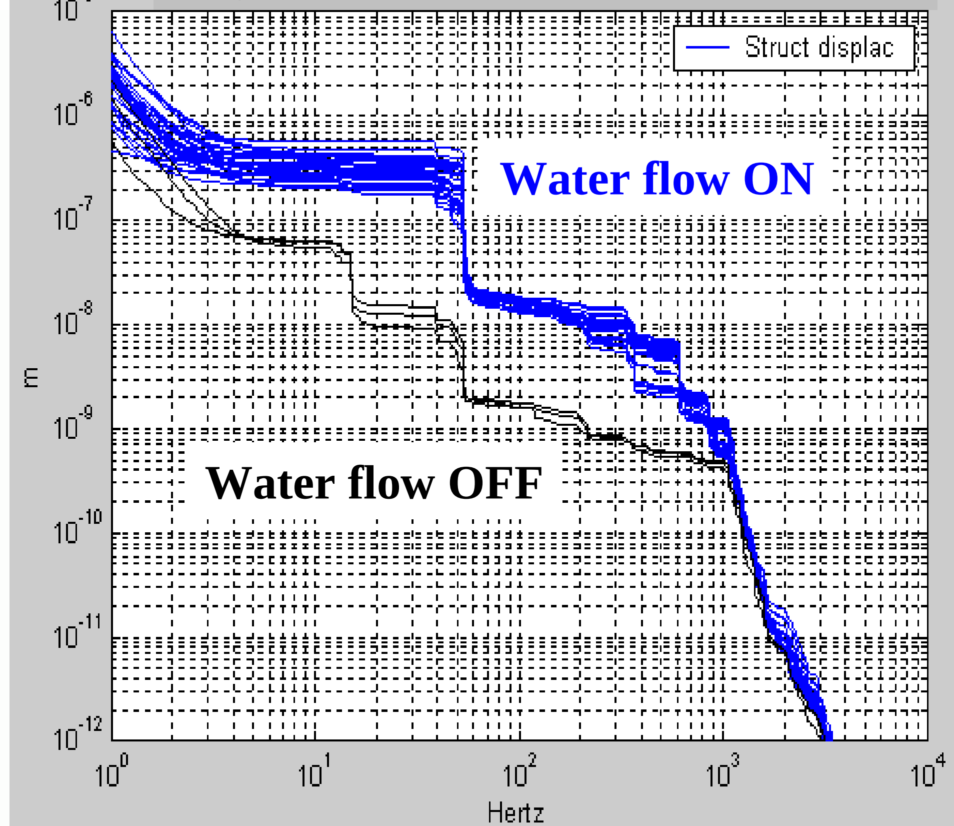
- Without flow vibration is much smaller (0.1 µm for structure)
- The concrete block is placed on rubber balls to reduce NLCTA high frequency noise on the block

Vibration of RF structure versus water flow

Displacement vs flow above 4 Hz

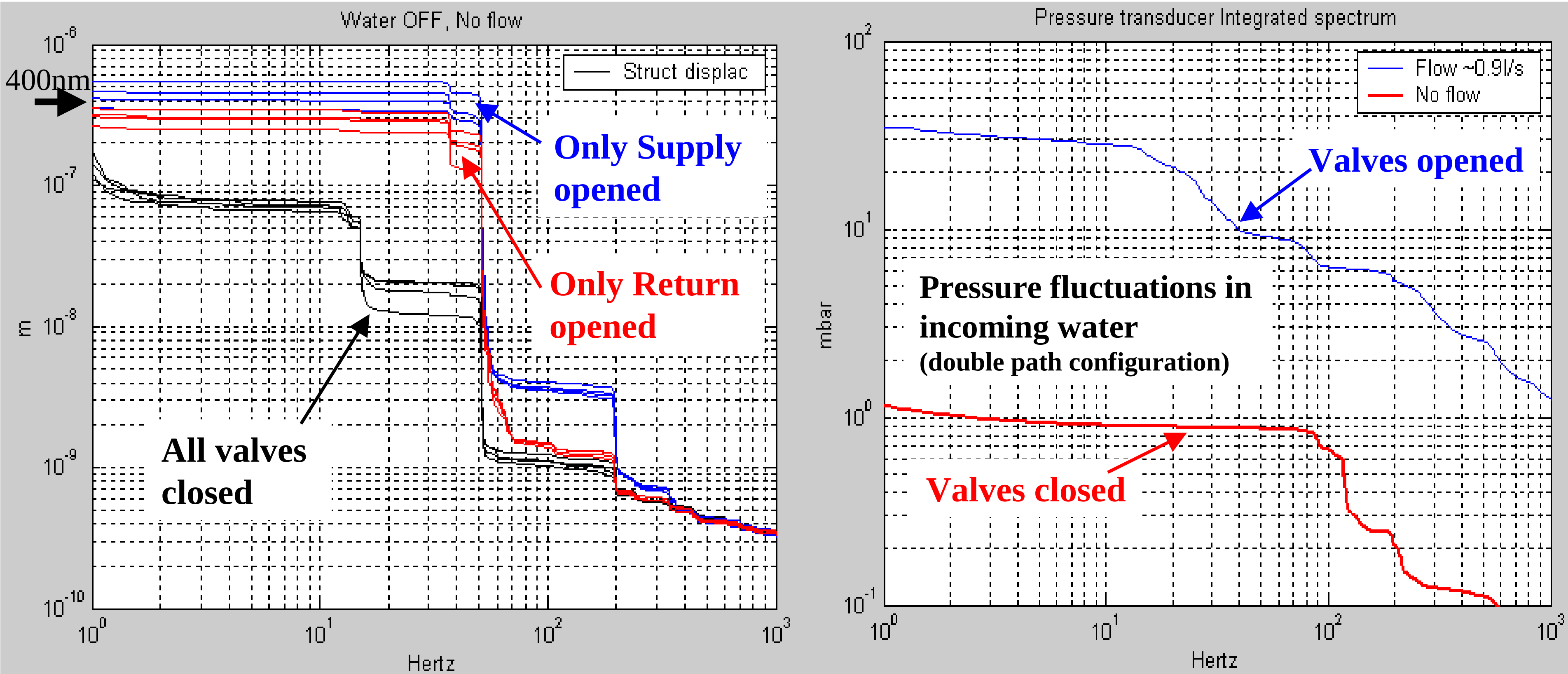


Integrated spectrum of vibrations, different flow



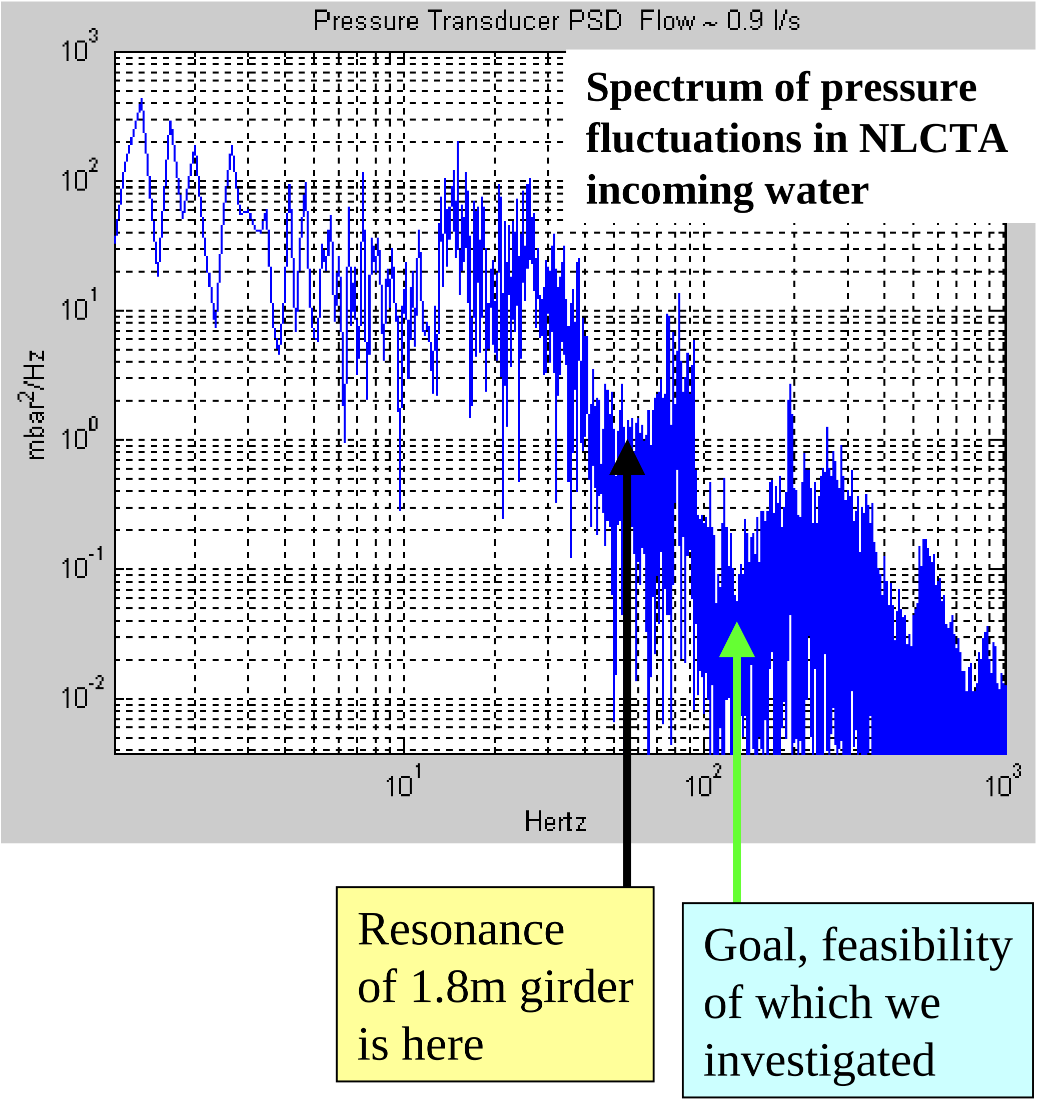
- Vibration depends only smoothly on the flow rate
- Flow changes 10 times , but vibration only 2 times

RF structure vibration without flow, caused by pressure fluctuations in incoming water



Most of vibration is caused not by turbulence in RF structure itself, but by pressure fluctuations in incoming water, I.e. by **turbulence in largest supplying pipes**

Why higher resonance frequency of a girder is a benefit



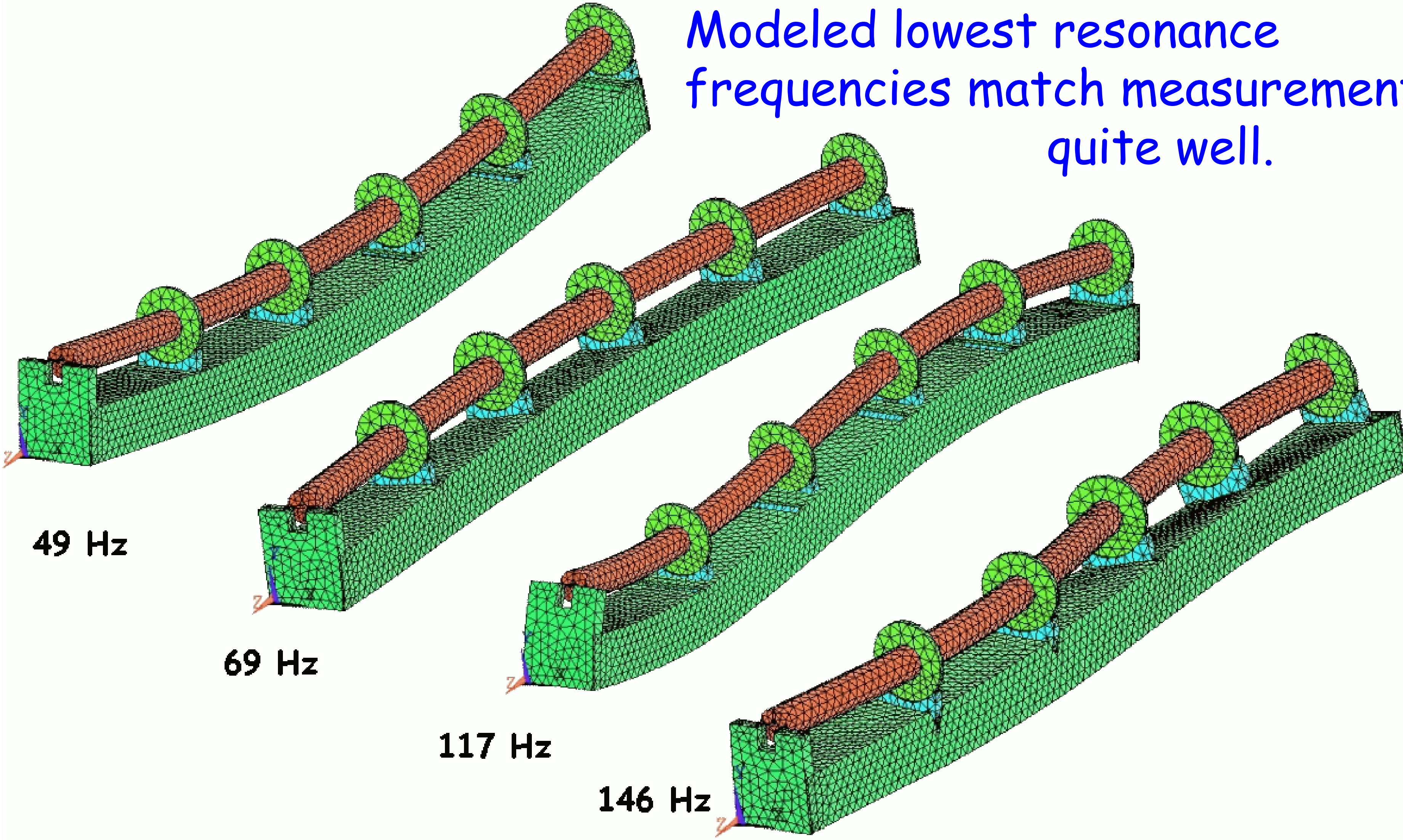
- Driving forces (ground motion, pressure ΔP/P, …) always higher at lower freq.

- The cooling water supplying system may need to be made more quiet
  - e.g. by means of standard for industry passive devices

- The girder design may need to be optimized to increase damping and avoid low F resonances

Mechanical resonances in existing girder-structure. ANSYS model.

Modeled lowest resonance frequencies match measurements quite well.



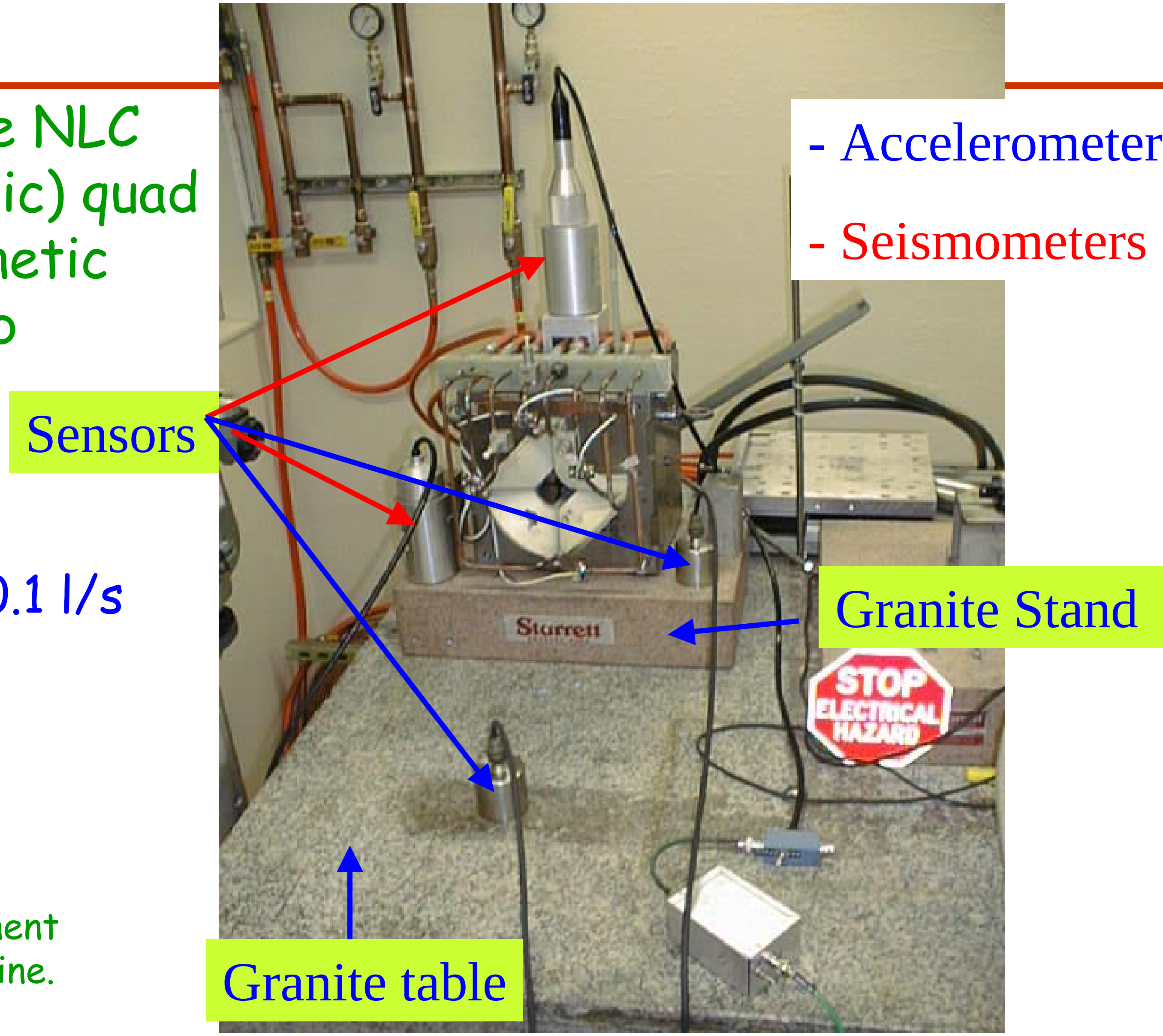
Mechanical resonances : Optimizations with ANSYS

- One way to reduce the problem of resonances is to increase the frequency of the lowest resonance
- ANSYS optimizations have shown that by increasing the girder dimensions from 4x6" to 10x10" (and increasing wall thickness from 0.25" to 1") will move the lowest frequency to 120 Hz.
- Such large improvements are probably unnecessary but they are possible with a simple modification
- Optimization will continue further

Water induced vibration in NLC EM Quad

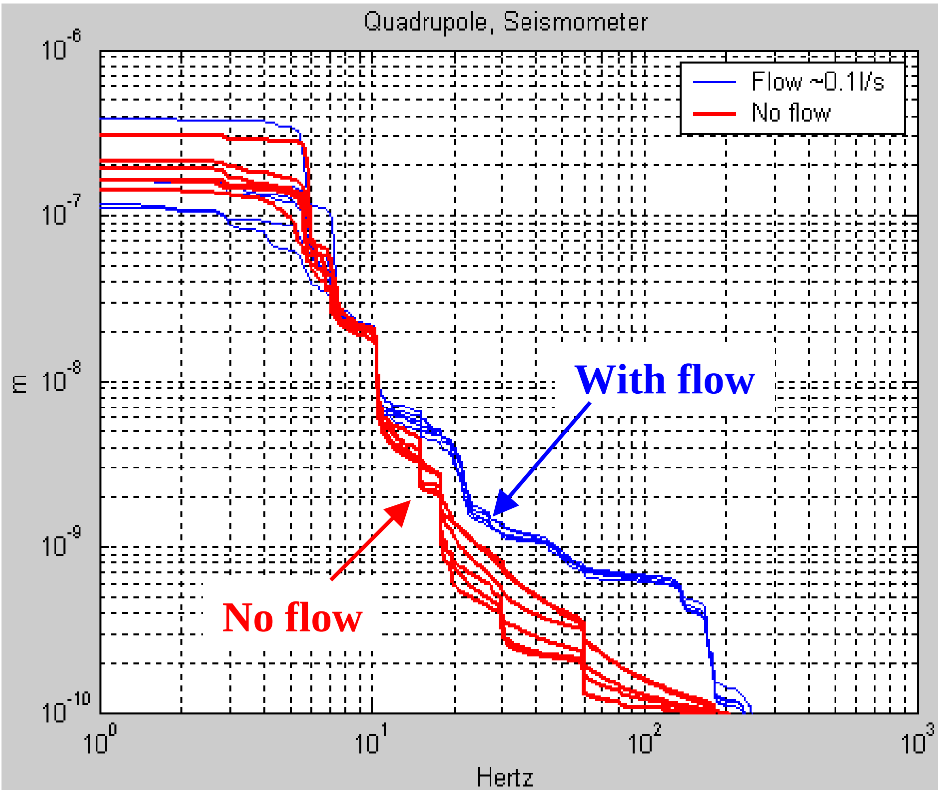
Prototype of the NLC (Electro Magnetic) quad installed in magnetic measurement lab

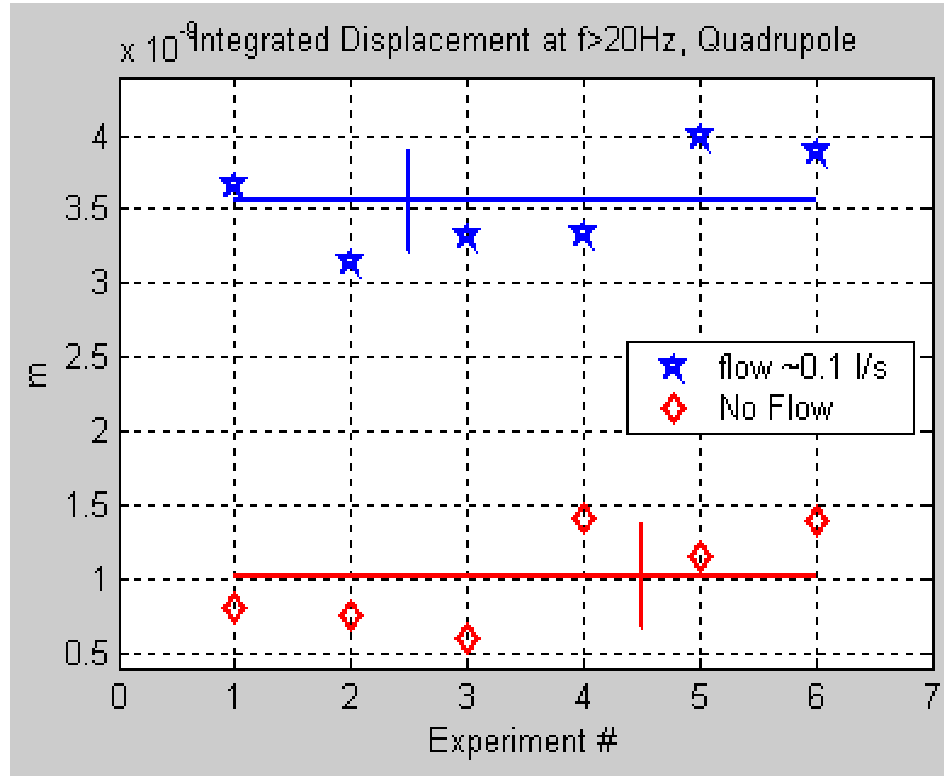
Nominal Flow : 0.1 l/s



[NLC design use Permanent Magnet quads as a baseline. EM quads are backup.]

EM quad vibration with cooling water





- EM quad vibrates **~3.35nm*** for **F>20Hz** due to cooling

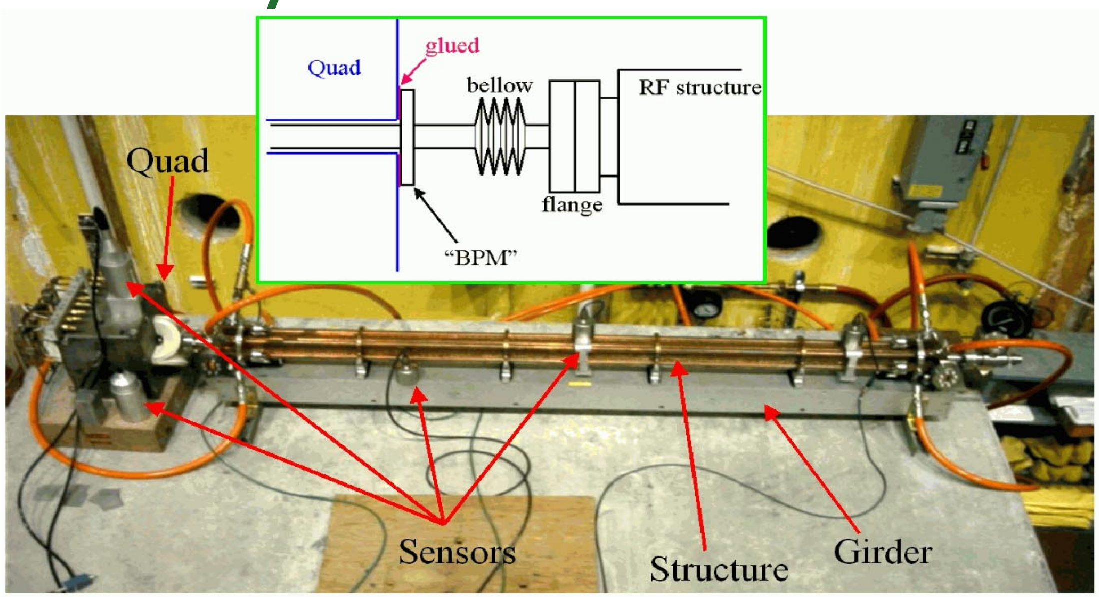
Measurements for frequency lower than 10Hz are not possible in magnetic lab because of high ambient vibration

* Assuming additional vibration is uncorrelated : $(3.5^2 - 1)^{\frac{1}{2}} = 3.35$nm

Vibration setup in SLD

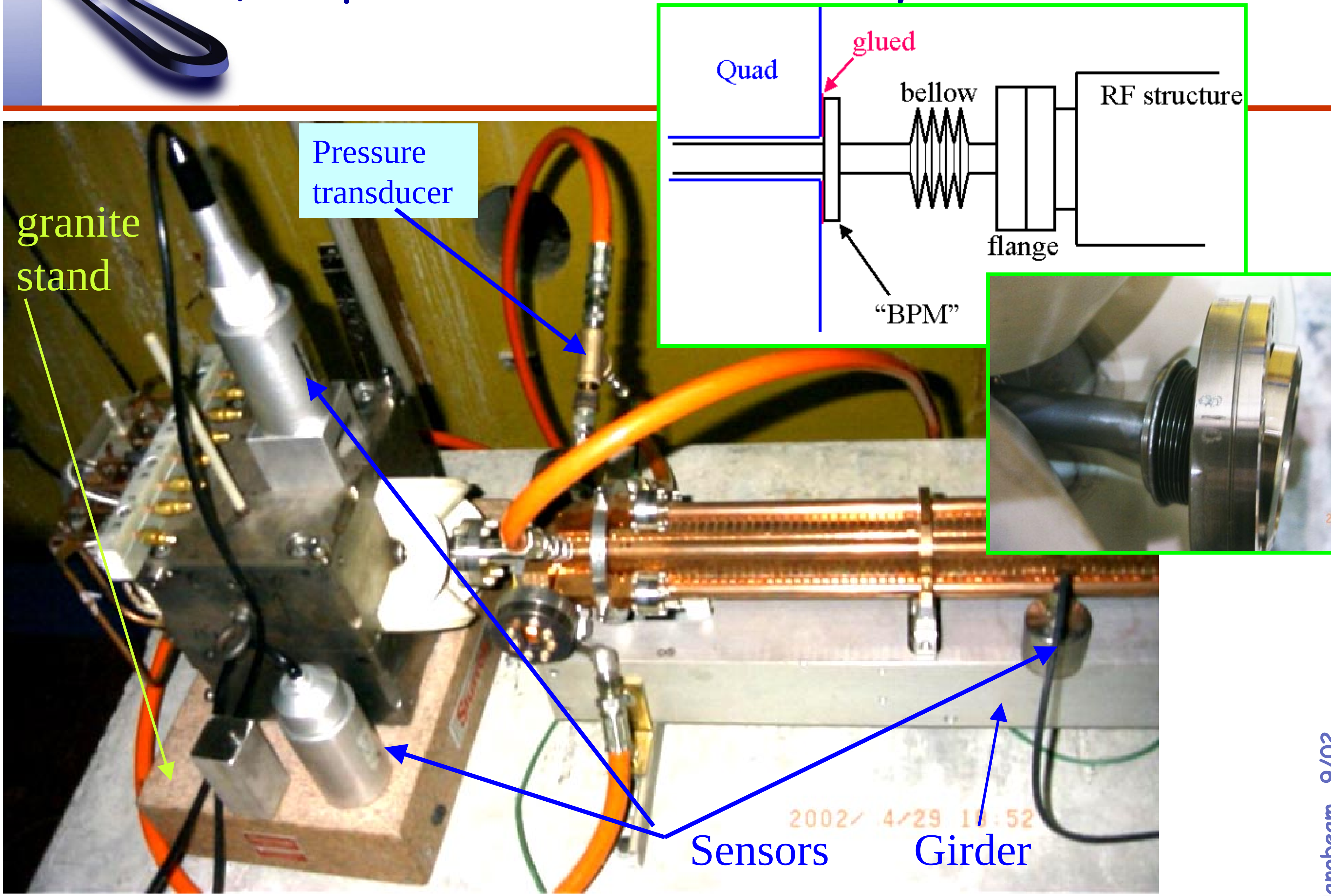
- Study vibration of the Structure - girder due to internal turbulence using gravity-fed water

- Study vibration transmission to quadrupole in a structure-quad assembly

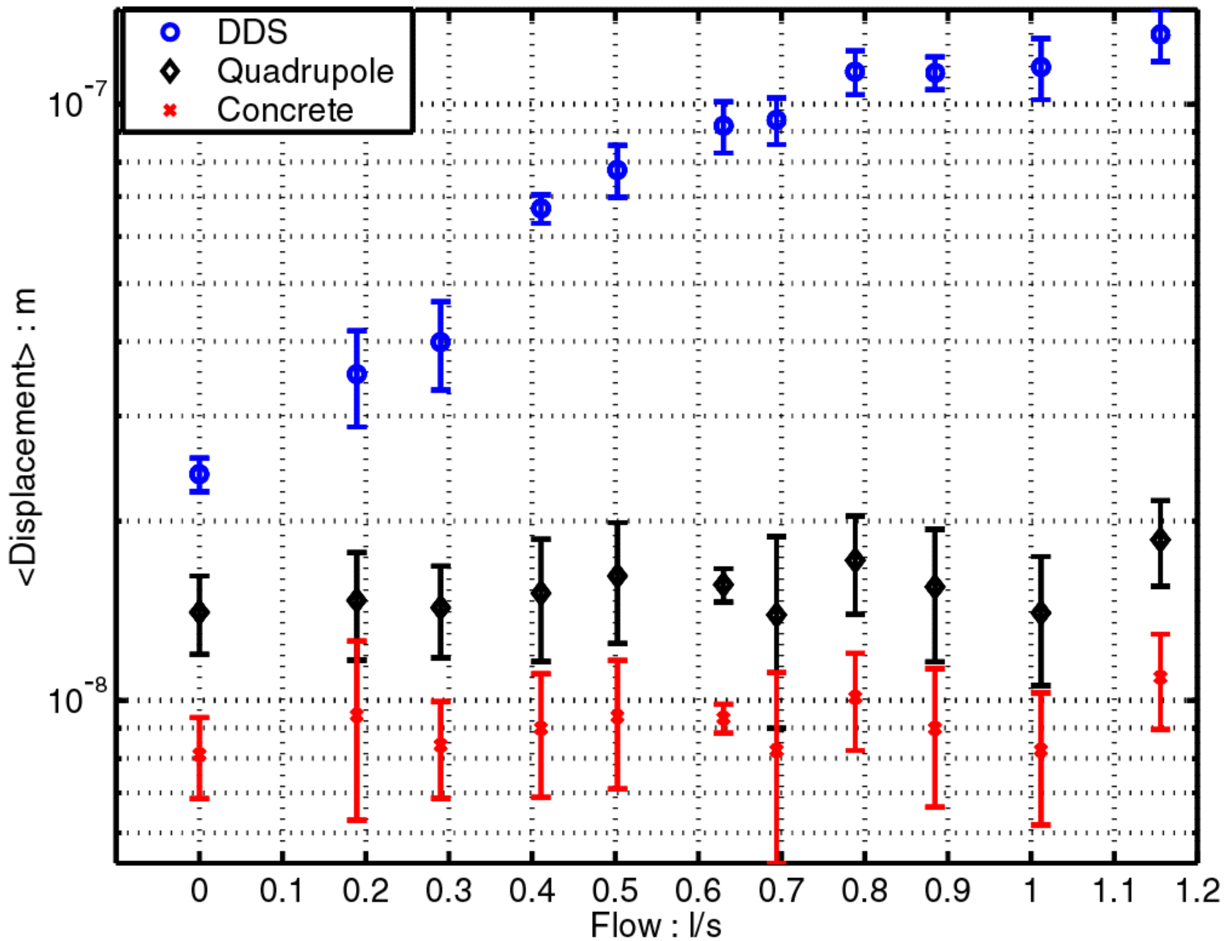


SLD pit. Gravity fed experiment

Quadrupole and RF structure assembly and sensors

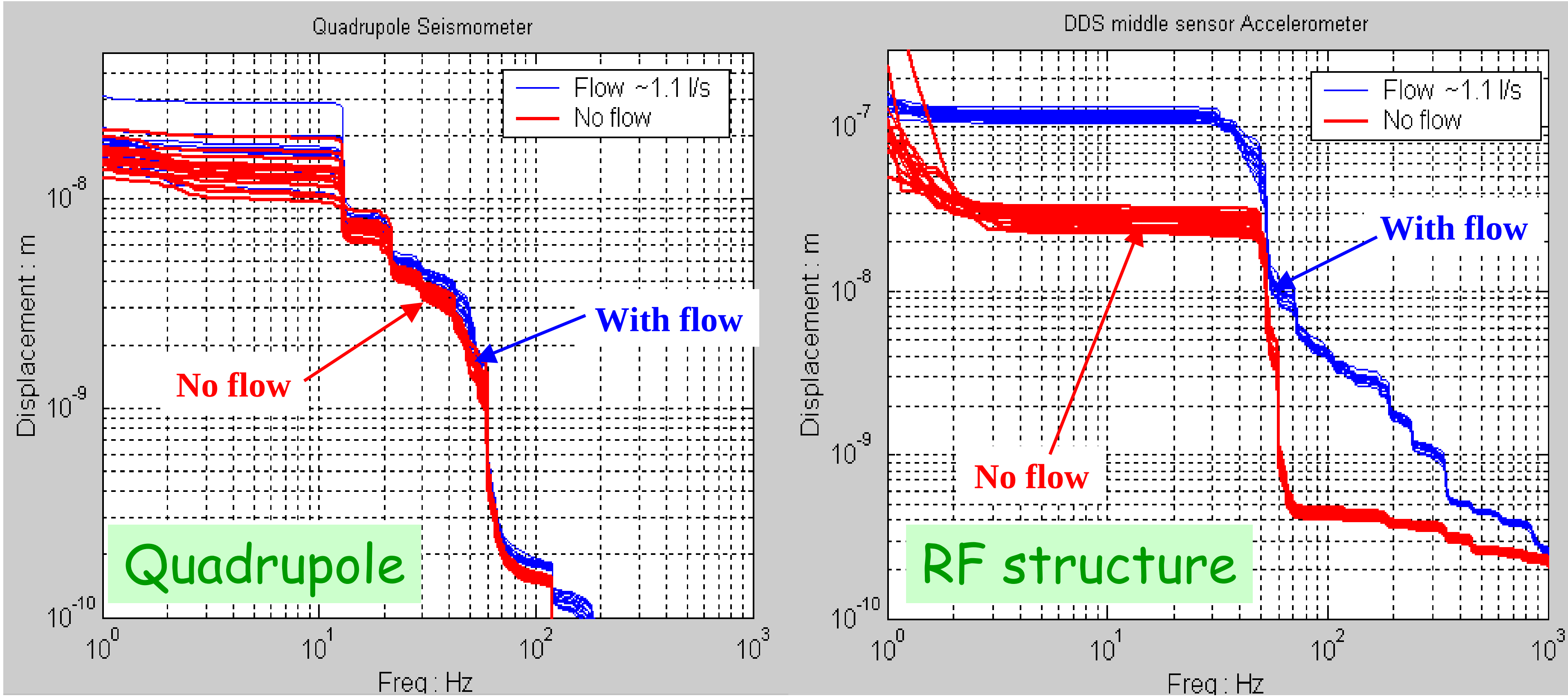


Structure vibration due to internal turbulence only



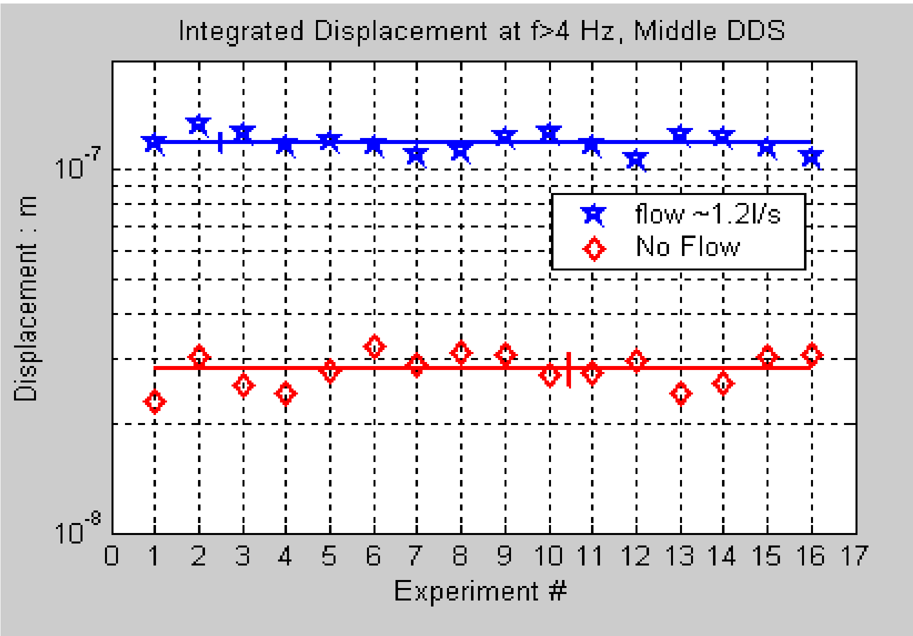
- Dependence of structure vibration vs flow in gravity fed experiment
- Dependence is more smooth than theory predicts
  (experiment wins, theory need more work)

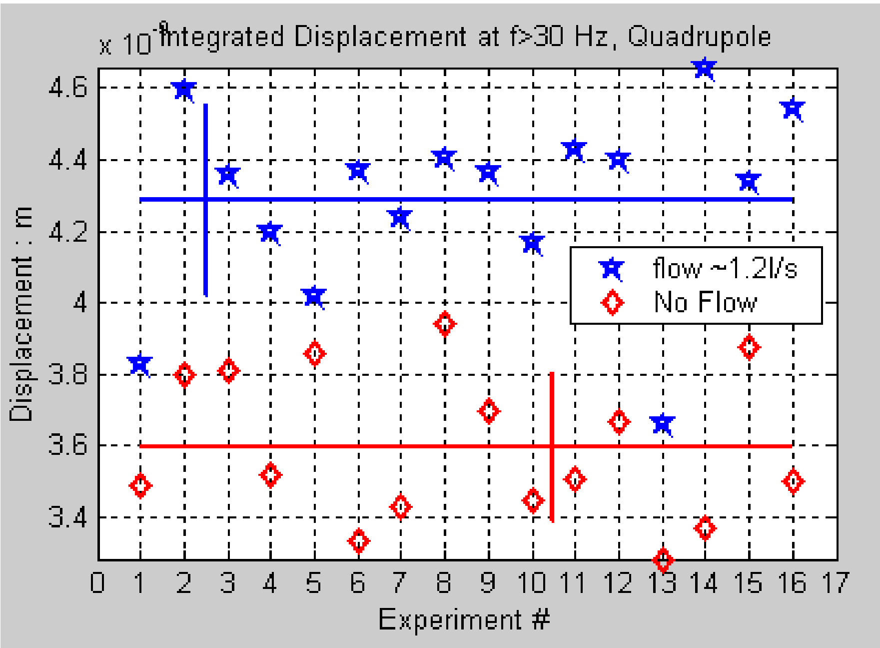
RF structure and Quad vibration in gravity fed case – Vacuum present



- RF structure vibrates ~110nm (twice less then in NLCTA)
- **about a nm** of vibration **penetrates to the quad**

RF structure to Quad vibration coupling in gravity fed case





110nm of RF structure vibration cause 2.4nm of quadrupole vibration *

The present mock-up is mechanically simplified. Actual NLC mechanical properties should be modeled.

* Assuming additional vibration is uncorrelated : $(4.3^2 - 3.6^2)^{\frac{1}{2}} = 2.4$nm

Simplifications in the present RF structure – quad mock up

- Girder is tied to concrete at the end points, and no movers under the girder
- Quad placed on shims – need to place on mover-like device
- Girder is not of the right length
- Gravity fed water is more quiet

Reality can make it worse (or better?)

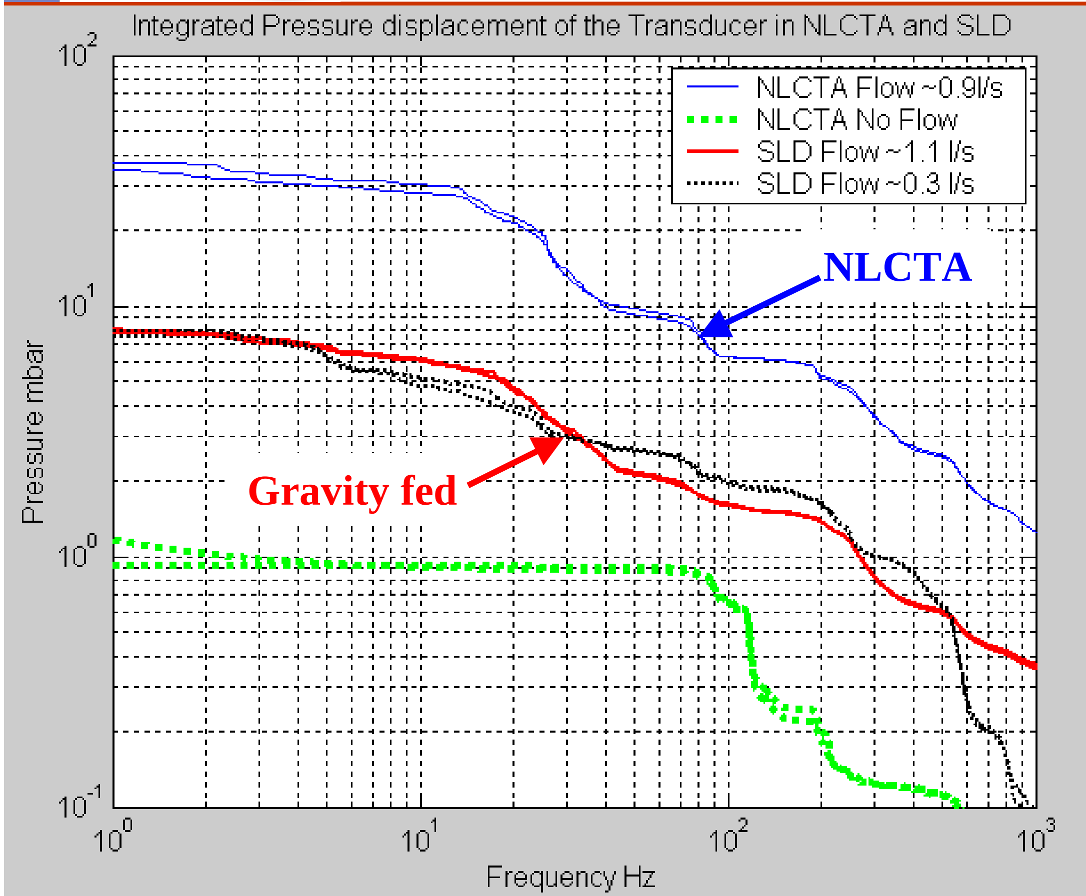
- Thought that vacuum will stiffen bellow and increase coupling, but observed that vacuum does not make any changes on the vibration level recorded

- Overall design can certainly be improved to increase damping and avoid high Q resonances

Better design can improve it

Further optimization is being done jointly with FNAL colleagues

How quiet is gravity fed water



Note: This particular case for NLCTA was measured with double path configuration of the system

- Gravity fed water is more quiet
- Industry often employs passive dampers to decrease dP/P in water. If needed, we can use similar approach

e.g. http://www.pulseguard.com/

Theoretical estimations of turbulence induced vibrations (Sri Adiga)

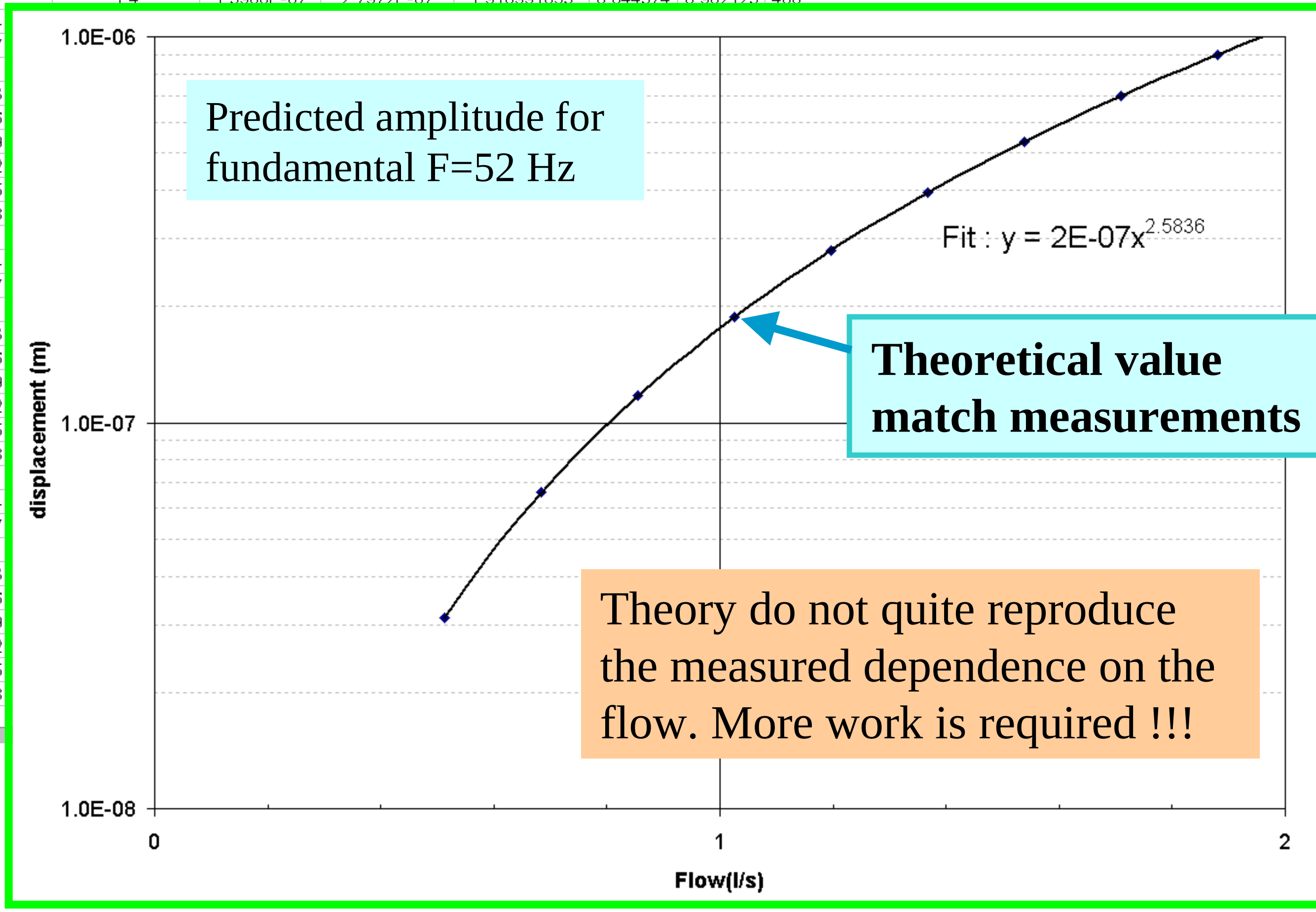
Spreadsheet analysis of velocities on vibration induced

	A	B	C	D	E	F	G	H	I	
1										
2										
3			**Velocities (l/s)**	**Velocities (m/s)**	**Vibration**	**Total Vibration**	**2*pi*H_r*f/v**	**Uc/V**	**Uc**	**4fL**
4			0.512919	**0.6**	1.56671E-08	3.13342E-08	4.477645791	0.595577	0.357346	103
5	frequency	Hydraulic Radius	0.683892	**0.8**	3.29443E-08	6.58887E-08	3.358234343	0.605104	0.484083	761
6	51.85461252	0.00825	0.854865	1	5.86351E-08	1.1727E-07	2.686587475	0.61746	0.61746	597
7			1.025838	1.2	9.3914E-08	1.87828E-07	2.238822896	0.630904	0.757085	487
8	**Length**	**Density of Fluid**	1.196811	1.4	1.3986E-07	2.7972E-07	1.918991053	0.644374	0.902123	408
9	1.778	1000	1.367784							
10			1.538757							
11	**Inner Diameter**	**Density of material**	1.70973							
12	0.0165	8230	1.880703							
13			2.051676							
14	**Outer Diameter**	mode shape function	2.222649							
15	0.025	1.060593887	2.393622							
16			2.564595							
17	Moment of Inertia	**no. of pipes**	2.735568							
18	1.55285E-08	4	2.906541							
19			3.077514							
20	**Young's Modulus**		3.248487							
21	1.75E+12		3.41946							
22			3.590433							
23	Mass per Unit Length		3.761406							
24	2.492675263		3.932379							
25			4.103352							
26	**no. of supports**		4.274325							
27	2		4.445298							
28			4.616271							
29			4.787244							
30	**All Bold values must be entered**		4.958217							
31			5.12919							
32	**Critical Velocity(m/s**	**Critical Velocity(l/s)**	5.300163							
33	629.7428205	538.3450963	5.471136							
34			5.642109							
35	Critical Velocity is that velocity		5.813082							
36	beyond which the pipe buckles		5.984055							
37			6.155028							
38			6.326001							

Chrt_1tube | 1tube simul | Sheet3 | Chrt_4tube | 4tube simul

Young's modulus adjusted to match F to be 52Hz

Simulations of structure-girder system supported at each end



 To appear as LCC-94

Preliminary evaluation for cooling induced vibration (nominal flow)

- RF structure vibration:
  - About 110nm if fed with quiet water (Slide 20)
  - About 350nm mostly due to turbulence in supplying pipes for water system similar as in NLCTA (Slide 7)
- EM quad receive
  - About 2.4nm due to coupling to structure if structure fed with quiet water, (Slide 20)
  - About 7.6nm *estimated* from coupling to structure (due to turbulence in supplying pipes in NLCTA like system)
  - About 3.3nm due to EM quad cooling (Slide 15)
- Total vibration (if all sources are independent) for EM quad with NLCTA-like water system (pessimistic assumption):

$$(3.3^2 + 7.6^2)^{\frac{1}{2}} = 8.3\text{nm} \pm$$ all "if" , all simplifications and difference from the real system

In summary, we studied :

- Vibration of RF structure-girder with NLCTA water supply
  - And found that external turbulence is important
- Vibration of RF structure-girder cooled with gravity fed water
  - And found that internal turbulence gives only 1/3 of the total effect
- Vibration coupling from RF structure to Linac quadrupoles
  - And found that coupling is small – on a percent level (~2%)
- Made ANSYS simulations
  - Further optimization of girder likely possible

Conclusion

- Vibration of RF structure and its coupling to LINAC quadruple are being studied.
- Even with pessimistic assumptions, additional vibration of the LINAC quadruples are below tolerance, but without much margin.
- Detailed vibration optimization of the full girder, with closer approximation to the real design, is possible and necessary.
- Designs of cooling water system is very important !