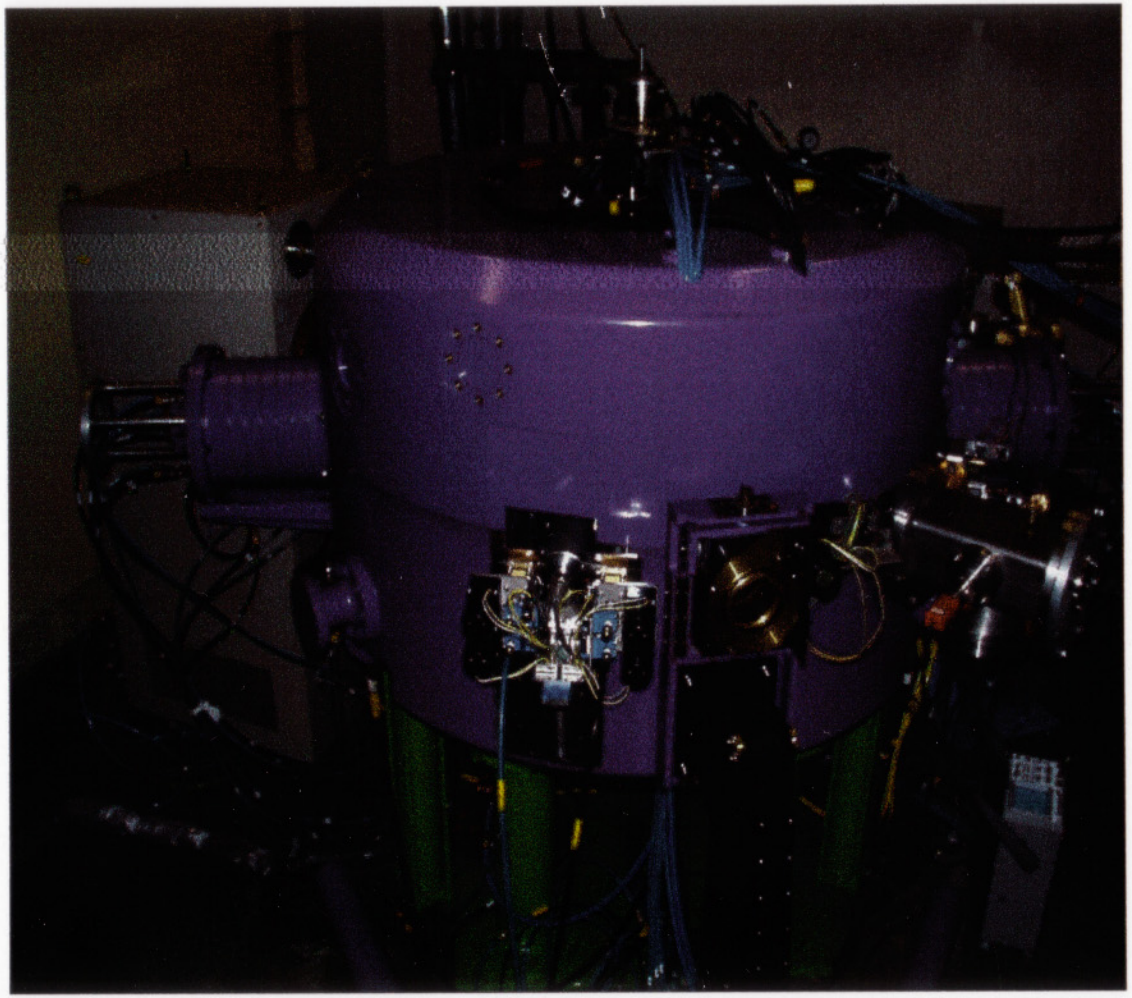
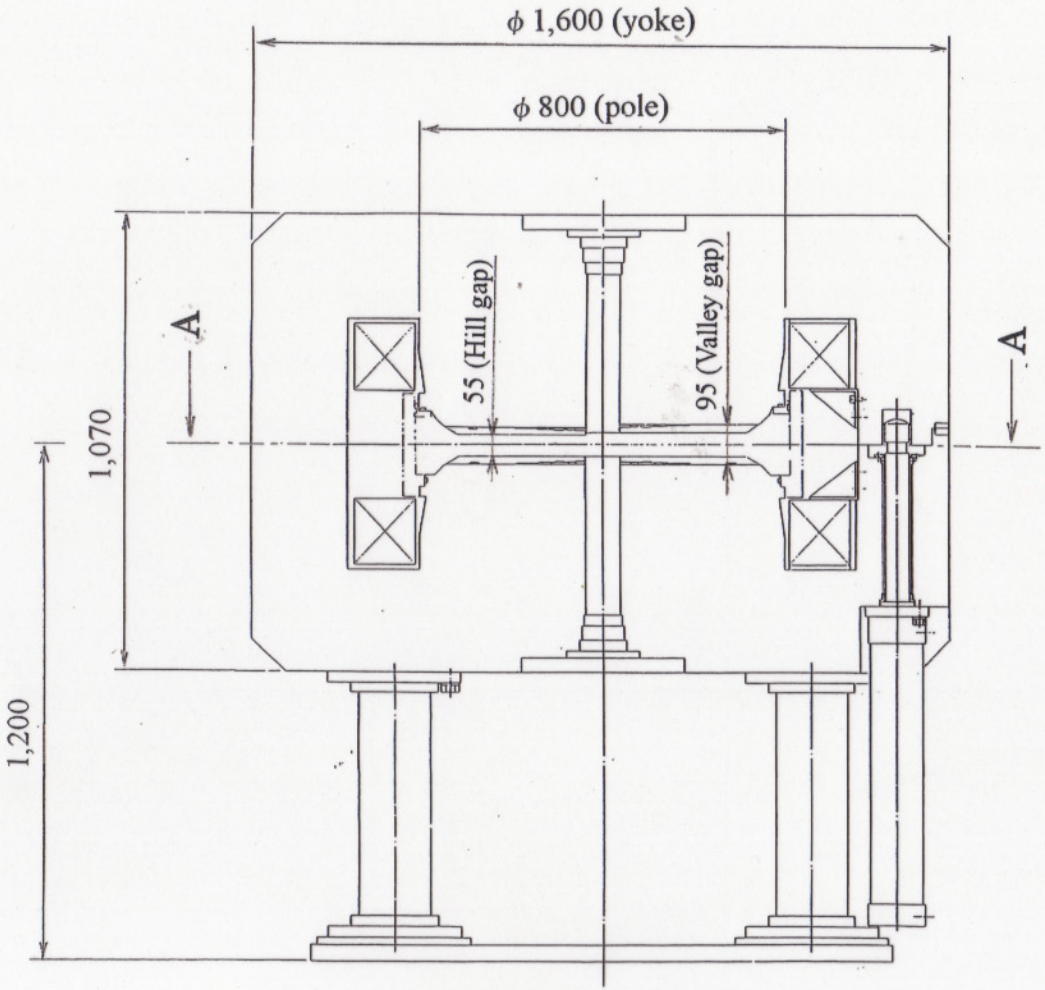
BABY CYCLOTRON as the injector of 150MeV FFAG

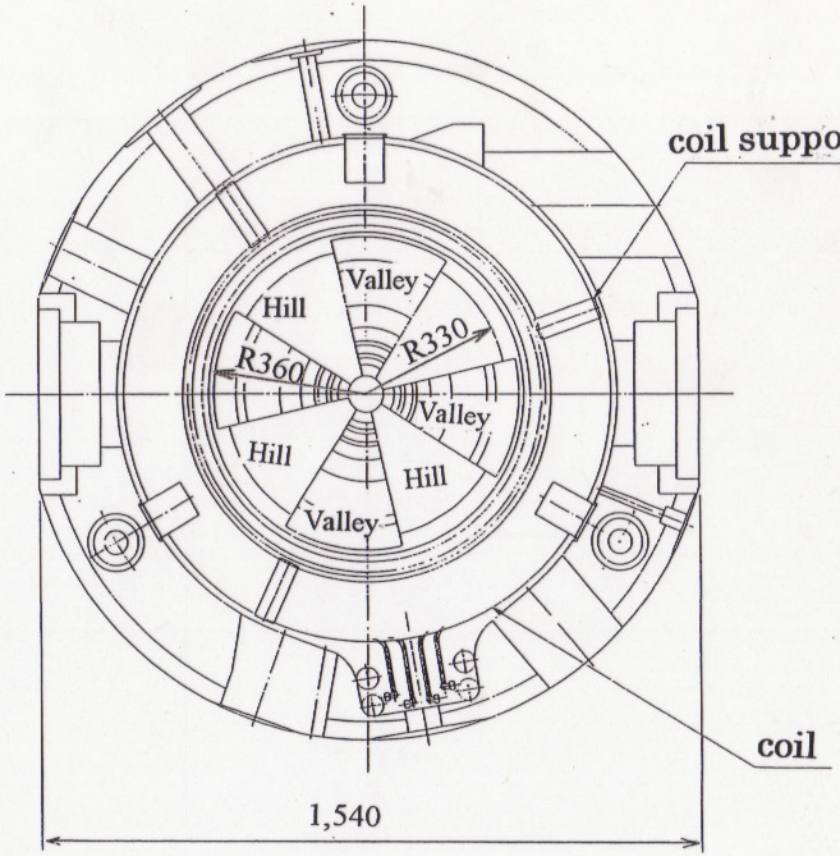


KEK/JSW YASUO SATO

Schematic view of Magnet Yoke and Pole

weight : 15 tons





A-A sectional view

Specifications of Injector Cyclotron （1）

AVF Cyclotron : 45° radial sector, Number of sectors : 4

Max. radius at Hill／gap between Hills : Max. R330mm／gap 55mm

Max. radius at Valley／gap between Valleys : Max. R360mm／gap 95mm

Dee Electrode for acceleration : angle 45° 2 −Dee Electrodes

Beam extraction radius／method : R300mm／electrostatic Deflector

Harmonic trimming coils : 2 sets, about 50gauss for a set of coils

Proton Energy	10MeV	12MeV
Magnetic Field （at R=200mm）	1.55T	1.68T
Isochronous Field at R=20mm at R=300mm	1.54T 1.56T	1.67T 1.69T
Particle revolution frequency 【acceleration harmonic number】	23.5MHz 【2nd】	25MHz 【2nd】
RF frequency	47MHz	50MHz
Betatron tune ; Horizontal νr Vertical νz	≒1 0.09～0.23	

Specifications of Injector Cyclotron （2）

RF Dee Voltage (for acceleration) : 30～40kVp

Q-value of RF cavity : around 3,000

Shunt impedance of RF cavity : about 40kΩ （47～51MHz)

RF AMP. Output power : about 20kW （CW mode)

Amplifier method : grounded grid B-class operation

Electron tube : 4 CW25,000A （final)， 4 CX3,000A （driving)

Ion source : H-／H+ PIG ion source PIG （cold cathode LaB_6)

Internal beam of H-; 50 μ A, Extracted beam of H+; 20～50 μ A

Main coil power supply : DC340A／140V, stability;$\pm 2 \times 10^{-5}$／Hr

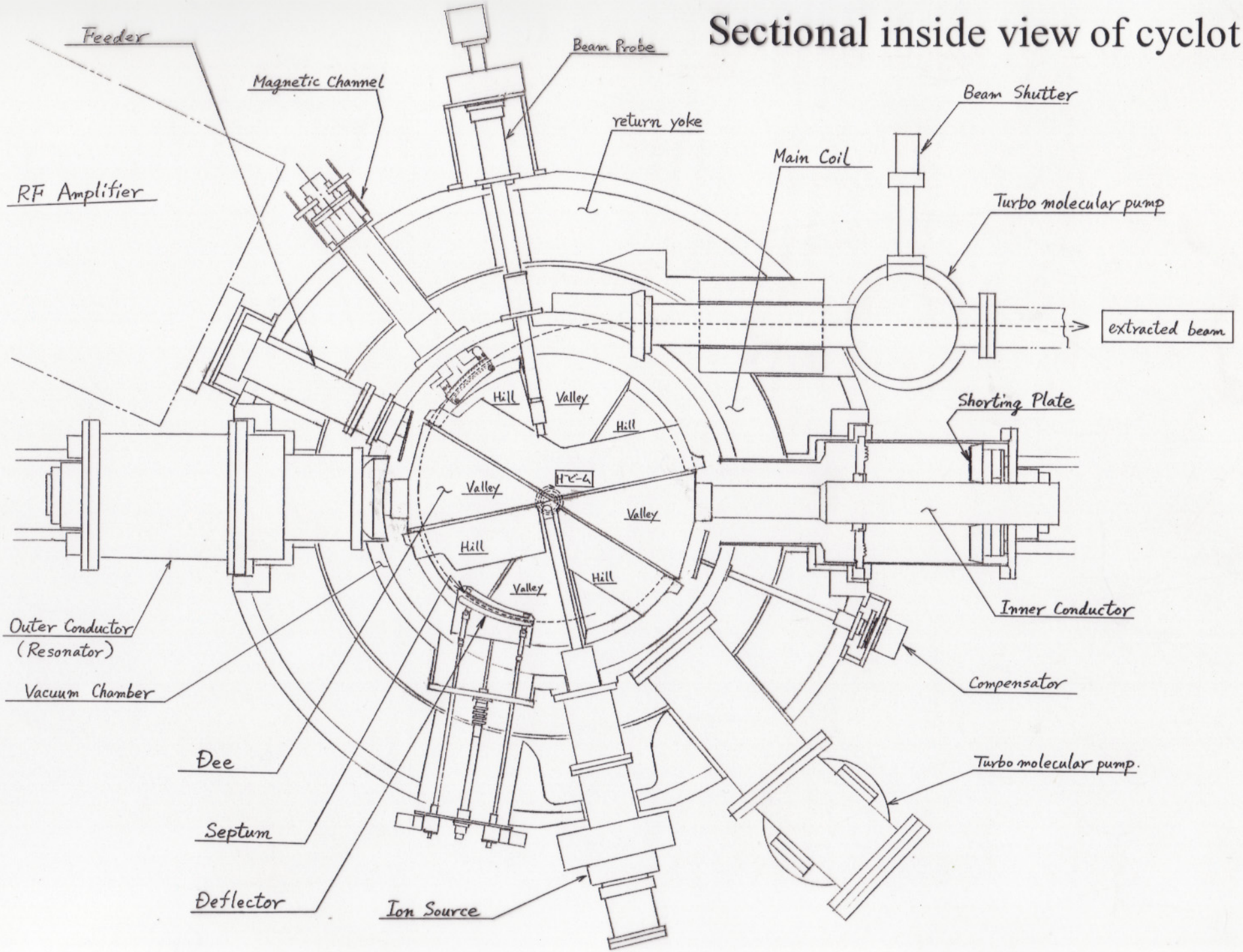
Trim coil power supply : DC50A／15V, stability;$\pm 1 \times 10^{-3}$／Hr

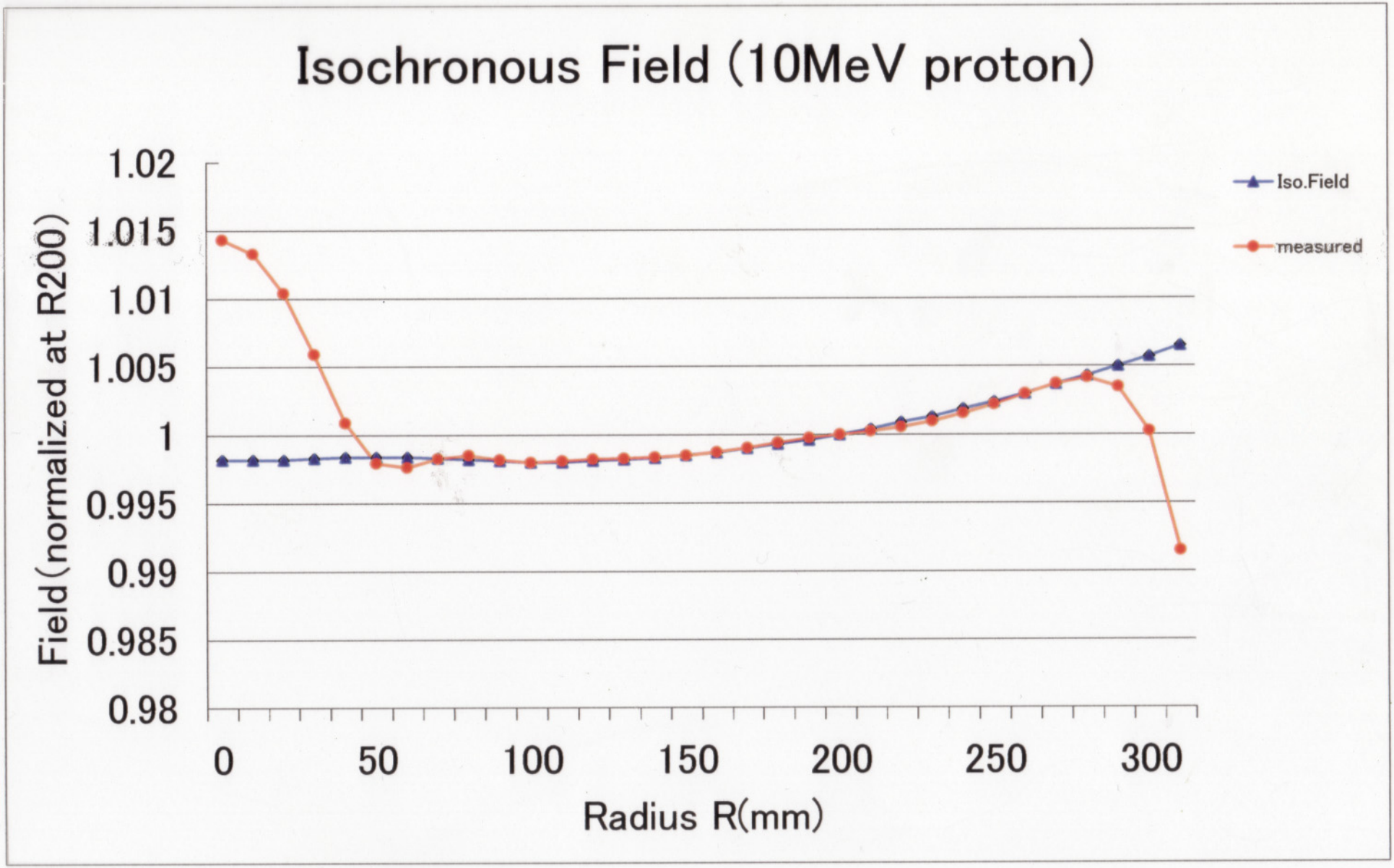
Arc power supply : DC5A／-500V （main power)，stability;$\pm 2 \times 10^{-4}$／Hr

DC50mA／-1.2kV （floating power)

Deflector power supply : DC±50kV／1.5mA （±polarity)，stability; $\pm 1 \times 10^{-3}$／Hr

Sectional inside view of cyclotron




Isochronous Field (10MeV proton)
Field(normalized at R200)
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
0
50
100
150
200
250
300
Radius R(mm)
Iso.Field
measured

Fundamental design for cyclotron

■ Constant cyclotron frequency: $f_0 = \dfrac{qB_0}{2\pi m_0}$ (1)

B_0: magnetic field at the central region (near radius≈ 0)

q : electronic charge m_0: proton mass

■ Magnetic field:

$B(r,\theta) = B_0(r) + \sum_i B_i(r)\cos[i\theta + \phi_i(r)] \quad (i = 1, 2, \cdots)$ (2)

r :radius, θ :azimuthal angle,

ϕ_i :field spiral (angular location for harmonic field)

■ Flutter:

$F(r) = \dfrac{\overline{B^2} - \overline{B}^2}{\overline{B}^2} = \dfrac{1}{2}\sum_i f_i(r)^2$ (3), where $f_i(r) = \dfrac{B_i(r)}{B_0(r)}$ (4)

■ Scalloped closed orbit:

$r(\theta) = \overline{r} \cdot [1 + \sum_{i\neq 1} q_i \cos(i\theta + \phi_i)]$ (5), where $q_i \approx \dfrac{f_i}{i^2 - 1}$ (6)

■ Isochronous field: $B_{\mathrm{isoc}} = B_0\overline{[1 - (2\pi f_0 \cdot r(\theta)/c)^2]^{-1/2}}$ (7)

■ n-value: $n = -\dfrac{r}{B}\dfrac{dB}{dr}$ (8),

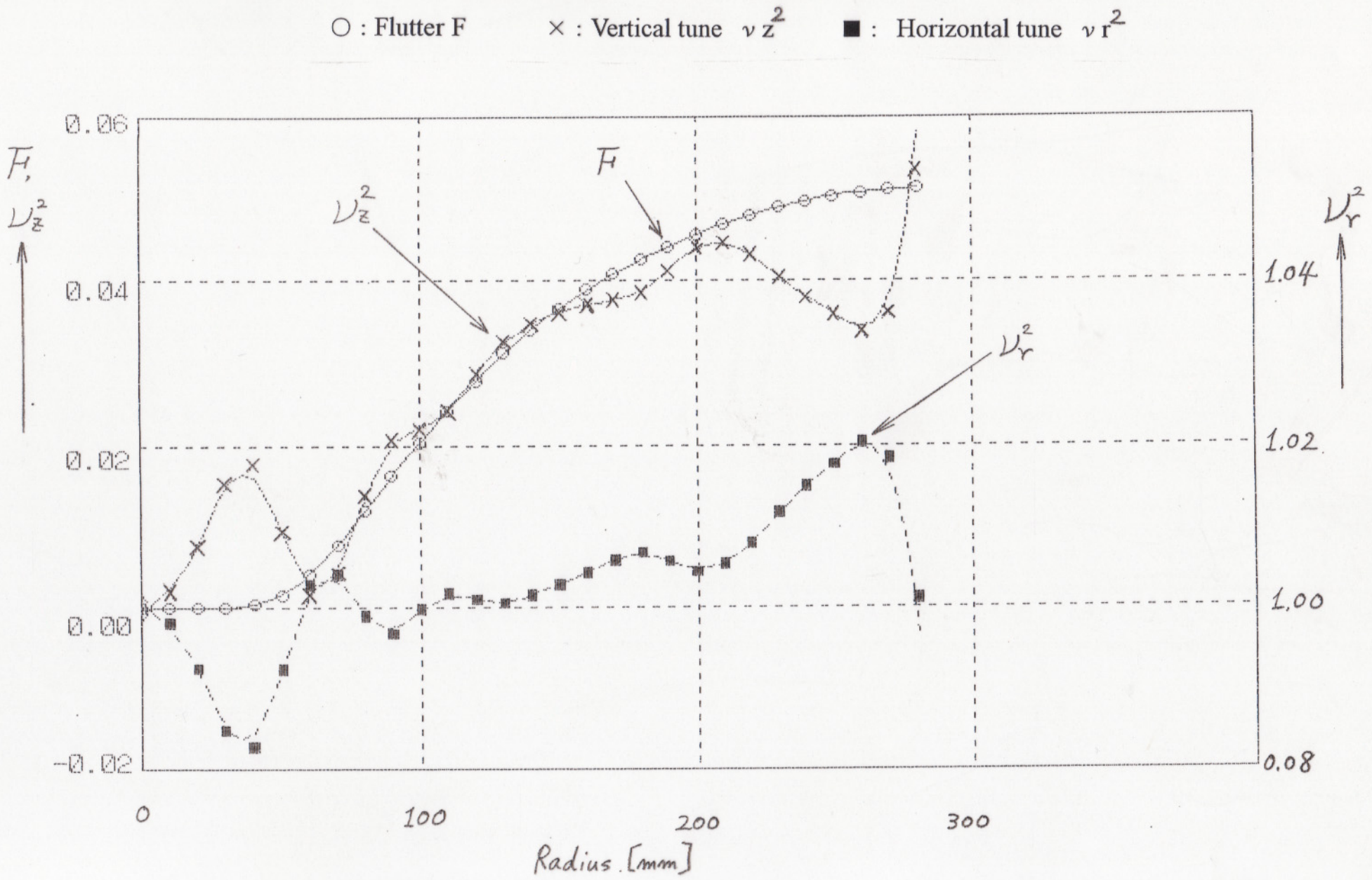
$n \approx -0.02$ (in case of the injector cyclotron)

■ Betatron tune:

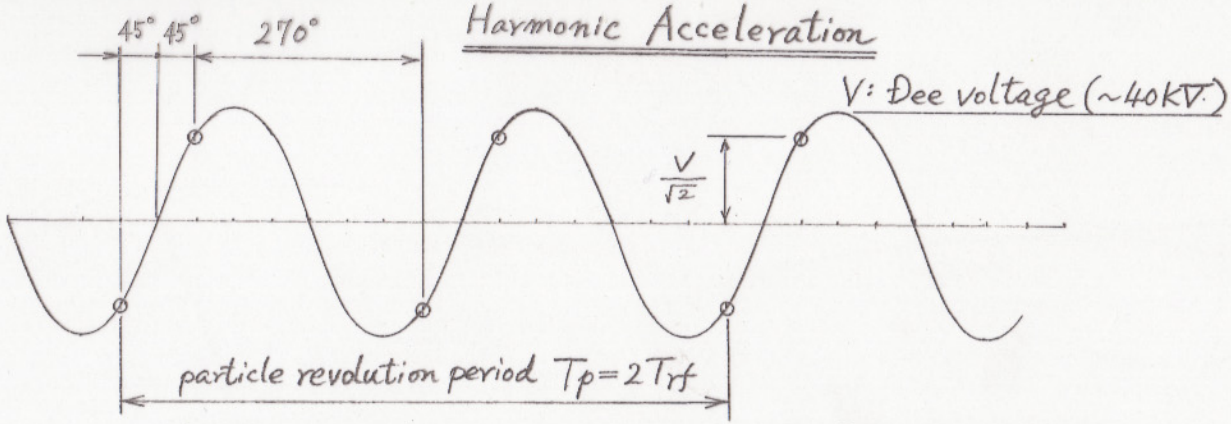
Horizontal $\nu_r^2 \approx 1 - n$ (9)

Vertical $\nu_z^2 \approx n + F(1 + 2\tan^2\alpha)$ (10) α: Spiral angle.

Betatron tune and Flutter

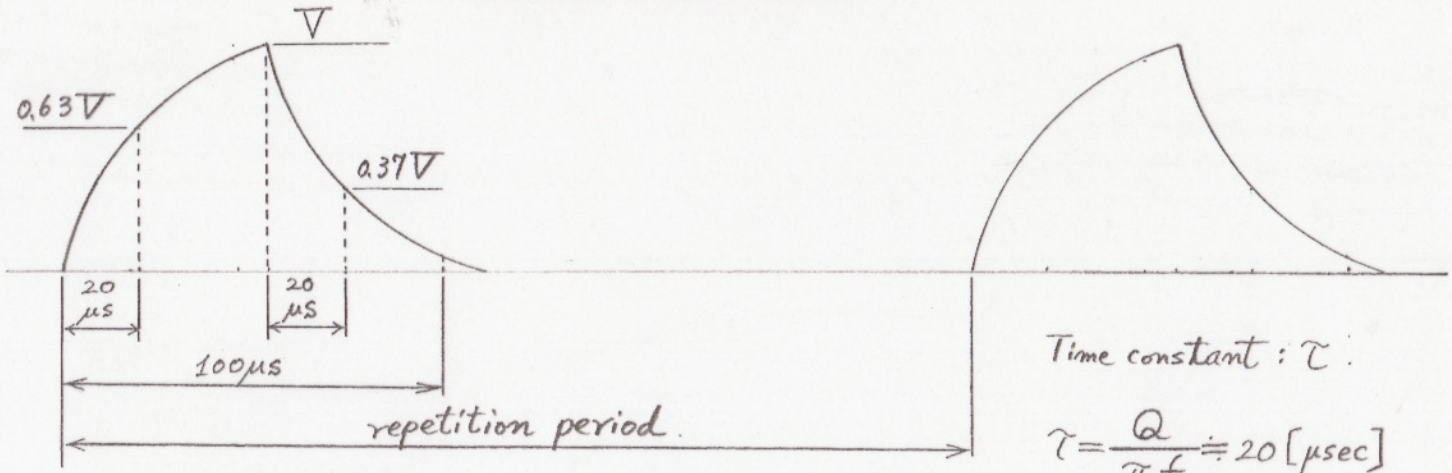


Harmonic Acceleration



T_{rf} : radio frequency period.

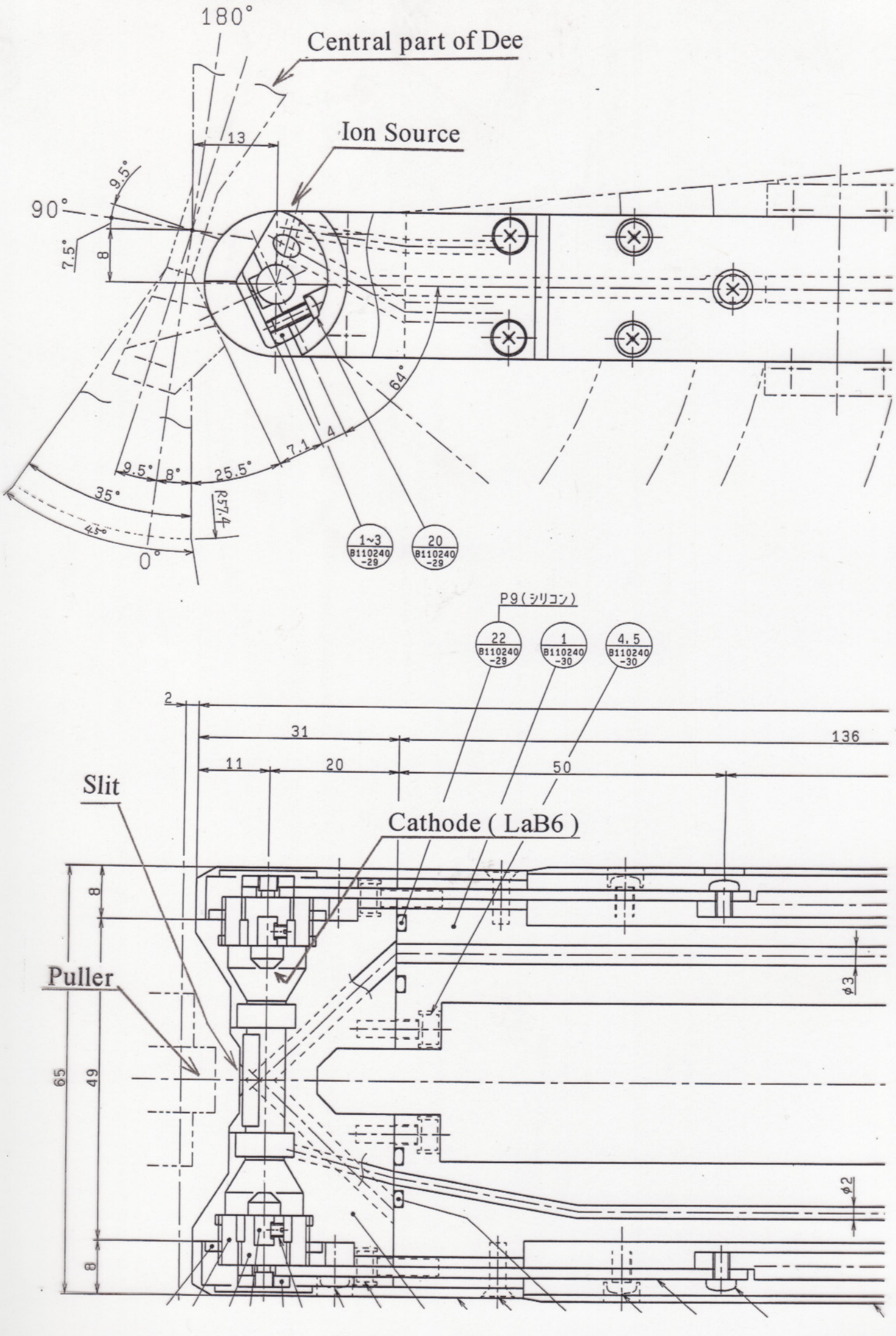
Pulsed Dee voltage



Time constant : τ.

$$\tau = \frac{Q}{\pi f} \fallingdotseq 20\,[\mu sec]$$

$Q \approx 3{,}000$, $f = 47\,[MHz]$


180°
Central part of Dee
Ion Source
13
9.5°
90°
7.5°
8
64°
7.1
4
9.5°
8°
25.5°
35°
45°
R57.4
0°
1~3
B110240
-29
20
B110240
-29
P9(シリコン)
22
B110240
-29
1
B110240
-30
4,5
B110240
-30
2
31
136
11
20
50
Slit
Cathode (LaB6)
8
Puller
65
49
8
φ3
φ2

Beam acceleration tests for the injector cyclotron

■ H- beam test : H- beam was not able to be extracted because of serious discharge in the deflector elecorode where positive high voltage was supplied.

■ Positive high voltage test for the deflector electrode

+30kV of initial supplied voltage on the conditions : Magnet ON(1.5T of field), RF OFF,

↓ Arc OFF, vacuum 6×10-6Torr

+21kV of discharge voltage on the conditions : Magnet ON, RF ON, Arc ON

discharge current; 0.2～0.4mA continuously (over 1mA instantaineosly)

discharge frequency; 2～3 times per second

There was no improvement after aging test that high voltage was being supplied to the electrode over three days.

There was many discharge signs on the electrode and the opposite side of it.

■ H+ beam test : The deflector voltage was able to rise to negative voltage of -40kV/0.2mA.

Extracted beam of 0.31 μA corresponding to internal beam of 2.5 μA

On the conditions : RF Duty1/30, Arc0.4A/50V, H2 gas of 1 sccm