Orbit Fluctuation of Electron Beam due to Vibration of Vacuum Chamber in Quadrupole Magnets

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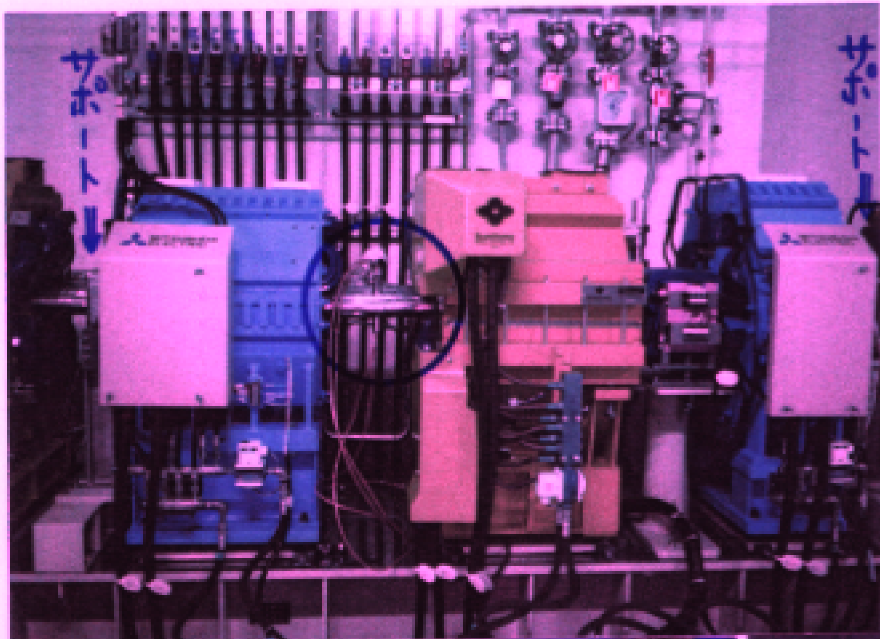
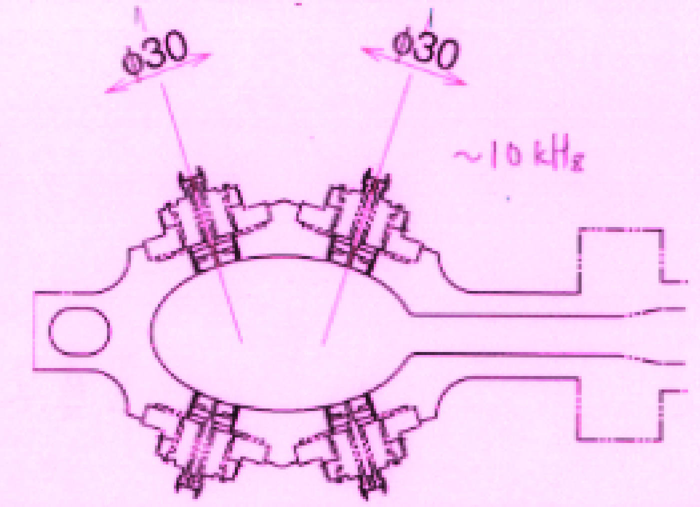
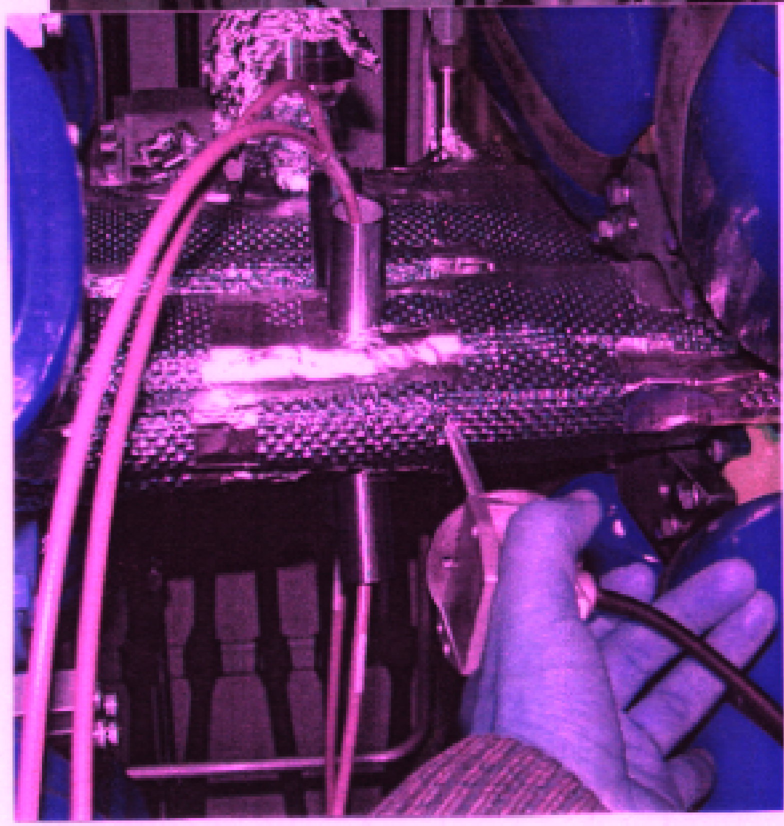
JASRI/SPring8

1. Orbit fluctuation
2. Survey of vibration source
3. Vibration Measurement of Vacuum Chamber
4. Induced magnetic field in the chamber
5. Fluctuation Comparison between calc and measured.
6. Vibration Coherency of chamber

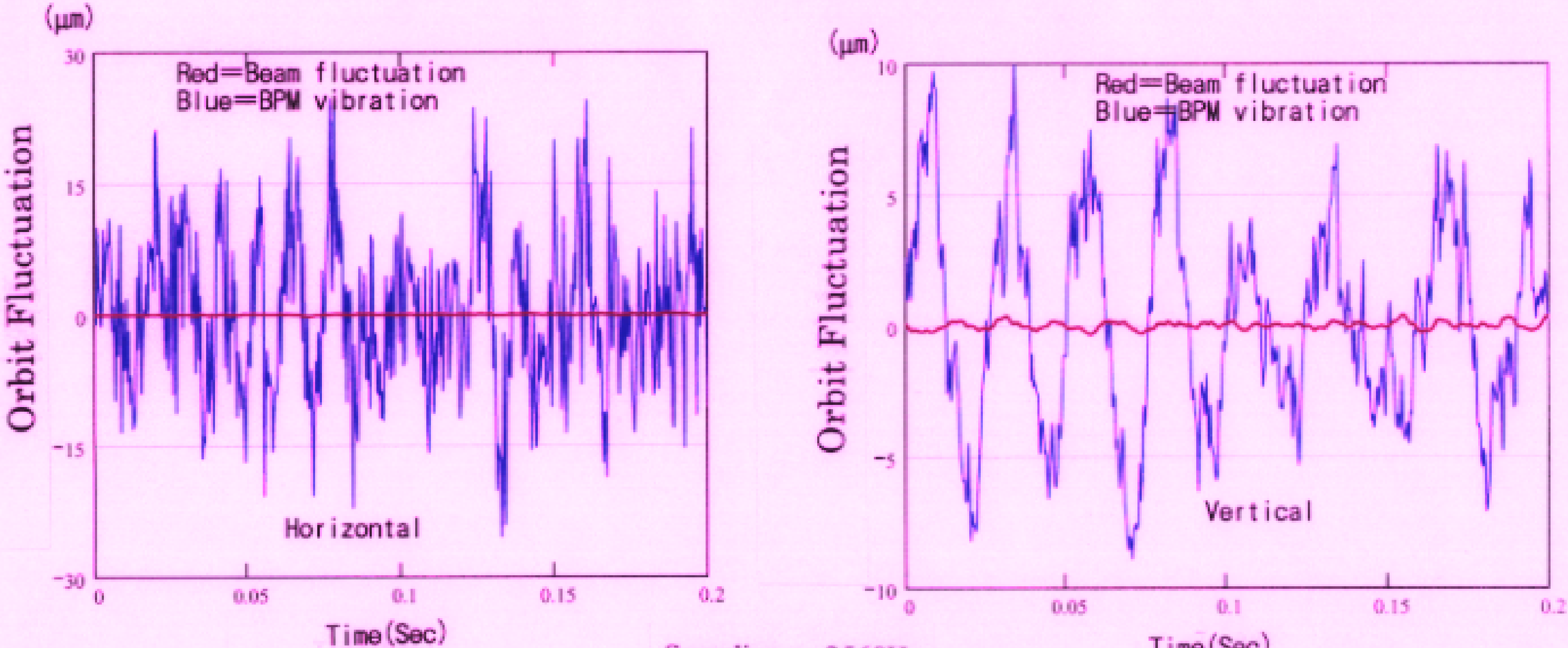

サポート
サポート


φ30
φ30
~10 kHz



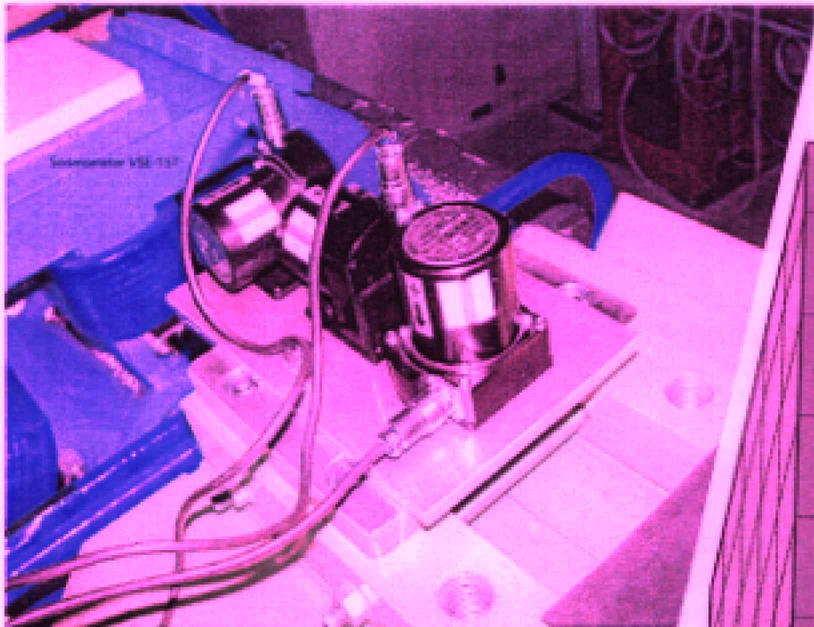

センサー
電源
LF-10
プリンター
加速度センサー
LS-10C
ADC,FFT

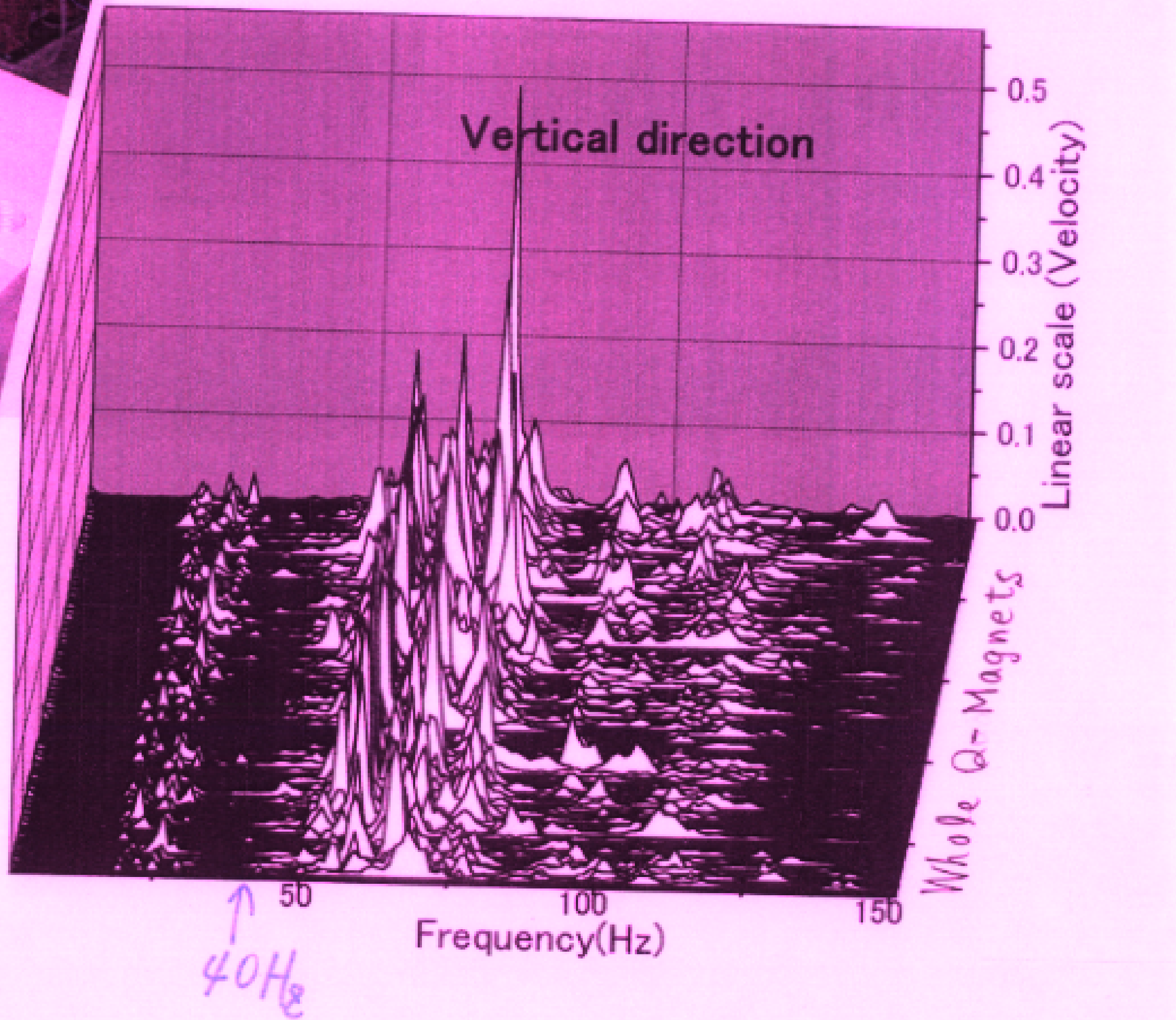
Orbit fluctuation



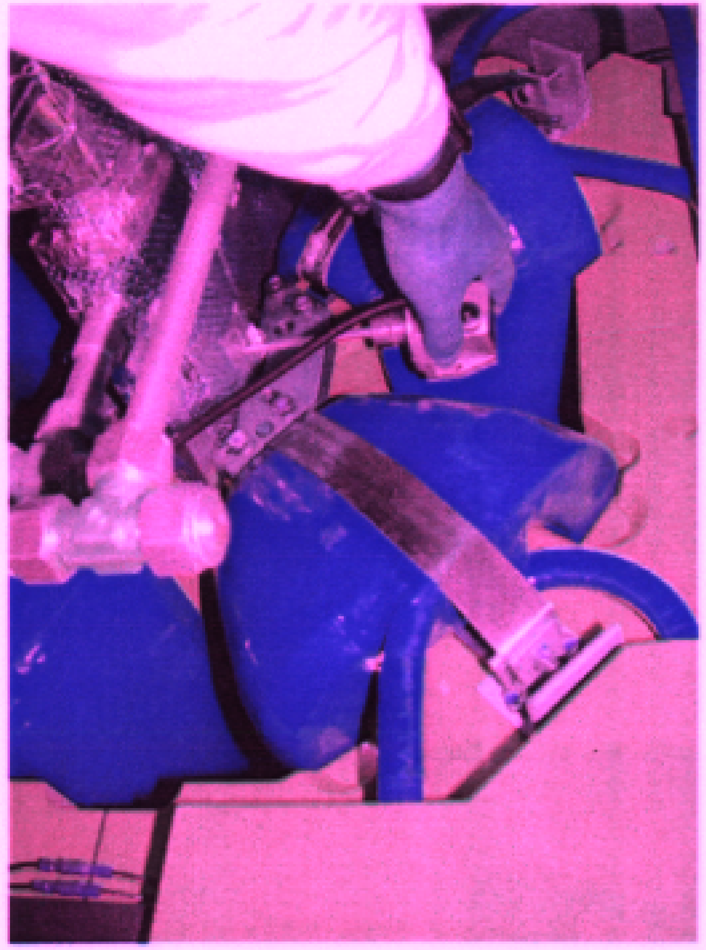
Sampling := 2560Hz

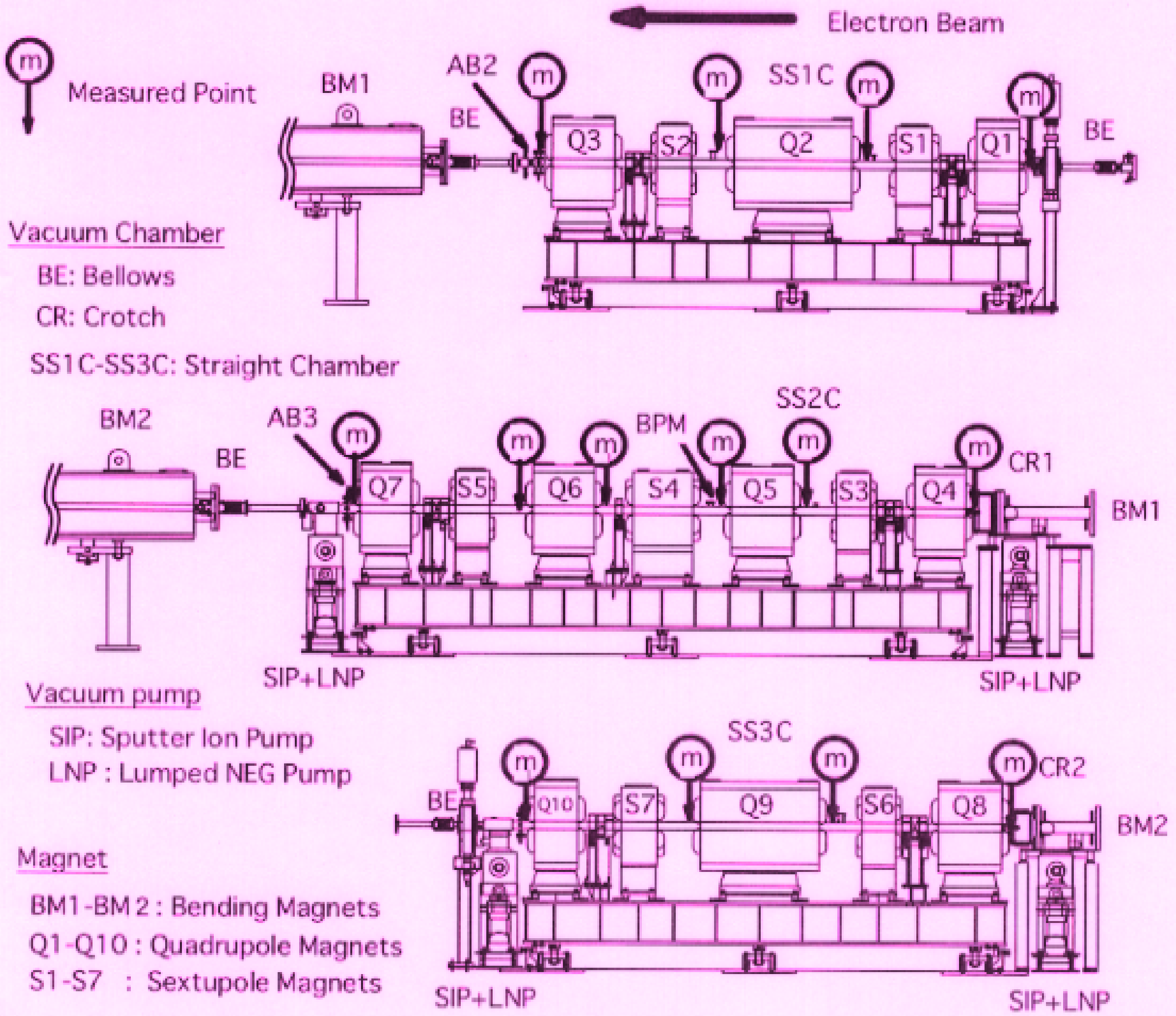
Before Improvement



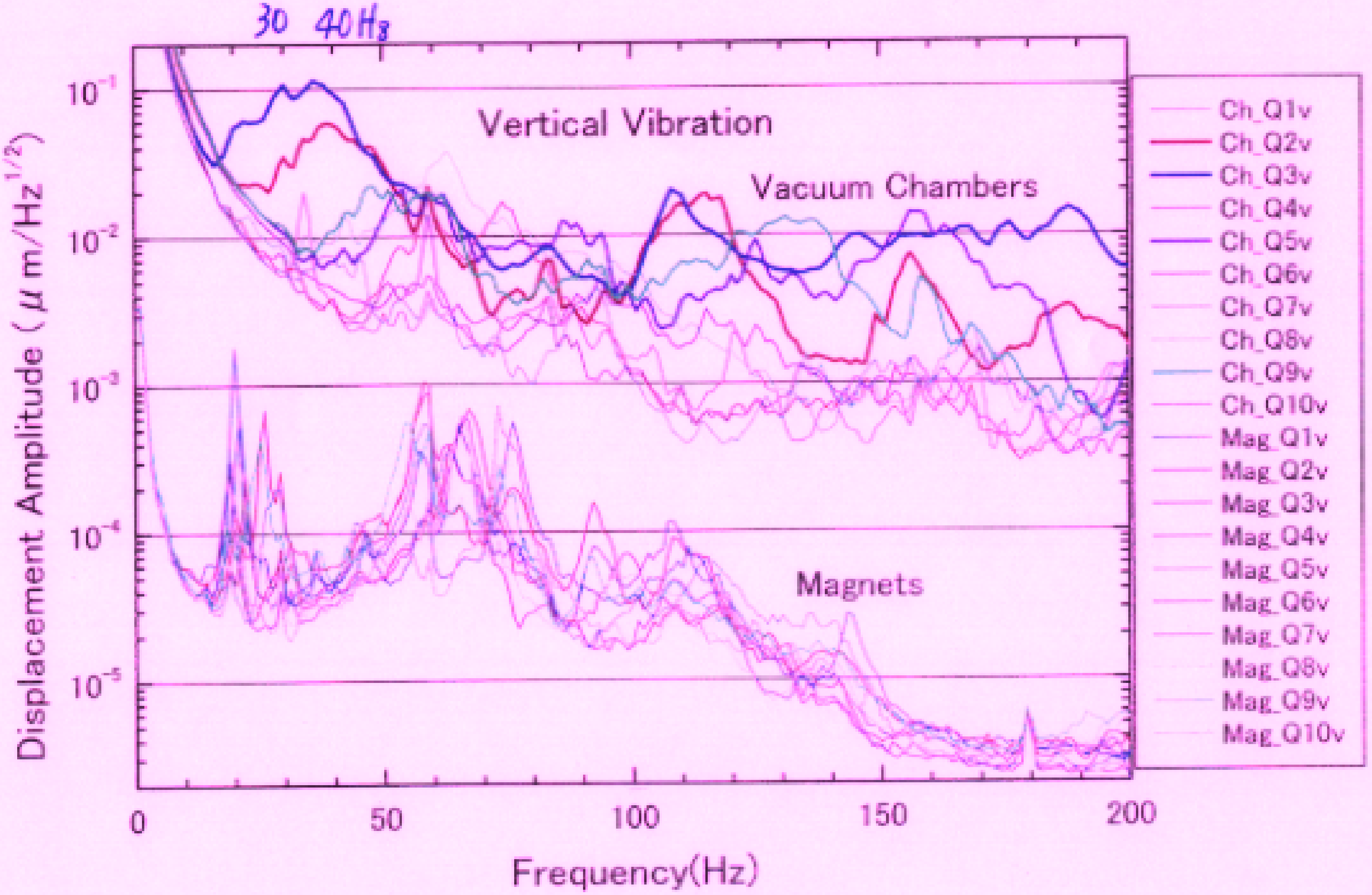


On the Quadrupole Magnets

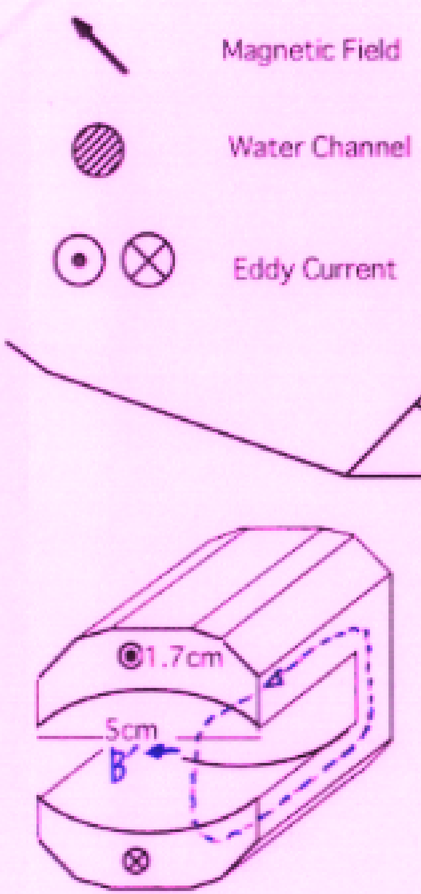




Electron Beam
m
Measured Point
BM1
BE
AB2
SS1C
Q3
S2
Q2
S1
Q1
BE
Vacuum Chamber
BE: Bellows
CR: Crotch
SS1C-SS3C: Straight Chamber
BM2
BE
AB3
BPM
SS2C
Q7
S5
Q6
S4
Q5
S3
Q4
CR1
BM1
SIP+LNP
SIP+LNP
Vacuum pump
SIP: Sputter Ion Pump
LNP : Lumped NEG Pump
SS3C
BE
Q10
S7
Q9
S6
Q8
CR2
BM2
Magnet
BM1-BM 2 : Bending Magnets
Q1-Q10 : Quadrupole Magnets
S1-S7 : Sextupole Magnets
SIP+LNP
SIP+LNP



30 40Hz
Vertical Vibration
Vacuum Chambers
Magnets
Displacement Amplitude (μm/Hz^(1/2))
Frequency(Hz)
0
50
100
150
200
10^-1
10^-2
10^-3
10^-4
10^-5
Ch_Q1v
Ch_Q2v
Ch_Q3v
Ch_Q4v
Ch_Q5v
Ch_Q6v
Ch_Q7v
Ch_Q8v
Ch_Q9v
Ch_Q10v
Mag_Q1v
Mag_Q2v
Mag_Q3v
Mag_Q4v
Mag_Q5v
Mag_Q6v
Mag_Q7v
Mag_Q8v
Mag_Q9v
Mag_Q10v

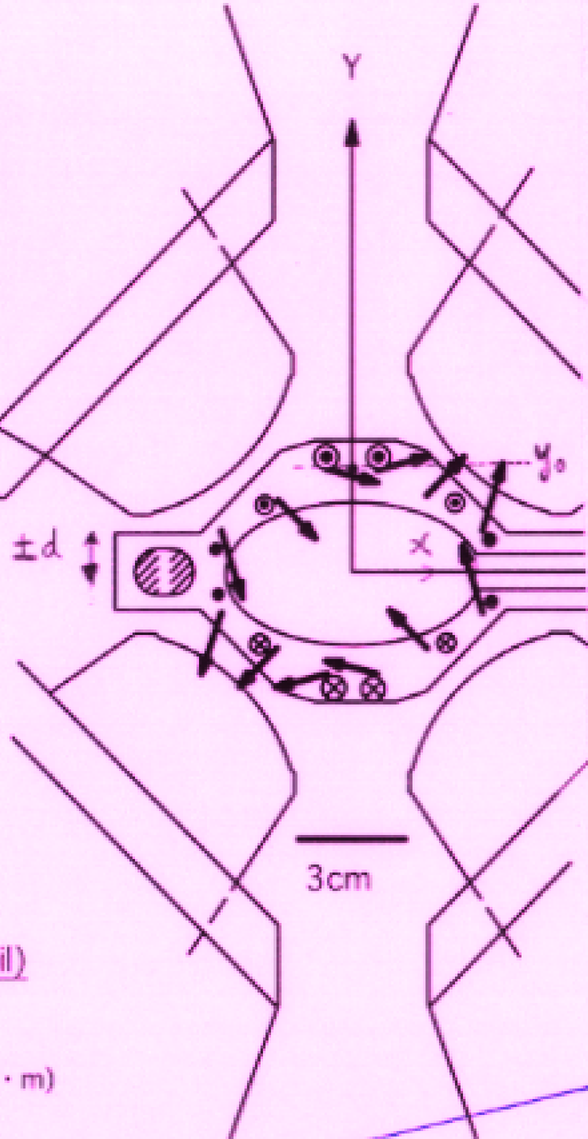


Current Loop(One turn Coil)

Cross section 5cmX1.7cm

Length 80cm

R=6.4X10-5Ω (ρ=6X10-8Ω・m)



Induced Magnetic Field

Quadrupole magnetic field B ($B_x=gy$, $B_y=gx$)

Chamber:Vetical Vibration

$y = y_0 + d\sin(\omega t)$ point (x_0, y_0)

d : displacement amplitude,

ω: angular frequency

v_y: chamber velocity

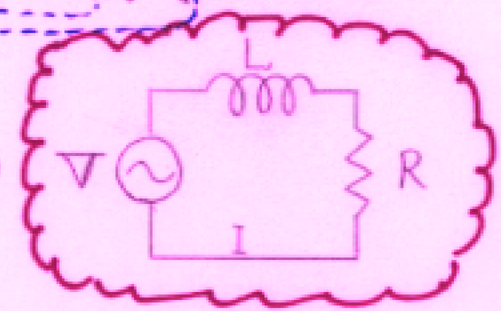
Induced electric field $E= v\times B$.

$$E_z = v_y \times B_x = gd\omega y_0 \cos(\omega t) + o(d^2)$$

One Turn Coil

l_Q : length of quadrupole magnetic field

$$V = 2\, l_Q E_z = 2\, g\, d\omega y_0\, l_Q \cos(\omega t) \qquad (1)$$



$I \equiv I_0 \sin(\omega t+\alpha)$

$$V = L\left(\frac{dI}{dt}\right) + RI$$

$$= \omega L I_0 \cos(\omega t+\alpha) + R I_0 \sin(\omega t+\alpha)$$

$$= \omega L I_0 \sqrt{1+\left(\frac{R}{\omega L}\right)^2} \sin(\omega t+\alpha+\alpha') \qquad (2)$$

B'_x : Field by induced current loop

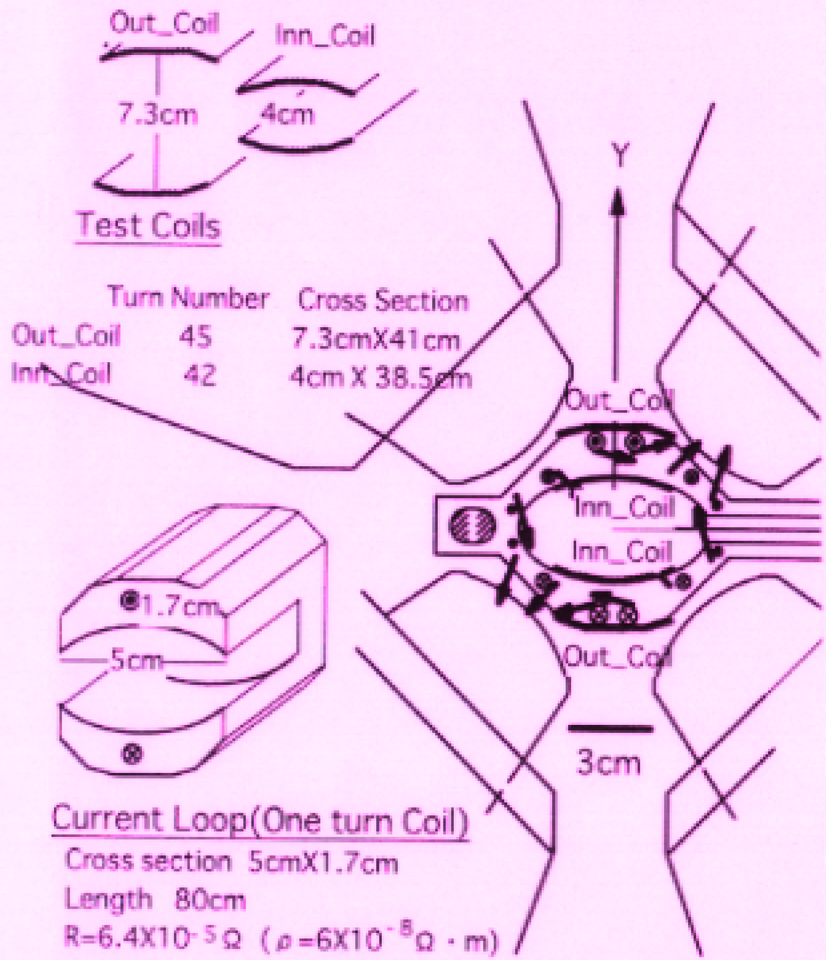
$S = 2\, y_0\, l_Q$ (S:Area of current loop)

$$B'_x S = LI$$

$$= L I_0 \sin(\omega t+\alpha) \qquad (3)$$

from eqs. (1), (2), (3)

$$B'_X = \frac{1}{\sqrt{1+\left(\frac{R}{\omega L}\right)^2}}\, gd \sin(\omega t + \alpha)$$



if $\omega L >> R$ $B'_x = gd\sin(\omega t + \alpha)$ = y

Equivalent to Q-mag Vibration

Reduction factor of Al one turn coil

$$\xi \equiv 1/\sqrt{1+(R/\omega L)^2}$$

R : 5.6×10^{-5} Ω

ρ : 6×10^{-8} Ωm

cross section: 1.7cm(Thickness)×5cm(Width)

(skin depth : 1.2cm at 100 Hz)

length:2×40cm

L : Normalized inductance(1turn·1cm²)×5.3cm×40cm

Normalized inductance

Average of two coils(depend on ω)

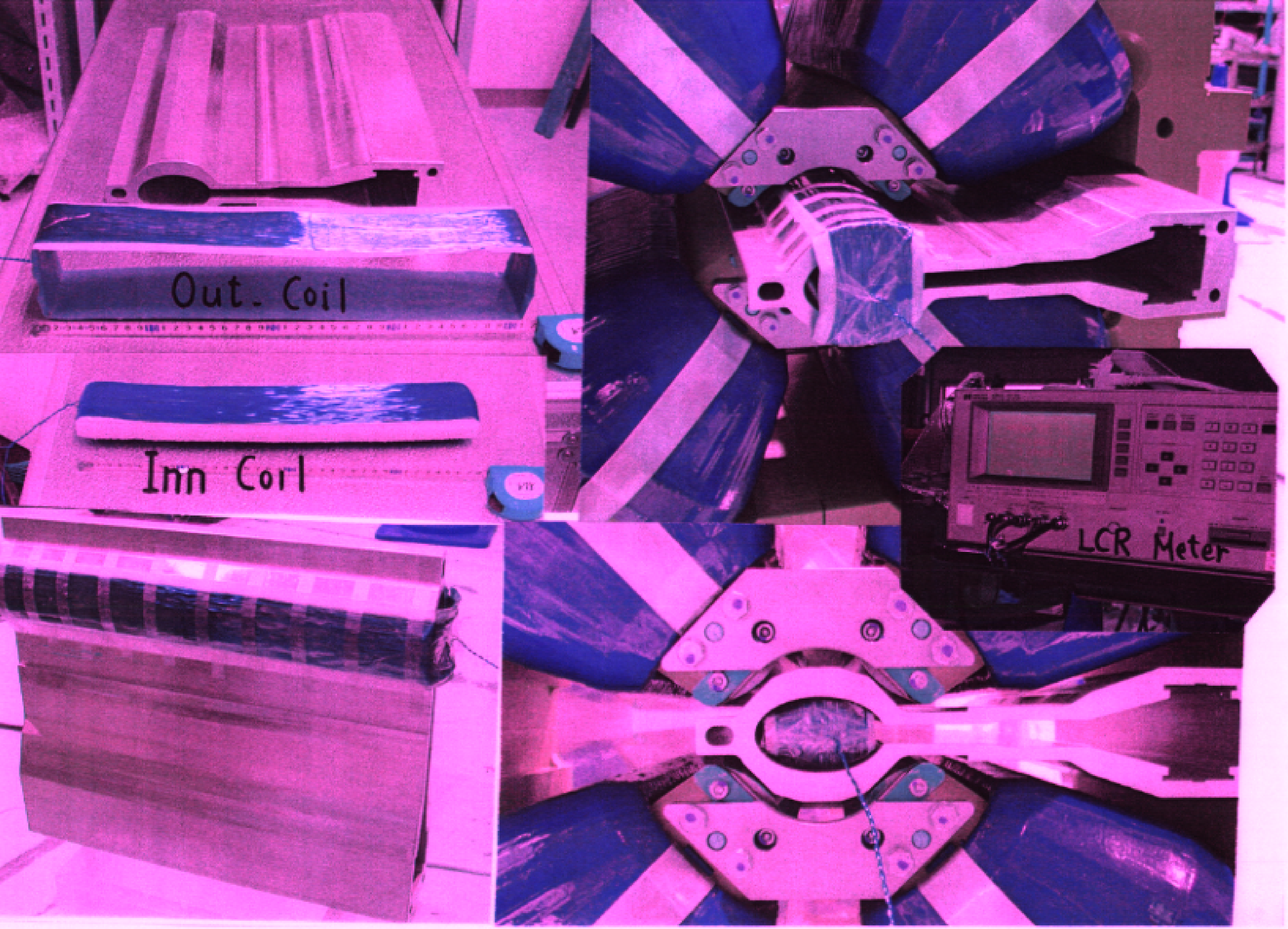
Width : 5 cm.

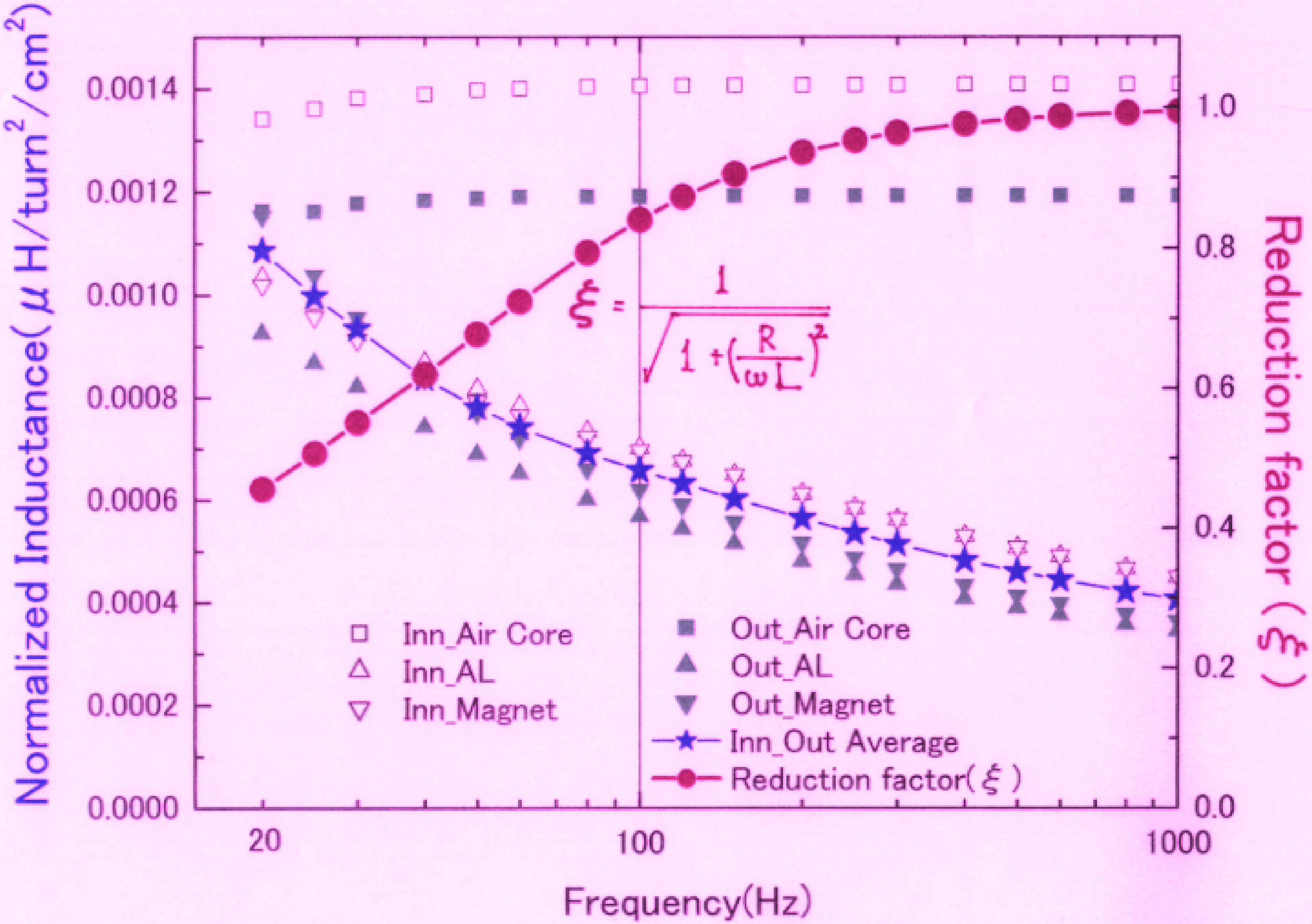
Length : 40 cm

Height:7.3cm(Out_Coil)

4 cm(Inn_Coil)

LCR meter (constant AC 10mA)


Out. Coil
Inn Coil
LCR Meter



Normalized Inductance(μ H/turn²/cm²)
Reduction factor (ξ)
Frequency(Hz)
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
0.0012
0.0014
0.0
0.2
0.4
0.6
0.8
1.0
20
100
1000
ξ = 1 / √(1 + (R/ωL)²)
Inn_Air Core
Inn_AL
Inn_Magnet
Out_Air Core
Out_AL
Out_Magnet
Inn_Out Average
Reduction factor(ξ)

Kick angle

$$\theta(\text{rad}) = 0.3B' l_m / p$$

l_m(m):Effective length
B'(T): Magnetic field
p(GeV/c): Electron momentum

Closed orbit distortion

$$y_c(s) = \sum_k \frac{\sqrt{\beta(s)\beta(s_k)}}{2\sin(\pi\nu)} \theta(s_k)\cos(\pi\nu - |\phi(s) - \phi(s_k)|)$$

s : Monitor Position

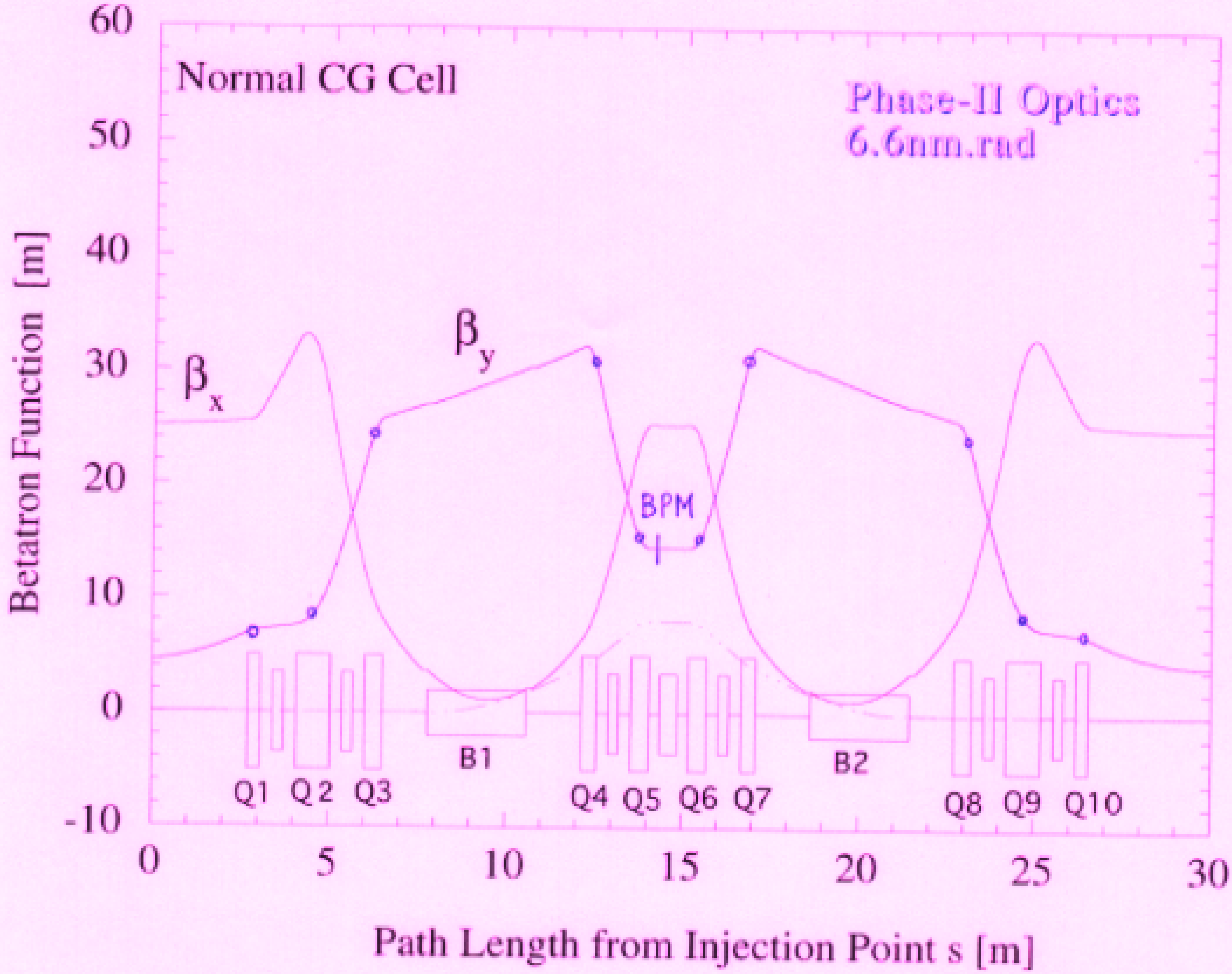
s_k : kick position

β : beta function (β(s)=15m)
θ : kick angle
ϕ : phase

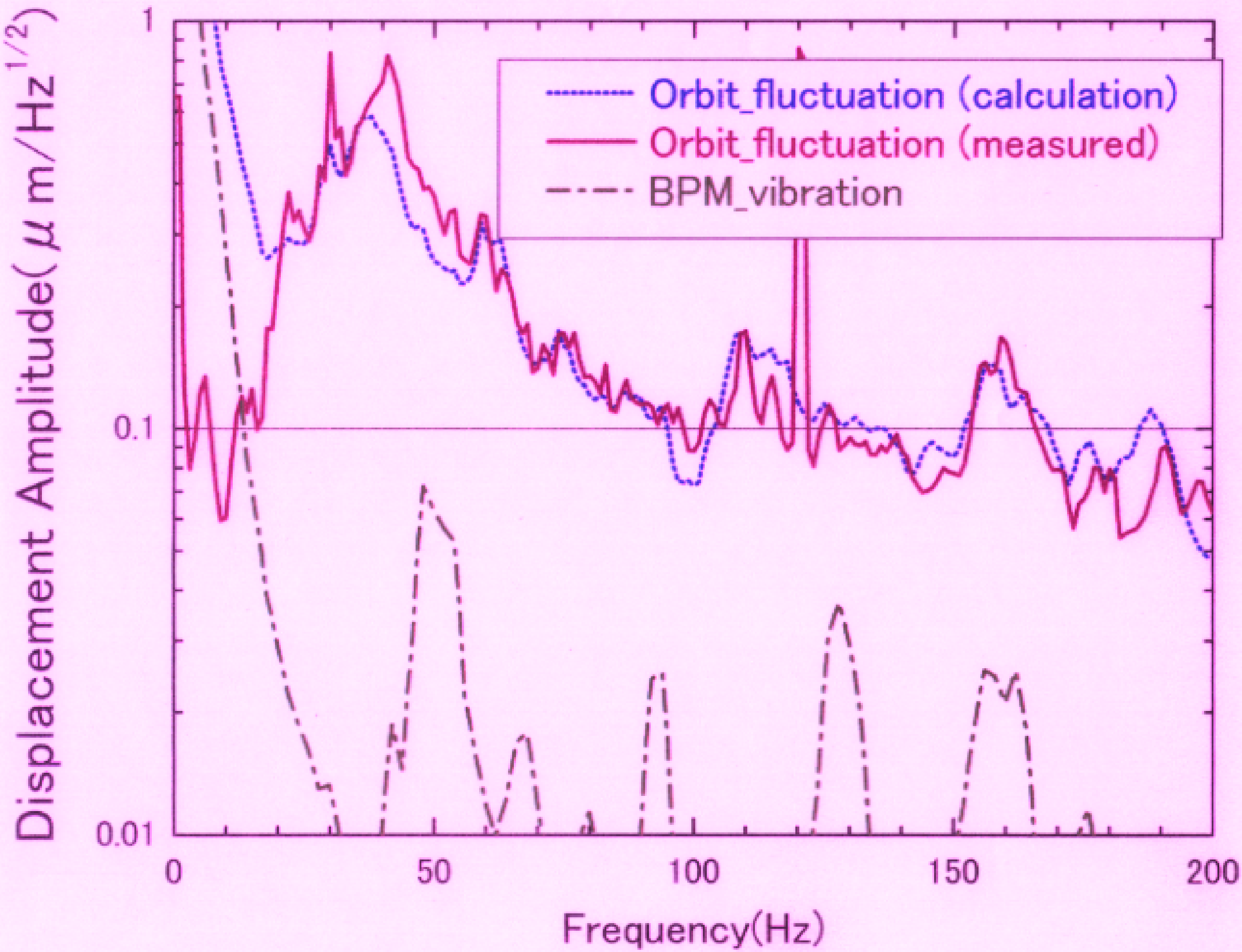
vertical tune(ν=18.36)

Assumption:Phases of the kicks = random
∴Sum : by rms (420 quadrupole magnets points)
cos()= 0.5

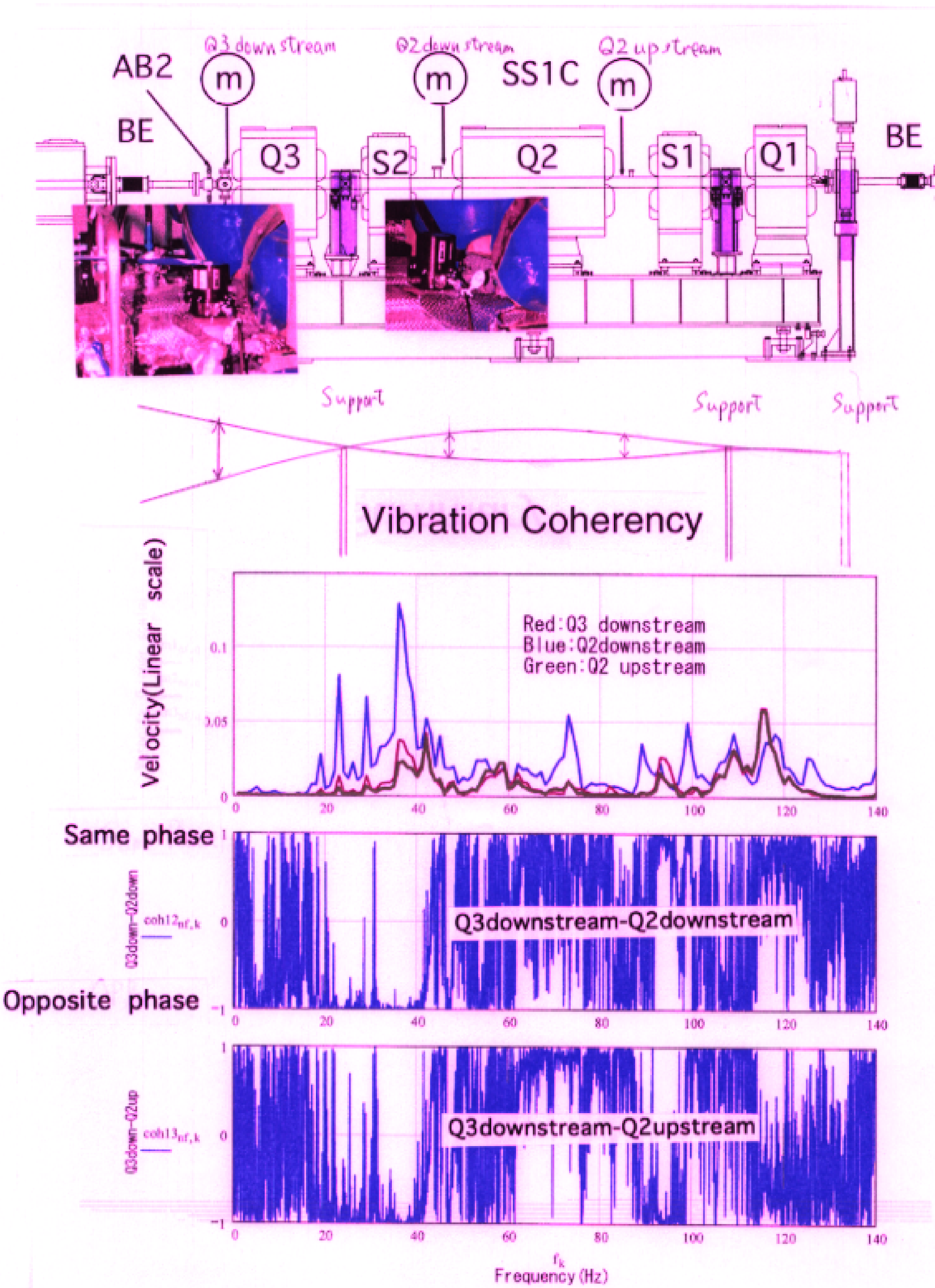
Calculated spectrum is:



	Q1v	Q2v	Q3v	Q4v	Q5v	Q6v	Q7v	Q8v	Q9v	Q10v
β (m)	7	9	25	32	15	15	32	25	9	7
Length(m)	0.35	0.97	0.51	0.41	0.51	0.51	0.41	0.51	0.97	0.35
Current(A)	221.4	324.8	377.6	512.8	530.1	530.1	512.8	377.6	324.8	221.4
Strength (T/m)	7.0	10.3	12.0	16.3	16.8	16.8	16.3	12.0	10.3	7.0
number	40	40	40	44	44	44	44	40	40	40



Orbit_fluctuation (calculation)
Orbit_fluctuation (measured)
BPM_vibration
Displacement Amplitude(μm/Hz^1/2)
1
0.1
0.01
0
50
100
150
200
Frequency(Hz)



Q3 down stream
Q2 down stream
Q2 up stream
AB2
SS1C
BE
Q3
S2
Q2
S1
Q1
BE
Support
Support
Support
Vibration Coherency
Velocity(Linear scale)
Red:Q3 downstream
Blue:Q2downstream
Green:Q2 upstream
Same phase
Opposite phase
Q3down-Q2down
Q3downstream-Q2downstream
Q3down-Q2up
Q3downstream-Q2upstream
Frequency (Hz)

Summary

1. Eddy current induced in the vibrating thick chamber in quadrupole magnets produces magnetic field, which kicks the electron beam.

2. The calculated orbit fluctuation based on this model agreed with the measured one.

3 . In the thick chamber, this field is equivalent to the vibration field of quadrupole magnet with same vibration amplitude

4 In high frequency, the chamber becomes more important relatively. Because the magnetic field is reduced by chamber.