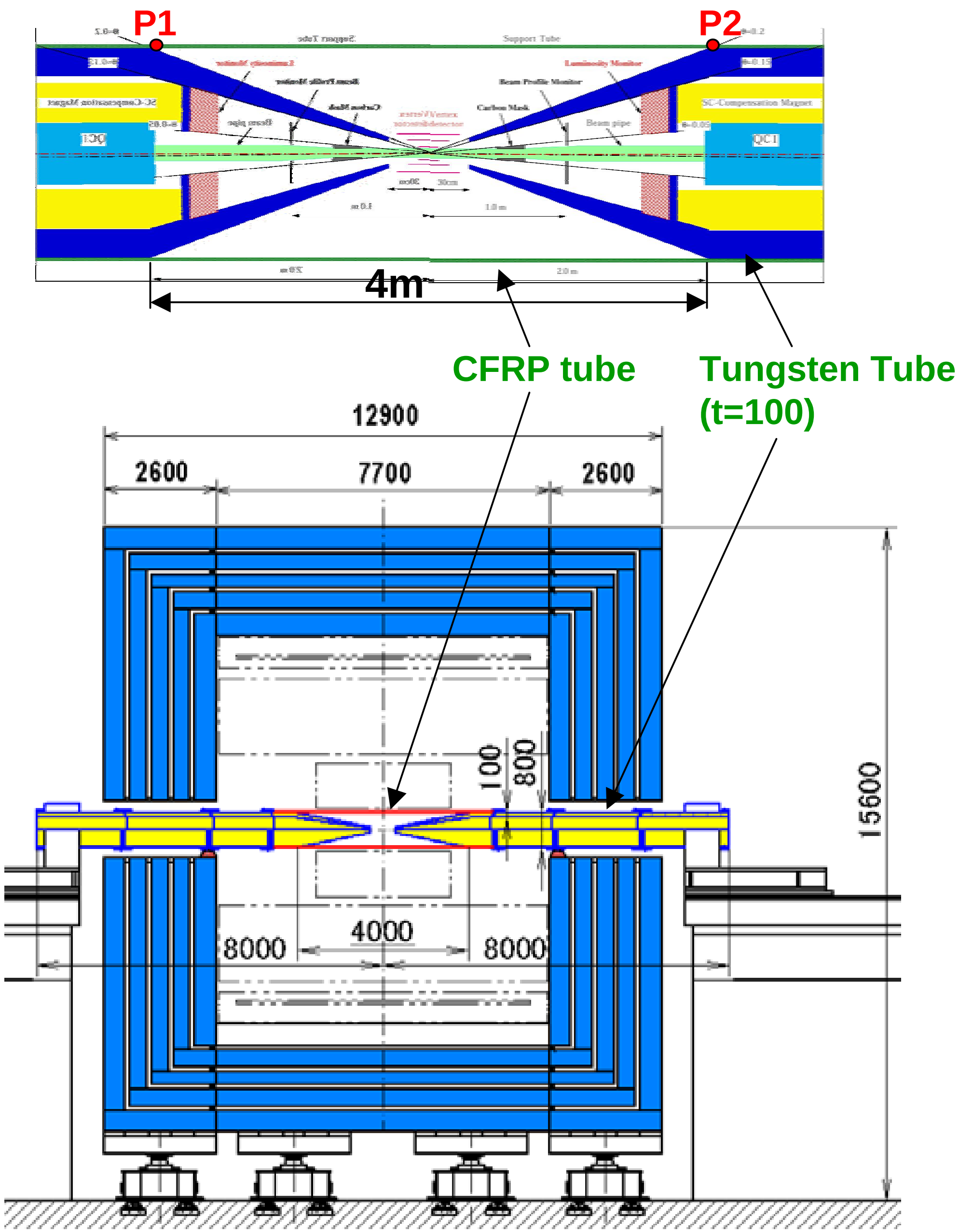
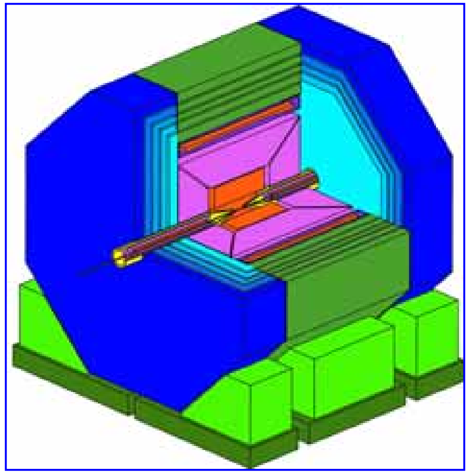
Nov. 11, '04

Summary of Support tube R&D

KEK H. Yamaoka

Introduction





- Components at IR region
  Supported by
  Tungsten tubes, CFRP tube
- For high luminosity
  Ground motion, culture Noise

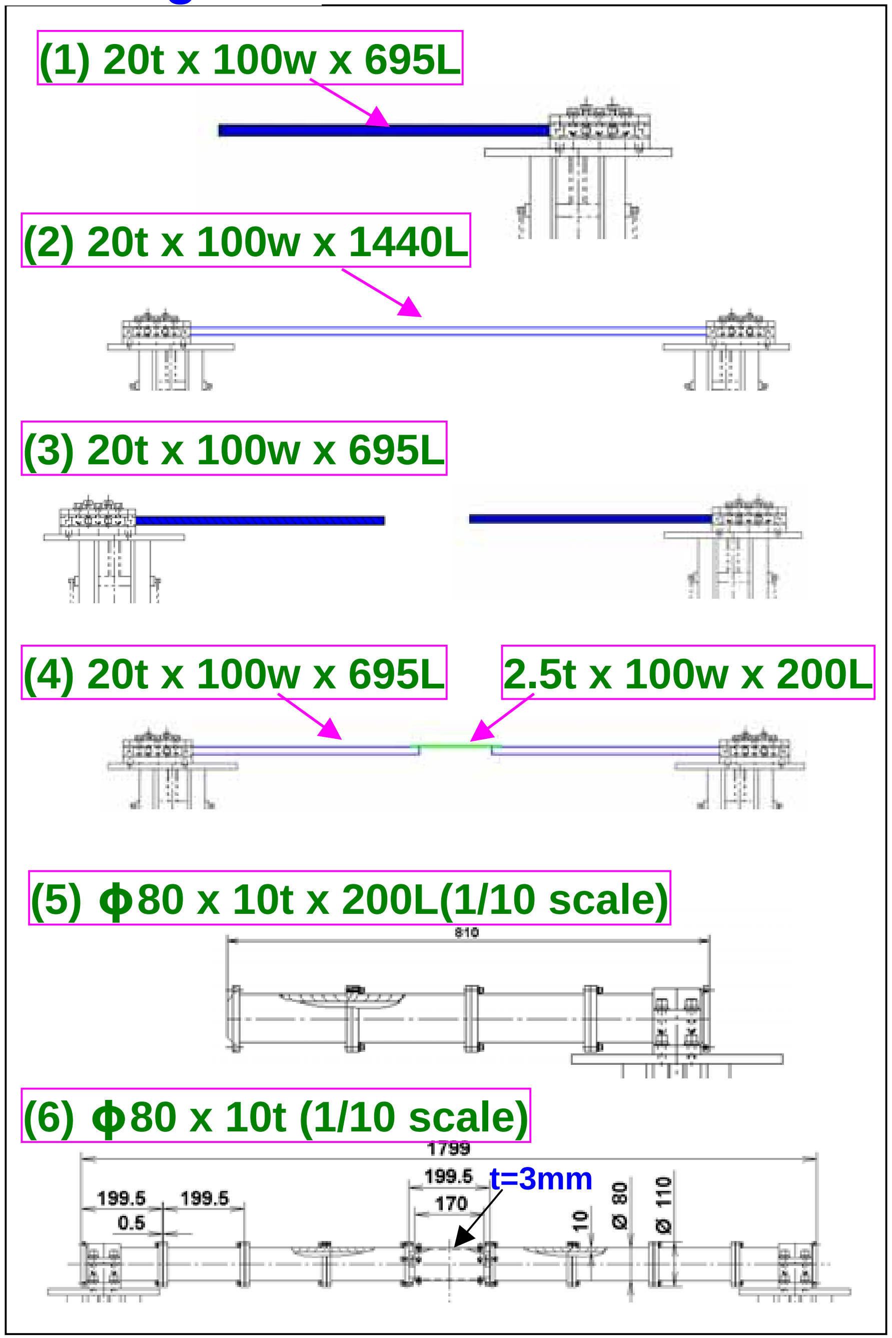
→ Analyses, Excitation tests

<u>Study Items;</u>

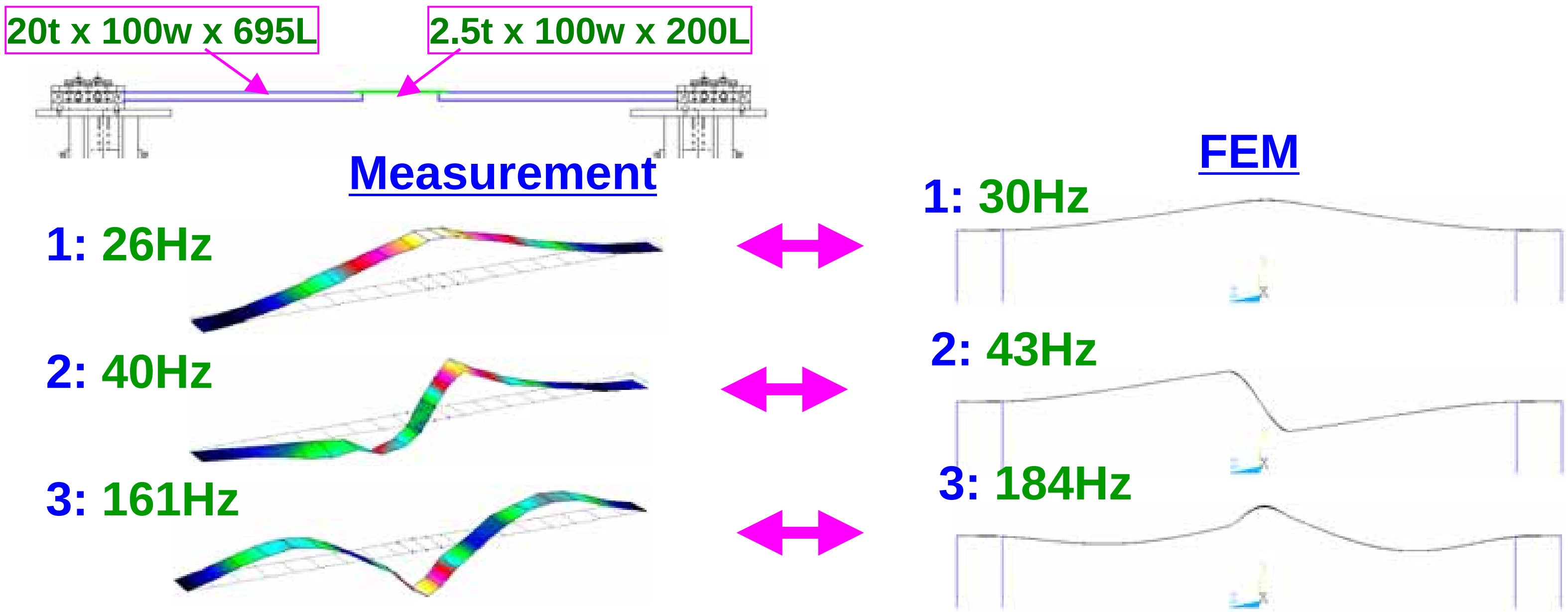
- Consistency of analyses
- How much is relative amplitude?
  |P1-P2| < 1nm(Criteria)
- Is necessary CFRP tube?

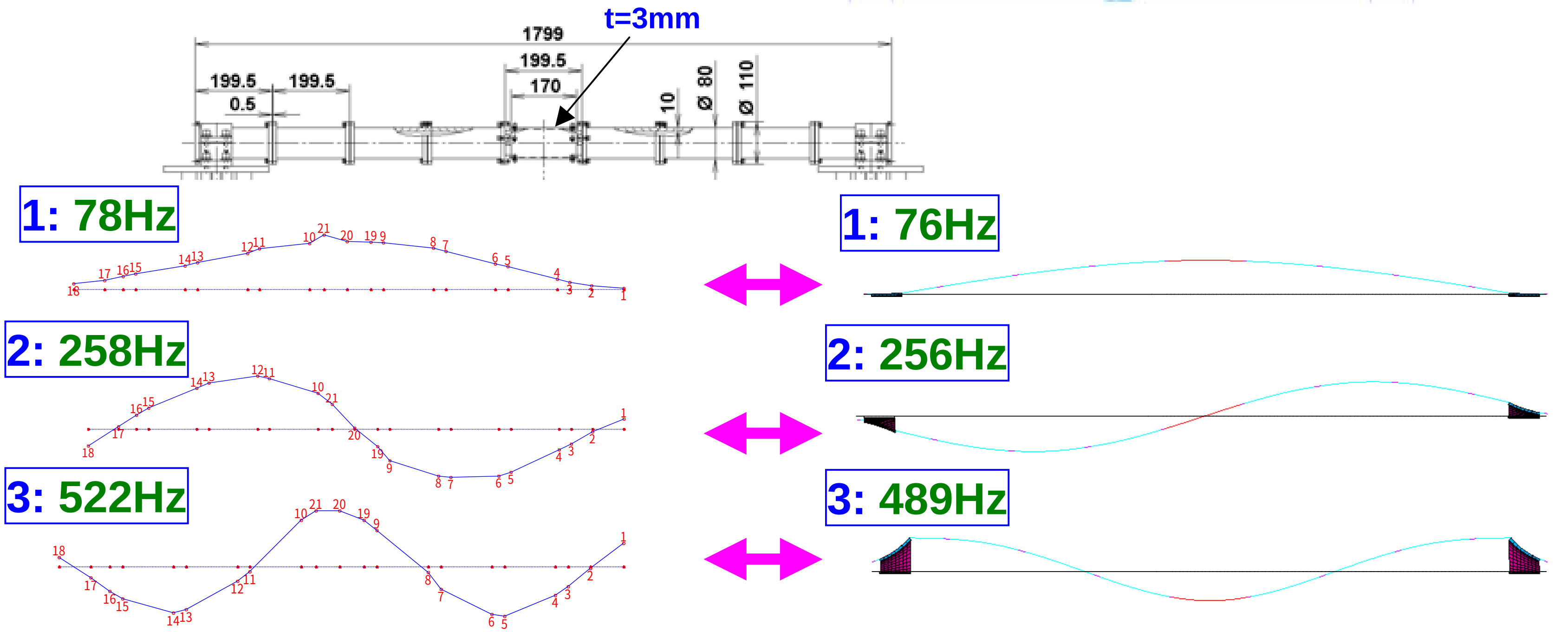
→ How much thickness?

Exciting Test



Input exciting force
(Excitation table or Impact hammer)
↓
Measurement: natural frequencies
Mode shape
↓
Compare to the FEM results

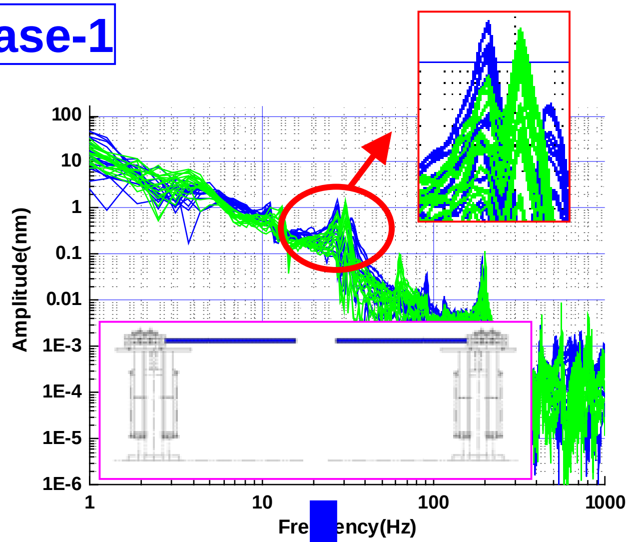


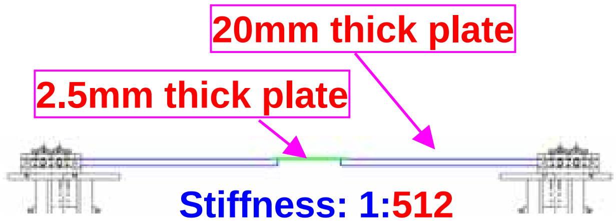


1st ～3rd mode: Good agreement with FEM

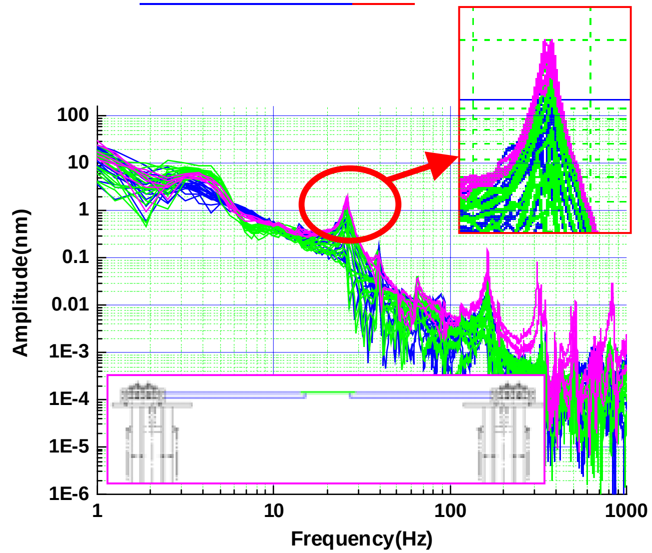
Support structure should be modeled in FEM.

Case-1

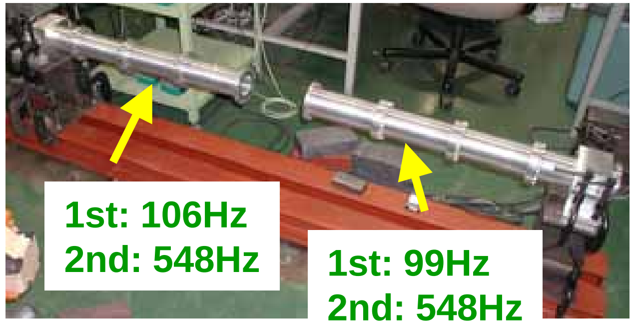




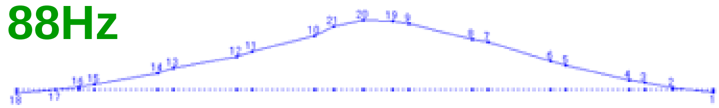
Stiffness: 1:512



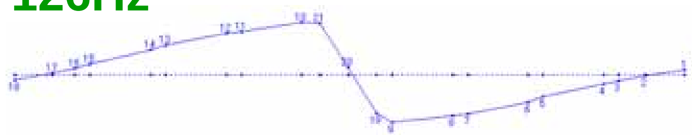
Case-2



1st: 88Hz



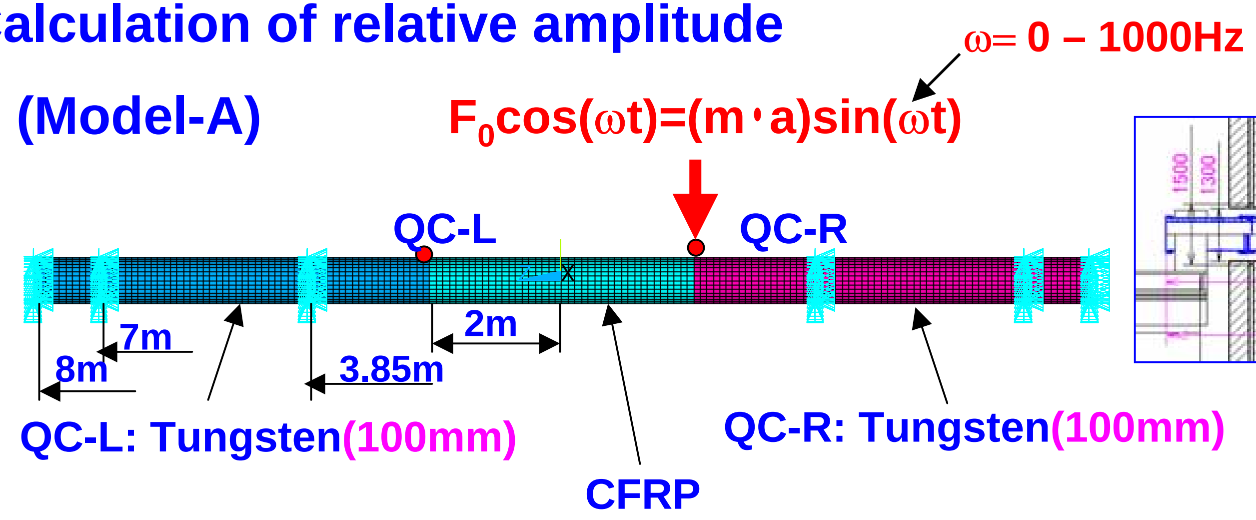
2nd: 126Hz

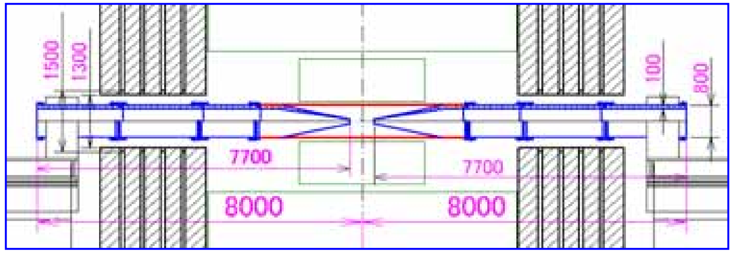


By connecting very weak structure,
Deviation can be absorbed.
Correlation can be given.
Relative amplitude can be estimated.

Calculation of relative amplitude

(Model-A)





	3mm	5mm	10mm
0Hz			
1Hz			
3Hz			
5Hz			

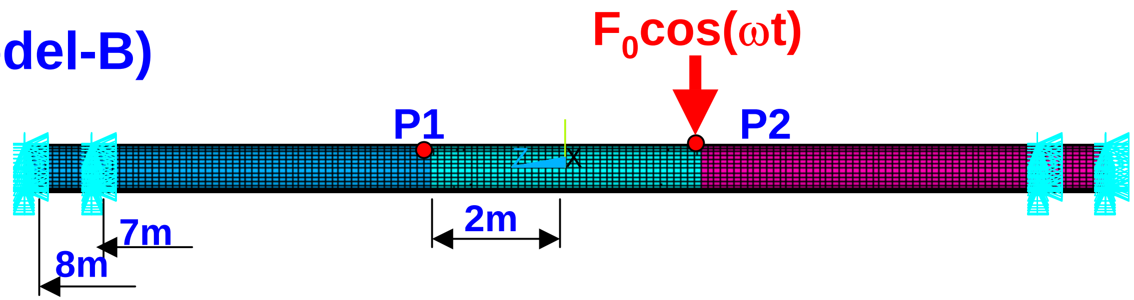
CFRP thick.

Get relative amplitude

(QC-R)-(QC-L)

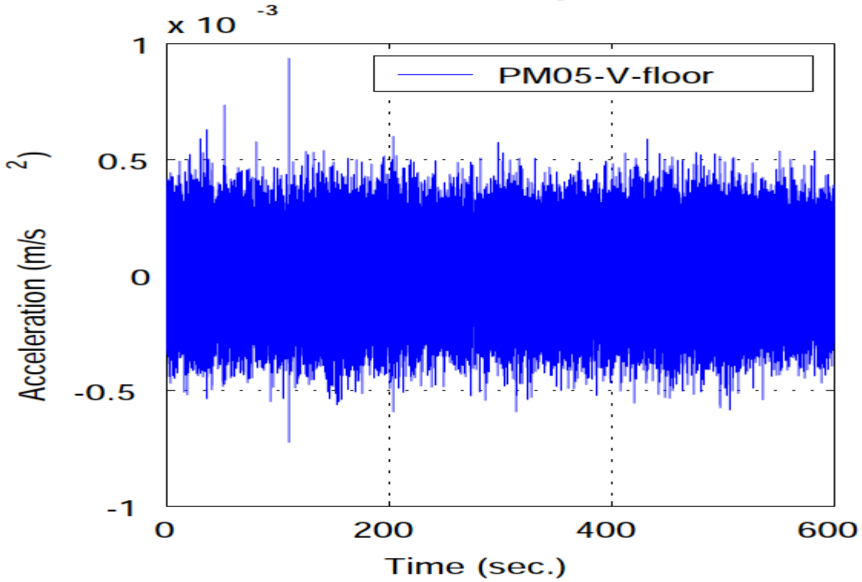
Difference of 1st mode of resonant frequency between QC-R and QC-L.

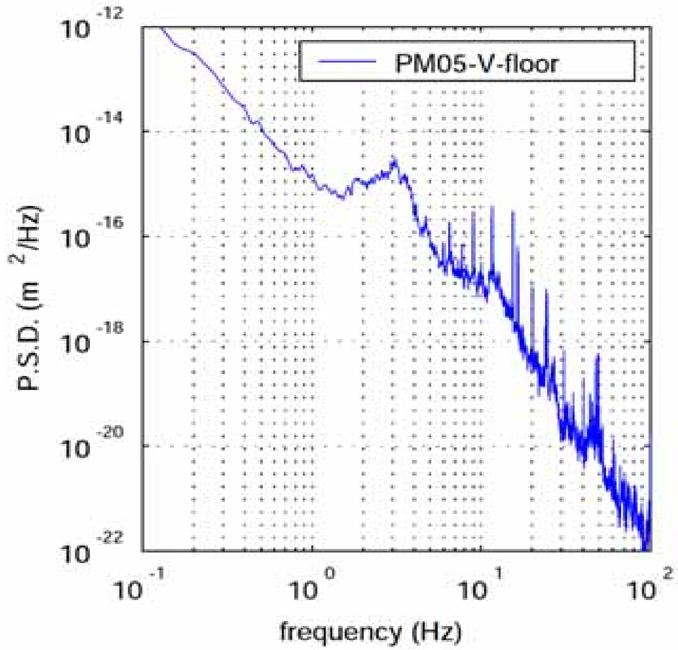
(Model-B)



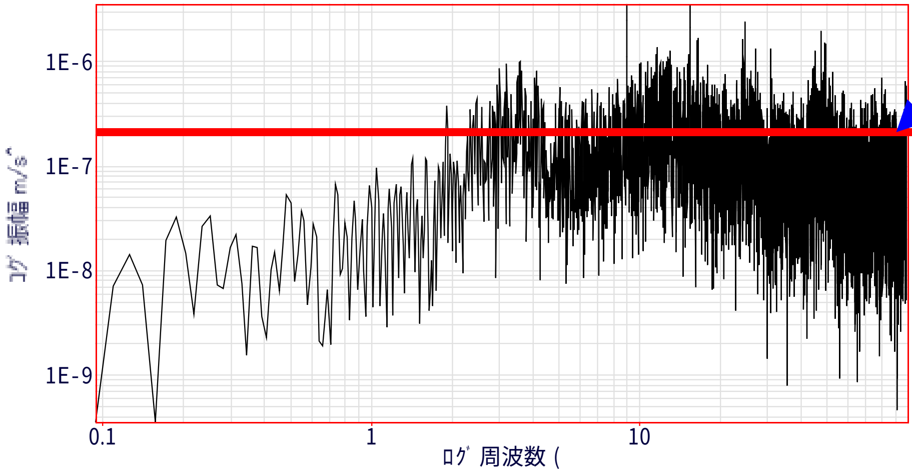
Estimation of Input Acc.

Data: Vertical @ATF(17:00 Feb. 10, 2004)





Linear Spectrum



$2x10^{-7}m/s^2$

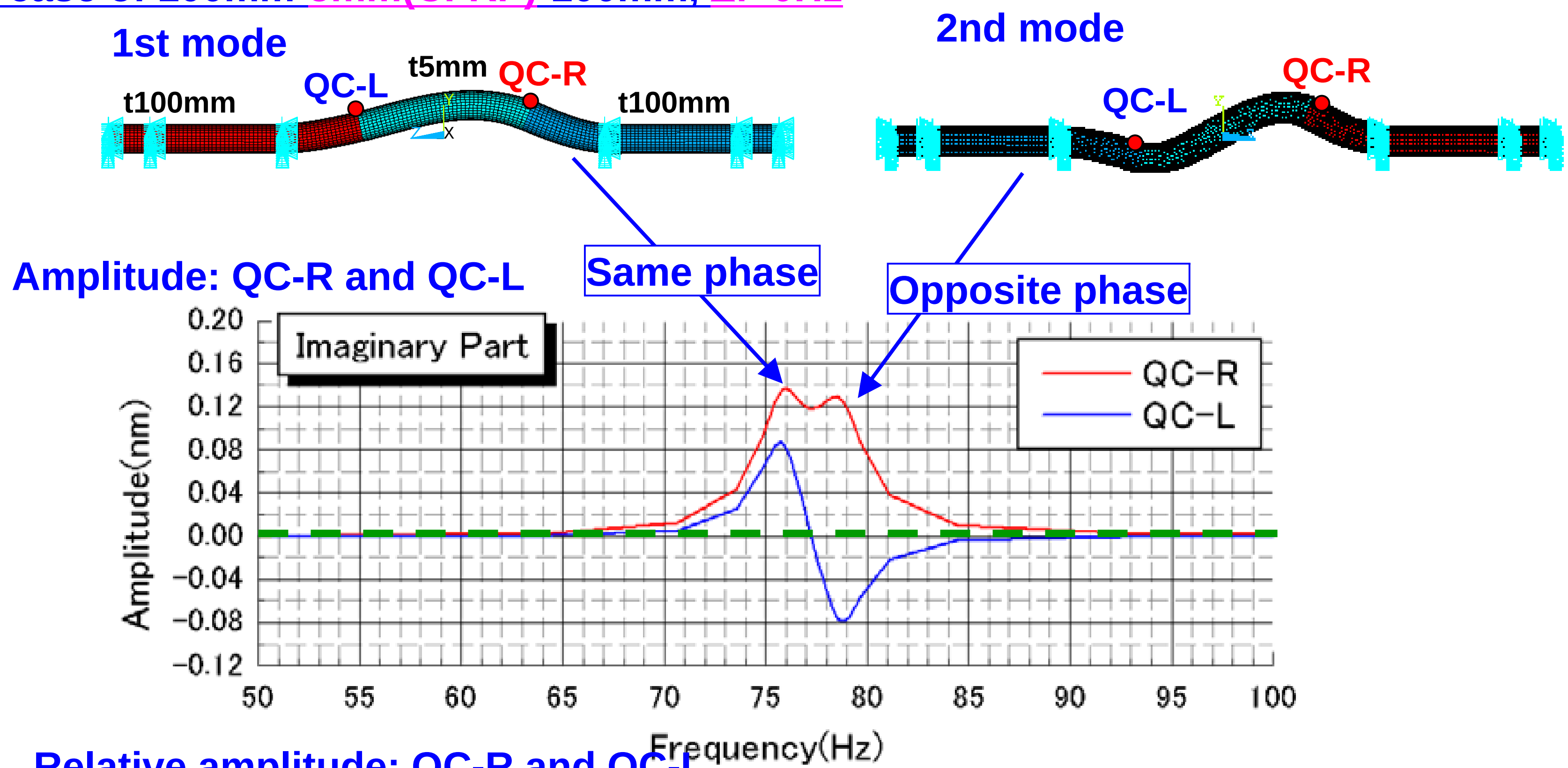
Input data

Input Acc. = $2x10^{-7}m/s^2$
Mass=90tons/9.8[m/s^2]

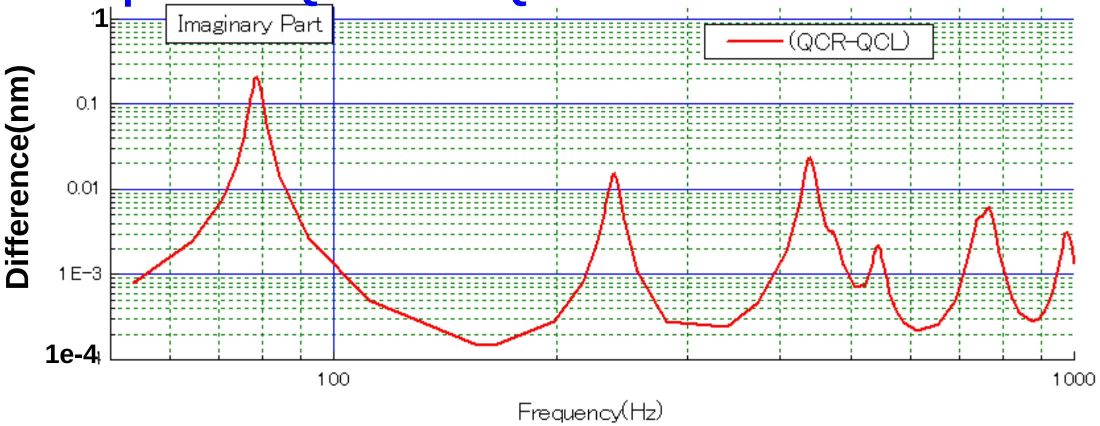
Self weight

Relative amplitude between QC-R and QC-L

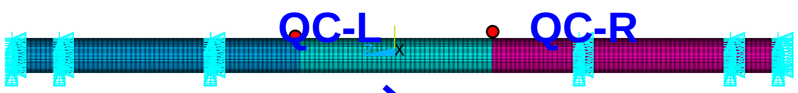
In case of 100mm-5mm(CFRP)-100mm, Δf=0Hz

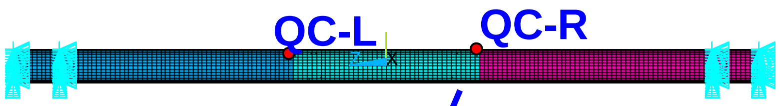


Relative amplitude: QC-R and QC-L



Other calculations



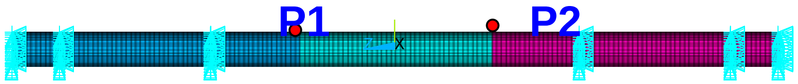


			3-Point fixed(Both end+3.85m)				2-Point fixed(Both end)			
			CFRP			Tungsten	CFRP			Tungsten
Δf	Mode		3mm	5mm	10mm	100mm	3mm	5mm	10mm	100mm
0Hz	1st	Freq.(Hz)	75.8	76.0	76.0	49.2	17.583	17.7	17.9	16.3
		Diff.(nm)	0.098	0.055	0.016	9.09E-05	0.065	0.026	0.008	2.60E-04
	2nd	Freq.(Hz)	77.5	78.6	81.4	113.0	20.2	21.8	25.0	44.4
		Diff.(nm)	0.213	0.206	0.192	0.080	2.816	2.398	1.763	0.325
1Hz	1st	Freq.(Hz)	75.2	75.3	75.5	49.0	17.0	17.1	17.3	16.0
		Diff.(nm)	0.129	0.080	0.035	1.10E-03	0.823	0.480	0.234	3.60E-02
	2nd	Freq.(Hz)	77.0	78.2	80.9	112.6	19.8	21.4	24.7	43.3
		Diff.(nm)	0.174	0.177	0.177	0.081	2.357	2.186	1.696	0.334
3Hz	1st	Freq.(Hz)	73.4	73.7	74.2	48.5	15.6	15.9	16.3	15.3
		Diff.(nm)	0.173	0.133	0.076	3.26E-03	2.339	1.496	0.752	1.30E-01
	2nd	Freq.(Hz)	76.9	77.8	80.4	111.9	19.5	20.9	24.1	41.0
		Diff.(nm)	0.094	0.116	0.143	0.082	1.547	1.726	1.532	0.349
5Hz	1st	Freq.(Hz)	71.5	72.0	72.7	48.1	13.9	14.4	15.1	14.4
		Diff.(nm)	0.204	0.172	0.113	5.62E-03	3.813	2.631	1.396	2.84E-01
	2nd	Freq.(Hz)	76.8	77.6	80.0	111.0	19.3	20.6	23.6	38.4
		Diff.(nm)	0.056	0.078	0.114	0.084	1.077	1.343	1.343	0.359
Canti	1st	Freq.(Hz)	75.6				17.4			
		Amp(p-p)	0.224				3.869			

Diff: Relative amplitude between QC-R and QC-L.

Results

(Model-A)



Natural frequency: 76Hz, relative amp. : 0.1nm <1nm

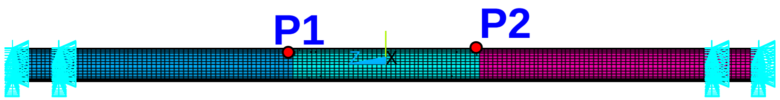
This is ideal configuration.

In case of no CFRP tube(Cantilever): Amplitude=0.2nm <1nm

CFRP tube is not necessary because of less than 1nm.

However, it is difficult to amount on a very stiff base stand. So actual natural frequency must be lower than this value.

(Model-B)



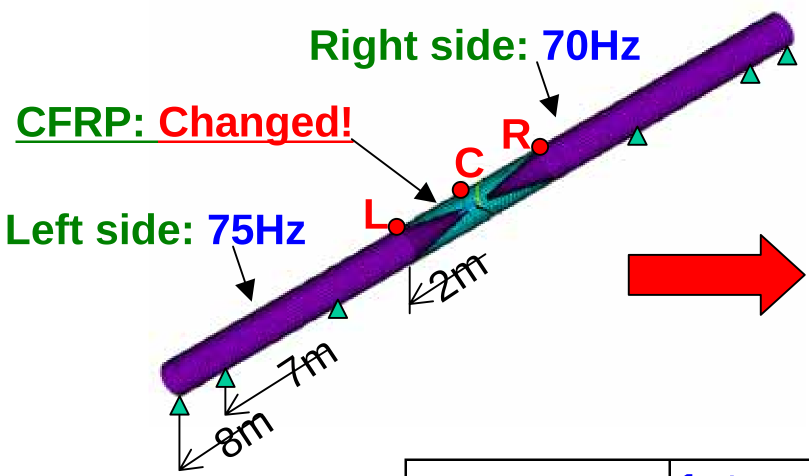
Natural frequency: 17Hz, relative amp. : 2〜3nm

In case of no CFRP tube(Cantilever): Amplitude= 4nm

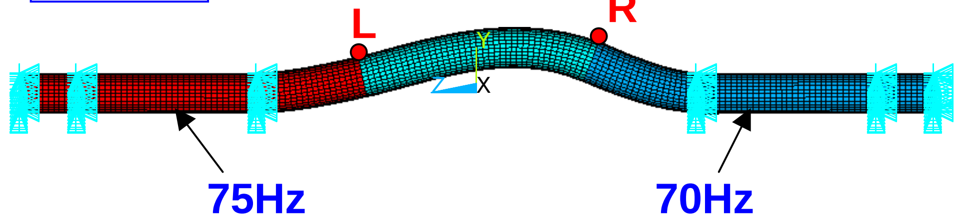
⇒ CFRP tube:

- No efficient to reduce amplitude.
- Deviation of natural frequency between two tubes can be absorbed.

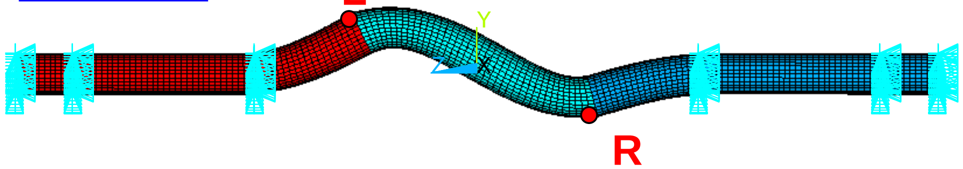
Optimization of CFRP tube thickness



1st mode



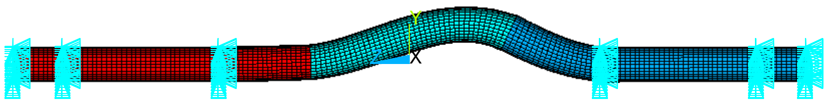
2nd mode



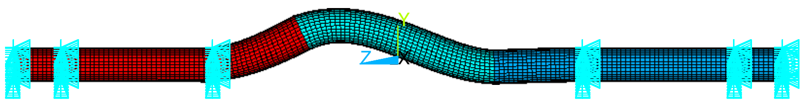
	1st mode	2nd mode
CFRP(mm)	Freq(Hz)	Freq(Hz)
20	73.6	85.2
10	72.9	80.1
5	75.5	78.4
3	72.0	76.5
1	71.5	75.7

Less than this thickness, correlation and opposite phase doesn't appear at 2nd mode.

1st mode(CFRP: 1mm)

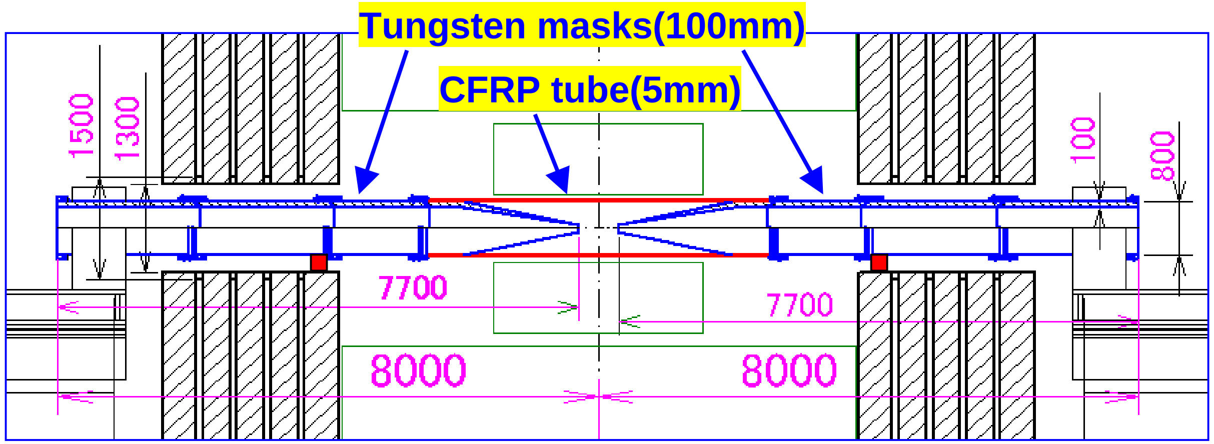


2nd mode



At least, thickness of CFRP: >3mm

Conclusion



<u>Configuration of support system</u>

・Both-ends supported structure with CFRP tube connection

→ Correlation is given to both-sides tubes in oscillating behavior.
Tungsten tube: 100mm thick, CFRP: 5mm thick
Support position: Both ends and 3.85m from I.P.

・Active vibration isolation system is necessary

→ Relative amplitude will be above 1nm. CFRP tube is not efficient to reduce amplitude less than 1nm.

・It is necessary to design the stiff support base as possible

→ Natural frequency becomes high.

→ Amplitude is decreased proportional to frequency.

Stiffness(CFRP tube)

- Natural frequency

$$f_i = \frac{\lambda_i^2}{2\pi} \cdot \frac{1}{l^2} \sqrt{\frac{EI}{\rho A}}$$

- Deformation

$$\omega = \frac{pl^3}{\alpha \cdot EI}$$

EI: Bending stiffness

E: Young's modulus

I : Moment of Inertia

$$I = \frac{\pi \cdot \left(d_O^4 - d_I^4\right)}{64}$$

CFRP tube(t=5mm)

E=150GPa

$I = \pi \cdot (d_1^4 - d_2^4)/64$

$= \pi \cdot (800^4 - 790^4)/64$

$= 9.9 \times 10^8 mm^4$

Tungsten(t=100mm)

E=415GPa

$I = \pi \cdot (d_1^4 - d_2^4)/64$

$= \pi \cdot (800^4 - 600^4)/64$

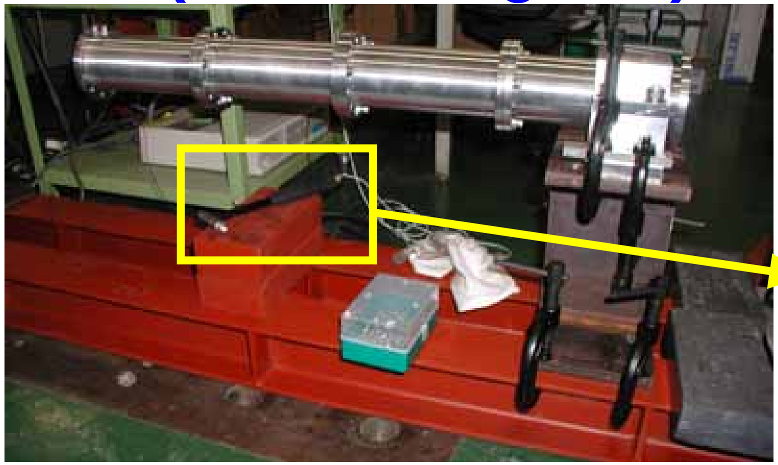
$= 1.4 \times 10^{10} mm^4$

Ratio = CFRP:Tungsten = 1 : 39

CFRP Tube

→Not efficient to increase natural frequency and decrease amplitude.

○ Tests(Hammering test)

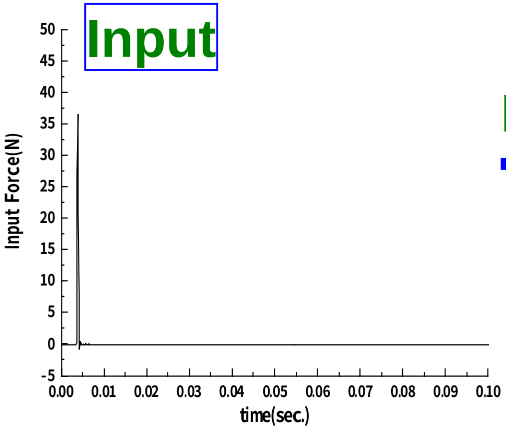


FRF(Frequency Response Function)

$$H_{ij}(f) = \frac{X_i(f)}{F_j(f)}$$

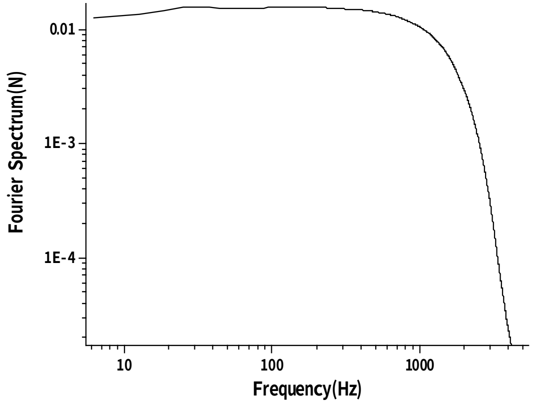
X_i: Output Acc.
F_j: Input force

Input

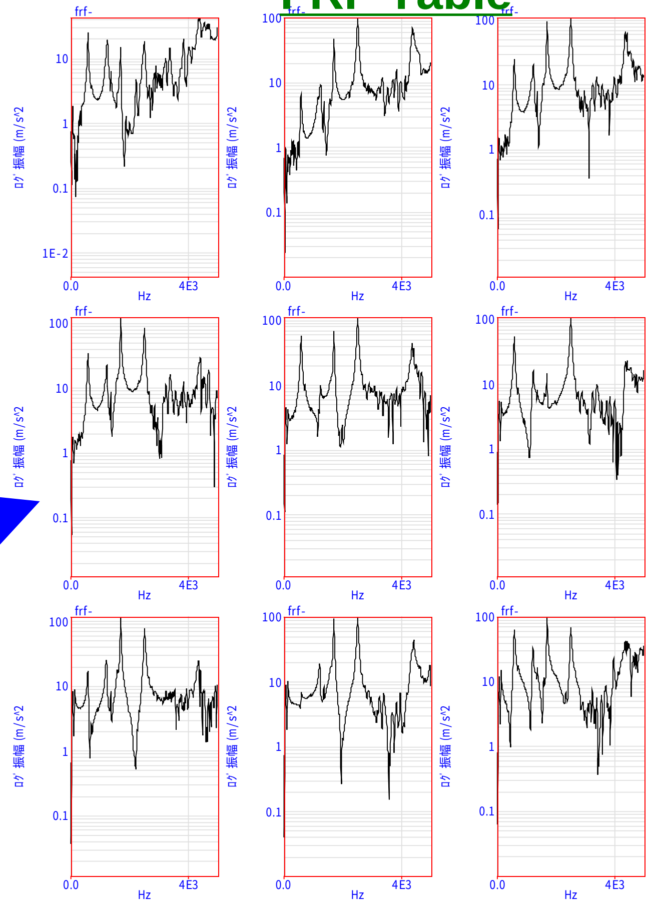


FFT

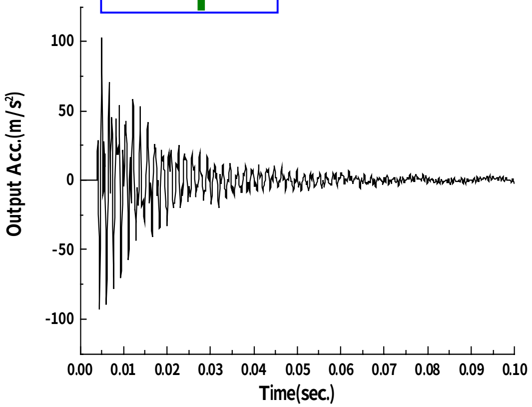
Input



FRF Table

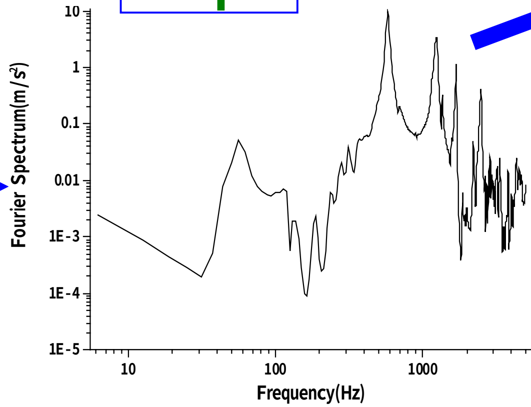


Output



FFT

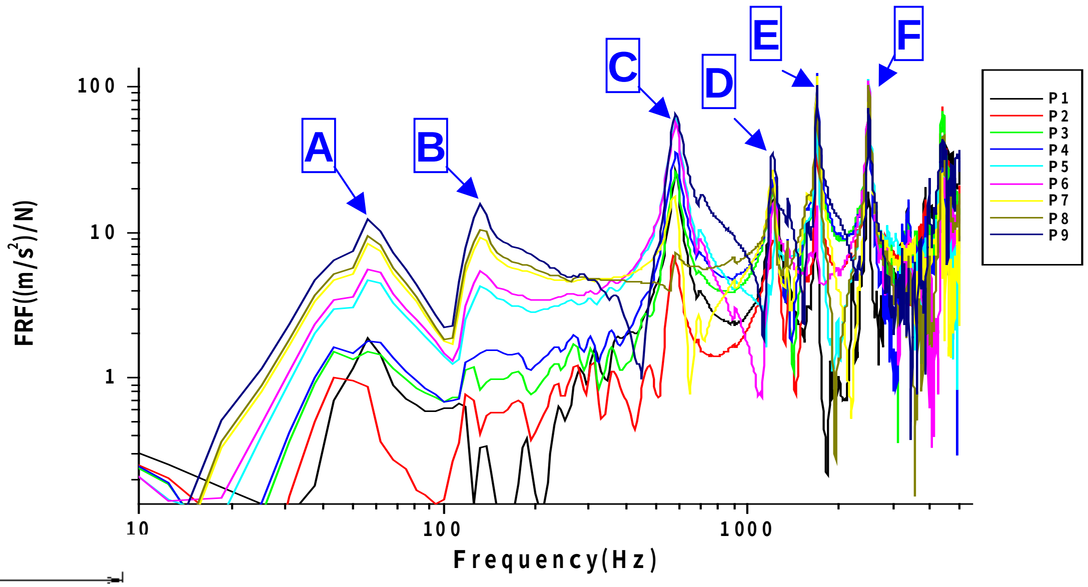
Output

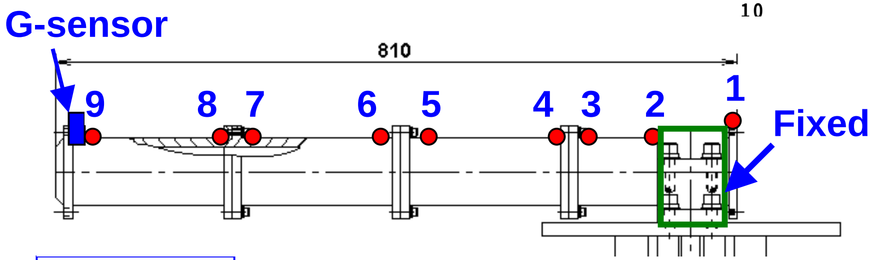


FRF

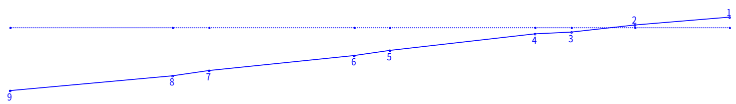
○ Results

(Taper flange, 12-M6)

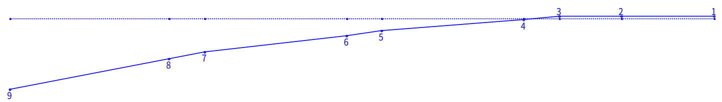




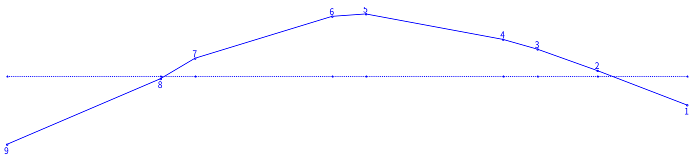
A: 57Hz



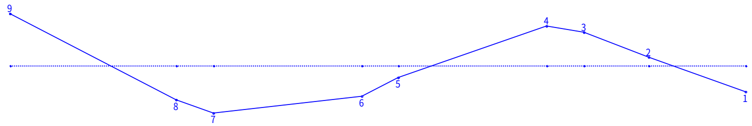
B: 129Hz



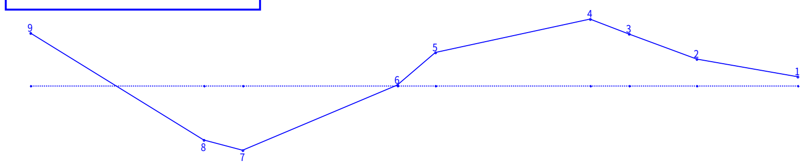
C: 585Hz



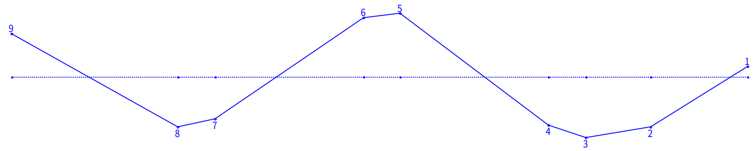
D: 1216Hz



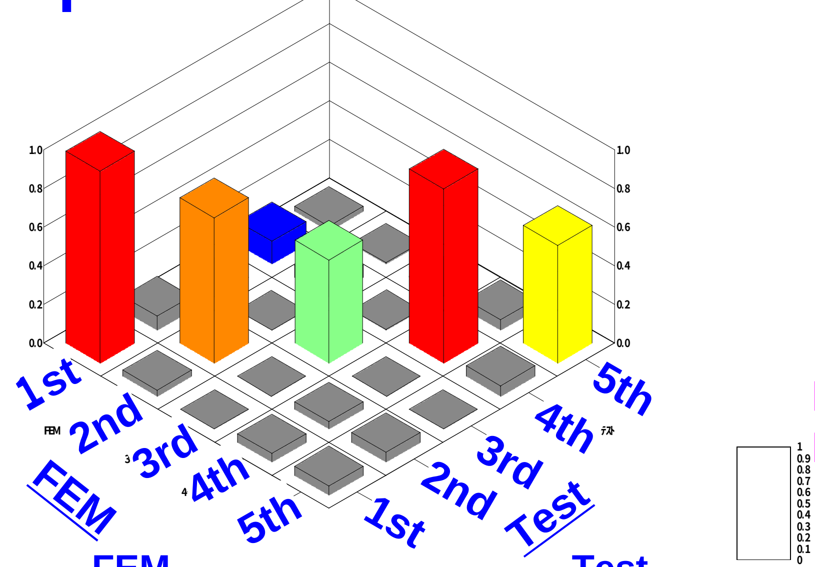
E: 1690Hz

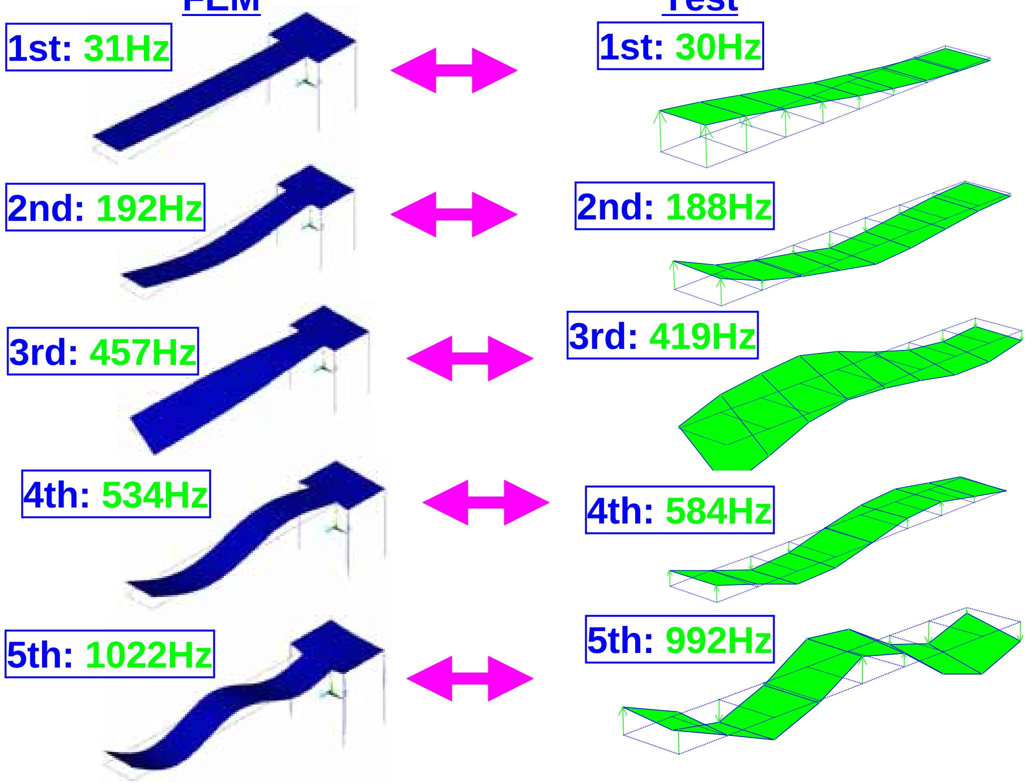


F: 2500Hz



Comparison with FEM





MAC(Modal Assurance Criteria)

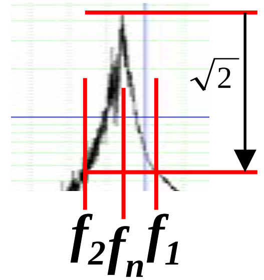
$$MAC_{rr'} = \frac{\left|\{\psi_r^{test}\}\{\psi_{r'}^{FE}\}^*\right|^2}{\left(\{\psi_r^{test}\}\{\psi_r^{test}\}^*\right)\left(\{\psi_{r'}^{FE}\}\{\psi_{r'}^{FE}\}^*\right)}$$

Modal assurance criteria quantitatively compare all the possible combinations of test and analysis mode shape pairs.

MAC=1: Mode shape pairs is exactly match

MAC=0: pairs that are completely independent

Damping ratio

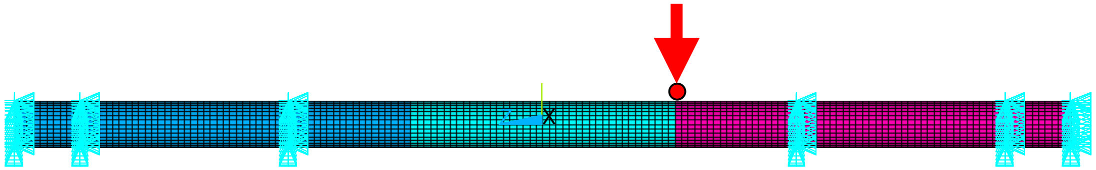


$$\zeta = \frac{f_1 - f_2}{2 \times f_n}$$

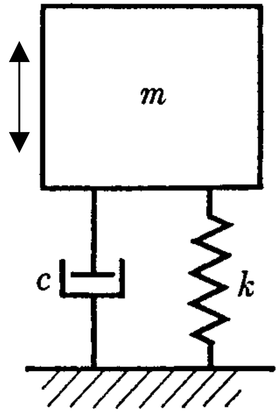
Mode	Freq.	Damping(%)
1	30.4Hz	1.68
2	188Hz	0.422
3	419Hz	0.303
4	584Hz	0.113
5	992Hz	8.02E-2

Harmonic analysis

$F_0\sin(\omega t)=(m\cdot a)\sin(\omega t)$



$F_0\sin(\omega t)$

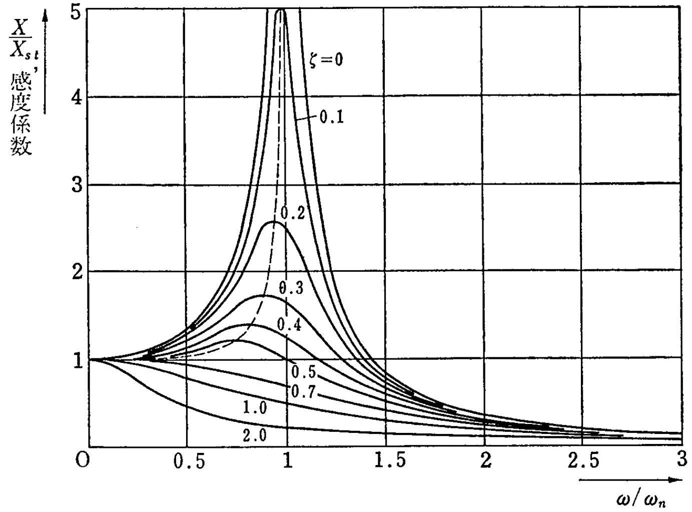


$F_0\sin(\omega t)$: Excitation force

ω= 0 – 1000Hz: Sweep frequency

$$m\ddot{x}+c\dot{x}+kx=F_0\sin\omega t$$

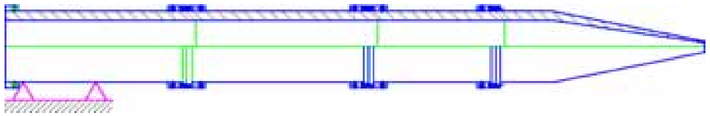
$$\frac{X}{X_{st}}=\frac{1}{\sqrt{\left\{1-(\omega/\omega_n)^2\right\}^2+(2\zeta\omega/\omega_n)^2}}$$



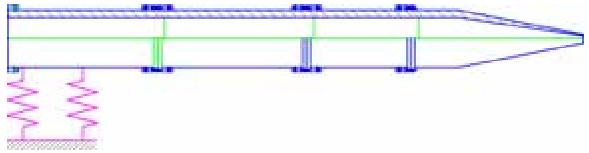
- F_0: Input force(F_0=ma)
- X: Amplitude
- X_{st}: Static deformation
- ζ: Damping ratio(2%)
- ω_n: Resonant frequency
- ω: Frequency

If $\omega=\omega_n$, X/X_{st}=25

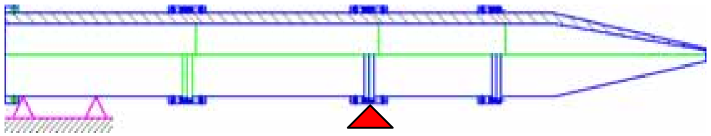
(Model-1A)



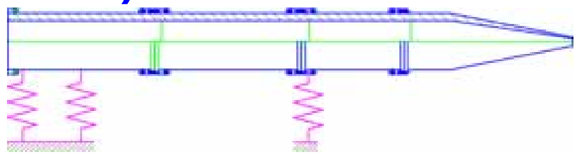
(Model-1B)



(Model-2A)



(Model-2B)



		Model-1A	Model1-B	Model-2A	Model-2B
Deformation(mm)		1.6	-	0.09	-
Stress(MPa)		23	-	5	-
Natural frequency(Hz) (Vertical)	1st mode	17	15	71	15
	2nd Mode	81	38	179	54
	3rd mode	173	105	202	93
Harmonic response(nm) @QC1		8.0	8.0	0.2	6.0
Spectrum analysis(nm) @QC1	1st mode	6.5	2.0	4.3	2.7
	2nd Mode	-1.7	1.1	0.2	0.2
	3rd mode	-0.4	0.1	1.9	0.002

現実に考えられる固有振動数のずれについて

$$f_i = \frac{\lambda_i^2}{2\pi} \cdot \frac{1}{l^2} \sqrt{\frac{EI}{\rho A}}$$

$$I = \frac{\pi \cdot \left(d_O^4 - d_I^4\right)}{64}$$

Young's modulusの違い

Aluminumの場合種類によって
6.9GPa – 7.3GPaの範囲がある。
→ f_i: 3% different
If 70Hz: 2Hz, 17Hz: 16.5Hz

寸法の誤差

寸法が多少ずれても断面2次モーメント（I）に大きな差は生まれない。
また、寸法を管理することができることから「寸法の誤差」による固有振動数のずれは小さいと考えられる。

組み立て及び設置誤差によるずれ

ネジ締めのトルク管理、寸法測定等で管理できるが完全にはできない。
３%以内の誤差にできるのではないだろうか。（根拠はすこしあいまい）

全体では5%ぐらいに抑えられるかもしれない。
→ どのくらいの誤差に収められるか試験。